Anticipatory prediction during online language processing

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ABSTRACT

Most investigations of linguistic prediction focus on evidence of predictability benefits when comprehenders encounter expected input during reading. However, there remain several unresolved empirical issues that are important for the broader question of whether prediction plays a fundamental role during real-time language comprehension. These include whether there are processing costs for misprediction, what the contents of predictions are, and whether readers differ in the extent to which they engage in prediction. In six experiments, these issues were systematically investigated by presenting different groups of readers with predictable words and unpredictable alternatives that were either semantically related or unrelated in constraining or non-constraining context conditions. The primary methodology was the recording of eye movements during natural reading for comprehension. Self-paced reading was also used to assess the contribution of stimuli presentation format on predictive processing. Across most experiments, there was evidence of early and late processing benefits for predictable completions in constraining contexts, which also extended to unpredictable completions that were semantically related. However, evidence of immediate processing costs for unexpected input that replaced readers' predictions was more mixed and appeared to depend on a variety of linguistic and non-linguistic factors. Overall, these results provide some support for the idea that the language processor is a "prediction machine" in line with general predictive accounts of cognitive functioning. The results also provide insight into the mechanisms underpinning prediction and provide opportunities for future research to refine theories of prediction.

Statement of Originality

This is to certify that, to the best of my knowledge, the content of this thesis is my own work. This thesis has not been submitted for any degree or other purposes.

I certify that the intellectual content of this thesis is the product of my own work and that all the assistance received in preparing this thesis and sources have been acknowledged.

Roslyn Wong

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Authorship Attribution Statement

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Roslyn Wong

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As supervisor for the candidature upon which this thesis is based, I can confirm that the authorship attribution statements above are correct.

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CHAPTER 1: General Introduction

1.1 Overview

Reading is one of the simplest tasks that individuals engage in on a daily basis, yet understanding how it unfolds poses an ongoing challenge for psycholinguistic research. Successful real-time language comprehension is a complex process – comprehenders must decode written text into abstract representations of individual letters and words, retrieve their meanings from long-term memory and integrate this information into the unfolding discourse representation. Despite its complexity, this entire process unfolds within hundreds of milliseconds with little conscious effect. One explanation for how readers are able to accomplish this feat so quickly and effortlessly lies in the idea of *prediction*.

In its broadest sense, prediction refers to any type of process that uses information about the past or present to estimate the immediately relevant future. In the context of language comprehension, readers encountering a phrase like "*The day was breezy so the boy went outside to fly a*…" can easily predict the word "*kite*" based on their prior knowledge and experiences (DeLong et al., 2005). These activated representations subsequently allow readers to process information faster when eventually encountered in the input stream. While psycholinguistic research over the past thirty or so years has provided robust evidence that readers do rely on prediction, it remains less clear whether these mechanisms are a fundamental component of online processing.

The primary goal of this thesis is to provide a more nuanced view of prediction as an important, but flexible, strategy during real-time language comprehension. The remainder of this chapter provides a review of the current literature relating to prediction processes during reading and explains the rationale behind each experiment conducted. Section 1.2 defines prediction in the context of cognition before Section 1.3 introduces prediction in the context of language comprehension. Section 1.4 discusses predictability effects in studies of reading which have typically been taken as evidence of prediction during online language comprehension. Section 1.5 examines some empirical issues that have been explored to provide insight into the nature of predictability effects during reading. Section 1.6 presents the ongoing empirical challenges for understanding prediction as a central component of reading. Finally, Section 1.7 provides a summary and outline of the current thesis.

1.2 Prediction in cognition

Prediction arguably plays a pervasive role in every aspect of human cognition. For example, in visual perception, individuals presented with a series of static images that imply motion, like a person diving off a cliff, anticipate ongoing mental representations of the unfolding event (Freyd, 1983; Senior et al., 2000). Similarly, in motor behaviour, individuals predict upcoming actions based on internal forward models to facilitate motor control (e.g., Wolpert & Flanagan, 2001) – for instance, when using the fingertips to grip an object whose load is increased by a self-generated action such as a moving arm, individuals adjust their grip force without delay to prevent the object from slipping (Flanagan & Wing, 1997; Johansson & Cole, 1992). While early investigations of anticipatory mechanisms and representations began in the context of these lower-order sensory modalities of visual and motor cognition, prediction has since become implicated in more complex cognitive processes such as music processing (Land & Furneaux, 1997), emotion processing (Herwig et al., 2007), and theory of mind (Frith & Frith, 2006).

Experimental evidence such as this has led to the growing realisation that the primary function of the brain is to anticipate future events and stimuli. While the classical view of the brain emphasised the role of lower-level sensory information in the construction of higher-level internal representations (e.g., Marr, 1982), the current twenty-first century perspective reverses this approach: “The brain is no longer viewed as a transformer of ambient sensations into cognition, but a generator of predictions and inferences that interprets experience according to subjective biases and statistical accounts of past encounters” (Mesulam, 2008, p. 368). Indeed, Clark (2013, p. 186) posits that prediction offers a “deeply unified account of perception, cognition, and action” and goes as far as to surmise that the brain is fundamentally a “prediction machine”.

In line with these perspectives, an increasing number of brain function models have become framed around predictive coding and minimising prediction error (Clark, 2013; Friston, 2010; Hohwy, 2013, 2020). According to this framework, the brain is a hierarchically structured device that predicts sensory inputs via the interplay between backward (top-down) and forward (bottom-up) flows of information. The “backward” flow delivers predictions from higher to lower hierarchical levels based on what the system “knows” about the world and its current context such that incoming sensory signals that are consistent with these predictions are “explained away”. However, if there is a discrepancy between the sensory signals encountered and those predicted, the “forward” flow computes an error, i.e., residual “unexpected” information that is propagated back up the hierarchy to refine top-down hypotheses about the current sensory data. Thus, the primary function of this multilevel bidirectional information exchange is to minimise overall prediction error or “free energy” – the probability of being in a state of surprise (Friston, 2010). This ensures that, in the long term, predictions about the world are being continuously updated and refined through prior knowledge and experiences (Bar, 2007; Lupyan & Clark, 2015) and an optimal model of the causes of incoming sensory signals are achieved across the different hierarchical levels (Friston, 2010).

Although empirical evidence that the brain implements predictive coding remains mixed (see Walsh et al., 2020 for a review), this general shift towards a predictive view of the brain is important for explaining cognitive processes for several reasons. Firstly, it has been posited that the brain would not be able to make sense of the world as rapidly as it does if it only relied on bottom-up information (Mesulam, 2008). Secondly, and perhaps more importantly, it has been argued that incoming sensory data is just too ambiguous and complex to deal with in a bottom-up fashion. As such, the continual generation of predictions helps the brain perceive stability and coherence in its environment (Bar, 2007). Consistent with this, prediction is now viewed as a, if not *the*, fundamental principle of human information processing.

1.3 Prediction in language comprehension

Given that language processing is realised by the brain, it is unsurprising that prediction has been used to explain how real-time language comprehension unfolds so rapidly and effortlessly (e.g., Ferreira & Chantavarin, 2018; Huettig, 2015; Kuperberg & Jaeger, 2016; Lupyan & Clark, 2015; Pickering & Gambi, 2018). If the language processor is able to predict linguistic input in advance based on prior knowledge and experiences, this information should facilitate subsequent processing when eventually encountered. From this perspective, the role of prediction in theories of language comprehension should not be so controversial. However, for decades, there have been doubts as to whether comprehenders can anticipate specific linguistic content in a way that goes beyond the effects of low-level intralexical priming.

The first major reason for this scepticism towards a central role for prediction in reading is that theories of language comprehension have traditionally espoused a strong bottom-up bias. For example, the classic modular views of language processing (e.g., Fodor, 1983; Forster, 1979) posited that words were recognised solely on the basis of sensory input and that context only had a postlexical impact by affecting the ease with which words were integrated into the unfolding sentence or discourse representation. As such, the notion that contextual information could have a prelexical impact by encouraging the anticipation of upcoming linguistic input seemed untenable. Even more lenient views of language processing such as those offered by the cohort model (Marslen-Wilson, 1987) and the shortlist model (Norris, 1994), which claimed to be more interactive, had a fundamentally bottom-up emphasis – contextual information could affect the outcome of word recognition and lexical access but only after the sensory input had activated an initial set of potential candidates.

The second major reason for why researchers have traditionally been uncertain about the idea of prediction in reading can be found in the inherently generative nature of language which allows infinite possible linguistic expressions for each upcoming word of a sentence (Jackendoff, 2002; Morris, 2006). For example, consider the cloze task in which individuals are instructed to continue a phrase or complete a sentence with the first word that comes to mind (Taylor, 1953). If most individuals converge on the same word, the context is considered *predictive* or *constraining* and the completion is deemed *predictable* or *high cloze*. However, most naturally occurring text is only weakly or moderately constraining (e.g., Luke & Christianson, 2016) so participants will often provide multiple plausible responses for these contexts (e.g., Bloom & Fischler, 1980). As such, predicting what will come next in a sentence is a relatively ineffective and potentially costly strategy unless contextual constraint is unusually strong – comprehenders are unlikely to make correct predictions the majority of the time and it may be more efficient to wait for the sentence to unfold naturally over the next few words (Forster, 1981; Jackendoff, 2002).

These anti-prediction views, however, began to shift in the late 1990s. The modular views of language processing gave way to interactive views that emphasised the availability of contextual information even before the current sensory input had been processed (e.g., Ferreira & Lowder, 2016; McClelland, 1987; Morton, 1969; Sedivy et al., 1999). Meanwhile, the argument about generativity was challenged by the fact that, while few words are highly predictable in natural reading, many words or aspects of words are still moderately predictable. For example, consider again the first example presented in this chapter: "*The day was breezy so the boy went outside to fly a kite*". Even though most comprehenders are unlikely to accurately predict in advance the word "*fly*" in this sentence, they can be fairly confident that the word in this location will be a verb. This syntactic information can then be used in conjunction with semantic and/or world knowledge to converge on a sufficiently plausible continuation. In line with these shifts in perspective, experimental evidence about the predictive nature of the language processor has become more widespread over the past thirty or so years. This has also coincided with the development of online methodologies such as eye-tracking and event-related potentials (ERPs) which are well-suited to the investigation of how real-time language comprehension unfolds because of their ability to provide continuous streams of data with high temporal resolution.

Some of the earliest evidence that comprehenders make use of linguistic prediction during online processing comes from studies using the *visual world paradigm* (Tanenhaus et al., 1995) in which participants' eye movements are recorded as they look at a visual scene while listening to a sentence. For example, in one of the most influential demonstrations, Altmann and Kamide (1999) presented participants with a visual context depicting a boy, a cake, and several other distractor objects while they listened to sentences such as "*The boy will eat the cake*" or "*The boy will move the cake*". They found that, before the final word had even been presented, participants were faster to move their eyes towards the cake, the only edible object, in the "*eat*" compared to the "*move*" condition, suggesting that participants had predicted a compatible theme based on the selectional information conveyed by the verb. This finding of anticipatory eye movements based on contextual information has since been replicated in a number of visual world studies (e.g., Kamide et al., 2003; Kukona et al., 2011; see Huettig et al., 2011 for a review). However, questions have been raised about whether these findings reflect genuine linguistic prediction given that the visual context places constraints on the potential candidates that can be heard in each sentence (DeLong, Troyer, & Kutas, 2014b; Huettig et al., 2011; Kutas et al., 2011). In other words, it is unclear whether evidence of prediction in studies using the visual world paradigm reflects anticipation due to linguistic or visual information.

Another approach that has been used to investigate linguistic prediction during online processing, which is more relevant to the present thesis, is studies of reading which have the potential to present a broad range of linguistic structures. In these studies, the clearest demonstration of prediction comes from evidence that a word has been activated even before it has been encountered. For example, DeLong et al. (2005) capitalised on the phonological rule in English where articles like "*a*" and "*an*" are used depending on whether the next word begins with a consonant or vowel to present sentences like "*The day was breezy so the boy went outside to fly*…" which were completed by either the predictable noun-phrase "*a kite*" or the less predictable, but plausible, noun-phrase "*an airplane*". They found that neural activity in the form of an N400 component correlated with how predictable the noun was – the more predictable the noun, the smaller the neural activity reflecting the ease of semantic processing. Critically, this inverse correlation was also obtained before the noun was presented, i.e., on the preceding article that carried no semantic information. This led DeLong et al. to conclude that comprehenders had used the preceding context to anticipate the predictable noun, or at least its first phoneme, and by extension its appropriate preceding article. Although the findings of this design could be taken as evidence of prediction, they should be interpreted with caution because subsequent studies have failed to replicate these effects on the article (e.g., Ito et al., 2017; Nieuwland et al., 2018). More generally, these manipulations are difficult to implement in English because there are few linguistic rules that allow the properties of lexical items to influence preceding words (but see Van Berkum et al., 2005 for evidence in Dutch; Wicha, Bates, et al., 2003a; Wicha, Moreno, et al., 2003b; Wicha et al., 2004 for evidence in Spanish).

Thus, most studies of reading in English have focused on demonstrating linguistic prediction via the effects of *predictability* – how well a word can be predicted from its prior context. The basic idea behind this is that if a word can be predicted in advance of its presentation then the way in which this word is processed when eventually encountered may depend on its level of predictability (Kutas et al., 2011). The most common approach to operationalising predictability is via a word's cloze probability which can be determined by aggregating the responses provided for a given sentence context in a cloze task (i.e., the number of productions divided by the total number of responses; Taylor, 1953). Words with cloze values close to 1 are almost perfectly predictable in their contexts while words with low cloze values are less predictable. As reviewed in the next section, there is substantial evidence across different methodologies that attests to the effects of predictability during real-time language comprehension.

1.4 Predictability effects in studies of reading

The following section provides a review of the current literature relating to predictability effects in studies of reading across eye-movement and ERP methodologies, with an emphasis on the former because it is the primary methodology used in the experiments presented in the current thesis.

1.4.1 Evidence from eye movements.

The recording of eye movements is a non-invasive behavioural method for measuring online cognitive processing during reading (Rayner et al., 2006). In the context of psycholinguistic research, eye movements offer certain advantages compared to traditional behavioural methods like lexical decision and speeded pronunciation (or "naming") tasks. Firstly, participants do not need to complete a secondary task during reading, such as make decisions about words or name them aloud, which could impose additional processing demands. Secondly, and perhaps more importantly, eye movements are fundamental to the reading process itself meaning that ongoing lexical processing is captured by where and when readers move their eyes.

Reading is characterised by a series of rapid, ballistic eye movements known as *saccades* which are separated by *fixations*. It is during fixations, when the eyes remain relatively still, that new information is extracted from the visual field. During saccades, on the other hand, no new information is usually acquired because vision is completely suppressed when the eyes are moving (Matin, 1974). Typically, fixations last 200-250 ms while saccades last 20-25 ms and move the eyes about 7-9 letter spaces, with considerable variability in both measures. Readers fixate on most words of a sentence during first-pass reading, but skip words approximately 30% of the time. They also make saccades that move the eyes forward the majority of the time, but approximately 10-15% of saccades are *regressions* back to previously fixated, or skipped, words (Rayner, 2009). This pattern of eye-movement behaviour is a consequence of limitations in visual acuity which is highest in the central 2° of vision (the *fovea*) and declines sharply with increasing eccentricity from this location (up to 5° from fixation, the *parafovea*, and beyond, the *periphery*). Figure 1.1 illustrates an example of the eye-movement record.

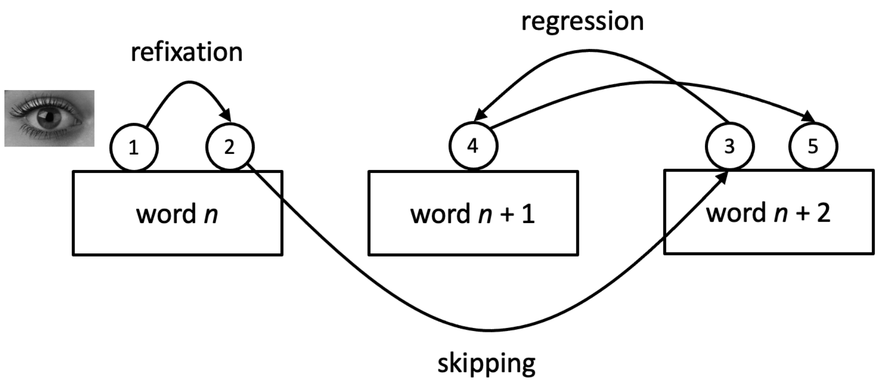

Figure 1.1 An example of the eye-movement record. The circles represent fixations in sequential order and the arrows represent saccades. Fixations 1, 2, and 3 are first-pass fixations while fixations 4 and 5 are second-pass fixations. Fixation 1 is first-fixation duration on word *n*. The sum of fixations 1 and 2 is gaze duration (as well as total fixation duration) on word *n*. Word *n* + 1 was skipped during first-pass reading. The sum of fixations 3 and 5 is total fixation duration on word *n* + 2. Adapted from Wotschak (2009).

Based on these characteristic patterns of oculomotor control, there are a variety of eye-movement measures used by researchers to investigate reading processes. Firstly, there are *global measures* of reading based on analyses of the entire text which provide an indication of overall processing difficulty. These include total sentence reading time, average fixation duration, number of fixations and regressions, average forward saccade length, and number of words skipped. Secondly, there are *local measures* of reading based on analyses of a specific interest area which provide an indication of processing difficulty for a particular word in the text. These include "first-pass" reading measures which occur during readers' first progression through a text and are thought to reflect early stages of processing (e.g., word recognition and lexical access; Vasishth et al., 2013). First-pass reading measures include *first fixation duration* (the duration of the first fixation on a word irrespective of the total number of fixations made on that interest area) and *gaze duration* (the sum of all fixations on a word before the eyes exit the interest area for the first time). These early reading measures are distinguishable from "late" reading measures which are thought to reflect late stages of processing (e.g., integration; Clifton et al., 2007) such as *total fixation duration* (the sum of all fixations on a word in first-pass reading and subsequent re-reading). In addition to these local measures of fixation duration, there are also local measures of fixation probability including *first-pass fixation probability* (the probability that a word receives a first-pass fixation, i.e., the inverse of *skipping probability*), *probability of regressions-out* (the probability that the reader makes a regression from a word back to an earlier part of the text), and *probability of regressions-in* (the probability that the reader makes a regressions back to a word from a later part of the text).

Given the fluency of skilled reading, considerable research has focused on understanding the extent to which eye-movement behaviour is under cognitive control. Two components that have been identified as important for oculomotor control are the decisions of *where* to move the eyes and *when* to initiate an eye movement. There is reliable evidence to suggest that these two decisions are largely independent of each other – the decision of where to move the eyes, i.e., fixation location, is determined by low-level information provided by word length and spaces between words (Rayner & McConkie, 1976; Rayner & Pollatsek, 1981), while the decision of when to move the eyes, i.e., fixation duration, is influenced by the ease or difficulty associated with processing the fixated word. The first major lexical property that affects how long readers spend on a word is word frequency – high frequency words (e.g., *dance*) receive shorter fixation durations than low frequency words (e.g., *waltz*) when controlling for word length (e.g., Inhoff & Rayner, 1986; Rayner & Duffy, 1986). The second major lexical variable that has been identified is word predictability.

Ehrlich and Rayner (1981) first demonstrated the effects of predictability on eye movements in a pair of experiments that manipulated predictability in two ways. The first experiment presented the same target in two different contexts, while the second experiment presented two different target words in the same contexts, so that, in both manipulations, one target was high cloze probability while the other was low cloze probability. Across both experiments, Ehrlich and Rayner found that words that could be predicted from the preceding context were more likely to be skipped and to receive shorter reading times if fixated than words that could not be predicted, consistent with the idea that the predictability of a word determines the time required to process it.

Similar predictability effects have since been reported extensively across a number of eye-movement studies using experimental manipulations (e.g., Balota et al., 1985; Fitzsimmons & Drieghe, 2013; Frisson et al., 2017; Rayner et al., 2004; Rayner et al., 2011; Rayner & Well, 1996) and corpus data (e.g., Andrews et al., 2022; Kliegl et al., 2004; Luke & Christianson, 2016). In most of these studies, predictability effects are observed on skipping and first-pass reading measures such as first fixation and gaze duration (e.g., Rayner et al., 2004; Rayner et al., 2011), suggesting that word predictability exerts its influence during early stages of processing. However, predictability effects are also observable on late reading measures including total fixation duration (e.g., Ehrlich & Rayner, 1981; Frisson et al., 2017; Rayner & Well, 1996) and the probability of making a regression (e.g., Calvo & Meseguer, 2002; Kretzschmar et al., 2015; Staub, 2011, 2020), possibly reflecting the influence of contextual information on later stages of processing. Thus, across different eye-movement studies, there is robust evidence that the predictability of a word is an important determinant of the temporal aspect of eye-movement control.

Computational models of eye-movement control during reading.

On the basis of these findings, a number of computational models have been put forward to explain eye-movement control during reading (see Reichle, 2021 for a review). Two of the most developed models are the *E-Z Reader* (Reichle et al., 1998; Reichle et al., 2009; Reichle et al., 2012) and *SWIFT* (Engbert et al., 2002; Engbert et al., 2005) models which are built on an earlier generation of models that aimed to explain perceptual and attentional processes in reading (e.g., Morrison, 1984). The two key differences between E-Z Reader and SWIFT lie in their assumptions about cognitive control in saccade generation and whether lexical processing proceeds in a serial or parallel manner. These models are discussed in further detail below, with an emphasis on their assumptions relating to how predictability guides where and when readers move their eyes.

The E-Z Reader model (Reichle et al., 1998; Reichle et al., 2009; Reichle et al., 2012) assumes that words are processed in a serial manner where attention is allocated sequentially and that readers initiate a program to move their eyes to the next word based on the completion of a preliminary stage of lexical processing of an individual word. In this model, a preattentive visual processing stage, during which raw visual information is extracted in parallel across the *perceptual span*, informs a two-stage process of lexical identification. The completion of the first stage (L_1 – the "familiarity check") indicates that the attended word *n* will be recognised imminently and provides a signal to the oculomotor system to begin saccadic planning to move the eyes to word *n* + 1. The saccade program also unfolds in two stages (a labile stage M_1 and a non-labile stage M_2). The completion of the second stage of lexical processing (L_2) corresponds to lexical access of word *n* and this both initiates postlexical processing of word *n* and shifts covert attention to word *n* + 1. Once attention shifts to word *n* + 1, L_1 for that word begins and the non-labile stage of saccadic planning (M_2) completes, i.e., a saccade is committed to move the eyes to word *n* + 1. Importantly, if the familiarity check for the word *n* + 1 is completed during the labile stage of saccadic planning (M_1), the saccade to this word is cancelled and the word is skipped over.

According to E-Z Reader, the time required to complete L_1, the first stage of lexical processing, is determined by a word's lexical properties, specifically its frequency and predictability. The duration of L_1 is either 0, when the word has been guessed in the parafovea and is therefore skipped, or a non-zero value that is an additive function of the word’s (log) frequency and cloze predictability. This duration is also adjusted to account for visual acuity, i.e., the mean absolute distance between the fixation location and each of the letters of word *n*, such that words that are longer or further from the point of fixation take longer to process than words that are shorter or closer to the point of fixation. The time required to complete L_2, the second stage of lexical processing, and achieve full lexical access is determined as a fixed proportion of the duration of L_1, excluding any effects of visual acuity.

In contrast, the SWIFT or Saccade-generation With Inhibition by Foveal Targets model (Engbert et al., 2002; Engbert et al., 2005) assumes that multiple words can be processed in parallel and that readers do not initiate eye movements on the basis of lexical information. Despite these fundamental differences, the architecture of this model shares some similarities with that of E-Z Reader. Lexical identification in this model unfolds across two stages: a *preprocessing stage* during which word *n* is activated from zero to a maximum level as a function of its frequency and predictability, followed by a *lexical completion stage* during which lexical access is completed and activation decreases back to zero. Saccadic planning in the SWIFT model also involves both labile and non-labile stages; however, unlike E-Z Reader, this comprises two distinct but parallel mechanisms: *saccade target selection* and *saccade timing*. Saccade target selection is random and proceeds according to the attentional window which extends asymmetrically to the right of fixation. However, the relative activation of individual words within this attentional window can change over time as a function of lexical processing such that words with higher levels of activation are more likely to be selected as the target of a saccade. Saccade timing is autonomous and initiated in order to maintain a mean rate of saccades during reading. However, difficulty with lexical processing on the foveal target can intervene with this random timer and delay the system from generating the next saccade.

Similar to E-Z Reader, SWIFT assumes that word predictability exerts its influence during both stages of lexical identification, i.e., during the preprocessing and the lexical completion stage. However, several researchers have pointed out issues with how this is implemented in the model (Reichle et al., 2008; Slattery et al., 2007; Staub & Goddard, 2019). The predictability of a given word *n* is derived from all words in the prior context leading up to and including word *n* - 1. However, SWIFT posits parallel lexical processing of multiple words, implying that the predictability of word *n* can influence how it is processed even before word *n* - 1 (and sometimes even *n* - 2) has been lexically identified. This is logically questionable because the lexical predictability of word *n* cannot be determined if words in its prior context have not been fully processed. As such, most researchers tend to rely on the architecture of E-Z Reader rather than SWIFT to explain how predictability effects influence eye-movement control during reading.

In addition to E-Z Reader and SWIFT, several other computational models have been proposed to explain eye-movement control during reading. The *EMMA* or Eye Movements and Movements of Attention model (Salvucci, 2001) was developed to explain eye movements in any visual task, such as equation solving and visual search in addition to reading. Like E-Z Reader, this model includes a two-stage process of lexical identification and labile and non-labile saccadic planning. The *Glenmore* model (Reilly & Radach, 2003, 2006) was also developed in response to E-Z Reader and shares the core assumption of SWIFT that multiple words can be processed and identified in parallel. However, in contrast to E-Z Reader or SWIFT, this model is largely implemented within several interacting connectionist networks which specify how letters and words are identified as well as how saccades are executed. A more recent model, *OB1-Reader* (Snell et al., 2018), also shares the core assumptions of SWIFT and Glenmore including parallel lexical processing of multiple words within an interactive activation framework. However, unlike Glenmore, the input to this model uses open bigrams rather than letter nodes and assumes that the spatial location of each word is represented in working memory. Finally, more recently, *Über-Reader* (Reichle, 2021; Veldre et al., 2020) has been developed to provide a more comprehensive account of the perceptual, cognitive, and motor processes involved in reading. This model is based on the E-Z Reader architecture but includes components that account for higher-order reading processes including sentence and discourse processing.

While it remains an ongoing debate as to which computational model of eye-movement control provides the best description of where and when the eyes move during reading, it is well-accepted that E-Z Reader and SWIFT are the most influential given their ability to explain a number of empirical phenomena and theoretical issues (see Reichle, 2021 for a review). In comparison, the other models described require additional modelling work in order to provide the same level of explanation as E-Z Reader and SWIFT. Moreover, in addition to E-Z Reader and SWIFT, only Glenmore and OB1-Reader to date are able to account for how predictability influences eye-movement control during reading.

1.4.2 Evidence from ERPs.

Another method that has been used to investigate predictability effects during reading is the recording of event-related potentials (ERPs) derived from electroencephalography (EEG) – a non-invasive technique for measuring neural activity during cognitive processing via electrodes placed on the scalp. Specifically, ERPs are small voltage fluctuations that are time-locked to an event or stimulus of interest such as the onset of the presentation of a word, reflecting the summation of synchronised postsynaptic activity generated by a large population of neurons during information processing. ERP components are characterised by polarity (either a positive or negative deflection labelled as *P* and *N*, respectively), latency (the time since the stimulus onset measured in ms), amplitude (the size of the voltage measured in µV) and scalp distribution (the underlying source of the signal). Typically, ERP waveforms with shorter latencies, i.e., generated within 100 ms of a stimulus, are thought to reflect sensory stages of processing determined by the physical characteristics of the stimuli, while ERP waveforms with longer latencies are thought to reflect cognitive stages of processing.

In the context of psycholinguistic research, ERPs are well-suited to the study of language for two main reasons. Firstly, ERPs provide high-resolution temporal information which makes it possible to determine the stages of processing influenced by an experimental manipulation (Luck, 2014). Secondly, ERPs can be measured even when participants' only task is to read for comprehension, ensuring that the data collected reflects genuine reading processes and not the demands of a secondary task (Kutas & Delong, 2008). Thus, it is unsurprising that ERP measures have been used extensively to investigate a range of language representations and processes (see Kutas & Federmeier, 2007; Swaab et al., 2011 for reviews) including those related to predictability effects.

Predictability effects during reading have been shown to impact an ERP component known as the N400 – a negative-going waveform with a centro-parietal distribution that begins 250 ms after the presentation of a word and peaks 400 ms after stimulus onset. Kutas and Hillyard (1980) initially discovered this neural waveform when they presented sentences like "*He spread the warm bread with*…" and found larger N400 amplitudes for semantically anomalous words like "*socks*" than appropriate control words like "*butter*". Subsequent research revealed that the sensitivity of this ERP component was not restricted to semantic anomalies per se: larger N400 amplitudes were also observable for unpredictable compared to predictable words even when both were equally plausible. This was first demonstrated when Kutas and Hillyard (1984) presented sentences completed by either a high, medium, or low cloze target word and found an inverse relationship between predictability and the N400 component. That is, the higher a word's cloze probability, the smaller the corresponding N400 amplitude, reflecting the fewer neural resources required to process a word. This graded relationship between predictability and the N400 component has since been replicated across a wide range of studies (e.g., DeLong et al., 2005; Federmeier & Kutas, 1999; Federmeier et al., 2002; Federmeier et al., 2007; Kutas et al., 1984; Wlotko & Federmeier, 2012; see Van Petten & Luka, 2012 for a review).

More generally, the N400 component also shows sensitivity to manipulations that go beyond predictability at the lexical level (see Federmeier, 2022; Kutas & Federmeier, 2011; Kutas et al., 2007 for reviews). This ERP waveform has also been found to be modulated by predictability manipulations at the orthographic and phonological level (e.g., Ito et al., 2016; Laszlo & Federmeier, 2009), as well as at the semantic level (e.g., Federmeier & Kutas, 1999; Federmeier et al., 2002). It has also been shown to be sensitive to other lexical properties of words such as their frequency (e.g., Rugg, 1990), concreteness (e.g., Barber et al., 2013), and position in the sentence (e.g., Van Petten & Kutas, 1990, 1991). Indeed, the N400 component does not even appear to be language-specific because it has also been elicited in response to any type of input that produces activity in long-term semantic memory including faces and objects, numeric symbols, and environmental sounds (see Federmeier et al., 2016 for a review). Taken together, the N400 component appears to be a default neural response to any potentially meaningful perceptual stimuli. Nonetheless, the fact remains that it is strongly correlated with word predictability as indexed by cloze probability.

The appearance of predictability effects on the N400 component, however, suggests that they occur relatively late in the time course of normal reading or, at least, that they take some time to appear in the ERP record. Given that the typical fixation lasts 200-250 ms, by 400 ms after a word has been fixated, readers have likely completed lexical access for that word and moved their eyes onto the subsequent word (e.g., Dimigen et al., 2011; Rayner & Clifton, 2009). This timing discrepancy is made more salient by the fact that the end of a fixation is typically reserved for oculomotor latency (i.e., the time required to program and execute the next eye movement) meaning that there is an even shorter interval – the first 100-150 ms of a fixation – during which lexical processing can occur (Rayner et al., 1983). As such, there remains an ongoing debate in the literature as to whether reduced N400 effects during reading reflect processing difficulty during the lexical or postlexical stage of processing (e.g., Kutas & Federmeier, 2011; Nieuwland et al., 2020) which, in turn, has implications for whether these effects can be taken as reflecting genuine prediction processes which would be expected to influence early stages of processing. While predictability effects have been shown to impact earlier ERP components, the reliability of these findings remains unclear (see Nieuwland, 2019 for an extensive review).

However, there are several factors that potentially limit the generalisability of ERP findings to normal reading. ERP studies often present stimuli using a *rapid serial visual presentation* (RSVP) paradigm in which sentences or texts are presented one word at a time in the centre of the screen at a fixed pace between 400-1000 ms – a stimuli presentation method that clearly differs from normal reading in many aspects. Firstly, the word-by-word presentation format prevents readers from engaging in natural eye-movement behaviour including skipping words, re-reading text, and extracting upcoming information from the parafovea. Secondly, the fixed-pace presentation rate does not allow readers volitional control over the rate of input. Instead, words are typically presented for longer than the standard 200-250 ms duration of fixations. Finally, readers are required to maintain central fixation and suppress eye movements including blinks during the task. As such, reading under RSVP is quite unnatural and could impose additional processing demands that are not part of normal reading. It is possible then that ERP studies do not accurately capture the processes underlying real-time language comprehension which is an important implication when considering discrepancies in the conclusions of eye-movement and ERP research.

To partly address the limitations associated with the RSVP paradigm, some ERP studies have presented stimuli using the *self-paced reading* paradigm in which sentences or texts are presented one word at a time but at the readers' own pace (Ditman et al., 2007). Although this methodology also uses a word-by-word presentation format, it does simulate normal reading more closely by allowing readers control over the presentation rate. Studies investigating predictability effects using the self-paced reading paradigm alone have reported the classic processing benefits on reading times for expected compared to unexpected words (e.g., Brothers et al., 2017; Jongman et al., 2022). Studies using this paradigm while recording ERPs have also revealed the expected smaller N400 amplitudes for predictable compared to unpredictable words (e.g., Ng et al., 2017; Payne & Federmeier, 2017; Wlotko & Federmeier, 2015). Thus, ERP studies using the self-paced reading paradigm appear to yield the same pattern of effects as those using the RSVP paradigm. However, like its fixed-pace counterpart, ERP findings based on self-paced reading should be interpreted with caution given that the word-by-word presentation format still imposes constraints on natural reading behaviour.

1.4.3 Summary.

There is robust evidence across eye-movement and ERP methodologies that the predictability of a word has a strong influence on how efficiently it is processed. This provides support for the notion that comprehenders routinely predict upcoming words in advance of their presentation which facilitates their subsequent processing when eventually encountered.

1.5 Empirical issues relating to predictability effects

The following section discusses some of the empirical issues that have been explored in the literature to provide further insight into the nature of predictability effects during real-time language comprehension. This section concludes by considering whether effects of predictability can be taken as evidence of genuine linguistic prediction during reading.

1.5.1 What is the best measure of predictability?

As mentioned earlier, most studies of reading operationalise predictability effects in terms of a word's cloze probability which is calculated by aggregating responses provided for a given sentence context in a cloze task (Taylor, 1953). However, there are other, more objective, approaches that have been proposed, including transitional probability and the information-theoretic metrics of surprisal and entropy. The following subsections review each of these approaches before discussing why cloze probability remains the chief metric for estimating a word's predictability.

Predictability as transitional probability effects.

One approach that has been investigated as a potential determinant of a word's predictability is forward *transitional probability* (TP), the conditional probability that a word will occur given its preceding word. Unlike cloze probability, this low-level statistical information is derived from corpus data and independent of high-level contextual information. For example, based on a typical corpus of texts, the verb *accept* is followed by the noun *defeat* more often than the noun *losses*. The first demonstration of TP effects was conducted by McDonald and Shillcock (2003a) who recorded participants' eye movements as they read verb-noun expressions in which the noun was manipulated for TP. Their critical finding was that high TP words yielded shorter first fixation durations than low TP words, although this benefit did not extend to gaze duration or skipping (see also McDonald & Shillcock, 2003b for similar evidence using corpus data).

However, in a subsequent eye-movement study, Frisson et al. (2005) demonstrated that these apparent effects of TP may actually be effects of cloze probability. Although the nouns presented in McDonald and Shillcock (2003a)'s study were very low in cloze probability, high TP nouns were rated as 10 times more predictable than low TP nouns (.08 vs .008) meaning that these two measures may have been confounded. Frisson et al. tested this possibility by presenting the same verb-noun expressions as McDonald and Shillcock in contexts that were designed to be either neutrally or highly constraining. While they found effects of cloze probability on the early measures of first and single fixation duration, they also reported an effect of TP on gaze duration. Notably, however, cloze probability varied substantially between the high and low TP nouns in both context conditions, suggesting that this effect of TP was only present when cloze probability had not been controlled. A follow-up experiment in which cloze probability was controlled revealed significant effects of cloze probability but no significant effects of TP. This led Frisson et al. to conclude that predictability effects were more accurately captured by cloze probability rather than transitional probability (but see Andrews & Reynolds, 2013).

Predictability as surprisal and entropy effects.

Another set of approaches that have been used to estimate a word's predictability is *surprisal* and *entropy* which are information-theoretic metrics that quantify each word's processing load within a sentence (Hale, 2001; Levy, 2008). In recent years, these metrics have been applied to the estimation of word predictability during incremental sentence processing (Hale, 2016). The first of these metrics, *surprisal*, captures the extent to which a word is unexpected in its context. The surprisal of a word is measured by taking its negative log probability given its prior context: surprisal (w_i) = $-log\ P(w_i | w1 \ldots w_i - 1)$. As such, words with higher surprisal, i.e., a lower probability of occurring in a sentence, are harder to process, while words with lower surprisal, i.e., a higher probability of occurring in a sentence, are easier to process. A number of studies using different methodologies have demonstrated the effects of surprisal on online processing measures. Words with higher surprisal have been found to be more difficult to process than words with lower surprisal as indexed by longer reading times in eye-movement (e.g., Boston et al., 2008; Cevoli et al., 2022; Demberg & Keller, 2008; Lowder et al., 2018; Smith & Levy, 2013) and self-paced reading studies (e.g., Frank, 2013; Smith & Levy, 2013). High surprisal words have also been shown to yield larger N400 amplitudes in ERP studies (e.g., Frank et al., 2015; Szewczyk &

Federmeier, 2022) and increased levels of activation in brain regions that support language processing in fMRI studies (e.g., Hale et al., 2015; Henderson et al., 2016).

The second of these metrics, *entropy*, is a related, but less-studied, information-theoretic metric that captures the degree of uncertainty about how a sentence will unfold. The entropy of a word is measured by taking the negative sum of the probabilities of all outcomes in the sentence multiplied by the logarithm of the probabilities of the outcomes: entropy $H(X) = -\Sigma P(x) log_2 P(x)$. As such, the higher the entropy, the less constraining the text, i.e., entropy is maximal when all possible continuations of a sentence are probable. On the other hand, the lower the entropy, the more constraining the text, i.e., entropy is zero when there is absolute certainty about the next continuation. Unlike surprisal then, entropy captures the degree of certainty *before* a target word is reached which has led some researchers to posit that it reflects a better measure of predictability (e.g., Pickering & Gambi, 2018). However, only a few behavioural studies have reported a link between higher entropy, i.e., greater uncertainty, and increased reading times (e.g., Cevoli et al., 2022; Roark et al., 2009), so overall evidence of effects of entropy is limited.

The idea of entropy, however, has also been used to estimate a word's predictability in terms of *entropy reduction* (Hale, 2003, 2006, 2016). On the assumption that entropy shifts with each incoming word, entropy reduction ($H_i - H_{i-1}$) provides an index of the amount of cognitive processing effort applied by the comprehender for a given word. This means that a larger entropy reduction where uncertainty reduces from one word to the next requires more processing effort compared to a smaller entropy reduction where uncertainty does not change between words. Consistent with this, several studies have demonstrated that increases in entropy reduction are associated with increased reading times (e.g., Frank, 2013; Lowder et al., 2018; Wu et al., 2010), and that this measure appears to make an independent contribution to that of surprisal.

Taken together, these information-theoretic metrics of surprisal and entropy appear to provide some useful approaches to estimating a word's predictability. However, it is important to note some limitations associated with these metrics. Firstly, these metrics are fundamentally based on statistical information which may not reflect the cognitive mechanisms underlying predictability effects in human comprehenders. Secondly, because these metrics are derived from some type of statistical (e.g., n-gram, topic, hidden Markov models) or large language model (e.g., GPT, BERT), researchers are required to make a number of technical choices including the corpus on which to train the model and, perhaps more importantly, the language model itself, which requires some level of commitment to a theory of language (Lowder et al., 2018). Indeed, when Hofmann et al. (2022) compared three different language models (n-gram, topic, and recurrent neural network models) for computing surprisal, they found that each accounted for different and independent proportions of variance in early eye-movement measures, suggesting that the choice of language model had implications for the online processes captured during reading. Thus, it is likely for these reasons that surprisal and entropy have not been widely implemented as indices of predictability in psycholinguistic research.

Cloze probability as the gold standard?

As reviewed above, there are several different approaches to estimating a word's predictability. However, cloze probability derived from the cloze task remains the preferred metric among researchers. One obvious reason for this is that there are various limitations associated with the alternate metrics used to estimate a word's predictability. A second important reason is that cloze probability is derived from human comprehenders themselves, reflecting their perceptions of what word will come next in a given sentence context. This means that, unlike objective measures which are influenced by the co-occurrence of words and phrases in the text, cloze probability provides a subjective but purer measure of what researchers are after: how predictable a word is in a given context. A final advantage is that the participants recruited to complete cloze tasks are typically similar to the participants recruited to take part in reading comprehension tasks, meaning that researchers can be fairly confident about the predictions generated by the latter during online processing based on the cloze responses generated by the former under offline conditions. It is important to note though that the metric of cloze probability is not without its own limitations. Firstly, cloze probability values can be noisy and subject to response biases – for example, some participants may get bored and write overly simple responses while others may overanalyse or misinterpret the task and write overly elaborate or unnatural responses. Secondly, it has been questioned whether cloze probability reflects a genuine measure of word predictability. Staub et al. (2015) conducted a speeded cloze task in which participants produced responses for a given sentence context and found that words with high cloze probability were produced faster than words with low cloze probability. Notably, words with low cloze probability were also produced faster in strongly compared to weakly constraining sentences (see also Ness & Meltzer-Asscher, 2021) which led Staub et al. to posit that the cloze task captured a race between lexical units to accrue activation towards a response threshold as the sentence unfolded. In other words, cloze probability may reflect the effects of contextual activation rather than predictability *per se*. Despite these limitations, however, cloze probability still remains the gold standard for estimating a word's predictability in psycholinguistic research.

1.5.2 What is the function of the relationship between predictability and processing difficulty?

Given the link between predictability and how efficiently a given word is processed, substantial research has focused on quantitatively defining this relationship in order to provide insight into the scope of prediction during reading. The simplest account is that the relationship between predictability and processing effort is linear. That is, if predictions about upcoming words are generated according to a probability matching scale, increases in predictability should correspond to decreases in processing effort. An alternate account based on theories of surprisal (Hale, 2001; Levy, 2008) and the Bayesian Reader model (Norris, 2006) is that the function of the relationship is logarithmic which predicts that the ratio, rather than the raw difference, of predictability determines the processing effort between items – a difference in predictability of .05 compared to .1 should yield the same effect on processing as a predictability difference of .5 compared to 1. The key difference between these two accounts then is how they expect contextual information to affect the processing of very unpredictable words – while logarithmic accounts expect even small differences in predictability to lead to large processing effects, linear accounts expect these effects to be negligible. Determining which function underlies predictability effects is important for understanding whether readers use context to predict upcoming words in proportion to their probability or to preactivate information across the entire lexicon.

A number of studies using behavioural measures have provided evidence in favour of a logarithmic account of predictability effects (e.g., Rayner & Well, 1996; Shain et al., 2022; Smith & Levy, 2013). For example, Rayner and Well (1996) first observed this function when they recorded participants' eye movements as they read sentences containing a target word that was either high, medium, or low cloze probability. They found that while reading times did not differ between high and medium cloze words, reading times were significantly longer for low cloze words, consistent with the predictions of the logarithmic account. However, there are reasons to interpret these findings with caution given that a subsequent eye-movement study using the same stimuli by Rayner et al. (2006) yielded the opposite pattern of effects: shorter reading times for high cloze words, but no difference in reading times between medium and low cloze words. More generally, the predictability ratings for the medium cloze words in these studies ranged from 13-68% meaning that the condition was actually made up of both predictable and unpredictable words which could account for the mixed pattern of results.

A subsequent study by Smith and Levy (2013) also demonstrated evidence of a logarithmic relationship between predictability and processing effort when analysing gaze duration on English words extracted from the Dundee corpus (Kennedy et al., 2003) and self-paced reading times on words extracted from the Brown corpus of American English (Kucera & Francis, 1967). Using a trigram co-occurrence measure as an index of predictability, they found a logarithmic effect of predictability on gaze durations and self-paced reading times for probability values across six orders of magnitude (i.e., 1 to .000001), leading them to conclude that processing times were affected by all levels of predictability but especially by effects at the lower end of the probability distribution. More recently, a large-scale investigation by Shain et al. (2022) also reported evidence of logarithmic effects when evaluating reading times from three different modalities (eye movements, self-paced reading, MAZE; Freedman & Forster, 1985) on words extracted from six naturalistic reading datasets. Using surprisal derived from five statistical language models as an index of predictability, they found that word predictability had a logarithmic rather than linear effect on reading times in models that were either constrained or unconstrained to have some fixed predictability function, providing further support for a logarithmic account of predictability effects. However, it is important to note the limitations of analysing corpus data in which there is no experimental control and words can vary on multiple uncontrolled dimensions that influence the predictor of interest (Angele et al., 2015; Rayner et al., 2007). Moreover, the use of predictability estimates derived from language models trained on corpus data could introduce some systematic bias given that corpus probability has been shown to be weakly to moderately correlated with subjective cloze probability (r=.5; Smith & Levy, 2011) and instead strongly correlated with word frequency which also has a logarithmic effect on processing time (r=.8; Ong & Kliegl, 2008).

Indeed, Brothers and Kuperberg (2021) found evidence of a linear relationship between predictability and processing effort when addressing the methodological limitations of previous literature. Using cloze probability to estimate predictability in a meta-analysis of eye-movement data (N=218), they found that linear models of predictability provided a better fit for the eye-tracking data than logarithmic models. This linear relationship was confirmed in two further tasks using self-paced reading and cross-modal picture naming, although these tasks clearly differ from normal reading in many aspects. As such, it appears that addressing the methodological issues of previous studies that have reported evidence of a logarithmic relationship (i.e., the use of corpus-based designs and corpus-derived probability) reveals a linear account of predictability effects. However, the generalisability of these findings may be limited by the fact that predictability estimates derived from the cloze task are inherently less sensitive to probability differences between very unpredictable words which are necessary to demonstrate a logarithmic function. As such, it remains unclear whether these linear effects of word predictability reflect the genuine absence of a logarithmic function or the lack of sufficient precision at the lower end of the probability distribution to detect this function.

The final study of note here was conducted by Szewczyk and Federmeier (2022) who examined the function between predictability and processing effort as indexed by the N400 component. Although many ERP studies have implicitly endorsed a linear or logarithmic view of predictability by generating estimates from the cloze task or language models, respectively, Szewczyk and Federmeier conducted the first study to formally assess this relationship using ERP rather than behavioural measures. Specifically, they reanalysed ERP data from five datasets (*N*=138) in which participants read sentences that were completed either by a predictable or unpredictable word. They found that, for expected words, predictability estimated via a cloze task or language model was linearly related to the N400 component. However, for unexpected words, whose predictability estimates could only be derived accurately from a language model, they found that the relationship between predictability and the N400 component was instead logarithmic in nature. Furthermore, they also observed that both linear and logarithmic components contributed to variance in the early time frame of the N400 component (i.e., 300-400 ms poststimulus onset) but only the logarithmic effect remained in a later time frame, which led them to suggest that this neural waveform was sensitive to context-based effects of a semantic and lexical nature. In other words, while the logarithmic effect captured reductions in the N400 due to semantic overlap between an upcoming word and its preceding context, the linear effect captured additional attenuation of the N400 due to activation of a specific lexical representation.

Thus, Szewczyk and Federmeier concluded that readers did not just use prior context to predict specific lexical candidates but also to preactivate relevant semantic information.

Taken together, there appear to be some inconsistencies across and within methodologies when quantitatively defining the relationship between predictability and processing effort. While studies using behavioural methods (Brothers & Kuperberg, 2021; Rayner & Well, 1996; Shain et al., 2022; Smith & Levy, 2013) provide evidence that this relationship could be either linear or logarithmic, one recent study using the ERP method (Szewczyk & Federmeier, 2022) suggests that this relationship combines both functions because of two separate, but temporally overlapping, context-based mechanisms during reading. There are several factors that could contribute to these discrepancies. Firstly, these discrepancies could reflect the obvious differences in the measures used to index processing effects, i.e., behavioural (e.g., eye movements, self-paced reading, and MAZE) versus ERP. Indeed, as previously mentioned, the findings of ERP studies should be interpreted with caution given that they typically employ the unnatural RSVP paradigm which could encourage readers to engage in different strategic processes to what they would during normal reading. Secondly, these discrepancies could be related to differences in how researchers have operationalised word predictability. Cloze tasks and language models differ substantially in how well they can estimate probability differences in unpredictable words (see Cevoli et al., 2022), which is precisely the lower end of the probability distribution that distinguishes linear and logarithmic effects. Finally, predictability effects themselves could reflect different underlying functions. Real-time language comprehension may involve using contextual information to not only predict specific lexical candidates but also to preactivate relevant information such as morphosyntactic, syntactic, and semantic features of upcoming words (Burnsky et al., 2022; Szewczyk and Federmeier, 2022); although, under certain circumstances, readers may preferentially apply one strategy over the other (Federmeier, 2022).

1.5.3 What stage of processing does predictability affect?

Another theoretical issue that has interested researchers is determining which stage(s) of processing is/are affected by effects of predictability. The answer to this issue is important for the broader question of whether or not predictability effects reflect genuine prediction processes, which would be expected to impact early lexical processing. As reviewed in Section 1.4, however, effects of predictability appear to be evident across the entire time course of processing.

One way in which researchers have been able to explore this issue further has been by investigating the effects of predictability on word recognition in sentence contexts. In general, word identification in context can be conceptualised as being made up of three stages: the *prelexical processing stage* which involves any processing that occurs before lexical access such as the selection of a word's visual and orthographic features, the *lexical processing* or *lexical access stage* which involves matching this sensory information to a representation in the mental lexicon, and the *postlexical processing stage* which involves any processing that occurs after lexical access. Several factors that have been identified as having an impact on distinct stages of word identification are word frequency, parafoveal preview, and stimulus quality. Investigating how these factors interact with contextual information has the potential to provide insight into the stage(s) of processing affected by word predictability. Based on the Additive Factors logic proposed by Sternberg (1969), interactive effects would suggest that these variables affect the same stage of processing while additive effects would suggest that these variables affect different stages of processing. The following subsections review studies that have manipulated each of these factors, and how these effects interact with predictability.

Predictability and word frequency effects.

The frequency of a word, as indexed by how often it occurs in corpora of written and/or spoken text, is one of the most robust predictors of the speed and accuracy of word identification. For example, in studies using eye movements, words that are higher frequency yield more skips (e.g., Drieghe et al., 2005; Rayner & Raney, 1996) and shorter first fixation and gaze durations (e.g., Inhoff & Rayner, 1986; Rayner & Duffy, 1986) than words that are lower frequency. The fact that these effects are observed on the earliest possible eye-movement measures is consistent with the idea that word frequency exerts its influence on early stages of processing. Similarly, in studies using ERPs, high frequency words yield smaller N400 components than low frequency words, although this effect is observed more consistently when words are presented in lists (e.g., Barber et al., 2004; Grainger et al., 2012; Rugg, 1990) or at the beginning of a sentence rather than in later positions (e.g., Dambacher et al., 2006; Van Petten & Kutas, 1990). While it is debated whether this ERP component necessarily reflects lexical processing (e.g., Kutas & Federmeier, 2011; Nieuwland et al., 2020), ERP research has also revealed effects of frequency in the earliest N1 time range, i.e., approximately 130-200 ms poststimulus onset (Hauk & Pulvermüller, 2004; Sereno et al., 1998). Thus, across different methodologies, evidence of frequency effects has been taken as evidence that lexical access has occurred (Sereno & Rayner, 2000, 2003).

Given the robust early influence of word frequency, researchers have been able to gain some insight into the temporal locus of predictability effects by investigating whether predictability interacts with frequency effects. According to modular views of language processing (e.g., Fodor, 1983; Forster, 1979), word predictability only operates during postlexical processing. Because this implies that predictability and frequency affect different stages of processing, these two variables should show additive effects on word recognition based on Sternberg's (1969) Additive Factors logic. According to more interactive views of language processing (e.g., McClelland, 1987; Morton, 1969), however, word predictability does influence lexical processing. Given that this implies that predictability and frequency affect the same stage of processing, there should be evidence of an early interaction between these two variables. That is, as formalised by probabilistic models which propose that frequency effects function as predictability effects (e.g., Hale, 2001; Levy, 2008; Norris, 2006), the predictability effect should be more pronounced for low compared to high frequency words. If a low frequency word is difficult to process, then placing it in a predictive context should facilitate its processing. However, a high frequency word may not benefit as much from a predictive context because it is already easy to identify.

Early behavioural studies demonstrated evidence of interactive effects of predictability and frequency (e.g., Becker, 1979; Stanovich & West, 1981, 1983; West & Stanovich, 1982). For example, Stanovich and West (1981, 1983) used a naming task to test the effects of predictability on pronunciation latencies of high and low frequency words. They found significant main effects of predictability and frequency, as well as an interaction in the direction described above, i.e., larger predictability effects for low compared to high frequency words, suggesting that contextual information did interact with word frequency to determine how easily a word was identified. Similar patterns of interaction effects have also been reported in studies using lexical decision tasks (e.g., Becker, 1979; West & Stanovich, 1982). However, there are reasons to question the extent to which these findings from behavioural tasks can be generalised to normal reading. For example, the presentation of the target word was always delayed relative to the preceding context which could have encouraged readers to adopt different strategic processes to that of normal reading. Moreover, the specific task demands of naming and lexical decision may recruit processing strategies that are not part of normal reading comprehension (Rayner & Liversedge, 2011).

Studies using eye movements and ERPs which are able to investigate reading processes under more natural conditions, however, have yielded contradictory evidence about the combined effects of predictability and frequency. For example, eye-movement studies that have factorially manipulated the two variables have reported main effects of each on fixation durations but no significant interaction (e.g., Altarriba et al., 1996; Ashby et al., 2005; Gollan et al., 2011; Hand et al., 2010; Rayner et al., 2004; Staub, 2020). Instead, some of these eye-movement studies trend towards the expected interaction where predictability effects are larger for low compared to high frequency words (e.g., Altarriba et al., 1996; Rayner et al., 2004), while others trend in the opposite direction where predictability effects are larger for high compared to low frequency words (e.g., Gollan et al., 2011). The pattern of these effects on skipping is less clear but, in general, there is also little evidence of interactive effects in the eye-movement record (see Staub, 2015 for a review). Furthermore, eye-movement studies that have investigated these variables using corpus data have also found no evidence of interaction effects (e.g., Kennedy et al., 2013; Kliegl et al., 2004). Thus, the repeated absence of significant interactions has led eye-movement researchers to conclude that these variables have additive, non-interactive effects during reading, suggesting that word predictability may not operate at the same stage of processing as word frequency. In other words, the predictability of a word may not exert its influence during lexical access itself.

In contrast, ERP studies have reported evidence of interactive effects of predictability and frequency on several different neural waveforms (see Sereno et al., 2019 for a review). The N400 component, for instance, is sensitive to effects of predictability that are larger for low compared to high frequency words presented in sentence contexts (e.g., Dambacher et al., 2006; Payne et al., 2015; Sereno et al., 2019; Van Petten & Kutas, 1990). Early ERP components such as the P1, which occurs approximately 80-120 ms poststimulus onset (e.g., Sereno et al., 2019), and the N1 (e.g., Sereno et al., 2003) have also yielded similar interaction effects. As such, these early interactive effects have led ERP researchers to conclude that word predictability does in fact modulate word frequency effects during lexical processing.

Thus, there appear to be two distinct patterns of predictability-frequency effects on online processing measures – eye-movement studies suggest that these variables yield additive effects while ERP studies suggest that they yield interactive effects which has implications for determining the temporal locus of predictability effects. There are two factors that could account for this discrepancy. Firstly, differences in the stimuli presentation method may be important because, as described above, ERP studies typically use the unnatural RSVP paradigm which could encourage the use of strategies that are not part of normal reading. Secondly, eye movements and ERPs may capture fundamentally different online processes during reading. Kretzschmar et al. (2015) investigated these two possibilities by presenting participants with sentences containing target words manipulated for predictability and frequency while simultaneously recording eye movements and EEG which allowed the latter to be time-locked to the onset of the fixation of the target word. As expected, in the eye-movement record, they replicated the additive effects of both variables on first fixation and gaze duration. However, in the fixation-related potential (FRP) record, they found effects of predictability on the N400 component, but no evidence of frequency effects or an interaction between the two variables. While the finding that predictability effects were evident in both methodologies led Kretzschmar et al. to conclude that the two distinct processing patterns overall were unlikely to be due to differences in stimuli presentation method alone, the fact that there were also no interactive effects in either methodology suggests that the unnatural RSVP paradigm may have contributed to evidence of interaction effects in previous ERP studies. However, the finding that frequency effects differed across both methodologies also indicated that the overall discrepancy could reflect the different underlying functions of eye movements and ERPs (see also Degno et al., 2019). Specifically, Kretzschmar et al. posited that the N400 component was sensitive not to processing difficulty during the lexical stage of processing but to the interplay between bottom-up and top-down processing which was more likely to prioritise predictability over frequency information under natural reading conditions. In other words, while the eye-movement record captures effects of predictability that reflect early stages of processing, the ERP records captures the effects of predictability that reflect more general semantic access (see also Burnsky, 2022; Federmeier, 2022).

Taken together, it remains far from clear what the nature of the relationship is between predictability and frequency and, in turn, the stage(s) of processing affected by predictability effects. While eye-movement data suggest that word predictability does not operate during the lexical processing stage, ERP data suggest that it does, although whether this finding is specific to the stimuli presentation method or the N400 component needs to be clarified further. The following subsections turn to discussing other factors that might provide clearer insight into the stage(s) of processing affected by word predictability.

Predictability and parafoveal preview effects.

This section so far has focused on the effects of predictability on word identification that are derived from text that lies at, or to the left of, the point of fixation. However, there is another source of information that lies to the right of the point of fixation, i.e., upcoming words in the parafovea.

The effects of parafoveal processing are typically investigated in eye-movement studies using the gaze-contingent *boundary paradigm* in which a target word is replaced by a preview word in its location until readers' eyes cross an invisible, predefined boundary at the end of the pretarget word (Rayner, 1975). Because readers are not usually aware of this display change due to saccadic suppression (Matin, 1974), this paradigm can be used to infer the types of information extracted parafoveally by comparing eye movements on target words between conditions displaying different types of information in parafoveal vision. The use of this technique has revealed a characteristic *parafoveal preview benefit* whereby targets following a valid preview (i.e., identical) compared to invalid preview (e.g., an unrelated word, pseudoword, or nonword) receive facilitated processing – although part of this effect likely reflects a preview cost from encountering misleading information parafoveally (Kliegl et al., 2013). Numerous experiments have converged on the finding that readers are able to preprocess orthographic, phonological, morphological, and some semantic information from upcoming words (see Andrews & Veldre, 2019; Schotter et al., 2012 for reviews). Given that parafoveal preview effects are generally interpreted as emerging during prelexical and lexical processing, investigating whether contextual information interacts with parafoveal information could provide further insight into the stage(s) of processing affected by word predictability.

Balota et al. (1985) conducted one of the first eye-movement studies to jointly investigate the effects of predictability and parafoveal preview during reading. Participants in this study were presented with sentences like "*Since the wedding was today, the baker rushed the wedding…*" which were completed by either the predictable word "*cake*" or an unpredictable but plausible word such as "*pies*". The type of preview information available before the reader fixated on the target word was also manipulated – the preview was either valid (i.e., the target word itself, e.g., "*cake*"), a non-word that was visually similar to this target (e.g., "*cahc*"), the other possible target word (e.g., "*pies*"), a non-word that was visually similar to this other target (e.g., "*picz*"), or an unrelated and visually dissimilar word (e.g., "*bomb*"). Balota et al. reported several important findings. Firstly, they observed higher skipping rates for predictable compared to unpredictable words when following a valid identical preview (i.e., "*cake*") and, to a lesser extent, an invalid but visually similar preview (i.e., "*cahc*"), suggesting that predictability-based skipping required a preview that at least visually matched the predictable word. Secondly, they observed an interaction between predictability and parafoveal preview validity on gaze duration because the predictability benefit was only present when following a preview that was identical or visually similar, providing further evidence that predictability effects require at least partial parafoveal preview information.

These interactive effects whereby the predictability effect is eliminated for invalid but not valid previews has since been demonstrated in a number of eye-movement studies, particularly on early reading measures (e.g., Burnsky et al., 2022; Chang et al., 2020; Luke, 2018; Staub & Goddard, 2019; Veldre & Andrews, 2018). Staub and Goddard recently provided an interpretation of these eye-movement patterns, suggesting that, when readers are denied valid previews, orthographic processing of the target word must unfold entirely in foveal vision, meaning that perceptual information is too clear for predictability information to have an effect on early processing stages. In contrast, when readers have access to valid previews, orthographic processing of the target word begins in parafoveal vision with the support of contextual information. From this perspective, it appears that word predictability exerts its influence when words are viewed parafoveally, i.e., based on degraded visual input before they are directly fixated. In other words, the effects of predictability may arise during the earliest stages of processing.

Further evidence of this comes from a recent co-registration study by Burnsky et al. (2022). Although most investigations of parafoveal processing effects have used eye-movement methods because ERP methods traditionally adopt the RSVP paradigm which does not allow for parafoveal processing, the development of the co-registration paradigm in which eye movements and EEG are simultaneously recorded has allowed researchers to investigate the relationship between parafoveal preview validity and different linguistic manipulations (see also Degno et al., 2019). Burnsky et al. presented participants with strongly and weakly constraining sentences containing the same target word that was either high or low cloze probability, respectively. The preview of the target word was manipulated so that it was either identical or a contextually implausible word that was unrelated. In the eye-movement record, they found interaction effects on early reading measures in the expected direction, i.e., predictability effects for valid but not invalid previews on early reading measures. In the FRP record, however, they also found an interaction but in the opposite direction because the predictability effect on the N400 time-locked to the onset of the fixation of the target word was larger for invalid compared to valid previews. Critically, this was reversed on the pre-target fixation: the N400-predictability effect was larger for valid compared to invalid previews, which was concluded to be consistent with Staub and Goddard's (2019) proposal that word predictability only exerts its effects when words are viewed in parafoveal vision.

Taken together, there appears to be reliable evidence across methodologies that predictability interacts with parafoveal information, suggesting that the temporal locus of word predictability is either during prelexical processing or very early lexical processing. If this is the case, predictability should also interact with factors that affect the earliest stages of letter or word processing such as stimulus quality. This possibility is considered in the next subsection.

Predictability and stimulus quality effects.

The quality of a stimulus has been shown to influence how long readers spend processing a word (e.g., contrast reduction, Becker & Killion, 1977; dot-pattern degradation, Meyer et al., 1975). One of the most naturalistic ways to manipulate stimulus quality is by adjusting the contrast between the word and its background, also known as *contrast reduction*. A number of studies using this method have shown that words that are presented in faint text tend to receive longer reading times on first fixation and gaze duration than words presented normally (e.g., Drieghe, 2008; Reingold & Rayner, 2006; White & Staub, 2012). The fact that these effects emerge on early reading measures has been taken to suggest that stimulus quality affects the early stages of word identification during which visual features are encoded and abstract letters are computed (Besner & Roberts, 2003). As such, if it is the case that word predictability modulates an early stage of processing, as indicated by its interaction with parafoveal information, predictability should also interact with the quality of the visual stimulus.

However, the question of whether stimulus quality interacts with higher-order information including predictability has received little investigation in the literature. The earliest relevant findings come from studies using lexical decision which reported that stimulus quality interacted with semantic priming because priming effects were larger for degraded compared to intact targets (e.g., Balota et al., 2008; Borowsky & Besner, 1993). On the assumption that a semantic prime in a lexical decision task functions like contextual information during normal reading in that both involve the preactivation of general semantic information and/or a specific lexical unit (Staub, 2015), these findings point to the possibility that word predictability may operate at the same stage of processing as stimulus quality. However, two recent studies investigating this issue using a more direct predictability manipulation have revealed a different set of findings. The first study conducted by Staub (2020) recorded participants' eye movements as they read sentences containing target words that were factorially manipulated for predictability and stimulus quality. While they found main effects of both variables, the interaction effect was very small and statistically unreliable albeit in the expected direction, i.e., the predictability effect was larger for faint compared to normal text. A subsequent study conducted by Burnsky et al. (2022) using a similar design via the co-registration of eye movements and EEG replicated these eye-movement patterns. In the FRP record, they also found effects of predictability but no evidence of stimulus quality effects or an interaction between the two variables. Thus, in the only two studies to directly investigate this issue, there appears to be little evidence of the interactive effects that would be expected if predictability operates at the same stage of processing as the effects of stimulus quality.

In summary, the findings across three separate literatures investigating how predictability interacts with factors that have been identified to impact word identification demonstrate that it remains unclear which precise stage(s) of processing is/are affected by a word's predictability. While it appears that word predictability does not influence lexical processing given that it does not reliably interact with frequency effects, evidence that it influences an even earlier stage of processing is mixed given that it interacts with preview validity but not stimulus quality. A tentative conclusion is that predictability effects operate at a very specific early stage of processing when words are viewed in parafoveal vision, which would be consistent with the idea that readers engage in the prediction of upcoming words in advance of their presentation. What is clear from these findings though is that, contrary to the classic modular views of language processing (e.g., Fodor, 1983; Forster, 1979), the effects of predictability do not appear to be restricted to postlexical stages of processing. Instead, it is likely that predictability exerts its influence across the entire time course of processing. The precise mechanisms implicated by "predictability effects" are addressed in the next section.

1.5.4 Do predictability effects index prediction?

In this chapter so far, evidence of predictability effects has been taken to index genuine prediction processes – if a word can be predicted in advance of its presentation then the way in which this word is processed when eventually encountered may reflect its level of predictability (Kutas et al., 2011). However, these predictability effects are also consistent with two alternative accounts: integration processes and/or priming processes. The following subsections review each of these possibilities.

Predictability effects as integration processes.

The most plausible alternative account of predictability effects is that they reflect *postlexical integration processes*, i.e., when a comprehender combines linguistic information that is activated as a result of processing the current input with a representation of the preceding input (Kutas et al., 2011; Pickering & Gambi, 2018; Van Petten & Luka, 2012). For example, consider again the first example presented in this chapter: "*The day was breezy so the boy went outside to fly a*…" for which the high cloze completion "*kite*" is processed the most efficiently. According to the prediction view, "*kite*" receives facilitated processing because comprehenders have activated it in advance of its presentation, making it easier to process than a low cloze completion like "*airplane*" which is unlikely to have been activated. According to the integration view, however, "*kite*" is still easier to process even if it has not been predicted because comprehenders have activated linguistic information related to "*kite*" based on the preceding input (e.g., some type of flying object with a boy as an agent), but, importantly, not the lexical item itself. As such, when "*kite*" is encountered, it is easier to integrate by combining the word's meaning with the representation of the preceding input.

While these two accounts of predictability effects can be distinguished theoretically, it can be difficult to find empirical evidence that is compatible with prediction but not integration processes. As discussed in Section 1.3, there are a few electrophysiological studies that have been able to demonstrate clear evidence of prediction by revealing that a word has been activated even before it has been encountered by the comprehender (e.g., DeLong et al., 2005; Van Berkum et al., 2005; Wicha et al., 2003a; Wicha et al., 2003b; Wicha et al., 2004); however, these studies are in the minority given issues with designing such manipulations, especially in English, and because some of these effects have proven difficult to replicate. As such, all other predictability effects described in the previous sections could be compatible with an integration account given that they involve measuring online processing that occurs during and not before the critical target word. Eye-movement evidence of fewer skips, shorter fixation durations, and fewer regressions for predictable words could reflect the fact that readers were faster to integrate these completions (see Veldre et al., 2020 for E-Z Reader simulations showing that skipping effects can be due to postlexical integration). More generally, even if predictability effects capture genuine prediction processes, the fact that some of these effects emerge on relatively late measures such as total fixation duration and the probability of regressions suggests that predictability effects may *also* have some postlexical impact. Furthermore, ERP evidence that predictability effects attenuate the N400 component could also reflect the fact that fewer neural resources were required to integrate predictable words into existing sentence representations (Brown & Hagoort, 1993; Hagoort et al., 2009). Given the prominent role of both prediction and integration processes, it is plausible that both contribute to predictability effects during real-time language comprehension.

Predictability effects as priming processes.

An alternate account of predictability effects is that they reflect simple priming processes. Based on associative neural networks of stored lexical information, automatic spreading activation from a prime could trigger information that makes it easier to process a subsequent target (e.g., Collins & Loftus, 1975). For example, consider a passage like "*The brave knight saw that the dragon threatened the benevolent sorcerer. Quickly he reached for his…*" for which the most predictable completion is the word "*sword*" (Otten & Van Berkum, 2008). Evidence of facilitated processing for "*sword*" relative to a less predictable word such as "*lance*" could reflect the fact that the former was activated, not because of genuine prediction processes based on the prior context, but because of spreading activation due to the presence of semantically related primes such as "*knight*", "*brave*", and "*dragon*". Indeed, target words primed by strong semantic associates have been shown to receive facilitated processing on response times (e.g., Neely, 1977), fixation durations (e.g., Camblin et al., 2007; Carroll & Slowiaczek, 1986; Traxler et al., 2000) and N400 amplitudes (e.g., Boudewyn et al., 2012). However, given that simple priming via spreading activation is assumed to be a passive process entailing the use of lower-level information to activate information at the same representation level (e.g., Duffy et al., 1989; Forster, 1981) – in contrast to anticipatory prediction which is understood to be an active, top-down process in which higher-level information is used to preactivate upcoming information at lower levels of representation – it is important to distinguish the potential contributions of both processes on predictability effects.

However, like the distinction between prediction and integration accounts described above, distinguishing priming processes from prediction can be difficult. Most studies investigating predictability effects use predictive contexts which are inherently more likely to contain primes that are related to the predictable target than non-predictive contexts. This could explain why relatively few studies to date have directly investigated this question.

One relevant study was conducted by Calvo and Meseguer (2002) who recorded participants' eye movements as they read passages that were either constraining or non-constraining towards a target word. Critically, the preceding context for both passages always contained the same set of words that could prime the target via associative links. Calvo and Meseguer found that while cloze probability was a significant predictor of late, but not early, eye-movement measures in the constraining passages, cloze probability did not affect any reading measures in the non-constraining passages, leading them to conclude that readers' eye-movement behaviour was determined by the effects of predictability rather than semantic priming. However, it should be noted that cloze probability of the targets was not matched across the passages – the mean target cloze probability was .96 in the constraining passages but only .04 in the non-constraining passages which could have contributed to the predictability effects observed in the former condition.

A more tightly controlled study by Otten and Van Berkum (2008) also investigated whether effects of predictability could be separated from semantic priming. In this study, readers' ERP responses were recorded as they read constraining or non-constraining sentences which were completed by an anomalous completion. Importantly, the preceding context also contained the same set of priming words. Their critical finding was that anomalous words presented in constraining contexts yielded a different ERP component to the same anomalous words presented in non-constraining contexts, suggesting that readers were sensitive to the presentation of a word that was inconsistent with their expectations. These findings led Otten and Van Berkum to conclude that effects of predictability did capture genuine prediction processes rather than merely the presence of primes.

Taken together, it appears that effects of predictability during reading cannot be entirely attributable to priming processes. However, like integration processes, it is likely that there is some role for priming during real-time language comprehension. As suggested throughout this chapter, prediction may involve not only the activation of individual words but the rapid convergence of semantic information in the prior context.

1.5.5 Summary.

There have been a range of empirical issues covered in this section relating to predictability effects during reading. Put together, the overall picture that emerges is that, to a certain extent, effects of predictability can be taken as demonstrating evidence that the language processor engages in linguistic prediction. However, as reviewed in more detail in the next section, there are clearly several empirical issues that remain unresolved. For example, is there further compelling evidence that the effects of predictability arise during early stages of processing or even before the critical word has been encountered which would provide the clearest demonstration of prediction? Moreover, does prediction involve predicting a specific lexical item or preactivating more general semantic information? Finally, do all readers make use of prediction strategies during online processing to the same extent?

1.6 Ongoing empirical challenges for language prediction

The following section discusses several unresolved empirical issues that are important for addressing the broader question of whether prediction plays a fundamental role in real-time language comprehension as posited by several theoretical accounts (e.g., Ferreira & Chantavarin, 2018; Huettig, 2015; Kuperberg & Jaeger, 2016; Lupyan & Clark, 2015; Pickering & Gambi, 2018).

1.6.1 Are there processing costs for misprediction?

The investigation of predictability effects during reading has typically focused on examining the processing benefits that arise from predicting linguistic input that is subsequently presented to the comprehender. However, as reviewed in Section 1.5, these predictability effects have led to questions about whether they reflect genuine prediction processes. Firstly, it is unclear whether word predictability reliably influences early stages of processing as would be expected if upcoming linguistic content is predicted in advance of its presentation – predictability effects have been shown to interact with some factors that impact the early stages of word identification (i.e., parafoveal preview; Balota et al., 1985; Burnsky et al., 2022; Chang et al., 2020; Luke, 2018; Staub & Goddard, 2019; Veldre & Andrews, 2018) but not others (i.e., stimulus quality; Burnsky et al., 2022; Staub, 2020). Secondly, it is also unclear whether predictability effects capture integration processes – facilitated processing for a predictable word in a constraining context could reflect the fact that it was activated in advance of its presentation, but it could also reflect the fact that it was easier to integrate into the preceding context (Kutas et al., 2011; Pickering & Gambi, 2018; Van Petten & Luka, 2012).

As such, another way in which researchers have been able to assess whether predictability effects reflect genuine prediction processes is by looking for evidence of the processing costs that would be expected to arise from predicting linguistic input that is subsequently disconfirmed. For example, consider a strongly constraining sentence frame like “*The children went outside to…*” for which the most predictable completion is the word "*play*". If this prediction were to be disconfirmed by a plausible but unexpected completion like "*look*", a *prediction error cost* should occur due to the mismatch between the word activated by the context and the input eventually encountered. However, the same, unpredictable completion "*look*" should not elicit a processing cost in a weakly constraining sentence frame like "*Joy was frightened to*…" given that readers are unlikely to have made any firm predictions about the upcoming text in advance. Thus, this paradigm can be used to infer whether the language processor has made any predictions about upcoming text by comparing how unexpected input is processed in strongly compared to weakly constraining contexts.

However, as elaborated in Chapters 2-4, there are notable inconsistencies about whether disconfirmed predictions give rise to the processing costs that would be expected to accompany linguistic prediction. Given that evidence of prediction error costs represents a useful diagnostic of whether the language processor routinely engages in prediction during real-time language comprehension, the current thesis aims to systematically investigate if and when the processing costs of misprediction arise during reading.

1.6.2 What exactly do readers predict?

On the assumption that readers do make use of prediction during real-time language comprehension, most psycholinguistic research to date has implicitly, if not explicitly, defined prediction as the "all-or-none process of activating a linguistic term (a word) in advance of perceptual input" (DeLong et al., 2014b, p. 632). This predictive process is assumed to yield processing benefits if predictions turn out to be correct, but processing costs if they turn out to be incorrect. Moreover, readers are only thought to predict a specific lexical candidate if the context is sufficiently constraining. Thus, this is the type of prediction that early researchers were initially opposed to given that most naturally occurring text is neither predictive nor constraining (e.g., Luke & Christianson, 2016). As elaborated in this chapter so far, there is some evidence to suggest that readers do engage in this type of prediction during online processing, which will be referred to as *lexical prediction* through the rest of this thesis.

An alternative definition that has been proposed in more recent years is that prediction involves the partial preactivation of upcoming words even if their full lexical identity cannot be predicted from the prior context (e.g., Brothers & Kuperberg, 2021; Federmeier, 2022; Luke & Christianson, 2016; Staub, 2015; Staub et al., 2015). Consistent with this view, a number of studies have shown that readers preactivate relevant information about upcoming words including syntactic structures (e.g., Cutter et al., 2022; Staub & Clifton, 2006), orthographic and phonological forms (e.g., Delong et al., 2005), and semantic features (e.g., Federmeier et al., 2002; Frisson et al., 2017; Luke & Christianson, 2016). This predictive process termed *graded prediction* is assumed to involve the passive activation of information related to the current discourse as part of the natural organisation of long-term memory in response to incoming linguistic input (Federmeier, 2022). As such, it is unlike lexical prediction because multiple lexical candidates can be generated for each upcoming word of a sentence without incurring any processing costs if they turn out to be incorrect. While there is accumulating evidence in the literature to support this type of prediction (see Staub, 2015 for a review), it remains unclear if and how graded prediction can be reconciled with lexical prediction within the overall framework of real-time language comprehension. One proposal that is explored throughout the current thesis is that these types of predictions are not mutually exclusive and that readers make use of both depending on their circumstances.

1.6.3 Do all readers predict?

While there is evidence that readers generate predictions about upcoming linguistic content during reading, most of these findings have been drawn from the reading patterns of skilled young, monolingual adult readers. In order to claim that prediction has a central role in real-time language comprehension, it is necessary to examine the extent to which other populations of readers make use of prediction strategies during online processing. However, evidence that all readers engage in prediction during reading remains elusive (Huettig & Mani, 2016). Instead, predictive processing appears to depend on a variety of factors including language experience and cognitive abilities.

Evidence that prediction depends on language experience comes from various investigations of children and adults with varying levels of literacy skills or language exposure. For example, a number of studies have shown that children across a range of ages predict upcoming linguistic content (e.g., 2-year-olds: Mani & Huettig, 2012; 6-year-olds: Nation et al., 2003; 8-year-olds: Mani & Huettig, 2014; 3-10-year-olds: Borovsky et al., 2012; but see Gambi et al., 2018). However, these predictive abilities appear to depend on individual differences in vocabulary (e.g., Borovsky et al., 2012; Mani & Huettig, 2012) and reading ability (e.g., Mani & Huettig, 2014), suggesting that prediction may be linked to one's degree of language experience which takes time to develop (e.g., Bion et al., 2013). Similarly, studies of adults have revealed that non-native speakers are slower and less likely to generate linguistic predictions than native speakers (see Ito & Pickering, 2021 for a review), although a subset of L2 speakers with high proficiency appear to exhibit native-like patterns of prediction (e.g., Dussias et al., 2013; Hopp, 2013). Finally, several studies have shown that adults with higher literacy skills have stronger predictive abilities than adults with lower literacy skills (e.g., Favier et al., 2021; Mishra et al., 2012; Ng et al., 2017). Taken together, these findings suggest that language experience plays an important role in readers' ability to generate predictions during online processing.

Unlike the relationship between prediction and language experience, fewer studies have assessed how prediction is mediated by cognitive abilities. If predictions are generated via the interplay between bottom-up input and top-down information as posited by predictive processing frameworks (Clark, 2013; Friston, 2010; Hohwy, 2013, 2020), cognitive abilities such as working memory and processing speed would be expected to modulate readers' prediction processes. Indeed, some studies have revealed that predictive eye movements are sensitive to readers' working memory and processing speed abilities (Huettig & Janse, 2016), as well as general memory load (Ito et al., 2018). While further research is clearly necessary, the preliminary picture that has emerged indicates that there is some role for cognitive abilities in readers' propensity to generate predictions during online processing.

Given the importance of language experience and cognitive abilities for predictive processing, it is unsurprising that researchers have been interested in how linguistic prediction unfolds in older readers (60+ years). Older readers have accumulated more language experience via reading over the course of their lifetime (Payne et al., 2012; Ryskin et al., 2020) meaning that they should be able to generate predictions that are more precise and fine-grained compared to their younger counterparts. However, normal ageing is also accompanied by an array of cognitive changes including lower processing speed, reduced attention and executive control, and smaller working memory (see Verhaeghen, 2013 for a review), which could simultaneously impact older readers' ability to engage in prediction. As such, investigating how older readers make use of predictive strategies during online processing should provide further insight into how linguistic prediction changes across the lifespan and, as such, whether it has a fundamental role in real-time language comprehension. However, as elaborated in Chapter 4, there are apparent inconsistencies as to whether older readers make use of prediction processes during reading. Thus, the current thesis investigates this issue further by examining whether older readers show evidence of processing costs for misprediction during reading.

1.7 A look ahead to the thesis

This chapter provided an overview of the current literature relating to prediction processes during reading focusing on evidence from predictability effects. However, there remain several unresolved empirical issues which are important for the broader question of whether prediction plays a fundamental role in how real-time language comprehension is able to unfold so rapidly and effortlessly (e.g., Ferreira & Chantavarin, 2018; Huettig, 2015; Kuperberg & Jaeger, 2016; Lupyan & Clark, 2015; Pickering & Gambi, 2018). To this end, the studies reported in the present thesis aim to systematically investigate how readers make use of predictive strategies during online processing, focusing in particular on the consequences of misprediction. The primary methodology used in the present research is eye-movement recording given its ability to measure online processing under natural reading conditions; however, the self-paced reading paradigm is also utilised to assess whether differences in stimuli presentation method impact predictive processing.

Chapter 2 reports an eye-movement experiment that investigates whether prediction error costs depend on the source of constraint violation provided by the context preceding the misprediction. Chapter 3 reports three eye-movement experiments that examine whether the consequences of misprediction extend beyond online processing in the moment. Chapter 4 reports separate eye-movement and self-paced reading experiments that assess whether older readers are sensitive to the processing costs of misprediction and provides a comparison to a sample of younger readers. Finally, Chapter 5 discusses the implications of the findings for theories of predictive processing and outlines some potential future research directions.

CHAPTER 2: Are there Independent Effects of Constraint and Predictability on Eye Movements during Reading?

The contents of this chapter are a minor revision of Wong, R., Veldre, A., & Andrews, S. (2022). Are there independent effects of constraint and predictability on eye movements during reading*? Journal of Experimental Psychology. Learning, Memory, and Cognition*.

2.1 Abstract

Evidence of processing costs for unexpected words presented in place of a more expected completion remains elusive in the eye-movement literature. The current study investigated whether such prediction error costs depend on the source of constraint violation provided by the prior context. Participants' eye movements were recorded as they read predictable words and unpredictable alternatives that were either semantically related or unrelated in three-sentence passages. The passages differed in whether the source of constraint originated solely from the global context provided by the first two semantically rich sentences of the passage; from the local context provided by the final sentence of the passage; from both the global and local context; or from none of the three sentences of the passage. The results revealed the expected processing advantage for predictable completions in any constraining context, although the relative contributions of the different sources of constraint varied across the time course of word processing. Unpredictable completions, however, did not yield any processing costs when the context constrained toward a different word, instead producing immediate processing benefits in the presence of any constraining context. Moreover, the initial processing of related unpredictable completions was enhanced further by the provision of a supportive global context. Predictability effects therefore do not appear to be determined by cloze probability alone but also by the nature of the prior contextual constraint especially when they encourage the construction of higher-level discourse representations. The implications of these findings for understanding existing theoretical models of predictive processing are discussed.

2.2 Introduction

The notion that readers generate predictions during online language comprehension has been a source of ongoing debate. Early accounts of language processing argued against a role for prediction in natural reading because, given the endless possible ways for linguistic input to unfold, highly predictable words were too rare for this processing mechanism to be useful or efficient (Jackendoff, 2002; see Van Petten & Luka, 2012 for discussion). For example, based on the cloze task in which an independent group of participants reports the first continuation that comes to mind for an unfinished sentence frame (Taylor, 1953), Luke and Christianson (2016) observed that in an analysis of naturalistic texts only 5% of words were highly predictable (>.67 cloze probability) and overall cloze probability was only .13. More recent accounts of language processing, however, have argued that the noisy and informationally dense input of natural language could not be processed so effortlessly and efficiently unless it was facilitated by readers generating predictions for upcoming text ahead of time (Clark, 2013; Friston, 2010; Kutas et al., 2011).

In line with these more recent accounts of predictive processing, a large body of evidence from eye-tracking and electrophysiological studies attests to the influence of word predictability during online language processing. There is robust eye-movement evidence that predictable words receive higher skipping rates, shorter reading times, and fewer regressions than unpredictable words (e.g., Balota et al., 1985; Ehrlich & Rayner, 1981; Rayner et al., 2011; Staub, 2015). Complementary evidence from electrophysiological studies using event-related potentials (ERPs) has revealed that word predictability is inversely related to the N400 component – a centro-parietal negative-going waveform that emerges between 300 to 500 ms poststimulus onset. Words that are predictable within a sentence context consistently yield smaller N400s than words that are unpredictable in the same context, which has led this ERP component to be interpreted as an index of semantic fit between a word and the context in which it appears (Federmeier et al., 2007; Federmeier & Kutas, 1999; Kutas & Hillyard, 1984; Kutas et al., 1984). However, eye-movement and ERP evidence of word predictability benefits do not necessarily mean that truly predictive processes have taken place. The processing facilitation observed for predictable words could reflect the efficient postlexical integration of contextually appropriate words rather than the anticipatory activation of upcoming linguistic input – however, disentangling these two accounts of predictability effects remains difficult (Kutas et al., 2011; but see Van Berkum et al., 2005; Wicha, Bates, et al., 2003a; Wicha, Moreno, & Kutas, 2003b; Wicha et al., 2004).

One way that researchers have attempted to assess whether predictability effects reflect genuine anticipatory prediction processes has been by investigating the processing consequences of linguistic information that disconfirms readers' predictions. For example, consider the strongly constraining sentence frame, "*The children went outside to* …" where the highly predictable completion "*play*" typically receives a processing advantage when presented. If readers rely on anticipatory prediction, the presentation of an unexpected but completely plausible word instead, such as "*look*", should elicit a processing disadvantage or *prediction error cost* on behavioral and neural indices due to its mismatch with "*play*" which was preactivated by the context. Detection of prediction error costs therefore involves comparison of a plausible unexpected word in a strongly constraining context to the same word in a weakly constraining context like "*Joy was frightened to* …" where "*look*" has equivalent low cloze probability to “*play*” and therefore does not violate a preactivated completion.

However, the results of different methodologies yield inconsistent conclusions about whether disconfirmed predictions give rise to the processing costs that would be expected to accompany anticipatory prediction. Early behavioral studies using naming and lexical decision tasks found little evidence of inhibited processing for low cloze probability completions in strongly constraining contexts (e.g., Schwanenflugel & LaCount, 1988; Schwanenflugel & Shoben, 1985; Stanovich & West, 1979, 1983; West & Stanovich, 1978; see Van Petten & Luka, 2012 for review). The few observations of longer response times for unexpected completions have been restricted to unnatural reading situations, for example, when targets were visually degraded (Stanovich & West, 1979) or semantically anomalous in the sentence context (Fischler & Bloom, 1979, 1980) or when readers were presented with a high proportion of trials that constrained toward a more expected completion (e.g., Schwanenflugel & Shoben, 1985; experiment 2). In general, it is unclear to what extent these “no cost” findings of behavioral tasks can be generalized to natural reading.

However, studies using eye-movement recording to investigate natural reading processes have also failed to find evidence of processing costs for unexpected input. Luke and Christianson (2016) conducted one of the first eye-movement studies to explicitly investigate prediction error costs by presenting readers with passages where predictability had been estimated for every word using the cloze responses of an independent group of participants. As expected, the eye-movement data for these passages showed strong facilitative effects of predictability across both early and late reading measures. However, there was no evidence of any processing costs for unexpected words in the form of lower skipping rates, longer fixation durations, or more regressions, even when the context strongly constrained toward another completion. Indeed, unexpected content words were processed more efficiently, indexed by more skips and fewer refixations, the higher the cloze probability of the best completion. Luke and Christianson concluded that readers did not generate specific lexical predictions about upcoming words. Instead, they were more likely to generate graded predictions involving the partial preactivation of upcoming words based on morphosyntactic, syntactic, and semantic information, which then could be used to facilitate processing of the expected completion if it appeared, or an unexpected alternative.

Following this corpus-based study, a controlled experimental study by Frisson et al. (2017) similarly failed to find evidence of prediction error costs for unexpected words presented in strongly constraining sentences (e.g., 1a) compared to weakly constraining sentences (e.g., 1b). In both contexts, a plausible target word was either the predictable completion for the strongly constraining context ("*church*"), unpredictable and semantically related to the best completion ("*sermon*"), or unpredictable and semantically unrelated to the best completion ("*garden*").

(1) a. *The priest wondered how he could get more people to come to the* ***church/sermon/garden*** *even though it was raining.*

b. *The widow thought that it was a lovely* ***church/sermon/garden*** *even though it was cold.*

Readers' eye movements replicated the classic processing benefits for predictable words under conditions of high constraint: higher skipping rates, shorter fixation durations, and fewer regressions than the average of the other conditions. But consistent with Luke and

Christianson (2016), there was no evidence of any processing costs for unpredictable words in a strongly constraining context regardless of their semantic relatedness to the best completion: unpredictable words did not yield lower skipping rates, longer fixation durations, or more regressions compared to the same words in a weakly constraining context. Instead, in strongly constraining contexts, unpredictable words that were semantically related to the best completion (e.g., "*sermon*" in 1a) received shorter total reading times and fewer regressions-out than unrelated words ("*garden*"), reflecting a processing benefit that extended beyond the most predictable word (see Federmeier et al., 2002; Federmeier & Kutas, 1999; Thornhill & Van Petten, 2012, for similar ERP findings). Notably, these effects emerged across relatively late eye-movement measures rather than the early measures on which anticipatory prediction processes would be expected, suggesting that the items were easier to *integrate* into the sentence context because of their shared semantic overlap with the most predictable target. Taken together, these eye-movement findings appear more compatible with the view that the observed predictability effects reflect efficient postlexical integration mechanisms rather than genuine anticipatory prediction processes.

In contrast to eye-movement findings, ERP evidence suggests that readers *do* generate predictions during reading because they are sensitive to linguistic input that violates these expectations. However, contrary to researchers' initial expectations, the evidence for such consequences does not appear to be captured by the N400 component, which has been shown to correlate only with the cloze probability of the target word, independently of its compatibility with prior contextual constraint (Federmeier et al., 2007; Wlotko & Federmeier, 2007). Instead, the consequences of prediction violation appear to be indexed by a post-N400 late frontal positivity, which emerges between 500 and 1000 ms after unexpected input (see Van Petten & Luka, 2012 for a review). For example, in an early observation of this effect, Federmeier et al. (2007) presented pairs of strongly and weakly constraining sentences like "*He bought her a pearl necklace for her* ***birthday/collection***" vs. "*He looked worried because he might have broken his* ***arm/collection***" which were completed either by a predictable word for the respective sentence (i.e., "*birthday*"/"*arm*") or by a plausible but unpredictable word (i.e., "*collection*"). As expected, unpredictable completions elicited larger N400 components than predictable completions, but there was no difference in the amplitudes depending on the context in which the unexpected input appeared. However, unpredictable completions also evoked a late frontal positivity but only when embedded in a strongly constraining context, suggesting that this ERP waveform reflected additional neural activity associated with processing an unpredictable target that violated a stronger, more expected, completion (see also Brothers et al., 2015; DeLong et al., 2012; Ness & Meltzer-Asscher, 2018; Thornhill & Van Petten, 2012).

The precise mechanisms responsible for the late frontal positivity remain under debate. There is accumulating evidence to suggest that this ERP waveform is not linked to the consequences of prediction violation alone – for example, unpredictable words do not elicit a late frontal positivity when presented with minimal context (e.g., Brothers et al., 2020; Lau et al., 2013, but see Federmeier et al., 2010) or when semantically incompatible with the broader sentence context (e.g., DeLong, Quante, & Kutas, 2014a; Kuperberg et al., 2020; Ness & Meltzer-Asscher, 2018). If this ERP waveform simply indexed the detection of a mismatch between unexpected input and the most expected completion, any unpredictable word, regardless of the context in which it appears, should elicit a late frontal positivity. Given that this does not appear to be the case, the late frontal positivity has been proposed to reflect higher-order processes related to the suppression or inhibition of the incorrectly predicted word (Federmeier et al., 2007; Kutas, 1993; Ness & Meltzer-Asscher, 2018). However, the late frontal positivity has also been observed for unpredictable words in weakly to moderately constraining contexts where the most expected completion is unlikely to have been preactivated (e.g., Brothers et al., 2015; Federmeier & Kutas, 2005; Freunberger & Roehm, 2016; Thornhill & Van Petten, 2012; Zirnstein et al., 2018). This neural waveform has therefore also been argued to reflect integration or context-updating processes because unexpected completions require more elaborate revision processes to successfully integrate into an unfolding discourse representation (Brothers et al., 2015; DeLong, Troyer, & Kutas, 2014b).

More recently, the late frontal positivity has also been linked to the nature of the constraints imposed by the prior context leading up to an unexpected completion. Brothers et al. (2020) demonstrated this when assessing readers' neural responses to predictable completions (e.g., "*dough*"/"*door*") and unpredictable completions (e.g., "*foil*"/"*laptop*") presented in sentence passages that were either globally constraining prior to the critical target, i.e., where constraint was determined by the entire preceding passage (e.g., 2a), or locally constraining prior to the critical target, i.e., where constraint was determined by the immediately preceding words only (e.g., 2b).

(2) a. *Tim really enjoyed baking apple pie for his family. He had just finished mixing the ingredients for the crust. To proceed, he flattened the* ***dough/foil*** *…*

b. *He was thinking about what needed to be done on his way home. He finally arrived. James unlocked the* ***door/laptop*** *…*

Readers' neural responses indicated equivalent N400 predictability effects regardless of the source of prior contextual constraint. However, the late frontal positivity only emerged in response to unpredictable completions when they were embedded in a globally constraining context (e.g., "*foil*" in 2a) but not a locally constraining context (e.g., "*laptop*" in 2b), even though both conditions disconfirmed more expected completions that were matched on cloze probability. These findings led Brothers et al. to reason that, rather than being triggered by a disconfirmed prediction at the lexicosemantic level, the late frontal positivity reflected the violation of a higher-level discourse representation. That is, because the semantically rich prior context in the globally constraining passages was strongly associated with the predictable target, it led readers to commit to an interpretation of the discourse incorporating this completion before the critical target occurred. However, upon encountering unexpected input, additional processes were required to suppress this incorrectly predicted information and construct a new discourse representation. In contrast, because the semantically impoverished prior context in the locally constraining passages was only weakly associated with the predictable target, it did not lead readers to commit to a discourse representation incorporating this completion. Therefore, encountering unexpected input was less likely to trigger similar suppression and integration processes.

This relationship between the late frontal positivity and higher-level discourse representations is interpretable within a generative framework of language comprehension (Brothers et al., 2020; Kuperberg et al., 2020). According to this framework, readers draw upon a hierarchically organized network of linguistic and non-linguistic information to establish deep comprehension during online language processing – the highest level of which is a *situation model* of the discourse which describes the full set of events, actors, and actions being communicated. Because it takes time for linguistic input to unfold and for deep comprehension to be achieved, readers can form hypotheses at the level of the situation model, i.e., make predictions about what they believe to be the communicator's intended message based on the information received so far. These hypotheses or predictions are then propagated down the hierarchical network to lower levels of representation, which include details about event structures and semantic features. As bottom-up information becomes available, representations that have already been predicted at these lower levels receive facilitated processing, while representations that have not been predicted are propagated back up the hierarchical network to update the situation model. Within this dynamic framework, the late frontal positivity is attributed to the process of successfully updating the situation model from its prior hypothesized state to its new actual state based on bottom-up input. As such, this additional neural activity is only elicited by unexpected input presented in semantically rich, globally constraining contexts that encourage readers to build a situation model of the discourse but not in semantically impoverished, locally constraining contexts that do not (e.g., Brothers et al., 2020).

From this perspective, the absence of observable prediction error costs in previous eye-movement studies (Frisson et al., 2017; Luke & Christianson, 2016) may reflect readers' failure to establish a situation model of the discourse during reading. For example, Frisson et al.'s (2017) materials were single sentences that provided minimal prior context and/or time for readers to build a situation model of the discourse. While Luke and Christianson's (2016) materials consisted of short naturalistic texts, few of their passages were high in constraint, which may have limited readers' opportunity to even engage prediction processes. Moreover, readers' comprehension of these passages was not assessed, reducing their incentive to build higher-level representations of the discourse. Although there are many factors that would influence whether readers rely on a situation model during reading (e.g., task and goal demands, level of motivation, individual differences), Brothers and colleagues' (2020) recent ERP findings provide clear evidence that the nature of the prior contextual constraint plays an important role in activating these higher-level discourse representations. While previous research has revealed facilitatory effects of global contexts on online processing during natural reading (e.g., Hess et al., 1995 using naming; Morris, 1994 using eye-tracking), there has been little systematic investigation of how different sources of contextual constraint influence predictability effects on eye-movement measures of reading.

The earliest study to our knowledge to investigate this issue by Calvo and Meseguer (2002) used multiple regression analyses to assess the unique contribution of word predictability to readers' eye movements on target words presented under different constraint conditions, while partialing out the effects of frequency and length. Their analyses revealed that, although predictability was a significant predictor of several late eye-movement measures when targets appeared in a Globally+Locally constraining passage where constraint was determined by the entire preceding context, predictability did not affect any reading measures when the same targets appeared in a Locally constraining passage where constraint was determined by the inclusion of words that were semantically related to the target. Predictability effects therefore appeared to be facilitated selectively by global constraint rather than lexicosemantic priming. However, Calvo and Meseguer did not match the cloze probability of their targets across the passages – the mean cloze probability of words in the Globally+Locally constraining condition was .96 compared to .04 in the

Locally constraining condition – so the stronger predictability effects observed in the former condition could have been due to higher target cloze probability. Furthermore, constraint in the Locally constraining passages was determined by a set of semantically associated words scattered throughout the prior context rather than the immediate prior context as in other studies investigating similar issues (e.g., Brothers et al., 2020; Fitzsimmons & Drieghe, 2013).

Fitzsimmons and Drieghe (2013) conducted a more controlled eye-movement study to investigate the effects of prior contextual constraint on word predictability. Readers were presented targets like "*spider*" which were either Gradually Predictable based on the entire preceding context (e.g., 3a), or Locally Predictable based on the preceding word only (e.g., 3b), and, importantly, of equivalently high cloze probability in both conditions.

(3) a. *Bill is scared of eight-legged creatures. He screamed when he saw the* ***spider*** *in the bath.*

b. *Bill has always been a fearful person. He screamed when he saw the hairy* ***spider*** *in the bath.*

c. *Bill has always been a fearful person. He screamed when he saw the* ***spider*** *in the bath.*

Despite the differing sources of constraint, targets presented in the Gradually and Locally Predictable conditions did not differ in skipping rates or fixation durations, but both targets showed processing facilitation relative to the same target presented in a baseline Neutrally Predictable condition (e.g., 3c). Fitzsimmons and Drieghe concluded that predictable completions were processed equivalently, based on their semantic fit in the sentence contexts, regardless of whether constraint originated from a global or local source. However, because the Gradually and Locally Predictable conditions differed in both the prior global context and the immediate local context, it is not possible to assess whether the presence of a global constraint activated higher-level discourse representations that provided a processing benefit over and above that of a local constraint. Moreover, Fitzsimmons and Drieghe's targets were all consistent with readers' expectations, so their data do not provide evidence about whether prior contextual constraint affects readers' eye movements on completions that disconfirm their expectations.

2.3 The present study

The present study was designed to systematically investigate how predictability effects on eye movements are influenced by the global and local constraints imposed by prior context independently of cloze probability. As well as disentangling the relative contributions of these different sources of constraint on processing benefits for expected completions, we also investigated their impact on processing costs for unexpected completions that were either semantically related or unrelated to the best completion. Given ERP evidence that a semantically rich, prior global context yields additional neural activity in the form of a late frontal positivity for unexpected input, such contexts may reveal similar prediction error costs in the eye-movement record that were not detected in previous studies because the stimulus materials and task demands did not support or encourage development of a situation model (Frisson et al., 2017; Luke & Christianson, 2016).

To investigate the current issues, predictable targets were presented or replaced by unpredictable words that were semantically related or unrelated in four different three-sentence context conditions that independently manipulated whether the global and/or local context constrained toward the most expected completion (see Table 2.1 for an example item set and Appendix for a complete list of stimuli). In the Global+Local context condition, the initial two sentences provided a prior global context that was semantically rich and strongly associated with the most predictable target, and the immediate local context provided by the strongly constraining final sentence was also highly predictive of the best completion. Thus, all three sentences constrained toward the most expected completion. The Global Only context condition comprised the same two initial semantically rich sentences, but the immediate local context provided by the weakly constraining final sentence was non-predictive of the best completion. The Local Only context condition included the same strongly constraining final sentence as the Global+Local condition so that the immediate local context was highly predictive of the best completion. However, the two initial sentences that provided a prior global context contained minimal semantic context and were not strongly associated with the most predictable target. Finally, the Weak context condition combined the semantically impoverished initial two sentences of the Local Only condition with the weakly constraining final sentence of the Global Only condition so that neither the prior global context nor the immediate local context constrained toward the most expected completion. Following previous studies (Brothers et al., 2020; Fitzsimmons & Drieghe, 2013), the level of constraint for the most expected completion, as indexed by cloze probability, was matched across the three constraining context conditions (i.e., Global+Local, Global Only, Local Only) to ensure that any differences in readers' eye movements on the target words could be attributed directly to differences in prior contextual constraint, independently of target predictability.

The current design therefore allowed us to assess the impact of a global source of constraint on eye-movement measures of reading by comparing the globally constraining

(Global+Local and Global Only) and globally non-constraining context conditions (Local Only and Weak). The impact of a local source of constraint was assessed by comparing the locally constraining (Global+Local and Local Only) and locally non-constraining context conditions (Global Only and Weak). The test of the *global constraint × local constraint* interaction assessed whether higher-level discourse representations encouraged by globally constraining contexts were used by readers in conjunction with lower-level lexicosemantic information activated by locally constraining contexts during real-time language processing.

Table 2.1

Example set of stimuli across the four context conditions with target word in bold

Constraint	Passage
Global+Local	Climbing up Mount Whitney was beautiful but challenging. Julia was looking forward to what she knew awaited her at the top. Finally, she stood at the summit and admired the breath-taking **view/scenery/birds** that surrounded her.
Global Only	Climbing up Mount Whitney was beautiful but challenging. Julia was looking forward to what she knew awaited her at the top. But her imagination did not prepare her for the magnificent **view/scenery/birds** all around her.
Local Only	The final challenge was formidable but Julia felt optimistic. She had spent a long time preparing for this day to arrive. Finally, she stood at the summit and admired the breath-taking **view/scenery/birds** that surrounded her.
Weak	The final challenge was formidable but Julia felt optimistic. She had spent a long time preparing for this day to arrive. But her imagination did not prepare her for the magnificent **view/scenery/birds** all around her.

Based on evidence from previous studies (Brothers et al., 2020; Fitzsimmons & Drieghe, 2013), the processing of predictable completions in constraining contexts was not expected to differ as a function of the source of prior contextual constraint. That is, processing benefits in the form of higher skipping rates, shorter fixation durations, and fewer regressions were expected to be determined by cloze probability alone and to be equivalent for predictable targets presented in either globally or locally constraining context conditions relative to non-constraining context conditions. However, if predictability benefits are sensitive to the nature of the constraints imposed by the prior context, a global constraint which is assumed to encourage the construction of higher-level discourse representations may yield additive, or even overadditive, processing benefits to that provided by a local constraint.

In contrast, the processing of unpredictable completions in constraining contexts was expected to reveal differential effects of prior contextual constraint. Based on Brothers et al.'s (2020) ERP findings, if unpredictable completions require additional processing in order to update a situation model of the discourse that has already incorporated a more predictable completion, prediction error costs should only be observed when readers have access to a semantically rich, prior global context that encourages construction of these higher-level discourse representations. As such, processing costs in the form of lower skipping rates, longer fixation durations, and more regressions were expected for unpredictable targets in globally constraining relative to globally non-constraining context conditions. However, no processing costs were expected for unpredictable targets in locally constraining relative to locally non-constraining context conditions given that the presence of an immediate local context alone is unlikely to lead to the development of a situation model that requires updating.

2.4 Method

2.4.1 Participants.

Sixty-nine participants took part in the experiment, including 54 undergraduate students from the University of Sydney who received course credit and 15 community individuals who received cash reimbursement. Seven participants were removed due to self-reported dyslexia, calibration difficulty, and/or comprehension accuracy that was ~3 *SD* below average in the eye-tracking task. Therefore, the final sample comprised 62 participants (M_{age} = 20.9 years; 43 females). All were native English speakers and had normal or corrected-to-normal vision.

2.4.2 Materials.

The critical stimuli were 116 sets of three-sentence passages that varied in the source of constraint for the most predictable target, which was either presented or replaced by an unpredictable target that was either semantically related or unrelated to the best completion.[1] The predictability of the target words in the passages was confirmed via a cloze norming task – between 21 and 22 cloze completions were collected for each version of the passages from 86 participants who did not complete the eye-tracking task (M_{age} = 20.30 years; 68 females). Each participant saw one version of each passage, with an equal number of each condition across the task. A separate, similarly counterbalanced, cloze

[1] 144 sets of passages were presented to participants in the eye-tracking task, but subsequent cloze norming identified 24 items for which the predictable completion had an average cloze value below 50% in one of the three constraining context conditions (i.e., Global+Local, Global Only, Local Only), 3 items for which the predictable completion had an average cloze value above 33% in the Weak context condition, and 1 item for which the related unpredictable completion had an average cloze value above 33% in the Global Only context condition. These items were excluded from the analysis to ensure consistent cloze predictability in each condition. Of the final item set, participants read between 19-20 items in each of the 12 (constraint × predictability) conditions.

norming task was conducted to ensure that the immediate local context in the final third sentence of the passages was appropriately constraining or non-constraining – a separate sample of 45 participants (M_{age} = 19.78 years; 29 females) provided between 22 and 23 cloze completions for each version of the final sentences. To ensure that the related and unrelated unpredictable targets were equivalently plausible across the conditions, the passages were judged on a 5-point scale from 1 (Highly Implausible) to 5 (Highly Plausible) by another sample of 60 participants (M_{age} = 21.6 years; 44 females) such that 5 ratings were provided for each version of the passages. Each individual judged one version of each passage, with an equal number of each condition across the task. To confirm the semantic relatedness of the targets, Latent Semantic Analysis (LSA; Landauer & Dumais, 1997) scores were calculated between the predictable target and each of the unpredictable targets, as well as between the passages up to the target and each of the targets. These LSA scores were based on the TASA (Touchstone Applied Science Associates, Inc.) semantic space which comprises 37,651 different documents covering a wide range of topics using the *LSAfun* package (Version 0.6.1, Günther et al., 2014) in *R*. Table 2.2 summarizes the mean lexical characteristics, including length and log HAL frequency, of the target words in each condition.[2]

[2] Statistical tests of differences in the lexical characteristics between the target words were unnecessary because, as described below, the analyses of the eye-movement data tested the effect of constraint separately for each target word.

Table 2.2

Mean (and standard deviation) cloze predictability and plausibility of passages and lexical characteristics of target stimuli

Predictability/Constraint	Overall passage cloze	Final sentence cloze	Plausibility	LSA between target and predictable target	LSA between target and passage	Length	Log HAL frequency
Predictable							
Global+Local	86.2 (12.5)	80.3 (14.6)	4.82 (0.27)	1.00 (0.00)	0.13 (0.10)	5.2 (1.2)	9.1 (1.5)
Global Only	76.0 (15.6)	2.7 (5.3)	4.73 (0.47)	1.00 (0.00)	0.09 (0.08)	5.2 (1.2)	9.1 (1.5)
Local Only	79.6 (15.1)	80.3 (14.6)	4.49 (0.54)	1.00 (0.00)	0.06 (0.07)	5.2 (1.2)	9.1 (1.5)
Weak	4.1 (7.1)	2.7 (5.3)	4.41 (0.62)	1.00 (0.00)	0.03 (0.04)	5.2 (1.2)	9.1 (1.5)
Related							
Global+Local	2.1 (5.6)	1.2 (3.4)	4.56 (0.55)	0.30 (0.22)	0.09 (0.08)	6.2 (1.9)	8.1 (1.9)
Global Only	2.3 (5.0)	0.3 (1.2)	4.61 (0.53)	0.30 (0.22)	0.08 (0.07)	6.2 (1.9)	8.1 (1.9)
Local Only	1.7 (4.6)	1.2 (3.4)	4.43 (0.60)	0.30 (0.22)	0.05 (0.05)	6.2 (1.9)	8.1 (1.9)
Weak	0.5 (2.5)	0.3 (1.2)	4.36 (0.61)	0.30 (0.22)	0.04 (0.04)	6.2 (1.9)	8.1 (1.9)
Unrelated							
Global+Local	0.0 (0.4)	0.1 (0.6)	4.06 (0.84)	0.01 (0.07)	0.04 (0.04)	6.8 (2.0)	7.6 (1.9)
Global Only	0.2 (2.2)	0.4 (2.5)	4.05 (0.78)	0.01 (0.07)	0.03 (0.04)	6.8 (2.0)	7.6 (1.9)
Local Only	0.1 (0.9)	0.1 (0.6)	4.13 (0.73)	0.01 (0.07)	0.03 (0.04)	6.8 (2.0)	7.6 (1.9)
Weak	0.5 (2.6)	0.4 (2.5)	4.21 (0.69)	0.01 (0.07)	0.03 (0.04)	6.8 (2.0)	7.6 (1.9)

2.4.3 Apparatus.

Participants read the passages on a 21-inch ViewSonic G225f CRT monitor which was set to a pixel resolution of 1024 x 768 and a 140 Hz refresh rate while their eye movements were tracked by a SR Research Ltd. Eyelink 1000 eye-tracker which had a sampling rate of 1000 Hz. Passages were presented across 2-3 lines in 14pt Consolas black font on a white background. Participants were seated 60 cm from the monitor with a chin and forehead rest used to minimize head movements. At this distance one degree of visual angle equated to 2.85 letter spaces. Viewing was binocular, but eye movements were recorded from the right eye.

2.4.4 Procedure.

Participants were instructed to read the passages for meaning and to respond to comprehension questions which appeared after 25% of the trials (mean accuracy = 94.5%). A nine-point calibration procedure was conducted before the start of the experiment. If mean calibration error was greater than .5° of visual angle, an additional calibration procedure was carried out. Before each trial, a fixation point appeared at the location of the first letter of the passage and a stable fixation on this point was required before the trial was displayed.

The passages were counterbalanced across six lists using a Latin square design ensuring that there was an approximately equal number of items across the constraint and predictability conditions. Each participant saw two items from each passage set which were always either the Global+Local and Weak context conditions, or the Global Only and Local Only context conditions to ensure that there was no overlap in the passages presented to a single participant. Items from the same passage set were always presented in two separate blocks which were each divided into three subblocks. Participants were randomly assigned to a list, for which the order of presentation of the blocks and sub-blocks was randomized.[3]

The experimental materials, data, and analysis code are publicly available on the Open Science Framework website: https://osf.io/sk7nt/ (Wong et al., 2022).

2.5 Results

Fixations shorter than 80 ms were automatically merged with adjacent fixations within 1-letter space (.2% of total fixations). Trials were removed if there was track loss or blinks on the target (2.7% of trials). Target fixations below 80 ms and first fixation and gaze durations above 800ms were also excluded (1.1% of trials). These exclusions left 13,827 trials (96.2% of the data) for analysis.

The following log-transformed reading measures were analyzed for the target word: *first fixation duration* (the duration of the first fixation on the target), *gaze duration* (the sum of all fixations before the eyes exit the target for the first time), and *total fixation duration* (the sum of all fixations on a target). The probability of skipping, regressions out of the target to earlier in the text, and regressions into the target from later in the text were also analyzed. The mean reading measures on the target words for each condition are presented in Table 2.3. Figure 2.1 presents the mean first fixation and total fixation duration on the target words for each condition, which index early and late stages of processing, respectively.

[3] The pattern of significance in the analyses reported below did not change when block order was controlled.

Table 2.3

Mean (and standard deviation) reading measures on the target word for each context condition

Measure	Predictable				Related				Unrelated			
	Global+ Local	Global Only	Local Only	Weak	Global+ Local	Global Only	Local Only	Weak	Global+ Local	Global Only	Local Only	Weak
Skipping (%)	38 (11)	33 (11)	35 (10)	33 (10)	25 (11)	25 (9)	25 (9)	22 (9)	23 (10)	20 (8)	20 (9)	19 (8)
First fixation (ms)	191 (17)	201 (17)	200 (18)	212 (16)	208 (20)	201 (14)	210 (19)	217 (18)	213 (17)	211 (17)	210 (17)	219 (18)
Gaze (ms)	200 (21)	211 (21)	209 (24)	225 (21)	223 (25)	220 (17)	229 (21)	237 (24)	237 (21)	231 (24)	235 (25)	242 (27)
Total fixation (ms)	227 (37)	239 (33)	240 (34)	268 (35)	258 (34)	252 (30)	265 (33)	299 (33)	316 (37)	296 (37)	317 (50)	321 (44)
Regressions out (%)	10 (7)	8 (5)	10 (7)	12 (9)	10 (7)	12 (8)	10 (6)	16 (9)	12 (8)	15 (7)	15 (8)	16 (8)
Regressions in (%)	10 (7)	11 (7)	10 (8)	16 (8)	11 (8)	14 (8)	12 (7)	17 (10)	22 (10)	19 (8)	19 (8)	19 (8)

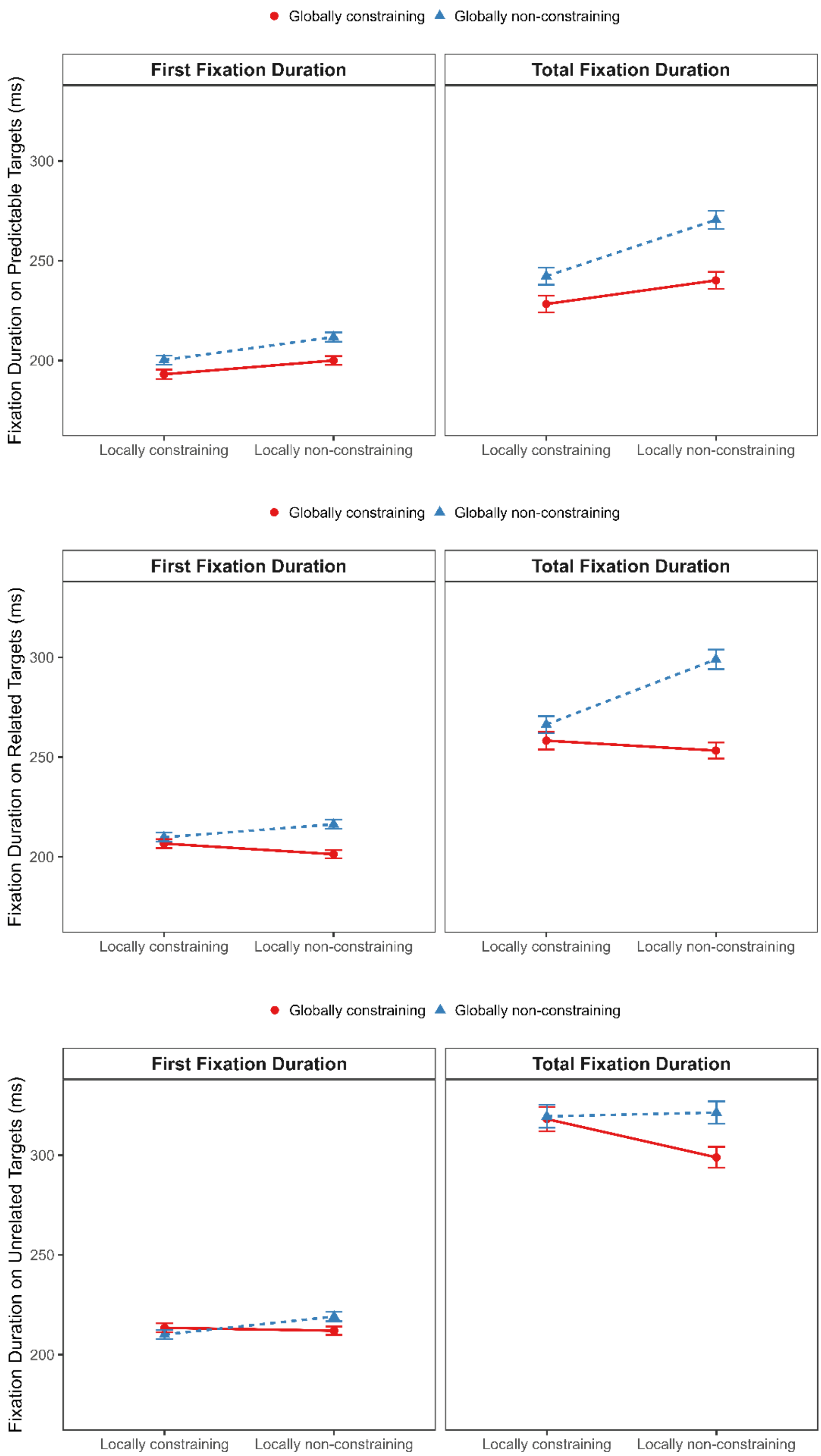

Figure 2.1 Mean first fixation and total fixation duration on predictable targets (upper panel), related unpredictable targets (middle panel), and unrelated unpredictable targets (lower panel) for each context condition. Error bars are +/-SEM.

The data were analyzed by (generalized) linear mixed effects models (GLMM/LMM) using the *lme4* package (Version 1.1-29.1; Bates et al., 2015) in *R*. The models tested the fixed effects of constraint nested under predictability, i.e., the main effect of predictability, and the effects of global constraint, local constraint, and their interaction separately for predictable, related, and unrelated targets. The use of nested contrasts therefore allowed us to assess predictability benefits and costs within the single model for each reading measure. Predictability was coded as a set of two orthogonal contrasts which tested the effect of: (a) *target predictability* – the difference between the predictable and the average of the related and unrelated unpredictable conditions, and (b) *target relatedness* – the difference between the related and unrelated unpredictable conditions.

All models either failed to converge or showed singular fit with the maximal random-effects structure (i.e., subject and item random intercepts and random slopes for the nested effects of global and local constraint under each level of target predictability). Therefore, the random-effects structure for each model was simplified: first by removing the correlation parameters between random intercepts and random slopes and second by sequentially removing random slopes that accounted for the least variance until model convergence without singular fit. Estimates yielding t/z values greater than $|1.96|$ were interpreted as significant at the .05 α level. Power analyses conducted with 100 Monte Carlo simulations using the *simR* package (Version 1.0.6; Green & MacLeod, 2016) in *R* demonstrated adequate power to detect the effects of global constraint (>.94) and local constraint (>.88) based on comparable effects reported in Fitzsimmons and Drieghe (2013; global constraint: 7 ms on first fixation duration, 12 ms on gaze duration; local constraint: 8 ms on first fixation duration, 9 ms on gaze duration). The models also had adequate power (>.80) to detect *global constraint* × *local constraint* interactions of 11 ms effect size on first fixation duration, and 15 ms effect size on gaze duration. A summary of the statistical analyses is presented in Table 2.4.

The main effect of *target predictability* was significant on all measures ($|t/z|$s > 5.11) reflecting higher skipping, shorter fixation durations, and fewer regressions for predictable compared to unpredictable targets. A significant main effect of *target relatedness* was also observed on all measures ($|t/z|$s > 3.09) reflecting higher skipping, shorter fixation durations, and fewer regressions for unpredictable targets that were semantically related rather than unrelated to the best completion.

For predictable targets, a significant effect of *global constraint* was observed on all reading measures except skipping (z = 1.05) which reflected shorter reading times ($|t|$s > 4.28) and fewer regressions-out and -in ($|z|$s > 2.27) for predictable targets in globally constraining compared to globally non-constraining context conditions. There was also a significant effect of *local constraint* on all reading measures except regressions-out (z= -.68), reflecting higher skipping rates (z = 2.56), shorter reading times ($|t|$s > 4.80), and fewer regressions-in (z = -3.46) for predictable words in locally constraining compared to locally non-constraining context conditions. The interaction between global and local constraint was not significant on skipping, first fixation, and gaze duration ($|t/z|$s < .95), suggesting that the two sources of constraint produced additive effects on early reading measures. But the *global constraint* × *local constraint* interaction was significant on total fixation duration (t = 2.20) and regressions-out and -in ($|z|$s > 2.22). This underadditive effect on late reading measures reflected minimal additional benefit of global constraint in passages with a locally constraining context, i.e., predictable targets had significantly shorter total reading times and fewer regressions in Global Only relative to Weak contexts, but there was only a small

(13 ms) difference on total reading time and no difference in regressions between Global+Local and Local Only contexts.

Contrary to our hypotheses, unpredictable targets that disconfirmed these predictable completions did not yield processing costs across any reading measures. Instead, for unpredictable targets that were semantically related to the best completion, a significant facilitatory effect of *global constraint* was observed on all measures except skipping and regressions-in ($|z|$s < 1.93), reflecting shorter reading times ($|t|$s > 3.85) and fewer regressions-out (z = -2.14) for related targets in globally constraining compared to globally non-constraining context conditions. There was also a significant facilitatory effect of *local constraint* on late reading measures – related targets received shorter total reading times (t = -3.22) and fewer regressions-out and -in ($|z|$s > 3.77) in locally constraining compared to locally non-constraining context conditions. The *global constraint* × *local constraint* interaction was significant on first fixation and total fixation duration ($|t|$s > 3.30). As shown in Figure 2.1 (middle panel), global constraint was more beneficial in passages with a locally non-constraining than locally constraining context, i.e., related targets had significantly shorter reading times in Global Only relative to Weak contexts but similar reading times in Global+Local and Local Only contexts.

Similarly, for unpredictable targets that were semantically unrelated to the best completion, there was a significant facilitatory effect of *global constraint* on skipping, total fixation duration, and regressions-out ($|t/z|$s > 2.21) and a significant facilitatory effect of *local constraint* on first fixation duration and regressions-out ($|t/z|$s > 2.07). The *global constraint* × *local constraint* interaction was significant on all fixation duration measures ($|t|$s > 2.17) because global constraint yielded a processing advantage only in passages with a locally non-constraining context. As shown in Figure 2.1 (lower panel), on the early measure of first fixation duration, the form of this interaction was of a benefit for any constraining context relative to a Weak context. However, on the late measure of total fixation duration, the benefit was restricted to the Global Only context.

Table 2.4

Results for the linear mixed effects models for log-transformed fixation duration measures and generalized linear mixed effects models for fixation probability measures on the target word

Measure	Fixed effect	*b*	*SE*	*t/z*
Skipping	**Intercept**	**-1.17**	**0.09**	**-13.37**
	Predictable vs. Unpredictable	**0.68**	**0.04**	**16.20**
	Related vs. Unrelated	**0.23**	**0.05**	**4.35**
	Predictable: Global constraint	0.07	0.07	1.05
	Predictable: Local constraint	**0.17**	**0.07**	**2.56**
	Predictable: Global × Local	0.05	0.13	0.41
	Related: Global constraint	0.10	0.07	1.36
	Related: Local constraint	0.11	0.07	1.46
	Related: Global × Local	-0.16	0.14	-1.13
	Unrelated: Global constraint	**0.17**	**0.08**	**2.21**
	Unrelated: Local constraint	0.13	0.08	1.72
	Unrelated: Global × Local	0.20	0.15	1.31
First fixation	**Intercept**	**5.29**	**0.01**	**358.70**
	Predictable vs. Unpredictable	**-0.05**	**0.01**	**-8.65**
	Related vs. Unrelated	**-0.02**	**0.01**	**-3.09**
	Predictable: Global constraint	**-0.05**	**0.01**	**-4.68**
	Predictable: Local constraint	**-0.05**	**0.01**	**-4.80**
	Predictable: Global × Local	0.02	0.02	0.95
	Related: Global constraint	**-0.04**	**0.01**	**-4.03**
	Related: Local constraint	-0.00	0.01	-0.43
	Related: Global × Local	**0.06**	**0.02**	**3.30**
	Unrelated: Global constraint	-0.01	0.01	-0.60

	Unrelated: Local constraint	**-0.02**	**0.01**	**-2.07**
	Unrelated: Global × Local	**0.05**	**0.02**	**2.47**
Gaze	**Intercept**	**5.35**	**0.02**	**337.67**
	Predictable vs. Unpredictable	**-0.09**	**0.01**	**-12.56**
	Related vs. Unrelated	**-0.03**	**0.01**	**-4.47**
	Predictable: Global constraint	**-0.05**	**0.01**	**-4.28**
	Predictable: Local constraint	**-0.06**	**0.01**	**-4.82**
	Predictable: Global × Local	0.02	0.03	0.95
	Related: Global constraint	**-0.04**	**0.01**	**-3.85**
	Related: Local constraint	-0.01	0.01	-0.70
	Related: Global × Local	0.04	0.02	1.78
	Unrelated: Global constraint	-0.01	0.01	-1.15
	Unrelated: Local constraint	-0.01	0.01	-0.62
	Unrelated: Global × Local	**0.05**	**0.02**	**2.46**
Total Fixation	**Intercept**	**5.50**	**0.02**	**296.63**
	Predictable vs. Unpredictable	**-0.16**	**0.01**	**-17.85**
	Related vs. Unrelated	**-0.13**	**0.01**	**-13.59**
	Predictable: Global constraint	**-0.08**	**0.01**	**-5.44**
	Predictable: Local constraint	**-0.08**	**0.01**	**-5.26**
	Predictable: Global × Local	**0.06**	**0.03**	**2.20**
	Related: Global constraint	**-0.09**	**0.01**	**-6.71**
	Related: Local constraint	**-0.04**	**0.01**	**-3.22**
	Related: Global × Local	**0.12**	**0.03**	**4.30**
	Unrelated: Global constraint	**-0.04**	**0.01**	**-2.62**
	Unrelated: Local constraint	0.02	0.01	1.50
	Unrelated: Global × Local	**0.06**	**0.03**	**2.17**
Regressions Out	**Intercept**	**-2.21**	**0.09**	**-24.48**
	Predictable vs. Unpredictable	**-0.31**	**0.06**	**-5.11**
	Related vs. Unrelated	**-0.27**	**0.07**	**-4.11**
	Predictable: Global constraint	**-0.23**	**0.10**	**-2.27**
	Predictable: Local constraint	-0.07	0.10	-0.68
	Predictable: Global × Local	**0.46**	**0.21**	**2.22**
	Related: Global constraint	**-0.20**	**0.09**	**-2.14**
	Related: Local constraint	**-0.36**	**0.09**	**-3.77**
	Related: Global × Local	0.30	0.20	1.49
	Unrelated: Global constraint	**-0.19**	**0.09**	**-2.22**
	Unrelated: Local constraint	**-0.19**	**0.09**	**-2.16**

	Unrelated: Global × Local	-0.08	0.19	-0.45
Regressions In	**Intercept**	**-1.98**	**0.09**	**-21.24**
	Predictable vs. Unpredictable	**-0.44**	**0.06**	**-7.88**
	Related vs. Unrelated	**-0.51**	**0.06**	**-8.56**
	Predictable: Global constraint	**-0.27**	**0.10**	**-2.78**
	Predictable: Local constraint	**-0.33**	**0.10**	**-3.46**
	Predictable: Global × Local	**0.44**	**0.19**	**2.29**
	Related: Global constraint	-0.17	0.09	-1.93
	Related: Local constraint	**-0.36**	**0.09**	**-4.06**
	Related: Global × Local	0.28	0.18	1.53
	Unrelated: Global constraint	0.09	0.08	1.17
	Unrelated: Local constraint	0.07	0.08	0.87
	Unrelated: Global × Local	0.22	0.15	1.42

Note. Significant effects are bolded.

2.6 Discussion

The aim of the current study was to investigate whether words that confirmed or disconfirmed readers' expectations were processed differently depending on the nature of the constraints imposed by the prior context independently of cloze probability. The most relevant eye-movement study to investigate this issue by Fitzsimmons and Drieghe (2013) observed that predictable completions received facilitated processing in strongly constraining contexts regardless of whether constraint originated from a global or local source, i.e., from the entire preceding discourse or the preceding word only. However, no eye-movement study to date has investigated whether the processing of unpredictable completions is modulated by the source of prior contextual constraint. The importance of this issue is highlighted by recent ERP evidence from Brothers et al. (2020) indicating that the presence of a globally constraining context elicits the late frontal positivity, an ERP waveform that captures additional neural activity associated with processing disconfirmed predictions. Given that previous eye-movement studies have failed to find evidence of observable prediction error costs for unexpected input (Frisson et al., 2017; Luke & Christianson, 2016), investigating whether such effects are modulated by the source of prior contextual constraint may provide some insight into the discrepancy between eye-movement and ERP literatures regarding how readers deal with prediction violations during reading.

As expected, predictable completions in the present study received facilitated processing when presented in any passages with a constraining context. Shorter fixation durations and fewer regressions were observed for predictable targets in globally constraining compared to globally non-constraining context conditions. Similarly, higher skipping rates, shorter fixation durations, and fewer regressions-in were observed for predictable targets in locally constraining compared to locally non-constraining context conditions. These findings align with previous eye-movement (Fitzsimmons & Drieghe, 2013) and ERP studies (Brothers et al., 2020) in showing that predictable completions were processed more efficiently due to their semantic fit within the passages, regardless of whether constraint originated from the prior global context provided by the initial two sentences of the passage or from the immediate local context provided by the final sentence of the passage. Moreover, these predictability benefits appeared across the entire time course of readers' eye movements. This indicates that, consistent with many previous eye-movement studies, readers sufficiently anticipated the most expected completion before its presentation to affect even the earliest eye-movement measures (e.g., Fitzsimmons & Drieghe, 2013; Frisson et al., 2017; Rayner et al., 2011; Rayner & Well, 1996), and efficiently integrated these contextually appropriate completions to influence late eye-movement measures (e.g., Luke & Christianson, 2016; Staub, 2010).

The relative contributions of global and local sources of constraint, however, appeared to differ across the time course of word processing. On early reading measures, the benefit of a global constraint was equivalent in passages containing a locally constraining compared to locally non-constraining context, i.e., predictable targets received the same processing advantage on skipping**,** first fixation, and gaze duration in Global+Local compared to Local Only context conditions, as in Global Only compared to Weak context conditions. This evidence of a global constraint benefit regardless of the immediate local context implies that global and local constraints made independent, additive contributions to the early processing of predictable completions. Consistent with Brothers et al.'s (2020) proposal, while an immediate local context was more likely to preactivate the most expected completion based on lower-level lexicosemantic information, a prior global context was more likely to encourage higher-level discourse representations that propagated the most expected completion through multiple representational levels of a hierarchical network. Readers' immediate processing of predictable completions therefore appears to be determined by not only cloze probability but also the nature of the constraints imposed by the prior context.

On late reading measures, however, the benefits of global and local constraint appeared to be underadditive. Specifically, the global constraint benefit was significantly smaller in passages containing a locally constraining compared to locally non-constraining context, i.e., predictable targets received a smaller processing advantage on total fixation duration and regressions in Global+Local compared to Local Only context conditions, than in Global Only compared to Weak context conditions. The fact that this interaction was restricted to late reading measures suggests that there was an integration cost for predictable targets in the Weak context condition given that neither the global nor local contexts constrained toward any particular completion. However, it is also plausible that this pattern of underadditivity reflected an upper limit on any integration benefit, which may be due to a floor effect on fixation durations, for predictable targets in the Global+Local context condition in which all three sentences strongly constrained toward the most expected completion. This would suggest that the independent, additive contributions of global and local constraints benefited early but not late stages of processing a predictable completion. In contrast to early eye-movement measures then, readers' late integration of predictable completions appears to be determined by semantic fit only regardless of the source of prior contextual constraint.

The current findings therefore extend Fitzsimmons and Drieghe's (2013) study by demonstrating that although predictable completions receive processing benefits from both global and local sources of constraint, these benefits are not simply due to a word's cloze probability and that the relative contributions of global and local constraints vary across different stages of processing. This observation that real-time predictability effects are linked to factors other than offline cloze probability is consistent with the findings of previous studies. For example, Staub et al. (2015) showed that item constraint determined response times on a cloze task when cloze probability was controlled for. More generally, Luke and Christianson (2016) observed that readers' eye movements on upcoming content words were predicted by available morphosyntactic, syntactic, and semantic information over and above cloze probability of the full word form.

Despite evidence that predictable completions in the present study were actively anticipated in advance of their presentation, unexpected input that disconfirmed these expectations did not appear to elicit any processing costs. Based on ERP evidence from

Brothers et al. (2020), unpredictable completions were hypothesized to require additional processing in the presence of a semantically rich, prior global context because the situation model of the discourse constructed would require updating in the event of incompatible bottom-up input. Indeed, unpredictable targets regardless of their semantic relatedness to the best completion did not reveal any processing costs in the form of lower skipping rates, longer fixation durations, or more regressions when presented in locally constraining compared to locally non-constraining context conditions because the presence of an immediate local context was unlikely to contribute to the activation of higher-level discourse representations that required updating. However, both related and unrelated unpredictable targets also failed to elicit any processing costs in globally constraining context conditions which encouraged readers to establish a situation model of the discourse compared to globally non-constraining context conditions which did not.

Instead, unpredictable completions that were semantically related to the best completion were more likely to receive facilitated processing, consistent with findings of previous eye-movement (Frisson et al., 2017; Luke & Christianson, 2016) and ERP studies (Federmeier et al., 2002; Federmeier & Kutas, 1999; Thornhill & Van Petten, 2012). Moreover, these processing benefits emerged following both global and local contexts that constrained toward a more expected completion. Readers showed shorter total reading times and fewer regressions for related targets in locally constraining compared to locally non-constraining context conditions suggesting that the presence of an immediate local context yielded late integration benefits for these completions due to their semantic overlap with the most expected completion. Readers also showed shorter fixation durations and fewer regressions-out for related targets in globally constraining compared to globally non-constraining context conditions, indicating that the presence of a prior global context yielded similar late integration benefits but also, importantly, early prediction benefits. This finding of an *early* processing advantage for related unpredictable completions implies that the situation model of the discourse encouraged by the presence of a prior global context led to the preactivation of general semantic expectancies rather than a specific lexical prediction at lower levels of the hierarchical network, meaning that processing benefits for highly predictable completions also extended to semantically related alternatives.

This global constraint benefit, however, was significantly smaller in passages containing a locally constraining compared to locally non-constraining context across both early and late eye-movement measures. Specifically, related unpredictable targets received a processing advantage on first fixation and total fixation duration in Global Only compared to Weak context conditions, but almost no processing advantage in Global+Local compared to Local Only context conditions. On first fixation duration, this appeared to be due to both a processing benefit in Global Only context conditions, and a processing cost in Weak context conditions for related targets, suggesting that these completions received an overall initial processing benefit from any constraining context, but especially in the presence of a prior global context that encouraged the preactivation of general semantic expectancies. On total fixation duration, there was evidence of a similar integration cost in the Weak context condition for related targets, implying that these completions were also otherwise easier to integrate in any constraining context regardless of whether the constraint originated from the global or local context.

Somewhat surprisingly, there was also evidence that unrelated unpredictable completions received *facilitated* processing from both global and local sources of constraint despite sharing minimal semantic overlap with the disconfirmed prediction. Like related unpredictable completions, these benefits appeared to differ across the time course of word processing – the global constraint benefit was not evident in passages containing a locally constraining compared to locally non-constraining context across all fixation duration measures, i.e., unrelated unpredictable targets received a clear processing advantage in Global Only compared to Weak context conditions but no processing advantage in Global+Local compared to Local Only context conditions. On first fixation and gaze duration, this was driven by a processing benefit for unrelated targets in all constraining context conditions relative to the Weak context condition, suggesting that these completions were easier to process in the presence of any constraining context. However, on total fixation duration, the processing benefit for unrelated targets was restricted to the Global Only context condition, indicating that the general constraint benefit on earlier reading measures was not sustained in passages containing a locally constraining context. In other words, only a supportive global context without local constraint facilitated the integration of any unrelated unpredictable completion.

Thus, as observed in previous eye-movement studies (Frisson et al., 2017; Luke & Christianson, 2016), there was no evidence of processing costs for unexpected input in constraining context conditions, even when semantically unrelated to the disconfirmed prediction. Instead, on early reading measures, unpredictable completions regardless of their semantic relatedness to the best completion yielded immediate processing benefits in the presence of any constraining context, reflecting the impact of partial preactivation of relevant morphosyntactic and syntactic information even if the full word form was not predictable from the sentence context (Luke & Christianson, 2016). Moreover, for related completions, these immediate processing benefits were enhanced further by the provision of a global context which appeared to encourage a situation model of the discourse that activated lower-level representations of not only the most expected completion but semantically related alternatives (Brothers et al., 2020; Kuperberg et al., 2020). Late reading measures further indicated that the processing of related completions was supported by the presence of any constraining context, while the processing of unrelated completions was supported by the presence of a global context without local constraint, reflecting the efficient postlexical integration of unpredictable but contextually appropriate words.

The present findings therefore deviate from ERP data that show evidence of a late frontal positivity for unexpected input – the ERP waveform assumed to reflect additional neural activity associated with processing disconfirmed predictions. More importantly, the lack of observable prediction error costs in the eye-movement record across different sources of constraint violation challenges Brothers and colleagues' (2020) proposal that globally constraining contexts play an important role in eliciting this neural waveform because such contexts are more likely to encourage a situation model of the discourse that requires updating in the event of incompatible bottom-up input. A number of procedural factors could contribute to this discrepancy. It is possible that readers in Brothers et al.'s study were more sensitive to the available prior context because they always read the first two sentences of the passage before pressing a button that triggered the presentation of the final third sentence one word at a time. Furthermore, the inclusion of anomalous completions as the critical target in a third of the final sentences may have encouraged readers to attend more closely to the coherence of the discourse context because their secondary task was to judge whether each passage made sense or not. These aspects of Brothers et al.'s procedure may have artificially enhanced the need for readers to update their situation model when the input violated their expectations in order to distinguish between anomalous and plausible, but unexpected, words. Further research using different contextual manipulations is thus required to determine the precise aspects of the prior context that could be responsible for eliciting effects of prediction error. Indeed, the late frontal positivity has sometimes been reported in single-sentence contexts (e.g., Federmeier et al., 2007; Ness & Meltzer-Asscher, 2018; Thornhill & Van Petten, 2012), and single-word contexts (e.g., Federmeier et al., 2010) that appear unlikely to support construction of a situation model, which makes it important to also investigate whether an extended discourse context is even necessary for these effects.

More generally, evidence of additional neural activity linked to unexpected input in ERP studies including Brothers et al. (2020) could reflect methodological factors that encourage stronger and more “conscious” prediction strategies than typically applied during natural reading. For example, ERP studies usually present stimuli in a rapid serial visual presentation (RSVP) format where each word is displayed one at a time at a fixed pace ranging from 400 to 1000 ms (Degno & Liversedge, 2020) which is substantially longer than the 200 to 250 ms duration of typical eye fixations during sentence reading (Rayner, 2009; Rayner & Clifton, 2009). Such formats also deprive readers of the ability to skip words, re-read previous parts of text, and use upcoming parafoveal information. The absence of these normal reading strategies in combination with the slower presentation rates may lead readers to rely more on higher-level cognitive processes including anticipatory prediction of specific lexical items (Dambacher et al., 2012; Wlotko & Federmeier, 2015) to achieve comprehension. Accordingly, the appearance of unexpected input may lead to processing costs that are specific to ERP but not eye-movement studies. Future research via the co-registration of eye-movements and ERPs may provide further insight into this discrepancy.

Taken together, the consistent evidence against observable prediction error costs in the eye-movement record suggests that, while readers do make use of anticipatory prediction during online processing, the language processor does not generate specific lexical predictions about upcoming words which involve the “all-or-none” preactivation of a single linguistic term. If this were the case, only words that could be fully predicted from the context would receive processing benefits, while less predictable but semantically plausible words would elicit processing costs from suppressing or inhibiting these predicted candidates. This strong lexical prediction strategy, however, would be inefficient and costly in natural reading – few words are predictable enough to benefit from “all-or-none” preactivation (Jackendoff, 2002; Luke & Christianson, 2016), and unpredictable words would require a level of processing beyond what would have been necessary if lexical prediction had not occurred in the first place.

Instead, the language processor appears to generate graded predictions during online processing which involve the partial preactivation of upcoming words even if the full word cannot be predicted from the sentence context (Brothers & Kuperberg, 2021; Federmeier, 2022; Levy, 2008; Luke & Christianson, 2016; Staub, 2015; Staub et al., 2015). This graded prediction strategy is assumed to entail the passive activation of information related to the current discourse which forms part of the natural organization of long-term memory in response to incoming linguistic text (Federmeier, 2022). As such, multiple lexical candidates are generated for each word of a sentence, which allow predictability effects to arise across a range of contextual constraints, including for less predictable completions (Brothers & Kuperberg, 2021; Luke & Christianson, 2016; Smith & Levy, 2013). Importantly, unlike “all-or-none” lexical prediction, this graded prediction strategy is relatively cost-free. Because the language processor generates graded predictions in an automatic and effortless manner, it does not make active commitments to any lexical candidates that would require suppression or inhibition if an unexpected input appeared. Consistent with this graded prediction strategy, disconfirmed predictions do not yield observable processing costs in eye-movement studies to date (Frisson et al., 2017; Luke & Christianson, 2016) including the present one, instead receiving processing facilitation when semantically related to the best completion. Even unrelated unpredictable completions in the current study demonstrated evidence of enhanced processing simply from being presented in a constraining context.

A recent proposal by Federmeier (2022) opens up the possibility that the language processor might generate both lexical and graded predictions during online processing. According to Federmeier, “connecting” incoming linguistic text with long-term semantic memory to create graded predictions is a fundamental, but passive, component of online language comprehension. However, these processes can lead to “considering” a set of more active comprehension processes, including prediction, whereby initial graded, semantic representations are transformed into more stable representations for the reader. These active comprehension processes, though, are neither obligatory nor universal – they depend upon factors such as task and goal demands, age, and individual differences. Such a framework could therefore accommodate the discrepant findings regarding effects of prediction error between existing eye-movement and ERP studies given that, as discussed above, the latter may be more likely to encourage stronger prediction strategies due to various methodological factors.

In summary, anticipatory prediction processes appear to be an important and necessary feature of the online language comprehension system. As expected, predictable completions in the present study benefited from any constraining context, although the relative contributions of different sources of constraint varied across the time course of readers’ eye movements. However, there was no indication that unpredictable completions disrupted readers' eye movements even when they disconfirmed these lexicosemantic predictions and challenged the existing situation model at the higher discourse level. Instead, unpredictable completions regardless of their semantic relatedness to the best completion produced immediate processing benefits in the presence of any constraining context. This initial processing benefit was enhanced further for related completions in the presence of a supportive global context. Predictability effects on eye-movement measures of reading therefore appear to be determined by not only cloze probability, but also the nature of prior contextual constraint especially when they encourage the construction of higher-level discourse representations. More generally, these findings provide support for a graded account of predictive processing – readers do not rely on full lexical predictions during natural reading even in highly constraining, semantically rich, multi-sentence discourse contexts. Instead, readers are more likely to generate graded predictions about upcoming text which appears to be a less costly and misleading strategy for achieving deep comprehension.

CHAPTER 3: Looking Downstream for Evidence of Lexical Prediction in Eye Movements during Reading

The contents of this chapter are a minor revision of Wong, R., Veldre, A., & Andrews, S. (in revision). Looking downstream for evidence of lexical prediction in eye movements during reading. *Quarterly Journal of Experimental Psychology*.

3.1 Abstract

Previous investigations of whether readers make predictions about the full identity of upcoming words have focused on the extent to which there are processing consequences when readers encounter linguistic input that is incompatible with their expectations. To date, eye-movement studies have revealed inconsistent evidence of the processing costs that would be expected to accompany lexical prediction. The current study investigated whether readers' lexical predictions were observable while processing text downstream from their initial point of activation. Three experiments assessed readers' eye movements to predictable and unpredictable words, and then to subsequent downstream words which probed the lingering activation of previously expected words. The results showed novel evidence of processing costs for unexpected input but only when supported by a plausible linguistic environment, suggesting that readers could strategically modulate their predictive processing. However, there was limited evidence that their lexical predictions impacted downstream processing. The implications of these findings for understanding the role of prediction in language processing are discussed.

3.2 Introduction

It is well established that a word's predictability, as indexed by cloze probability (i.e., the proportion of individuals that provide a given word for an unfinished sentence frame in an offline task; Taylor, 1953), is an important factor that determines how readers process words within a sentence. Early behavioural studies using naming (Stanovich & West, 1983; Traxler & Foss, 2000) and lexical decision tasks (Fischler & Bloom, 1985; Kleiman, 1980; Schwanenflugel & LaCount, 1988; Schwanenflugel & Shoben, 1985) have demonstrated that predictable words elicit decreased response times compared to unpredictable words. Similarly, eye-movement studies of sentence reading have found that predictable words are more likely to be skipped and to receive shorter fixation durations compared to unpredictable words (Balota et al., 1985; Drieghe et al., 2005; Ehrlich & Rayner, 1981; Frisson et al., 2017; Luke & Christianson, 2016; Rayner et al., 2011; see Staub, 2015 for a review). Research using event-related potentials (ERPs) has also revealed a graded relationship between word predictability and the N400 component, a centro-parietal negativity that peaks around 300 to 500 ms poststimulus onset. Predictable words consistently yield smaller N400 components than unpredictable words, which is thought to reflect the ease of semantic processing (Federmeier et al., 2007; Kutas & Hillyard, 1984; Kutas et al., 1984; Thornhill & Van Petten, 2012). Thus, there is consistent evidence across different methodologies that words that can be predicted from prior context are processed more efficiently during online language comprehension (see Kuperberg & Jaeger, 2016 for a review).

Despite the extensive research into predictability effects, there is still considerable debate about whether these facilitatory effects are the result of anticipatory prediction –

the “all-or-none process of activating … a word in advance of perceptual input” (DeLong, Troyer, & Kutas, 2014b, p. 632). Although anticipatory prediction is assumed to ease the burden of processing noisy and informationally dense language input (Clark, 2013; Friston, 2010; Kutas et al., 2011), researchers have traditionally argued against a role for prediction during online processing. Firstly, predictability effects have been proposed to reflect processes of *postlexical integration* rather than prediction, i.e., a predictable word is easier to process, not because it has been preactivated ahead of time but because other linguistic information has been activated as a result of processing the input which makes it easier to integrate into an unfolding discourse representation (Pickering & Gambi, 2018). Although prediction is difficult to disentangle from integration because both processes entail facilitated processing for predictable words (Kutas et al., 2011; but see Van Berkum et al., 2005; Wicha, Bates, et al., 2003a; Wicha, Moreno, et al., 2003b; Wicha et al., 2004), predictability effects are typically observed on early eye-movement measures including skipping (e.g., Balota et al., 1985; Rayner et al., 2011) which would appear to be incompatible with postlexical integration processes (Abbott & Staub, 2015; but see Veldre et al., 2020). Secondly, even if prediction does play a genuine part during online processing, very few words are predictable in natural language (Gough, 1983; Gough et al., 1981; Luke & Christianson, 2016; but see Cevoli et al., 2022) – the unconstrained nature of language means that infinite options are available as plausible continuations for each word of an unfolding sentence (Jackendoff, 2002). If this is the case, prediction would have limited utility for language comprehension beyond highly constraining, “prediction-friendly” contexts (Huettig & Mani, 2016). Finally, it remains unclear exactly what readers predict – although readers appear to preactivate morphosyntactic, syntactic, and semantic information during online processing (Luke & Christianson, 2016), there is inconsistent evidence that readers routinely make predictions about the full lexical identity of upcoming words.

If readers make lexical predictions about upcoming words, there should be evidence of processing consequences when the anticipated input does not eventuate. For example, consider a strongly constraining sentence frame like "*The children went outside to...*" for which most readers will expect the predictable completion "*play*". If this prediction were to be disconfirmed by a plausible but unexpected completion like "*look*", a *prediction error cost* should occur due to the mismatch between the word preactivated by the context and the input eventually encountered. However, the same, equally unpredictable completion "*look*" should not elicit a similar processing cost in a weakly constraining sentence frame like "*Joy was frightened to...*" for which readers are unlikely to have made any predictions in advance of the upcoming text. Thus, the appearance of processing costs for unexpected input in strongly but not weakly constraining contexts should provide strong evidence that readers have made a predictive commitment to a specific lexical item.

Across studies and methodologies, however, there are notable inconsistencies about whether disconfirmed predictions give rise to the processing costs that would be expected to accompany lexical prediction. For example, Frisson et al. (2017) presented readers with strongly constraining (e.g., 1a) and weakly constraining (e.g., 1b) sentences in which the plausible target word was either the predictable completion of the strongly constraining context ("*church*"), unpredictable but semantically related to the best completion ("*sermon*"), or unpredictable but semantically unrelated to the best completion ("*garden*").

(1) a. *The priest wondered how he could get more people to come to the* ***church/sermon/garden*** *even though it was raining.*

b. *The widow thought that it was a lovely* ***church/sermon/garden*** *even though it was cold.*

As expected, predictable completions like "*church*" received stronger processing benefits under conditions of high constraint, i.e., higher skipping rates, shorter fixation durations, and fewer regressions than the average of the other conditions. But there was no evidence that either of the unpredictable completions (i.e., "*sermon*" and "*garden*") presented in place of these more expected competitors disrupted readers' eye movements in strongly relative to weakly constraining contexts. Instead, unpredictable completions that were semantically related to the best completion received shorter total reading times and fewer first-pass regressions in the strongly constraining contexts (i.e., "*sermon*" in 1a), suggesting that these items were easier to integrate due to their semantic overlap with the most predictable completion (see Federmeier & Kutas, 1999; Federmeier et al., 2002; Thornhill & Van Petten, 2012 for similar ERP findings). Similar findings were obtained in a recent eye-movement study by Wong et al. (2022) in which unpredictable completions were presented in three-sentence passages that varied in whether the source of constraint violation originated from the global or local context.

Luke and Christianson (2016) also found no evidence of prediction error costs when readers were presented with a corpus of naturalistic text passages for which cloze probability values had been calculated for each word. Instead, as the cloze probability of the best completion increased, unexpected content words were processed more efficiently as indexed by a higher rate of skipping and fewer refixations (see also Andrews et al., 2022). More recently, however, Cevoli et al. (2022) reported evidence of prediction error costs when analysing Luke and Christianson's eye-movement data using two predictability metrics derived from a language model. Firstly, *surprisal* which refers to the degree of surprise when a target word is reached as indexed by its negative log cloze probability, and *entropy* which refers to the degree of uncertainty before a target word is reached as indexed by the extent to which a context is neutral or constraining (see also Lowder et al., 2018). Specifically, first fixation durations were longer when high surprisal or 'unexpected' targets were presented in low entropy contexts where it was possible to make a lexical prediction about upcoming text, suggesting that readers' eye movements were immediately disrupted by the mismatch between the predicted word and the input eventually encountered. These early prediction error costs, however, were resolved soon after – gaze and total fixation durations were reduced for unexpected targets that were semantically related to the best completion, indicating that integration processes facilitated their subsequent processing. Cevoli et al. concluded that readers did rely on lexical prediction during online processing although the immediate consequences of violating these expectations appeared to be short-lived. Thus, eye-movement studies to date provide mixed evidence of the processing costs that would be expected to occur if readers make lexical predictions that subsequently turn out to be incorrect.

ERP studies, on the other hand, have linked disconfirmed predictions to additional neural activity in the form of a late frontal positivity that emerges 500-1000 ms poststimulus onset (see Van Petten & Luka, 2012 for a review). Plausible unexpected completions consistently yield this late neural waveform in strongly constraining contexts where a more expected competitor is available, but not in weakly constraining contexts where no strong predictions can be made (DeLong et al., 2012; Federmeier et al., 2007; Ness & Meltzer-Asscher, 2018; Thornhill & Van Petten, 2012). This late frontal positivity has also been distinguished from a late parietal positivity that arises for unexpected completions that are anomalous in the sentence context (DeLong, Quante, & Kutas, 2014a; Kuperberg et al., 2020), providing further evidence that it reflects the consequences of prediction violation rather than general linguistic incongruity. To the extent that this ERP waveform is not just a simple indicator of prediction violation, the additional neural activity captured by the late frontal positivity has been hypothesised to reflect the processing consequences of suppressing the previously expected completion (Federmeier et al., 2007; Kutas, 1993; Ness & Meltzer-Asscher, 2018) and/or revising the unfolding discourse representation based on the novel unexpected input (Brothers et al., 2015; Brothers et al., 2020; DeLong et al., 2014b) – processes that should not occur for anomalous completions because they cannot be integrated into an unfolding discourse representation. In contrast to eye-movement studies then, ERP studies provide more consistent evidence that readers *do* generate specific lexical predictions during online processing because they are sensitive to the costs of misprediction. Taken together, there are clear discrepancies across studies and methodologies in the apparent consequences of encountering unexpected input in place of a more predictable completion.

Recent ERP evidence suggests that the effects of lexical prediction are observable not just during the immediate processing of critical words but downstream from their initial presentation (Hubbard et al., 2019; Lai et al., 2021; Rommers & Federmeier, 2018a, 2018b). For example, when Rommers and Federmeier (2018a) presented sentences completed by predictable or unpredictable completions that appeared three sentences later, both types of repeated words elicited a repetition effect at the N400 component relative to a word that had not been previously seen. The size of this repetition effect, however, was smaller for previously expected completions, leading Rommers and Federmeier to speculate that predictable words were encoded less thoroughly during their initial presentation resulting in a more impoverished downstream representation.

More relevant to our current research is a subsequent study by Rommers and Federmeier (2018b) which revealed that readers' lexical predictions were observable downstream even if they did not materialise and were replaced by less expected input. Readers in this study were presented unpredictable targets like "*hot*" in weakly constraining sentences (e.g., 2a), or equally unpredictable targets like "*dirty*" in strongly constraining sentences like (e.g., 2b) which replaced the more expected completion "*hot*". Three sentences later, the critical target "*hot*" was presented in an unconstraining sentence like "*The proofreader asked her to replace the word **hot***" which assessed readers' processing of a repeated word when following sentences like (2a) or a disconfirmed prediction when following sentences like (2b).

(2) a. *He was surprised when he found out that it was **hot***.

b. *Be careful, because the top of the stove is very **dirty**.*

At initial presentation, unpredictable targets in strongly constraining contexts yielded the expected late frontal positivity, reflecting readers' sensitivity to disconfirmed predictions. Further downstream, repeated words elicited the expected repetition effect at the N400 component relative to a word being presented for the first time. However, disconfirmed predictions which were not presented but merely expected also elicited a similar attenuated N400. Although the size of this N400 reduction was smaller than the repetition effect, Rommers and Federmeier concluded that previously predictable words were still active in readers' memory even though their occurrence in the sentence had been disconfirmed. Hubbard et al. (2019) provided converging evidence using a word recognition task that revealed higher rates of false alarms to “lures” that were predicted, but never presented, compared to items that had not been previously seen.

These ERP findings therefore provide further evidence that readers generate specific lexical predictions during online processing because these expectations can linger and facilitate downstream processing even if they do not eventuate and are replaced by less expected input. Importantly, because unexpected input also initially elicited the late frontal positivity, this implies that these expectations were likely suppressed and the existing discourse representation was likely revised based on the input actually encountered. As such, the fact that previously predictable words were facilitated downstream suggests that the effects of misprediction were only temporary because these expectations subsequently lingered to impact processing. This idea that the processing consequences of misprediction are short-lived could account for why evidence of prediction error costs across previous eye-movement studies has been inconsistent, and generally elusive, during the immediate processing of unexpected input (Andrews et al., 2022; Cevoli et al., 2022; Frisson et al., 2017; Luke & Christianson, 2016; Wong et al., 2022). Accordingly, it raises the possibility that readers’ expectations could also remain active downstream in the eye-movement record even if they are disconfirmed by unexpected input.

Thus, the aim of the present set of experiments was to extend existing eye-movement investigations of anticipatory prediction by looking further downstream for evidence that readers make specific lexical predictions during online processing. The experiments reported below present short, connected sentence pairs in which the first sentence contained a target word that either confirmed or disconfirmed readers’ expectations, while the second sentence presented previously predictable words close to their initial point of activation. This design allowed us to assess prediction error costs at target words that have not been observed in previous controlled eye-movement studies (e.g., Frisson et al., 2017; Wong et al., 2022), and, more specifically, to determine whether readers' predictions have downstream consequences even if they do not eventuate and are replaced by less expected input.

3.3 Experiment 1

Readers' eye movements were recorded as they read two-sentence passages. The first sentence was either strongly constraining towards a specific word or weakly constraining. The *initial target word* was either the predictable word or an unpredictable word (see Table 3.1 for an example item set and Appendix for a complete list of stimuli). Unpredictable words were either semantically related to the best completion of the strongly constraining context, semantically unrelated to the best completion, or syntactically and semantically anomalous within the sentence context. These manipulations allowed for investigations of the impacts of semantic relatedness (Frisson et al., 2017), and anomaly (Van Petten & Luka, 2012) on predictability effects during online processing.

On the basis of previous eye-movement studies using similar controlled experimental designs (Frisson et al., 2017; Wong et al., 2022), predictable words in strongly constraining contexts were expected to elicit the largest processing benefits relative to the same words in weakly constraining contexts. However, no immediate consequences of prediction failure were expected when plausible unpredictable words were presented in strongly compared to weakly constraining contexts, regardless of their semantic relatedness to the best completion. Instead, related unpredictable words under conditions of strong constraint were expected to elicit processing benefits on late eye-movement measures due to their semantic overlap with the best completion. Anomalous words, on the other hand, were expected to elicit processing costs in both context conditions due to their overall linguistic incongruity (Braze et al., 2002; Rayner et al., 2004; Veldre et al., 2020) rather than to the violation of readers' predictions *per se*.

Immediately following the first sentence, readers were presented with a thematically related unconstraining sentence that probed the downstream activation of the predictable word from the initial sentence as a function of whether it had been confirmed or disconfirmed. The *downstream target word* was therefore either a *repeated word* when readers previously encountered the predictable word in either of the context conditions, or a *new word* when readers previously encountered any of the unpredictable words, although this new word would have been previously expected in the strongly constraining contexts. These connected sentence pairs ensured that, unlike previous repetition paradigms used in ERP studies (e.g., Rommers & Federmeier, 2018a, 2018b), readers' processing of the downstream target words relative to their initial point of activation was not delayed by several unrelated intervening sentences. However, the second sentence was always neutrally constraining to ensure that readers did not generate any other predictions that could interfere with the downstream activation of the previously predictable word.

Downstream targets that were repeated words were expected to yield different processing patterns following predictable completions in strongly compared to weakly constraining contexts. If predictable words are encoded less thoroughly because they simply confirm readers' expectations (Rommers & Federmeier, 2018a), repeated words may yield repetition costs following predictable words in strongly compared to weakly constraining contexts. However, if predictable words are processed more thoroughly because their preactivation ahead of time frees up more of readers' cognitive resources, repeated words may yield repetition benefits following predictable words under conditions of strong constraint.

Furthermore, if readers make predictions about upcoming words that involve the prediction of a specific lexical item (DeLong et al., 2014b), downstream targets that were new words were expected to yield different processing patterns following plausible unpredictable completions in strongly compared to weakly constraining contexts given that these new words would have been previously expected, although never presented, in strongly constraining contexts. If the consequences of misprediction are short-lived, previously predictable words should still have active representations downstream despite being temporarily suppressed. As such, facilitated processing should be observed for new words following plausible unpredictable words in strongly but not weakly constraining contexts. But if the consequences of misprediction are long-lasting, previously predictable words should have suppressed representations downstream owing to more persistent inhibition processes (Federmeier et al., 2007; Kutas, 1993; Ness & Meltzer-Asscher, 2018). As such, inhibited processing should be observed for new words following plausible unpredictable words in strongly but not weakly constraining contexts.

If readers do not make predictions that involve a specific lexical item because they preactivate upcoming morphosyntactic, syntactic, and semantic information instead (Luke & Christianson, 2016), downstream targets that were new words were only expected to receive facilitated processing following unpredictable words that are semantically related to the best completion in strongly constraining contexts. Conversely, new words should be processed equivalently following unrelated unpredictable words in both context conditions given minimal semantic overlap with the best completion.

Finally, regardless of the type of predictions readers make about upcoming words, downstream targets that were new words were expected to receive facilitated processing following anomalous unpredictable words in strongly constraining contexts – the previously predictable word should not be suppressed given that anomalous words cannot be integrated into the unfolding discourse representation in the first place (Kutas, 1993).

3.3.1 Method.

Participants.

Sixty-two undergraduates from The University of Sydney participated in the eye-tracking task in return for course credit. The data from three participants were removed due to self-reported dyslexia, calibration difficulty, and comprehension accuracy in the eye-tracking task that was 3 *SD* below the mean. Therefore, the final sample comprised 59 participants (M_{age} = 20.2 years; 34 females). All were native English speakers and had normal or corrected-to-normal vision. This research was approved by the University of Sydney Human Research Ethics Committee, and all participants provided written informed consent prior to participating in the study.

Materials.

The critical stimuli were 76 pairs of two-sentence passages which were adapted from materials used in Frisson et al. (2017). Each pair was constructed such that in the strongly constraining passage, the initial target was high in predictability, while in the weakly constraining passage, the same initial target was low in predictability. Predictable words were compared to length- and frequency-matched unpredictable words that were either semantically related or unrelated to the predictable word, or anomalous in the sentence context. The second sentence was identical across all conditions and always contained the downstream target, i.e., the predictable initial target from the strongly constraining context.

The constraint of the first sentence and the predictability of the initial target was confirmed by cloze completions collected from a separate sample of 17 participants who did not complete the eye-tracking task (M_{age} = 20.1 years; 11 females). Plausibility ratings of the first sentence were also collected to ensure that the related and unrelated unpredictable words were equivalently plausible continuations in both constraint conditions – a separate sample of 80 participants (M_{age} = 52.9 years; 47 females) judged the plausibility of the first sentence on a 5-point scale from 1 (Highly Implausible) to 5 (Highly Plausible). The semantic relatedness of the initial target was assessed by computing Latent Semantic Analysis (LSA; Landauer & Dumais, 1997) scores between the predictable word and each of the unpredictable words. Table 3.1 presents an example item pair with the mean lexical characteristics of the target words for each condition.

Apparatus.

Participants read the passages on a 21-inch ViewSonic G225f CRT monitor which was set to a pixel resolution of 1024 x 768 and a 140 Hz refresh rate while their eye movements were tracked by a SR Research Eyelink 1000 eye-tracker which had a sampling rate of 1000 Hz. Passages were presented across two double-spaced lines in 14pt Consolas black font on a white background. Target words were never positioned at the beginning or end of a line. Participants were seated 60 cm from the monitor with a chin and forehead rest used to minimise head movements. At this distance, one degree of visual angle equated to 2.85

letter spaces. Viewing was binocular, but eye movements were recorded from participants' right eye.

Procedure.

Participants were instructed to read the passages for meaning and to respond to comprehension questions which appeared after approximately 34% of the trials (mean accuracy = 90.5%).[1] A nine-point calibration procedure was conducted before the start of the experiment. If mean calibration error was greater than .5° of visual angle, an additional calibration procedure was carried out. Before each trial, a fixation point appeared at the location of the first letter of the passage and a stable fixation on this point was required before the trial was displayed.

The passages were counterbalanced across four lists using a Latin square design so that each participant always saw a different target word in the strong and weakly constraining version of each pair. Across all passages, each participant saw an equal number of target words per condition. Participants were randomly assigned to a list which randomly presented the passages across four equal blocks interspersed with 30 neutrally constraining filler passages.

The experimental materials, data, and analysis code for all experiments reported in this chapter are publicly available on the Open Science Framework website: https://osf.io/5rgck/.

[1] The responses to eight comprehension questions were removed as less than 66% of participants answered them correctly. The original comprehension accuracy was 86.3%. These eight comprehension questions were rewritten for the subsequent two experiments.

Table 3.1

Example set of items and mean (and standard deviation) stimulus characteristics

Condition	Example item (Initial target bolded; Downstream target underlined)	Initial target cloze probability	Initial target frequency (logHAL)	Initial target length (letters)	Initial target sentence plausibility (1-5 scale)	Initial target relatedness to predictable word (LSA)	Constraint of first sentence
Strongly constraining context							
Predictable	Irene and her husband travelled by boat to the tropical **island** for their honeymoon. It was close to the <u>island</u> they had chosen for their wedding.	.81 (.13)	9.5 (1.4)	5.4 (1.3)	4.9 (0.2)	1 (0)	.81 (.13)
Related	Irene and her husband travelled by boat to the tropical **resort** for their honeymoon. It was close to the <u>island</u> they had chosen for their wedding.	.01 (.03)	8.8 (1.9)	5.3 (1.3)	4.6 (0.6)	0.3 (0.2)	.81 (.13)
Unrelated	Irene and her husband travelled by boat to the tropical **garden** for their honeymoon. It was close to the <u>island</u> they had chosen for their wedding.	.00 (.02)	9.4 (1.8)	5.4 (1.2)	4.2 (0.8)	0.1 (0.1)	.81 (.13)
Anomalous	Irene and her husband travelled by boat to the tropical **seeing** for their honeymoon. It was close to the <u>island</u> they had chosen for their wedding.	.00 (.00)	8.9 (2.2)	5.4 (1.3)	1.1 (0.2)	0.1 (0.1)	.81 (.13)

Weakly constraining context							
Predictable	Today we visited a beautiful **island** famous for exotic birds. Tomorrow, we will go to the island where the capital is located.	.01 (.04)	9.5 (1.4)	5.4 (1.3)	4.7 (0.5)	1 (0)	.18 (.07)
Related	Today we visited a beautiful **resort** famous for exotic birds. Tomorrow, we will go to the island where the capital is located.	.01 (.04)	8.8 (1.9)	5.3 (1.3)	4.6 (0.6)	0.3 (0.2)	.18 (.07)
Unrelated	Today we visited a beautiful **garden** famous for exotic birds. Tomorrow, we will go to the island where the capital is located.	.01 (.05)	9.4 (1.8)	5.4 (1.2)	4.6 (0.6)	0.1 (0.1)	.18 (.07)
Anomalous	Today we visited a beautiful **seeing** famous for exotic birds. Tomorrow, we will go to the island where the capital is located.	.00 (.00)	8.9 (2.2)	5.4 (1.3)	1.2 (0.3)	0.1 (0.1)	.18 (.07)

Note. The Anomalous conditions were not included in Experiments 2 or 3. The Predictable conditions were not included in Experiment 3.

3.3.2 Results.

Fixations shorter than 80 ms were automatically merged with adjacent fixations within 1-letter space (.35% of total fixations). Trials were removed if a participant prematurely ended the trial (.2% of trials), or if there was track loss or blinks on the region of interest (Initial target: 5.3% of trials; Downstream target: 2.2% of trials). Fixations on the initial and downstream targets below 80 ms, first fixation durations above 800 ms, gaze durations above 1200 ms, and total fixation durations above 2000 ms were also excluded (Initial target: 1.3% of trials; Downstream target: 1.4% of trials). These exclusions left 8357 initial target data points (93.2% of the data) and 8619 downstream target data points (96.1% of the data) for analysis.

For both the initial and downstream targets, log-transformed reading measures were analysed: *first fixation duration* (the duration of the first fixation on a region), *gaze duration* (the sum of all fixations on a region before the eyes exit this region for the first time), and *total fixation duration* (the sum of all fixations on a region). The probability of skipping, regressions out of the target word to earlier in the text, and regressions into the target word from later in the text were also analysed. The average reading measures on the initial and downstream targets for each condition are presented in Table 3.2.

The data were analysed by (generalised) linear mixed effects models (GLMM/LMM) using the *lme4* package (Version 1.1-30; Bates et al., 2015) in *R*. The models tested the fixed effect of constraint nested under initial target type which returned estimates of the constraint effect separately for predictable, related, unrelated, and anomalous words, similar to the analyses carried out by Frisson et al. (2017). The effect of constraint for the predictable words was equivalent to testing the benefit of making a correct prediction

Table 3.2

Mean (and standard deviation) reading measures on the initial and downstream target words for each condition in Experiment 1

		Strongly constraining context				Weakly constraining context			
	Reading measure	Predictable initial target	Related initial target	Unrelated initial target	Anomalous initial target	Predictable initial target	Related initial target	Unrelated initial target	Anomalous initial target
Target Word	Skipping (%)	30 (12)	26 (10)	24 (11)	23 (11)	21 (9)	24 (9)	22 (9)	21 (11)
	First fixation (ms)	216 (26)	231 (25)	227 (22)	255 (28)	222 (22)	231 (19)	230 (22)	244 (25)
	Gaze (ms)	237 (38)	254 (28)	254 (28)	295 (40)	242 (32)	258 (27)	251 (28)	283 (35)
	Total fixation (ms)	279 (79)	316 (60)	343 (63)	594 (123)	316 (55)	354 (52)	349 (56)	598 (137)
	Regressions out (%)	10 (7)	11 (9)	13 (7)	19 (11)	11 (7)	11 (8)	11 (6)	19 (11)
	Regressions in (%)	7 (9)	14 (9)	17 (8)	52 (16)	19 (9)	25 (9)	25 (10)	58 (13)
Downstream Word	Skipping (%)	35 (9)	36 (8)	34 (10)	35 (10)	33 (11)	32 (11)	32 (10)	28 (10)
	First fixation (ms)	204 (20)	205 (22)	208 (22)	208 (26)	206 (24)	203 (26)	214 (22)	207 (23)
	Gaze (ms)	226 (24)	224 (28)	227 (31)	229 (32)	233 (29)	230 (33)	241 (33)	236 (28)
	Total fixation (ms)	286 (41)	279 (34)	288 (37)	282 (40)	297 (42)	289 (45)	307 (45)	287 (40)
	Regressions out (%)	15 (8)	15 (9)	16 (8)	16 (8)	16 (8)	19 (9)	18 (9)	19 (9)
	Regressions in (%)	23 (7)	20 (8)	21 (8)	19 (9)	21 (9)	20 (9)	22 (10)	18 (9)

because these words were high cloze in the strongly constraining context but low cloze in the weakly constraining context. Meanwhile, the effect of constraint for each of the unpredictable words was equivalent to testing the cost of making an incorrect prediction because these words disconfirmed a more expected completion in the strongly constraining context but not in the weakly constraining context. The models also tested the main effect of initial target type, which was coded as a set of three orthogonal contrasts: (1) the *predictability* effect – the difference between the predictable condition and the two plausible unpredictable conditions, (2) the *relatedness* effect – the difference between the related unpredictable condition and the unrelated unpredictable condition, and (3) the *anomaly* effect – the difference between the anomalous condition and the three plausible conditions. Given that these contrasts are averaged over constraint, they are not directly relevant to the interpretation of the initial target; but their inclusion is important for the purpose of accounting for variance in the models (Schad et al., 2020). These contrasts, however, are relevant to the interpretation of the downstream target because the predictability effect is equivalent to testing the repeated word effect (i.e., the difference between the repeated and new words), while the relatedness and anomaly effects are equivalent to testing the new word effect (i.e., the difference between the new words depending on the initial target presented). Thus, the outcomes of these contrasts are reported for both target words, but interpretations are restricted to the downstream target.

All models either failed to converge or showed singular fit with the maximal random-effects structure (i.e., subject and item random intercepts and random slopes for the nested constraint effect under each level of predictability). Therefore, the random-effects structure for each model was simplified: first by removing the correlation parameters between random intercepts and random slopes, and second by sequentially removing random slopes that accounted for the least variance until model convergence without singular fit. Estimates yielding *t/z* values greater than |1.96| were interpreted as significant at the .05 α level. Power analyses conducted with 100 Monte Carlo simulations using the *simR* package (Version 1.0.6; Green & MacLeod, 2016) in *R* demonstrated adequate power to detect the constraint effect for predictable initial targets (>.97) and related initial targets (>.94) based on comparable effects reported in Frisson et al. (2017; predictable targets: 16 ms on first fixation duration, 24 ms on gaze duration; 63 ms on total fixation duration; related targets: 51 ms on total fixation duration). The models also had adequate power (>.80) to detect the constraint effect for downstream targets following each of the unpredictable words of 11 ms effect size on first fixation duration, 15 ms effect size on gaze duration, and 25 ms effect size on total fixation duration. Summaries of the statistical analyses for the initial and downstream targets are presented in Table 3.3.[2]

Initial target.

The predictability effect was significant on all reading measures except skipping and regressions-out (|*z*|s < 1.63) because, averaged over constraint, predictable targets received shorter fixation durations and fewer regressions-in (|*t/z*|s > 5.07) compared to plausible unpredictable targets. While the relatedness effect was not significant on any reading measures (|*t/z*|s < 1.69), the anomaly effect was significant on all reading measures

[2] Eye-tracking participants also provided cloze completions after a 1-2-week delay to obtain individualised estimates of cloze probability for the target words (*n* = 57 as two participants did not return). These individualised cloze data were virtually identical to the cloze data collected from the independent sample of participants and are therefore not reported. Based on these individualised cloze data, a separate set of (G)LMMs were conducted excluding: (a) trials where participants did not generate the predictable initial target in the strongly constraining contexts and (b) trials where participants generated the unpredictable initial target in the weakly constraining contexts (9.9% of trials). The pattern of significant results of these restricted analyses was identical to the unrestricted analyses with the following exceptions: for the initial target, the relatedness effect was significant on regressions-in (*z*=-2.69); for anomalous initial targets, the constraint effect was not significant on first fixation duration (*t*=-1.70) or regressions-in (*z*=1.94).

($|t/z|$s > 2.20) because, averaged over constraint, readers showed lower skipping rates, longer fixation durations, and more regressions for anomalous relative to plausible targets.

For predictable targets, the constraint effect was significant on skipping, first fixation duration, total fixation duration, and regressions-in ($|t/z|$s > 1.99) because predictable targets received higher skipping rates, shorter reading times, and fewer regressions-in when presented in strongly compared to weakly constraining contexts. For related unpredictable targets, the constraint effect was significant on total fixation duration and regressions-in ($|t/z|$s > 3.14) reflecting shorter total reading times, and fewer regressions-in for related unpredictable targets under conditions of strong compared to weak constraint. For unrelated unpredictable targets, the facilitatory constraint effect was restricted to regressions-in (z = 3.27) due to fewer regressions-in from later parts of the text in strongly compared to weakly constraining contexts. Finally, for anomalous unpredictable targets, the constraint effect was significant on first fixation duration and regressions-in ($|t/z|$s > 2.11) due to *longer* initial fixations but fewer regressions-in for anomalous unpredictable targets under conditions of strong compared to weak constraint.

Thus, as expected, predictable targets showed the largest predictability benefits in strongly constraining contexts. Plausible unpredictable targets that disconfirmed these expectations also received facilitated, rather than slowed, processing on late reading measures in strongly compared to weakly constraining contexts. The only evidence of predictability costs was restricted to anomalies presented under strong constraint.

Downstream target.

The predictability effect was not significant on any of the reading measures at the downstream target (i.e., the predictable word from the initial sentence; $|t/z|$s < 1.65) because repeated words following predictable words were processed equivalently to new words following any of the plausible unpredictable words. The relatedness effect was significant on first fixation and total fixation duration ($|t|$s > 2.33) because new words received shorter fixation durations when following related compared to unrelated words. The anomaly effect was significant on regressions-in (z = -3.01) because new words received fewer regressions-in when following anomalous compared to plausible words. Thus, downstream repeated targets were processed equivalently to downstream new targets, although the latter showed some processing facilitation depending on the completion that appeared in the first sentence.

For downstream targets following predictable words, the constraint effect was not significant on any reading measures ($|t/z|$s < 1) because repeated words were processed equivalently following predictable words in the initial sentence across both constraint conditions. For downstream targets following related or unrelated words, the constraint effect was not significant on any reading measures ($|t/z|$s < 1.93) as new words were processed equivalently following related or unrelated words in the initial sentence across both constraint conditions. Finally, for downstream targets following anomalous words, the constraint effect was significant on skipping (z = -2.60) because new words were more likely to be skipped if the anomalous word in the initial sentence was presented under conditions of strong compared to weak constraint. Thus, downstream repeated targets were processed equivalently when following a predictable completion in strongly compared to weakly constraining contexts. Similarly, downstream new targets were not processed differently when following plausible but unpredictable completions under conditions of strong constraint. However, downstream new targets were more likely to be skipped when following an anomalous unpredictable completion in strongly constraining contexts.

Table 3.3

Results for the nested linear mixed effects models for log-transformed fixation duration measures and generalised linear mixed effects models for fixation probability measures on the initial and downstream target words in Experiment 1

Measure	Fixed effect	Initial target word			Downstream target word		
		b	*SE*	*t/z*	*b*	*SE*	*t/z*
Skipping	Intercept	**-1.30**	**0.10**	**-12.60**	**-0.78**	**0.10**	**-7.80**
	Predictability	0.11	0.07	1.63	0.04	0.06	0.59
	Relatedness	0.10	0.08	1.25	0.05	0.07	0.72
	Anomaly	**-0.14**	**0.06**	**-2.20**	-0.11	0.06	-1.90
	Predictable target: Constraint effect	**-0.52**	**0.13**	**-4.11**	-0.09	0.15	-0.62
	Related target: Constraint effect	-0.14	0.13	-1.08	-0.22	0.11	-1.93
	Unrelated target: Constraint effect	-0.15	0.11	-1.35	-0.13	0.14	-0.93
	Anomalous target: Constraint effect	-0.13	0.12	-1.12	**-0.37**	**0.14**	**-2.60**
First fixation	Intercept	**5.39**	**0.02**	**314.78**	**5.27**	**0.02**	**298.98**
	Predictability	**-0.05**	**0.01**	**-5.07**	-0.01	0.01	-1.02
	Relatedness	0.01	0.01	0.66	**-0.03**	**0.01**	**-2.36**
	Anomaly	**0.10**	**0.01**	**11.02**	0.00	0.01	0.41
	Predictable target: Constraint effect	**0.03**	**0.02**	**1.99**	-0.01	0.03	-0.32
	Related target: Constraint effect	-0.00	0.02	-0.25	-0.01	0.02	-0.54
	Unrelated target: Constraint effect	0.02	0.02	0.76	0.01	0.02	0.27
	Anomalous target: Constraint effect	**-0.04**	**0.02**	**-2.11**	-0.01	0.02	-0.38

Gaze duration	Intercept	**5.47**	**0.02**	**276.26**	**5.36**	**0.02**	**279.11**
	Predictability	**-0.06**	**0.01**	**-5.37**	-0.01	0.01	-0.43
	Relatedness	0.01	0.01	0.68	-0.02	0.01	-1.53
	Anomaly	**0.13**	**0.01**	**12.56**	0.01	0.01	0.68
	Predictable target: Constraint effect	0.03	0.02	1.31	0.00	0.03	0.07
	Related target: Constraint effect	0.00	0.02	0.19	0.02	0.03	0.62
	Unrelated target: Constraint effect	-0.01	0.02	-0.34	0.04	0.03	1.26
	Anomalous target: Constraint effect	-0.05	0.03	-1.76	0.03	0.03	0.88
Total fixation	Intercept	**5.78**	**0.03**	**200.20**	**5.53**	**0.02**	**225.39**
	Predictability	**-0.13**	**0.01**	**-8.87**	0.00	0.01	0.27
	Relatedness	-0.02	0.02	-1.32	**-0.04**	**0.02**	**-2.33**
	Anomaly	**0.57**	**0.01**	**43.86**	-0.01	0.01	-0.51
	Predictable target: Constraint effect	**0.12**	**0.03**	**4.14**	0.01	0.04	0.28
	Related target: Constraint effect	**0.10**	**0.03**	**3.14**	0.03	0.03	0.98
	Unrelated target: Constraint effect	0.03	0.03	0.79	0.06	0.03	1.92
	Anomalous target: Constraint effect	0.02	0.03	0.56	0.01	0.03	0.41
Regressions out	Intercept	**-2.06**	**0.09**	**-22.41**	**-1.78**	**0.09**	**-19.98**
	Predictability	-0.09	0.09	-1.01	-0.03	0.08	-0.33
	Relatedness	-0.08	0.10	-0.85	-0.00	0.09	-0.02
	Anomaly	**0.67**	**0.07**	**9.45**	0.07	0.07	1.01
	Predictable target: Constraint effect	0.15	0.15	1.01	0.13	0.17	0.76
	Related target: Constraint effect	0.07	0.20	0.37	0.26	0.20	1.28
	Unrelated target: Constraint effect	-0.20	0.14	-1.42	0.22	0.20	1.08
	Anomalous target: Constraint effect	-0.07	0.15	-0.48	0.27	0.19	1.46

Regressions in	Intercept	**-1.25**	**0.10**	**-12.76**	**-1.70**	**0.13**	**-12.74**
	Predictability	**-0.67**	**0.08**	**-7.92**	0.12	0.07	1.65
	Relatedness	-0.14	0.08	-1.69	-0.13	0.09	-1.47
	Anomaly	**1.98**	**0.06**	**32.54**	**-0.23**	**0.07**	**-3.01**
	Predictable target: Constraint effect	**1.13**	**0.17**	**6.57**	-0.14	0.20	-0.68
	Related target: Constraint effect	**0.81**	**0.14**	**5.97**	-0.04	0.25	-0.16
	Unrelated target: Constraint effect	**0.47**	**0.14**	**3.27**	0.04	0.22	0.19
	Anomalous target: Constraint effect	**0.27**	**0.12**	**2.24**	-0.08	0.25	-0.34

Note. Significant effects are bolded.

3.3.3 Discussion.

The aim of this experiment was to go beyond existing eye-movement investigations of prediction error costs (e.g., Frisson et al., 2017; Wong et al., 2022) by assessing whether lexical prediction has observable downstream consequences even if readers' expectations do not materialise and are replaced by less expected input. Consistent with previous eye-movement findings (e.g., Andrews et al., 2022; Frisson et al., 2017; Luke & Christianson, 2016; Wong et al., 2022), at initial presentation, there was no indication that plausible unexpected input in strongly constraining contexts elicited immediate processing costs despite violating a more expected completion. The only evidence that disconfirmed predictions disrupted readers' eye movements was when unexpected input was also syntactically and semantically incongruous in the sentence context. Specifically, anomalous unpredictable targets in strongly compared to weakly constraining contexts elicited longer first fixation durations, although the rate of regressions-in from later in the text was subsequently reduced, reflecting short-lived processing costs that were resolved across later eye-movement measures. However, the fact that this processing disruption was limited to anomalous input suggests that, rather than being due to the violation of readers' predictions, it was more likely due to the linguistic incongruity between the input and the context, which was detected more rapidly under conditions of strong constraint. This is consistent with ERP findings of two distinct neural components for congruent compared to incongruent unexpected input in strongly constraining contexts (see Van Petten & Luka, 2012 for a review).

Following this initial sentence, a thematically related unconstraining sentence containing the predictable completion from the initial sentence was presented to probe the downstream activation of previously confirmed and disconfirmed predictions. Surprisingly, downstream targets that were repeated words did not appear to be processed more efficiently than downstream targets that were new words, suggesting that, unlike previous eye-movement findings (e.g., Hyönä & Niemi, 1990; Lowder et al., 2013; Raney & Rayner, 1995), readers did not benefit from encountering the same input more than once. Moreover, contrary to our hypotheses, downstream repeated words did not appear to be processed differently following the most expected completion in strongly compared to weakly constraining contexts, leaving open the question of how thoroughly predictable words in the first sentence were processed, i.e., whether predictable words were processed less thoroughly because they simply confirmed readers' expectations (Rommers & Federmeier, 2018a) or more thoroughly because their preactivation ahead of time allowed readers to devote more cognitive resources.

New downstream targets, on the other hand, yielded processing benefits on first fixation and total fixation duration when following a related compared to unrelated unpredictable completion, suggesting that readers benefited from encountering input that shared semantic overlap with an earlier completion. New downstream targets also received fewer regressions-in when following an anomalous compared to plausible completion. But the only evidence that downstream targets presented for the first time were impacted by the presence of a previously predictable, but never presented, completion was on skipping rates – new downstream targets were more likely to be skipped following anomalous completions in strongly constraining contexts where readers were encouraged to make a specific lexical prediction compared to weakly constraining contexts where they were not. These facilitatory effects on new downstream targets following anomalous unpredictable completions were expected because these items, which could not be integrated, were unlikely to interfere with the incorrectly predicted word (Kutas, 1993). However, the lack of any downstream effects on new downstream targets following either the related or unrelated unpredictable completions under conditions of strong constraint suggests that readers may not have actually generated any predictions about the upcoming text, reducing their sensitivity to encountering what was previously an incorrect prediction.

One possible explanation for the absence of robust downstream consequences following either confirmed or disconfirmed predictions is the weaker than expected predictability effects observed at the target word in the initial sentence. Previous eye-movement studies have shown that cloze probability reliably influences readers' earliest fixations on a word as indexed by first fixation and gaze duration (e.g., Balota et al., 1985; Fitzsimmons & Drieghe, 2013; Rayner & Well, 1996; but see Calvo & Meseguer, 2002; Hyöna, 1993), and sometimes even before readers make these fixations as indexed by skipping rates (e.g., Balota et al., 1985; Rayner et al., 2011; Rayner, & Well, 1996) and parafoveal processing of upcoming words (e.g., Schotter et al., 2015; Veldre & Andrews, 2018). In the current experiment, predictable targets in strongly constraining contexts received facilitated processing across several reading measures, but, on early measures, this effect was only significant on skipping, and just reached significance on first fixation duration because of a relatively small benefit (6 ms effect). The absence of strong predictability effects is unlikely to be due to a weak manipulation of target predictability because the average cloze probability of the predictable completions in the strongly constraining contexts was very high (.81). Meanwhile, the same completions in the weakly constraining contexts were very rarely produced (.01).

Instead, the failure to observe robust first-pass predictability effects in the strongly constraining contexts could be because the inclusion of anomalous completions disrupted readers' normal processing strategies (Braze et al., 2002; Rayner et al., 2004; Veldre et al., 2020). Readers have previously been shown to vary the strength of their predictive processing based on information in their broader linguistic environment (Brothers et al., 2017; Brothers et al., 2019; Kuperberg & Jaeger, 2016; Lau et al., 2013; Lupyan & Clark, 2015). For example, Brothers et al. (2017) manipulated the proportion of filler sentences that ended with an expected completion in a self-paced reading task and found that predictable words received shorter reading times when the linguistic environment contained a high proportion of predictable filler sentences, but these benefits disappeared when the majority of filler sentences were unpredictable. Similarly, the presence of anomalous targets in the present experiment, which comprised 25% of the critical stimuli, could have implicitly discouraged readers from generating strong lexical predictions about upcoming words, resulting in the weaker than expected context-specific predictability effects on reading measures at the target and downstream words. Accordingly, Experiment 2 investigated the same research questions as Experiment 1 but removed all anomalous completions to create a more naturalistic linguistic environment for readers.

3.4 Experiment 2

Experiment 2 was designed to investigate the immediate and downstream consequences of lexical prediction in the eye-movement record without the inclusion of anomalous completions that may have limited the extent to which readers actively committed to a specific lexical prediction in Experiment 1. If readers are encouraged to rely more strongly on lexical prediction during online processing, this should be reflected in stronger effects of constraint for predictable targets especially on first-pass reading measures, and subsequently in downstream effects for confirmed and disconfirmed predictions.

3.4.1 Method.

Participants.

Sixty-five undergraduates from The University of Sydney who did not complete any part of Experiment 1 took part in the eye-tracking task in return for course credit. The data of five participants were removed due to calibration difficulty in the eye-tracking task. Therefore, the final sample comprised 60 participants (M_{age} = 22.25 years; 42 females). All were native English speakers and had normal or corrected-to-normal vision.

Materials.

The critical stimuli were the same 76 pairs of two-sentence passages used in Experiment 1. Each pair comprised a strongly constraining and weakly constraining passage which was completed either by the predictable word for the strongly constraining context, or by a semantically related or unrelated alternative. The second sentence was identical across all conditions and contained the downstream target which was the predictable initial target from the strongly constraining context. The lexical characteristics of the target words for each condition were identical to Experiment 1.

Apparatus.

There were no changes in the apparatus from Experiment 1.

Procedure.

The procedure was identical to Experiment 1. Comprehension questions appeared after approximately 34% of the trials (mean accuracy = 94.4%).

3.4.2 Results.

Data handling was the same as Experiment 1. Fixations shorter than 80 ms were automatically merged with adjacent fixations within 1-letter space (.26% of total fixations). Trials were removed if there was track loss or blinks on the region of interest (Initial target: 5.9% of trials; Downstream target: 2.7% of trials). Fixations on the initial and downstream targets below 80 ms, first fixation durations above 800 ms, gaze durations above 1200 ms, and total durations above 2000 ms were also excluded (Initial target: .7% of trials; Downstream target: 1.8% of trials). These exclusions left 8515 initial target data points (93.4% of the data) and 8711 downstream target data points (95.5% of the data) for analysis. The average reading measures on the initial and downstream targets for each condition are presented in Table 3.4.

As in Experiment 1, (G)LMMs were used to test the fixed effect of constraint nested under initial target type which returned estimates of the main effect of initial target type and the constraint effect separately for predictable, related, and unrelated words. Initial target type was coded as a set of two orthogonal contrasts which tested the same predictability and relatedness effects as Experiment 1. As in the previous experiment, the outcomes of these contrasts are reported for both target words, but interpretations are restricted to the downstream target. Power analyses using the same procedure as Experiment 1 demonstrated adequate power to detect the constraint effect for predictable initial targets across the three fixation duration measures (>.99) and for related initial targets on total fixation duration (>.99) based on comparable effects reported in Frisson et

Table 3.4

Mean (and standard deviation) reading measures on the initial and downstream target words for each condition in Experiment 2

		Strongly constraining context			Weakly constraining context		
	Reading measure	Predictable initial target	Related initial target	Unrelated initial target	Predictable initial target	Related initial target	Unrelated initial target
Target Word	Skipping (%)	33 (9)	28 (10)	28 (8)	27 (9)	25 (8)	27 (9)
	First fixation (ms)	207 (17)	221 (19)	221 (18)	210 (17)	221 (16)	213 (15)
	Gaze (ms)	223 (25)	245 (26)	243 (27)	230 (24)	247 (23)	234 (25)
	Total fixation (ms)	304 (51)	357 (58)	375 (47)	362 (51)	407 (63)	402 (59)
	Regressions out (%)	11 (5)	15 (7)	14 (7)	16 (8)	16 (8)	15 (9)
	Regressions in (%)	16 (9)	21 (7)	27 (10)	30 (10)	35 (10)	35 (10)
Downstream Word	Skipping (%)	35 (10)	36 (9)	35 (8)	36 (9)	32 (9)	33 (10)
	First fixation (ms)	193 (18)	197 (18)	200 (21)	195 (16)	196 (17)	200 (19)
	Gaze (ms)	211 (22)	214 (20)	218 (25)	222 (24)	223 (25)	227 (27)
	Total fixation (ms)	300 (39)	299 (40)	311 (34)	323 (37)	315 (37)	326 (37)
	Regressions out (%)	20 (7)	18 (7)	19 (8)	17 (7)	21 (8)	20 (7)
	Regressions in (%)	26 (7)	28 (8)	29 (8)	29 (10)	27 (9)	29 (8)

al. (2017). The models also had adequate power (>.80) to detect the constraint effect for downstream targets following each of the unpredictable words of 9 ms effect size on first fixation duration, 12 ms effect size on gaze duration, and 24 ms effect size on total fixation duration. Criteria for the random-effects structures and significance thresholds were identical to Experiment 1. Summaries of the statistical analyses for the initial and downstream targets are presented in Table 3.5.

Initial target.

The predictability effect was significant on all reading measures except regressions-out (z = -1.55) because, averaged over constraint, predictable targets received higher rates of skipping, shorter fixation durations, and fewer regressions-in from later parts of the text ($|t/z|$s > 3.02) than plausible unpredictable targets. The relatedness effect was significant on gaze duration and regressions-in ($|t/z|$s > 2.79) because, averaged over constraint, related unpredictable targets received longer gaze durations but fewer regressions-in than unrelated unpredictable targets.

For predictable targets, the constraint effect was significant on all reading measures except first fixation and gaze duration ($|t|$s < 1.73) because predictable targets received higher skipping rates, shorter total reading times, and fewer regressions-out and -in ($|t/z|$s > 3.19) when presented in strongly compared to weakly constraining contexts. For related unpredictable targets, there was a significant facilitatory constraint effect on total fixation duration and regressions-in ($|t/z|$s > 3.56) due to shorter total reading times, and fewer regressions-in for related unpredictable targets under conditions of strong compared to weak constraint. Finally, for unrelated unpredictable targets, the constraint effect was significant on gaze and total fixation duration, and regressions-in ($|t/z|$s > 2.00) because unrelated unpredictable targets received *longer* first-pass reading times but subsequently shorter total reading times and fewer regressions-in under conditions of strong compared to weak constraint.

Thus, the current results were virtually identical to Experiment 1 with respect to predictable and related unpredictable targets which were processed more efficiently in strongly constraining contexts. However, Experiment 2 provided novel evidence of a prediction error cost for first-pass reading of unrelated unpredictable targets under conditions of strong constraint.

Downstream target.

The predictability effect was significant on first fixation and gaze duration at the downstream target ($|t|$s > 1.98) because repeated words received shorter fixation durations compared to new words. The relatedness effect was significant on all fixation duration measures ($|t|$s > 2.28) and regressions-in (z = -2.14) because new words received shorter fixation durations and fewer regressions-in when following related versus unrelated unpredictable words. The constraint effect was not significant on any of the reading measures at the downstream target regardless of the completion that appeared in the first sentence ($|t/z|$s < 1.76).

Thus, in contrast to Experiment 1, downstream repeated targets were processed more efficiently than downstream new targets, while the latter were also processed more efficiently when following a related than unrelated unpredictable completion in the initial sentence. But there was no evidence that downstream targets showed any processing consequences when following any of the initial targets in the strongly compared to weakly constraining contexts.

Table 3.5

Results for the nested linear mixed effects models for log-transformed fixation duration measures and generalised linear mixed effects models for fixation probability measures on the initial and downstream target words in Experiment 2

Measure	Fixed effect	Initial target word			Downstream target word		
		b	*SE*	*t/z*	*b*	*SE*	*t/z*
Skipping	Intercept	**-1.05**	**0.10**	**-10.21**	**-0.76**	**0.12**	**-6.22**
	Predictability	**0.16**	**0.05**	**3.02**	0.08	0.05	1.60
	Relatedness	-0.06	0.06	-1.02	0.00	0.06	0.03
	Predictable target: Constraint effect	**-0.30**	**0.09**	**-3.19**	0.02	0.12	0.15
	Related target: Constraint effect	-0.15	0.10	-1.44	-0.20	0.12	-1.67
	Unrelated target: Constraint effect	-0.05	0.10	-0.53	-0.08	0.12	-0.69
First fixation	Intercept	**5.32**	**0.02**	**317.62**	**5.21**	**0.02**	**279.76**
	Predictability	**-0.05**	**0.01**	**-6.57**	**-0.02**	**0.01**	**-2.45**
	Relatedness	0.02	0.01	1.79	**-0.02**	**0.01**	**-2.28**
	Predictable target: Constraint effect	0.02	0.02	1.26	0.00	0.02	0.16
	Related target: Constraint effect	0.00	0.01	0.30	-0.00	0.02	-0.16
	Unrelated target: Constraint effect	-0.03	0.02	-1.87	-0.01	0.02	-0.54
Gaze duration	Intercept	**5.39**	**0.02**	**273.62**	**5.31**	**0.02**	**251.26**
	Predictability	**-0.07**	**0.01**	**-7.09**	**-0.02**	**0.01**	**-1.98**
	Relatedness	**0.03**	**0.01**	**2.79**	**-0.03**	**0.01**	**-2.77**
	Predictable target: Constraint effect	0.03	0.02	1.73	0.04	0.03	1.18
	Related target: Constraint effect	0.01	0.02	0.30	0.02	0.03	0.79

	Unrelated target: Constraint effect	**-0.04**	**0.02**	**-2.07**	0.02	0.03	0.74
Total fixation	Intercept	**5.73**	**0.03**	**170.55**	**5.58**	**0.03**	**186.70**
	Predictability	**-0.14**	**0.01**	**-11.05**	-0.01	0.01	-1.16
	Relatedness	-0.01	0.01	-0.38	**-0.04**	**0.01**	**-3.14**
	Predictable target: Constraint effect	**0.17**	**0.03**	**5.43**	0.06	0.03	1.76
	Related target: Constraint effect	**0.11**	**0.03**	**3.56**	0.03	0.03	1.18
	Unrelated target: Constraint effect	**0.06**	**0.03**	**2.00**	0.03	0.03	1.07
Regressions out	Intercept	**-1.98**	**0.11**	**-18.36**	**-1.60**	**0.09**	**-17.40**
	Predictability	-0.11	0.07	-1.55	-0.05	0.06	-0.88
	Relatedness	0.07	0.08	0.90	-0.03	0.07	-0.36
	Predictable target: Constraint effect	**0.56**	**0.13**	**4.20**	-0.19	0.16	-1.14
	Related target: Constraint effect	0.10	0.14	0.70	0.21	0.18	1.17
	Unrelated target: Constraint effect	0.12	0.17	0.70	0.07	0.16	0.46
Regressions in	Intercept	**-1.11**	**0.10**	**-11.18**	**-1.19**	**0.13**	**-9.27**
	Predictability	**-0.40**	**0.06**	**-6.91**	-0.07	0.06	-1.24
	Relatedness	**-0.17**	**0.06**	**-2.80**	**-0.14**	**0.07**	**-2.14**
	Predictable target: Constraint effect	**0.91**	**0.13**	**6.73**	0.17	0.20	0.82
	Related target: Constraint effect	**0.75**	**0.13**	**5.84**	-0.10	0.19	-0.51
	Unrelated target: Constraint effect	**0.41**	**0.13**	**3.12**	-0.09	0.18	-0.49

Note. Significant effects are bolded.

3.4.3 Discussion.

This experiment aimed to determine whether the weaker than expected immediate and downstream consequences of lexical prediction observed in Experiment 1 were due to the inclusion of anomalous completions that may have limited the extent to which readers actively committed to a specific lexical prediction. Experiment 2 therefore removed anomalous completions to encourage a more naturalistic linguistic environment for readers.

The results revealed that, at initial presentation, predictable targets in strongly constraining contexts yielded the expected processing benefits in the form of higher skipping rates, shorter total reading times, and fewer regressions-out and -in compared to the same targets in weakly constraining contexts. However, similar to Experiment 1, these facilitatory effects did not consistently impact early reading measures (i.e., first fixation and gaze duration), suggesting that the removal of anomalous completions did not enhance the immediate processing benefits for expected input. Nonetheless, these processing benefits did extend to semantically related alternatives – related unpredictable targets in strongly constraining contexts received shorter total reading times and fewer regressions-in, providing further evidence that unexpected input were easier to integrate when semantically compatible with the best completion. But contrary to the findings of Experiment 1, unpredictable targets that were semantically unrelated to the best completion elicited an immediate processing cost on gaze duration in strongly compared to weakly constraining contexts, suggesting that readers were immediately sensitive to the mismatch between the expected word and the input actually presented. This early prediction error cost though was temporary because unrelated unpredictable targets subsequently received shorter total reading times and fewer regressions-in from later parts of the text under conditions of strong constraint, implying that readers were able to resolve their incorrect predictions via integration processes that were supported by information extracted from the rest of the sentence and/or passage. These findings therefore indicate that although evidence of immediate processing benefits for predictable targets was restricted to higher skipping rates only, readers did appear to make an active commitment to a specific lexical item because violation of these predictions elicited an immediate, albeit short-lived, processing cost. This prediction error cost may have been obscured in Experiment 1 because the presence of anomalous completions discouraged readers from making strong lexical predictions.

Further downstream, the impact of removing anomalous completions was also evident. Consistent with previous eye-movement findings (e.g., Hyönä & Niemi, 1990; Lowder et al., 2013; Raney & Rayner, 1995), downstream targets that were repeated words because a predictable completion was previously encountered elicited the expected repetition benefit in the form of shorter first fixation and gaze durations compared to downstream targets that were new words because any of the unpredictable completions were previously encountered. However, like Experiment 1, there was no evidence that these repeated downstream targets were processed differently following a predictable completion in strongly compared to weakly constraining contexts, even though preactivation of the expected completion would have been greater under conditions of strong constraint. This suggests that although removing anomalies contributed to a linguistic environment that enhanced sensitivity to repeated words, prior predictability did not appear to impact subsequent processing of these completions any further. Moreover, similar to Experiment 1, downstream targets that were being encountered for the first time elicited processing benefits in the form of shorter fixation durations and fewer regressions-in when following a related versus unrelated unpredictable completion. But there was no evidence that these new downstream targets following either of the unpredictable completions were impacted by the presence of a previously predictable, but never presented, word, suggesting that the processing benefits for new downstream targets following related completions most likely reflected their semantic overlap. Thus, even under more naturalistic linguistic environments which elicited immediate processing costs for unexpected input, there appears to be no evidence that readers' lexical predictions were observable downstream from their initial point of activation.

Therefore, the major novel finding of Experiment 2 was evidence of an immediate processing cost for unexpected input when semantically unrelated to the most expected competitor. Given that this prediction error cost did not emerge in Experiment 1, which presented the same sentence frames excluding the anomalous completions, it appears that, consistent with previous observations (e.g., Brothers et al., 2017; Brothers et al., 2019), readers did modulate their use of predictive processing based on information in their broader linguistic environment. However, this processing cost was relatively small (9 ms effect) and restricted to a single eye-movement measure, which raises questions about its reliability (von der Malsburg & Angele, 2017). Accordingly, Experiment 3 was conducted to increase statistical power to detect a small effect by removing the predictable condition, thereby increasing the number of items in the critical unpredictable conditions.

3.5 Experiment 3

Experiment 3 was designed to replicate and confirm the novel evidence of prediction error cost in Experiment 2 by increasing statistical power to detect this effect. Readers' eye movements were recorded as they read strongly and weakly constraining sentences that contained plausible unpredictable words that were either semantically related or unrelated to the most expected completion of the strongly constraining context.

Following this sentence, readers were presented with a thematically related unconstraining sentence that contained either the predictable, but never presented, completion from the strongly constraining sentence or the other plausible, unpredictable completion. Readers' eye-movement patterns on the downstream target are not reported below because, similar to the previous experiments, there were minimal downstream consequences following any of the completions that appeared in the first sentence (see Appendix for more details).

3.5.1 Method.

Participants.

Fifty-eight participants from The University of Sydney who did not complete any part of the previous experiments took part in the eye-tracking task in return for course credit (M_{age}=20.0 years; 44 females). All were native English speakers and had normal or corrected-to-normal vision.

Materials.

The sentence context preceding the initial target for most of the 76 pairs of two-sentence passages were taken directly from Experiment 2.[3] The average cloze probability of the related and unrelated unpredictable words was very low in both the strongly and weakly constraining contexts, but, importantly, very high for the predictable but never presented

[3] Cloze completions for eight modified items were collected from a separate sample of 19 participants (M_{age} = 18.9 years; 12 females).

completions in the strongly constraining contexts, indicating that the unpredictable words disconfirmed a highly probable completion in these contexts. The other lexical characteristics of the target words for each condition did not differ from those of Experiment 2.

Apparatus.

There were no changes in the apparatus from the previous experiments.

Procedure.

The procedure was identical to the previous experiments. Comprehension questions appeared after approximately 36% of the trials (mean accuracy = 94.2%).

3.5.2 Results.

Data handling was identical to the previous experiments. Trials were removed either due to track loss or blinks on the region of interest (6.0% of trials). Fixations on the initial target below 80ms, first fixation durations above 800 ms, gaze durations above 1200 ms, and total durations above 2000 ms were also excluded (1.0% of trials). These exclusions left 8201 initial target data points (93.0% of the data) for analysis. The average reading measures on the initial target for each condition are presented in Table 3.6.

As in the previous experiments, (G)LMMs were used to test the fixed effect of constraint nested under initial target type which returned estimates of the main effect of initial target type and the constraint effect separately for related and unrelated targets. Power analyses using the same procedure as the previous experiments demonstrated sufficient power to detect the constraint effect for unrelated initial targets on gaze duration (.84) based on the 9 ms effect size observed in Experiment 2. Criteria for the random-effects structures and significance thresholds were identical to the previous experiments. A summary of the statistical analyses for the initial target is presented in Table 3.7.

Table 3.6

Mean (and standard deviation) reading measures on the initial target word for each condition in Experiment 3

	Strongly constraining context		Weakly constraining context	
Reading measure	Related initial target	Unrelated initial target	Related initial target	Unrelated initial target
Skipping (%)	26 (7)	23 (7)	23 (8)	23 (7)
First fixation (ms)	219 (16)	218 (14)	215 (16)	210 (16)
Gaze (ms)	244 (18)	240 (20)	235 (22)	228 (17)
Total fixation (ms)	314 (42)	336 (35)	346 (39)	335 (36)
Regressions out (%)	14 (6)	15 (6)	17 (6)	16 (6)
Regressions in (%)	18 (7)	22 (7)	26 (7)	23 (8)

Initial target.

The main effect of initial target type was not significant on any reading measures ($|t/z|$s < 1.95). For related unpredictable targets, there was a facilitatory constraint effect on total time, regressions-out and regressions–in ($|t/z|$s > 2.60) because related unpredictable targets received shorter reading times and fewer regressions-out and –in when presented in strongly compared to weakly constraining contexts. For unrelated unpredictable targets, there was evidence of prediction error cost because the constraint effect was significant on first fixation and gaze duration ($|t|$s > 2.76) reflecting longer reading times for unrelated unpredictable targets under conditions of strong compared to weak constraint.

Thus, the current results were almost identical to that of Experiment 2 in that strongly constraining contexts yielded processing benefits for related unpredictable targets and processing costs for unrelated unpredictable targets, although there was no evidence that readers subsequently recovered from encountering unrelated unexpected input in place of a more expected completion.

Table 3.7

Results for the nested linear mixed effects models for log-transformed fixation duration measures and generalised linear mixed effects models for fixation probability measures on the initial target word in Experiment 3

Measure	Fixed effect	*b*	*SE*	*t/z*
Skipping	**Intercept**	**-1.32**	**0.11**	**-12.08**
	Initial target type	-0.10	0.05	-1.88
	Related target: Constraint effect	-0.14	0.10	-1.39
	Unrelated target: Constraint effect	-0.01	0.09	-0.06
First fixation	**Intercept**	**5.33**	**0.02**	**342.05**
	Initial target type	-0.01	0.01	-1.25
	Related target: Constraint effect	-0.02	0.02	-1.09
	Unrelated target: Constraint effect	**-0.04**	**0.01**	**-2.76**
Gaze	**Intercept**	**5.40**	**0.02**	**292.55**
	Initial target type	-0.02	0.01	-1.95
	Related target: Constraint effect	-0.03	0.02	-1.71
	Unrelated target: Constraint effect	**-0.05**	**0.02**	**-3.22**
Total fixation	**Intercept**	**5.66**	**0.03**	**189.96**
	Initial target type	0.02	0.01	1.38
	Related target: Constraint effect	**0.09**	**0.03**	**3.70**
	Unrelated target: Constraint effect	-0.00	0.02	-0.16
Regressions out	**Intercept**	**-1.90**	**0.12**	**-16.08**

	Initial target type	0.04	0.06	0.60
	Related target: Constraint effect	**0.33**	**0.13**	**2.60**
	Unrelated target: Constraint effect	0.09	0.11	0.79
Regressions in	**Intercept**	**-1.39**	**0.10**	**-13.55**
	Initial target type	0.03	0.06	0.53
	Related target: Constraint effect	**0.51**	**0.11**	**4.44**
	Unrelated target: Constraint effect	0.06	0.12	0.53

Note. Significant effects are bolded.

3.5.3 Discussion.

This experiment aimed to replicate and confirm the novel evidence of prediction error cost on the initial target word observed in Experiment 2. Experiment 3 increased statistical power by removing the predictable condition, leading to an increased number of items in the critical unpredictable conditions.

The results revealed that, consistent with the previous experiments, at initial presentation, related unpredictable targets elicited processing benefits in strongly constraining contexts despite violating a more expected completion. This included shorter total reading times due to fewer regressions-out and -in compared to the same targets in weakly constraining contexts. Furthermore, consistent with Experiment 2, unrelated unpredictable targets elicited immediate processing costs on gaze duration, as well as on the earlier measure of first fixation duration, in strongly compared to weakly constraining contexts. Unlike Experiment 2 though, there was no evidence that readers necessarily recovered from these immediate prediction error costs because there was no subsequent benefit on later measures for these unexpected words. Thus, across two experiments, there appears to be strong evidence that readers do generate lexical predictions during online processing because they are sensitive to the costs of misprediction. More generally, according to the present findings, these predictive processes do not appear to depend on the proportion of confirmed predictions in the linguistic environment, as long as the stimuli are plausible.

3.6 General Discussion

Previous investigations of whether readers make predictions about the full identity of upcoming words have focused on the extent to which there are processing consequences when readers encounter linguistic input that is incompatible with their expectations. However, eye-movement studies to date have revealed contradictory, but generally elusive, evidence of such prediction error costs for unexpected input, leading researchers to conclude that readers do not routinely predict or anticipate upcoming words during online processing (Andrews et al., 2022; Frisson et al., 2017; Luke & Christianson, 2016; Wong et al., 2022; but see Cevoli et al., 2022). This is despite evidence from ERP studies that unexpected input presented in place of a more expected completion elicits a late frontal positivity that has been linked to higher-order suppression and revision processes following initial semantic access (see Van Petten & Luka, 2012 for a review). The present eye-movement research using controlled experimental designs observed novel evidence of prediction error costs during the immediate processing of unexpected input – a finding elaborated in further detail below. A further major novel contribution of the present research was to use a repetition paradigm adapted from Rommers and Federmeier (2018a, 2018b) to investigate whether anticipatory prediction was also observable further downstream from the initial point of activation even if readers' expectations were disconfirmed and replaced by less expected input.

As prefaced above, at initial presentation, unexpected input that disconfirmed a more expected completion revealed evidence of prediction error costs. Specifically, unpredictable completions that were semantically unrelated to the best completion disrupted readers' eye movements in strongly constraining contexts on gaze duration in Experiment 2 when only plausible stimuli were included, and on first fixation and gaze duration in Experiment 3 when only unpredictable stimuli were included. These immediate prediction error costs, however, were absent in Experiment 1, which presented a subset of the same sentence frames with anomalous completions, suggesting that readers modulated the strength of their predictive processing based on information in their broader linguistic environment (Brothers et al., 2017; Brothers et al., 2019; Lupyan & Clark, 2015). That is, when a noticeable proportion of sentences were implausible (i.e., Experiment 1), the language processor was more likely to prioritise bottom-up input in the preceding context, allowing predictions to unfold passively via lexical co-occurrence or spreading activation of associated concepts (Huettig, 2015). However, when all sentences were plausible (i.e., Experiments 2 and 3), the language processor was more likely to rely actively on top-down comprehension strategies including genuine lexical prediction, leading to a "surprisal" response (Levy, 2008) when unexpected input that violated readers' expectations was encountered. Notably, these two pathways for achieving predictive processing need not be mutually exclusive, and appear to be dependent on information in the broader linguistic environment, as demonstrated in the present study, and/or other factors including task and goal demands, age, and individual differences (see Federmeier, 2022).

If readers' propensity to make predictions in a top-down manner is based on information in their broader linguistic environment, the fact that immediate prediction error costs were observable in Experiment 3 when readers' predictions were never explicitly confirmed appears somewhat contradictory. While this finding might suggest that predictive processing is a genuine feature of the language processing system, i.e., readers make predictions about upcoming words even in situations where there are no valid prediction cues, previous studies have reported diminished predictability effects in such linguistic environments (e.g., Brothers et al., 2017; Brothers et al., 2019; Lau et al., 2013). Thus, it is plausible that even though readers' predictions were never confirmed by the presentation of the predictable completion in the strongly constraining contexts in Experiment 3, the presence of related unpredictable completions confirmed readers' general semantic expectancies despite being a different lexical entity. Further research should confirm that lexical prediction occurs in low prediction validity environments even when semantically related concepts are not available. Nonetheless, given that readers were more likely to reduce their level of anticipatory prediction in the presence of anomalous completions, the present findings at the target word provide clear evidence of flexible prediction strategies during online processing.

This evidence of immediate prediction error costs for unexpected input, however, did not extend to unpredictable completions that were semantically related to the best completion of the strongly constraining contexts. Instead, consistent with previous eye-movement (Frisson et al., 2017; Luke & Christianson, 2016; Wong et al., 2022) and ERP investigations (Federmeier & Kutas, 1999; Federmeier et al., 2002; Thornhill & Van Petten, 2012), related unpredictable completions received facilitated processing in strongly compared to weakly constraining contexts across all three experiments, suggesting that these items may have been partially preactivated either due to spreading activation from the most expected completion (Neely, 1977) or because the context independently activated a set of plausible continuations based on the available semantic information (Luke

& Christianson, 2016; Roland et al., 2012). These facilitatory effects, however, did not affect the early measures on which predictability effects are typically observed (e.g., Balota et al., 1985; Fitzsimmons & Drieghe, 2013; Rayner & Well, 1996). Instead, they were restricted to the late measures of total reading time and regressions-in, implying that related unpredictable completions were easier to integrate into the unfolding discourse representation. The apparent immediate cost of encountering unexpected input therefore appears to be mitigated entirely by semantic similarity with the disconfirmed prediction which instead serves to facilitate subsequent integration processes.

The current experiments therefore provide stronger evidence of anticipatory prediction of specific lexical items than previous eye-movement studies using similar controlled experimental designs (Frisson et al., 2017; Wong et al., 2022). In particular, this includes Frisson et al. (2017) who presented identical experimental conditions to Experiment 2 but observed no evidence of processing costs for unexpected input. One possible reason for this discrepancy is that our materials had a stronger predictability manipulation – the average cloze probability of the predictable targets under conditions of strong constraint were slightly higher in our experiments that revealed evidence of prediction error costs (.81 and .83, respectively) compared to Frisson et al.'s experiment that did not (.77). More generally, our experiments had higher statistical power – compared to 20 items per condition in Frisson et al.'s study, participants read ~25 items per condition in Experiment 2, and 38 items per condition in Experiment 3. Evidence of prediction error costs in the eye-movement record therefore appears to depend not only on the strength of readers' predictive processing during reading, but also on an adequately powered experimental design to detect the relatively small and short-lived effects on early fixation duration measures.

The present findings also provide support for Cevoli et al.'s (2022) recent work – the only eye-movement study to date to demonstrate that readers are sensitive to the costs of making an incorrect prediction. While there are several important aspects of Cevoli et al.'s study that differ from the current study (e.g., the use of corpus-based analyses and the use of surprisal and entropy derived from a language model to estimate word predictability), the converging findings suggest that readers are capable of using their prior knowledge and experiences about the context and the world to generate predictions about upcoming text. This evidence of predictive processing during real-time language comprehension is in line with broader predictive accounts of cognitive functioning (e.g., Clark, 2013; Friston, 2010).

Notably, the evidence of processing costs for unexpected input emerged despite weaker than expected first-pass processing benefits for the most expected completion in strongly constraining contexts. That is, despite an immediate cost for committing to an incorrect prediction, the benefit of encountering a correct prediction was restricted to lower skipping rates and marginally shorter first fixation durations in Experiment 1, and to lower skipping rates only in Experiment 2, contrasting the robust first-pass predictability effects typically observed in previous eye-movement studies (e.g., Balota et al., 1985; Fitzsimmons & Drieghe, 2013; Rayner & Well, 1996; but see Calvo & Meseguer, 2002; Hyöna, 1993). As elaborated earlier, this is unlikely to be due to a weak manipulation of predictability given the large differences in cloze probability for the predictable target across the constraint conditions. However, it may be relevant that previous eye-movement studies have typically assessed predictability effects by comparing predictable and unpredictable targets within the same sentence context (e.g., Balota et al., 1985; Fitzsimmons & Drieghe, 2013) rather than by comparing the same predictable completion in strongly and weakly constraining contexts like in the current study. Further research could elaborate whether there are different impacts of lexical-driven and context-driven predictability effects on readers' eye movements (see e.g., Wong et al., 2022).

The major novel question of the present research was whether evidence of anticipatory prediction was also observable downstream from the initial point of activation, and, more specifically, when readers' expectations did not eventuate and were replaced by less expected input. Thus, after each initial sentence, a thematically related unconstraining sentence was presented to probe the downstream activation of the previously predictable completion as a function of whether it had been confirmed or disconfirmed (Experiments 1 and 2). Downstream targets that were repeated words, because a predictable completion was previously encountered, were processed more efficiently than downstream targets that were new words, because an unpredictable completion was previously encountered, but this was only observed in Experiment 2 and not in Experiment 1 which included anomalous stimuli. This finding suggests that, consistent with previous observations across different methodologies (e.g., Lowder et al., 2013 using eye-tracking; Scarborough et al., 1977 using lexical decision; Van Petten et al., 1991 using ERPs), readers generally benefited from seeing a word more than once, and that, more importantly, there were observable downstream consequences of processing the initial sentence. Nonetheless, this repetition benefit was eliminated when the broader linguistic environment contained a noticeable proportion of implausible stimuli, supporting the idea that readers' normal reading strategies were disrupted by the presence of linguistic incongruity (Braze et al., 2002; Rayner et al., 2004; Veldre et al., 2020). However, across both experiments, there was no evidence that this repetition benefit was affected when previously predictable completions were presented in strongly compared to weakly constraining contexts, suggesting that prior predictability did not necessarily strengthen the encoding of expected input perhaps because the language system was simply verifying what the context already supported (Hubbard et al., 2019; Rommers & Federmeier, 2018a; Van Berkum, 2010).

Moreover, downstream targets that were new words also received processing facilitation across both experiments, most consistently when following related compared to unrelated initial targets, providing further evidence of downstream processing consequences when initial and downstream targets were semantically similar. However, downstream new targets were minimally impacted by the presence of a previously predictable, but never presented, word. The only evidence that disconfirmed predictions had downstream consequences was following the presence of anomalous unpredictable completions in Experiment 1 which led to higher skipping rates for new downstream words. These facilitatory downstream effects, however, were restricted to a single eye-movement measure and were not replicated in the subsequent experiment that revealed readers' immediate sensitivity to failed predictions. Thus, in contrast to previous ERP studies (Hubbard et al., 2019; Lai et al., 2021; Rommers & Federmeier, 2018a, 2018b), there was no consistent evidence that anticipatory prediction was observable downstream from the initial presentation of disconfirmed predictions.

One possible explanation for this discrepancy is that the impact of anticipatory prediction during online processing is genuinely short-lived or at least only observable during the immediate processing of critical words in the eye-movement record. However, the impact of anticipatory prediction may have been enhanced in ERP studies because of the stimuli presentation format. Because ERP studies typically present sentence stimuli word-by-word for a fixed duration that not only increases the processing time for each word (Degno & Liversedge, 2020; Rayner, 2009; Rayner & Clifton, 2009) but also precludes readers' ability to skip words, re-read previous parts of text, and use upcoming parafoveal information, readers could be implicitly encouraged to rely on predictive processes more than would be expected during normal reading (Dambacher et al., 2012; Wlotko & Federmeier, 2015). Such a possibility would account for the consistent ERP evidence of immediate and downstream effects of disconfirmed predictions. Furthermore, several aspects specific to Rommers and Federmeier's (2018b) study could have contributed to the increased impact of lexical prediction on readers' downstream processing. Participants in this study were presented with sequences of unrelated sentences in which readers' expectations were confirmed or disconfirmed several sentences before the critical target was presented to probe their downstream representation. Because the inclusion of unrelated, intervening sentences could have prevented the construction of a coherent discourse representation especially when comprehension probes were not included throughout the task, readers may have been less likely to suppress and revise their prior expectations following unexpected input beyond the first sentence in which it appeared, leading to the facilitatory downstream effects observed. Thus, it appears important for future research to clarify the extent to which these methodological factors are responsible for the downstream consequences of lexical prediction observed in ERP studies.

In summary, the present findings provide some of the first eye-movement evidence within a controlled experimental design of readers making predictions about the precise lexical identity of upcoming words in advance of their presentation. The consequences of making an incorrect prediction, however, appeared to be short-lived and observable only during the immediate, and not downstream, processing of unexpected input. Notably, these immediate prediction error costs only emerged in plausible linguistic environments, suggesting that readers strategically modulated their predictive processing based on information in their broader linguistic environment. This extends previous observations that predictive processes can depend on a variety of factors including age, individual differences, and task and goal demands (see Huettig, 2015). Taken together, while predictive processes can serve to facilitate language processing, its usage may not be as automatic or ubiquitous as previously assumed.

CHAPTER 4: Anticipatory Prediction in Older Readers

The contents of this chapter are a minor revision of Wong, R., Veldre, A., & Andrews, S. (in preparation). Anticipatory prediction in older readers.

4.1 Abstract

It is well-established that skilled, young-adult readers rely on predictive processing during online language comprehension; however, fewer studies have investigated whether this extends to healthy, older adults (60+ years). The aim of the present research was to assess whether older readers make use of anticipatory prediction by investigating whether they demonstrate processing costs for incorrect predictions in a controlled experimental design. The eye movements of a sample of older adults (60-86 years) were recorded as they read strongly and weakly constraining sentences containing either a predictable word or an unpredictable alternative that was semantically related or unrelated. To determine whether older readers' use of predictive strategies depends on the stimuli presentation format, a separate group read the same materials in a self-paced reading task. Older adults revealed similar processing benefits for expected input as a comparison sample of younger adults (17-32 years) on eye-movement measures of reading. Both age groups also showed processing costs for unexpected input across both methodologies but only when semantically unrelated to the best completion. Taken together, the results suggest that the use of predictive processes remains relatively preserved with age. The implications of these findings for understanding whether predictive strategies are a fundamental component of online language comprehension are discussed.

4.2 Introduction

The notion that human comprehenders make use of anticipatory prediction has become widely accepted in the language comprehension literature (Altmann & Mirković, 2009; DeLong, Troyer, & Kutas, 2014b; Kuperberg & Jaeger, 2016; but see Huettig & Mani, 2016). Upcoming words that can be predicted in advance of their presentation require less time and cognitive resources to identify when encountered, allowing for faster and more efficient language processing. Eye-movement studies have shown that words that are predictable in a sentence context receive shorter fixation durations, higher skipping rates, and fewer regressions compared to unpredictable words (Balota et al., 1985; Drieghe et al., 2005; Ehrlich & Rayner, 1981; Frisson et al., 2017; Luke & Christianson, 2016; Rayner et al., 2011; see Staub, 2015 for a review). Event-related potential (ERP) studies have also found that predictable words are associated with a reduced N400 component, which reflects decreased neural processes for words that are semantically congruous within a sentence context (Federmeier et al., 2007; Kutas & Hillyard, 1984; Kutas et al., 1984; Thornhill & Van Petten, 2012). Thus, predictive processes appear to play an important role in real-time language comprehension – an idea that has been formalized in several recent theoretical accounts (e.g., Dell & Chang, 2013; Kuperberg & Jaeger, 2016; Pickering & Gambi, 2018).

However, much of what is known about predictive processing is based on data from skilled, young-adult readers. Fewer studies have investigated the nature of anticipatory prediction (or, indeed, online language comprehension more broadly) in other populations including healthy, older adults (60+ years). It is important to address this gap in the literature to understand how linguistic prediction changes across the lifespan and, as such, whether predictive strategies are truly a fundamental component of online language comprehension, in line with more general predictive accounts of cognitive functioning (e.g., Clark, 2013; Friston, 2010).

Normal aging is accompanied by widespread neural changes, including grey and white matter atrophy, synaptic degeneration, and neurochemical alterations, many of which would be expected to have consequences for cognitive functioning (Cabeza et al., 2004; Hedden & Gabrieli, 2004). Indeed, it is well-established that aging is associated with an array of cognitive changes including lower processing speed, reduced attention and executive control, and smaller working memory capacity (see Verhaeghen, 2013 for a review). But not all aspects of cognitive functioning are affected by age-related decline – many language-related functions remain stable, or even improve, with age, especially those that depend on "crystallized" abilities which augment with age and experience. For example, compared to younger adults, older adults retain high levels of vocabulary (e.g., Alwin & McCammon, 2001; Verhaeghen, 2003) and word-related knowledge (e.g., Salthouse, 1993). Older adults also organize information in semantic memory as efficiently as their younger counterparts when assessed offline via word associations (e.g., Bowles et al., 1983; Burke & Peters, 1986) and online via semantic priming tasks (e.g., Laver & Burke, 1993).

Real-time language comprehension, however, is a complex and multi-faceted activity that involves more than just processing individual words – readers must extract lexical information from the written text, retrieve their meanings from long-term memory, and integrate this information into the unfolding discourse representation. As such, crystallized abilities like word and semantic knowledge, which are preserved with age, must be coordinated with fluid abilities, such as working memory and attentional control, which are known to be impacted by aging. Indeed, the typical pattern of older adults' eye movements shows that they read more slowly compared to younger adults, as a result of more, and often longer, fixations and more regressions (Kliegl et al., 2004; Rayner et al., 2010; Rayner et al., 2006; Rayner et al., 2013; see Paterson et al., 2020, for a review). Studies of alphabetic languages also report that older adults skip words more frequently and make longer forward saccades compared to their younger counterparts (Laubrock et al., 2006; Rayner et al., 2006). Thus, it has been suggested that older adults adopt a *risky reading strategy* during online processing (Rayner et al., 2006) in which they rely more heavily on contextual information to compensate for declines in their visual and cognitive abilities. However, whether normal aging also has consequences for the use of predictive strategies, as would be expected under the risky reading hypothesis, remains less clear.

Eye-movement studies to date point to at least equivalent effects of predictability during online processing in older and younger adults. For example, in an analysis of corpus data, Kliegl et al. (2004) observed that both older and younger readers spent less time processing highly predictable words, although this effect manifested differently in the two populations – older readers made fewer refixations on highly predictable words while younger readers were more likely to skip over them altogether. A meta-analysis of experimental data by Zhang et al. (2022) also confirmed that predictability effects did not differ significantly as a function of age among readers of English, implying that older readers were not more likely to use contextual information to predict upcoming words than younger readers. However, the authors noted that their finding was based on relatively few studies that met the inclusion criteria (*n*=3 for predictability effects on word skipping; Cheimariou et al., 2021; Choi et al., 2017; Rayner et al., 2006) and therefore should be interpreted with caution. More recently, Veldre et al. (2022) used a gaze-contingent boundary paradigm and found larger predictability effects in older readers on first fixation, go-past duration, and the probability of regressions-out and -in compared to younger readers (see also Cheimariou et al., 2021; Choi et al., 2017 for similar evidence of increased predictability effects).

Thus, the findings of existing eye-movement studies could be taken to suggest that predictability effects remain relatively preserved, if not enhanced, with age. However, it should be noted that these effects of predictability are mostly restricted to late measures, rather than the early measures on which effects of anticipatory prediction would be expected (e.g., Rayner et al., 2011; Rayner & Well, 1996). This suggests that older readers may be facilitated in their processing of predictable words not only because these items are *preactivated* in advance of their presentation but because these items are easier to *integrate* into the unfolding discourse representation (Ferreira & Chantavarin, 2018; Pickering & Gambi, 2018), leading to less reanalysis as indexed by shorter fixation durations and fewer regressions. In practice, however, predictive processes are difficult to disentangle from integrative processes because both accounts expect facilitated processing for words that can be predicted from the preceding context (Kutas et al., 2011; but see Van Berkum et al., 2005; Wicha, Bates, et al., 2003a; Wicha, Moreno, et al., 2003b; Wicha et al., 2004).

One way that researchers have attempted to investigate the extent to which online processing depends on genuine anticipatory prediction, independently of postlexical integration, has been by looking at whether there are processing consequences when readers encounter input that is plausible but inconsistent with their expectations. For example, readers are presented with strongly and weakly constraining sentences like "*The shepherd spent all day looking for his lost…"* and "*The farmer reported that some…*" respectively, which are completed either by the predictable target for the strongly constraining context ("*sheep*") or by an unpredictable target that is semantically related ("*cows*") or unrelated ("*tools*") to the best completion. Importantly, both unpredictable but plausible targets are matched on 0% cloze probability across the constraint conditions, ensuring that any additional processing for these words in the strongly compared to weakly constraining contexts reflects the consequences of violating the expected, but never presented, completion. Using this paradigm, Frisson et al. (2017) found that young adults showed no evidence of processing costs for either of the unpredictable words in the strongly compared to weakly constraining contexts, suggesting that young readers did not appear to be sensitive to the consequences of prediction failure. Instead, unpredictable words that were semantically related to the best completion received shorter total reading times and fewer regressions-out in strongly constraining contexts, implying that young readers were more likely to generate graded predictions about upcoming text, which involve the passive activation of broad linguistic features such as morphosyntactic, syntactic, and semantic information, rather than an "all-or-none" lexical prediction that would incur processing costs when disconfirmed by unexpected input (see also Andrews et al., 2022; Luke & Christianson, 2016; Wong et al., 2022).

More recently, Wong et al. (in revision) observed evidence of prediction error costs on first-pass reading of unexpected input in young adults when using a similar paradigm to Frisson et al. (2017) but with a larger number of critical items. Specifically, unpredictable words that were semantically unrelated to the best completion yielded a processing cost on gaze duration in strongly compared to weakly constraining contexts, indicating that, with sufficient power, there was evidence that young readers were sensitive to the immediate processing costs that would be expected to accompany lexical prediction (see also Cevoli et al., 2022 for similar evidence from corpus data). But, as in Frisson et al.'s data, this processing disadvantage did not extend to unpredictable words that were semantically related to the most expected completion. Instead, related unpredictable words in strongly constraining contexts were processed more efficiently on late reading measures, implying that young readers also made use of graded prediction during online processing. Wong et al. further examined the consequences of young readers' failed predictions by presenting the critical sentences within a connected two-sentence passage in which the second sentence contained the most predictable word from the initial sentence. This design allowed an assessment of whether young readers' predictions had downstream consequences even when their expectations did not materialize and were replaced by less expected input. However, there was no indication that encountering an unpredictable word in the first sentence impacted subsequent processing of the previously predictable, but never presented, word, suggesting that the costs of misprediction were short-lived, occurring immediately after unexpected input (but see Rommers & Federmeier, 2018).

From this perspective, it is plausible that if older adults make greater use of contextual information than younger adults (e.g., Cheimariou et al., 2021; Choi et al., 2017; Rayner et al., 2006; Veldre et al., 2022), they may show evidence of immediate processing costs when their predictions turn out to be incorrect. However, there has been little eye-movement investigation of whether aging has consequences for the processing of disconfirmed predictions. Steen-Baker et al. (2017) investigated this issue in a sample of readers aged 16-64 years by presenting predictable and unpredictable completions in sentences that were either strongly or weakly constraining. While they found greater facilitation for predictable completions with age on go-past duration, an index of integration and reanalysis, there was no evidence of processing costs for unpredictable completions in strongly compared to weakly constraining contexts with age on any reading measures. While these findings suggest that, across the lifespan, there are no consequences of misprediction, it is important to note that the average participant age was ~37 years, meaning that they represented middle-aged rather than older participants. Given that the midlife is a time during which linguistic experience via reading is well-developed but declines in other cognitive areas such as processing speed, attention and working memory are not yet in effect (Salthouse, 2012), the reading patterns of this sample of participants may not reflect those of older participants over the age of 60.

More recently, Andrews et al. (2022) investigated this issue further by comparing older (60-88 years) and younger (18-30 years) adults' reading of naturalistic texts from the Provo corpus (Luke & Christianson, 2017). They found that, as expected, both older and young adults' reading times were significantly predicted by cloze probability, although, for younger readers, this effect was more pronounced for expected than unexpected words, suggesting that they had made specific lexical predictions about upcoming text. However, neither age group showed evidence of prediction error costs because unexpected words were more likely to receive facilitated processing even as the cloze probability of the best completion increased. As such, Andrews et al. concluded that while older adults did make use of anticipatory prediction during online processing, they generated multiple possible continuations for upcoming text, which were less likely to incur processing costs when disconfirmed by unexpected input compared to the preactivation of a single lexical candidate. Notably, however, only 5% of the words in the Provo corpus presented to readers were highly predictable (>.67 cloze probability), which may have limited the possibility of observing evidence of prediction error costs in the eye-movement record. More generally, corpus data may not be ideal for assessing prediction error costs because predictable and unpredictable words within naturalistic texts vary on multiple uncontrolled dimensions which may interact with or obscure the effects of interest (Angele et al., 2015).

Thus, it is important to investigate whether older adults also demonstrate processing costs for unexpected input in a controlled experimental design to provide insight into the broader question of whether aging has consequences for the use of predictive processes during online language comprehension.

A further motivation for investigating the nature of prediction error among older adults is that evidence from ERP studies has been taken to suggest that older readers are *less* sensitive to contextual information than younger adults. The late frontal positivity is a positive-going component that is observed in young adults approximately 500-1000 ms after the presentation of unexpected input, specifically in strongly constraining contexts that encourage the preactivation of a more expected competitor (Brothers et al., 2015; DeLong et al., 2012; Federmeier et al., 2007; Thornhill & Van Petten, 2012; see Van Petten & Luka, 2012 for a review). Although its precise functional role remains under debate, this late-emerging waveform is argued to reflect the additional neural activity required to suppress the more expected completion (Federmeier et al., 2007; Kutas, 1993) and/or revise the existing discourse representation (Brothers et al., 2015; DeLong, Quante, & Kutas, 2014a) so that the less expected completion can be integrated successfully. Unlike their younger counterparts, older adults do not show evidence of this late frontal positivity when processing unexpected input (Federmeier et al., 2010; Wlotko et al., 2012; but see Dave et al., 2018), suggesting that they are less reliant on anticipatory prediction and therefore less likely to be affected by the consequences of misprediction. This failure to recruit predictive strategies during online processing is thought to be consistent with the more general declines in executive control and working memory with age which could impact older readers' ability to coordinate higher-order processes like anticipatory prediction (see Wlotko et al., 2010 for a review). Indeed, the N400 component, which decreases in amplitude for words that can be predicted from the preceding context (Federmeier et al., 2007; Kutas & Hillyard, 1984; Kutas et al., 1984), is also consistently smaller in amplitude and/or delayed in latency for older adults (DeLong et al., 2012; Federmeier & Kutas, 2005; Federmeier et al., 2010; Federmeier et al., 2003; Wlotko & Federmeier, 2012, see Payne & Silcox, 2019 for a review), providing further evidence that aging compromises the effective use of top-down contextual information. Thus, in contrast to eye-movement findings that predictability effects remain relatively preserved with age, ERP studies provide little evidence that older adults recruit predictive processes to guide online language comprehension.

However, there are reasons to question whether these ERP findings can be generalized to normal reading. Typically, ERP studies use a rapid serial visual presentation (RSVP) paradigm in which each word of a sentence appears one at a time at a fixed pace ranging from 400 to 1000 ms in a central location on the screen. Although this slower word-by-word presentation rate may allow for increased strategic prediction (Dambacher et al., 2012; Wlotko & Federmeier, 2015), readers are simultaneously unable to engage in typical reading strategies including skipping words, making regressions to previous parts of text, and extracting upcoming parafoveal information. As such, the results of RSVP tasks may not capture the genuine online processes underlying normal reading, raising the possibility that the evidence of reduced anticipatory prediction in older readers could be restricted to tasks that do not encourage normal reading.

One way to bridge the gap between eye-movement and ERP techniques and to provide insight into whether older adults' predictive processes depend on stimuli presentation methods is via the self-paced reading paradigm in which each word of a sentence appears one at a time but at the readers' own pace. Although this methodology uses a word-by-word presentation format, it does simulate normal reading more closely by allowing readers to have control over the presentation rate. For example, Payne and Federmeier (2017) found that young adults who were able to self-pace their reading produced the late frontal positivity for unexpected input in strongly constraining contexts on individually fast trials which were roughly equivalent in duration to the fixed-pace presentation rate used in RSVP studies (~2 words per second). Moreover, they found that, on individually slow trials, young adults produced an anterior N2, a negative-going component approximately 200-350 ms poststimulus onset that was taken to index a motor inhibitory signal to immediately slow down reading and engage in conflict resolution (see Folstein & Van Petten, 2008 for a review). Thus, volitional control over the rate of input does play some role in modulating how young adults respond to contextual information.

Although studies of older adults using self-paced reading have found that older readers are sensitive to contextual information like their younger counterparts (e.g., DeDe, 2014; Liu, 2021; Madden, 1988; Stine-Morrow et al., 2008), few of these studies have directly assessed whether older readers use this contextual information in a predictive manner during self-paced reading (but see Cutter et al., 2022 for evidence of syntactic prediction in older adults). As such, investigating this issue will contribute to the broader question of whether older adults' predictive processing is determined by the stimuli presentation method. More generally, it is also useful to examine whether the outcomes of self-paced reading are comparable to that of normal reading. Although self-paced reading does not simulate all aspects of normal reading, it is a methodology that remains popular in language research because of its low cost and ease of administration even outside laboratory settings (Marsden et al., 2018). These factors are particularly beneficial when working with certain populations such as older adults who can be difficult to recruit for laboratory-based studies. It is therefore critical to evaluate the generalizability of self-paced reading findings to determine whether it can be used as a proxy for normal reading in language research.

4.3 The present research

The overall aim of the present research was to investigate older adults' use of anticipatory prediction during online processing. The primary goal was to establish whether older adults show evidence of processing costs for incorrect predictions in a controlled experimental design. Thus, Experiment 1 recorded older adults' eye movements as they read sentence materials adapted from Wong et al. (in revision) which revealed evidence of immediate prediction error costs in young adults. A further goal was to assess whether older adults' predictive processing depends on the stimuli presentation method. Therefore, Experiment 2 recorded older adults' reading times as they read the same stimuli in a self-paced reading paradigm. Evidence that the pattern of predictability benefits and/or costs differs between the two methodologies may account for the discrepant conclusions that have been drawn from the eye-movement and ERP literatures regarding the impact of aging on linguistic prediction during online language comprehension.

4.4 Experiment 1

Older adults' eye movements were recorded as they read sentences that were either strongly or weakly constraining towards a specific word. The target word that was actually presented was either the predictable word for the strongly constraining context or an unpredictable word (see Table 4.1 for an example item set and Appendix for a complete list of stimuli). In order to investigate the type of information preactivated by older adults during online processing, unpredictable words were either semantically related or unrelated to the best completion.

It was expected that if older readers do make use of anticipatory prediction during online processing, as suggested by previous eye-movement studies (e.g., Andrews et al., 2022; Cheimariou et al., 2021; Choi et al., 2017; Kliegl et al., 2004; Rayner et al., 2006; Veldre et al., 2022), predictable words in strongly constraining contexts should yield larger processing benefits relative to the same words in weakly constraining contexts. If these predictions involve the preactivation of semantic features of upcoming words, rather than a specific lexical candidate, these processing benefits should also extend to related unpredictable words in strongly compared to weakly constraining contexts. Finally, if older readers do make predictions about upcoming text ahead of time, there should be evidence of immediate processing costs when their expectations turn out to be incorrect, i.e., unrelated unpredictable words should be processed less efficiently on early reading measures in strongly compared to weakly constraining contexts.

4.4.1 Method.

Participants.

Forty-four healthy, cognitively intact older adults (M_{age} = 70.5 years, range: 60-86 years, 32 females) who were living independently in the community participated in the study in return for cash reimbursement.[1] Most participants had completed some form of post-secondary education and 78% had a college degree. All were native English speakers.

[1] The data for a further six participants were excluded due to eye-tracker calibration difficulty and/or self-reported visual impairments.

Participants' corrected visual acuity was assessed by a modified Snellen test at the experimental viewing distance to be better than 20/40.

Materials.

The critical stimuli were 66 pairs of sentences which were adapted from materials used in Wong et al. (in revision), which were in turn adapted from Frisson et al. (2017). Each pair was constructed such that in the strongly constraining version, the target word was high in predictability, while in the weakly constraining version, the same target word was low in predictability. The predictable target was compared to length- and frequency-matched unexpected targets that were either semantically related or unrelated to the predictable target. The predictability of the targets was confirmed by cloze completions collected from a separate sample of 20 participants (M_{age} = 20.4 years; 19 females) who did not complete the eye-tracking task.[2] To ensure that the related and unrelated unpredictable targets were equivalently plausible across the conditions, a separate sample of 60 participants (M_{age} = 19.7 years; 49 females) judged the sentences on a 5-point scale from 1 (Highly Implausible) to 5 (Highly Plausible). The semantic relatedness of the targets was assessed by computing Latent Semantic Analysis (LSA; Landauer & Dumais, 1997) scores between the predictable target and each of the unpredictable targets. Table 4.1 presents an example item with the mean lexical characteristics for each condition.

[2] Wlotko and Federmeier (2012) demonstrated that cloze probability ratings collected from older and younger adults were highly correlated, *r*=.86. As such, cloze probability ratings for the current stimuli were collected from a sample of young adults who were easier to recruit.

Table 4.1

Example set of items and mean (and standard deviation) stimulus characteristics

Condition	Example item (Target bolded)	Target cloze probability	Target frequency (logHAL)	Target length (letters)	Sentence plausibility (1-5 scale)	Target relatedness to predictable word (LSA)	Sentence constraint
Strongly constraining context							
Predictable	The shepherd spent all day looking for his lost **sheep** in the fields despite the rain.	.84 (.12)	9.5 (1.4)	5.4 (1.3)	4.9 (0.1)	1 (0)	0.84 (0.12)
Related	The shepherd spent all day looking for his lost **cows** in the fields despite the rain.	.01 (.03)	8.7 (1.9)	5.4 (1.4)	4.8 (0.4)	0.3 (0.2)	0.84 (0.12)
Unrelated	The shepherd spent all day looking for his lost **tools** in the fields despite the rain.	.00 (.01)	9.3 (1.8)	5.4 (1.3)	4.5 (0.4)	0.1 (0.1)	0.84 (0.12)
Weakly constraining context							
Predictable	The farmer reported that some **sheep** had been stolen from his property.	.02 (.04)	9.5 (1.4)	5.4 (1.3)	4.9 (0.1)	1 (0)	0.18 (0.07)
Related	The farmer reported that some **cows** had been stolen from his property.	.01 (.02)	8.7 (1.9)	5.4 (1.4)	4.8 (0.3)	0.3 (0.2)	0.18 (0.07)
Unrelated	The farmer reported that some **tools** had been stolen from his property.	.01 (.03)	9.3 (1.8)	5.4 (1.3)	4.7 (0.4)	0.1 (0.1)	0.18 (0.07)

Apparatus.

Participants read the sentences on a 21-inch ViewSonic G225f CRT monitor which was set to a pixel resolution of 1024 x 768 and a 140 Hz refresh rate while their eye movements were recorded by a SR Research Ltd. Eyelink 1000 eye-tracker which had a sampling rate of 1000 Hz. Each sentence was presented in 14pt Consolas black font on a white background. Participants were seated 60 cm from the monitor with a chin and forehead rest to minimize head movements. At this distance, one degree of visual angle equated to 2.85 letter spaces. Viewing was binocular, but eye movements were recorded from participants' right eye.

Procedure.

Participants were instructed to read each sentence silently for meaning and to respond to comprehension questions that appeared after approximately one third of the trials (mean accuracy = 94.1%). A nine-point calibration procedure was conducted before the start of the experiment. If mean calibration error was greater than .5° of visual angle, an additional calibration procedure was carried out. Before each trial, a fixation point appeared at the location of the first letter of the sentence and a stable fixation on this point was required before the trial was displayed.

The sentences were counterbalanced across three lists using a Latin square design so that each participant always saw a different target word in the strongly and weakly constraining version of each pair. Across all sentences, each participant saw 22 target words in each of the six conditions. Participants were randomly assigned to a list which randomly presented the sentences across four equal blocks interspersed with 26 filler items.

The experimental materials, data, and analysis code for all experiments reported in this chapter are publicly available on the Open Science Framework website: https://osf.io/w6594/.

4.4.2 Results.

Fixations below 80 ms were automatically merged with adjacent fixations within one letter space (1.4% of total fixations). Trials were removed if there was track loss or blinks on the target (2.5% of trials). Remaining target fixations below 80 ms or above 800 ms, gaze durations above 1200 ms, and total fixation durations above 2000 ms were also excluded (1.7% of trials). These exclusions left 5,562 trials (95.7% of the data) for analysis.

Log-transformed reading measures were analyzed: *first fixation duration* (the duration of the first fixation on the target), *gaze duration* (the sum of all fixations before the eyes exit the target for the first time), and *total fixation duration* (the sum of all fixations on a target). The probability of skipping, regressions out of the target to earlier in the sentence, and regressions into the target from later in the sentence were also analyzed. The mean reading measures on the target for each condition are presented in Table 4.2.

The data were analyzed by (generalized) linear mixed effects models (GLMM/LMM) using the *lme4* package (Version 1.1-30; Bates et al., 2015) in *R*. To test predictability benefits and costs within a single model for each reading measure, the models tested the fixed effect of constraint nested under target type. This returned estimates of the main effect of target type and the constraint effect (strong vs. weak) separately for predictable, related, and unrelated words, similar to the analyses carried out by Frisson et al. (2017). Target type was coded as a set of two orthogonal contrasts which tested the effect of: (1)

target predictability – the difference between the predictable and the average of the related and unrelated unpredictable conditions, and (2) *target relatedness* – the difference between the related and unrelated unpredictable conditions.

Table 4.2

Mean (and standard deviation) reading measures on the target word for each condition in Experiment 1

	Predictable		Related		Unrelated	
	Strong constraint	Weak constraint	Strong constraint	Weak constraint	Strong constraint	Weak constraint
Skipping (%)	25 (9)	19 (8)	24 (9)	19 (8)	21 (9)	21 (9)
First fixation (ms)	203 (19)	211 (17)	220 (20)	222 (22)	222 (21)	217 (19)
Gaze (ms)	223 (25)	228 (20)	247 (23)	244 (26)	250 (27)	235 (22)
Total fixation (ms)	260 (53)	317 (47)	314 (49)	368 (52)	354 (42)	342 (40)
Regressions out (%)	11 (6)	14 (8)	12 (8)	14 (7)	14 (10)	13 (8)
Regressions in (%)	12 (7)	22 (10)	20 (10)	31 (11)	25 (9)	27 (9)

All models showed singular fits with the maximal random effects structure (i.e., by-subject and by-item random intercepts and slopes for the effect of constraint nested under target type). Therefore, the random effects structure for each model was simplified: first by removing the correlation parameters between random intercepts and random slopes, and second by sequentially removing random slopes that accounted for the least variance until model convergence without singular fit. Estimates yielding t/z values greater than $|1.96|$ were interpreted as significant at the .05 α level. Power analyses conducted with 100 Monte Carlo simulations using the *simR* package (Version 1.0-6; Green & MacLeod, 2016) in *R* demonstrated sufficient power (>.80) to detect the constraint effect for each target type of at least 10 ms on first fixation duration, 15 ms on gaze duration, and 31 ms on total fixation duration. A summary of the statistical analyses for the reading measures on the target is presented in Table 4.3.

The effect of target predictability was significant on all fixation duration measures ($|t|$s > 6.31) and regressions-in (z = -7.39) because, averaged over constraint, predictable words received shorter fixation durations and fewer regressions-in compared to unpredictable words. There was no significant effect of target relatedness on any of the reading measures averaged over constraint ($|t/z|$s < 1.07).

For predictable targets, the effect of constraint was significant on all reading measures ($|t/z|$s > 2.06) except gaze duration (t = 1.02) because these words showed higher skipping rates, shorter fixation durations, and fewer regressions in strongly compared to weakly constraining contexts. For related targets, the effect of constraint was significant on skipping, total fixation duration and regressions-in ($|t/z|$s > 2.64) due to higher skipping rates, shorter total reading times, and fewer regressions-in for these words under conditions of strong compared to weak constraint. For unrelated targets, the effect of constraint was significant on gaze duration (t = -2.05) – readers had *longer* first-pass reading times when these words were presented in strongly compared to weakly constraining contexts.

Thus, predictable completions received early and late processing benefits in strongly constraining contexts. Related unpredictable completions that violated these expectations also yielded similar processing benefits under conditions of strong constraint. However, there was evidence of a prediction error cost for unrelated unpredictable completions –

older adults showed immediate disruption when processing these words in strongly compared to weakly constraining contexts.

Table 4.3

Results for the (generalized) linear mixed effects models for reading measures on the target word in Experiment 1

Measure	Fixed effect	*b*	*SE*	*t/z*
Skipping	**Intercept**	**-1.48**	**0.14**	**-10.93**
	Predictability	0.02	0.07	0.32
	Relatedness	-0.00	0.08	-0.00
	Predictable target: Constraint effect	**-0.40**	**0.14**	**-2.86**
	Related target: Constraint effect	**-0.33**	**0.12**	**-2.64**
	Unrelated target: Constraint effect	-0.03	0.13	-0.25
First fixation	**Intercept**	**5.32**	**0.02**	**217.74**
	Predictability	**-0.06**	**0.01**	**-6.31**
	Relatedness	0.00	0.01	0.02
	Predictable target: Constraint effect	**0.04**	**0.02**	**2.16**
	Related target: Constraint effect	0.01	0.02	0.26
	Unrelated target: Constraint effect	-0.01	0.02	-0.63
Gaze	**Intercept**	**5.39**	**0.03**	**182.31**
	Predictability	**-0.08**	**0.01**	**-7.01**
	Relatedness	0.00	0.01	0.18
	Predictable target: Constraint effect	0.02	0.02	1.02
	Related target: Constraint effect	-0.02	0.03	-0.75
	Unrelated target: Constraint effect	**-0.05**	**0.02**	**-2.05**
Total fixation	**Intercept**	**5.62**	**0.04**	**136.92**
	Predictability	**-0.17**	**0.01**	**-12.00**
	Relatedness	-0.01	0.02	-0.86
	Predictable target: Constraint effect	**0.17**	**0.03**	**5.00**
	Related target: Constraint effect	**0.13**	**0.04**	**3.43**
	Unrelated target: Constraint effect	-0.02	0.03	-0.71
Regressions out	**Intercept**	**-2.14**	**0.14**	**-14.82**
	Predictability	-0.08	0.09	-0.87
	Relatedness	-0.02	0.10	-0.19
	Predictable target: Constraint effect	**0.33**	**0.16**	**2.06**

	Related target: Constraint effect	0.27	0.16	1.67
	Unrelated target: Constraint effect	-0.23	0.20	-1.11
Regressions in	**Intercept**	**-1.38**	**0.11**	**-12.97**
	Predictability	**-0.58**	**0.08**	**-7.39**
	Relatedness	-0.09	0.08	-1.07
	Predictable target: Constraint effect	**0.76**	**0.18**	**4.22**
	Related target: Constraint effect	**0.68**	**0.18**	**3.70**
	Unrelated target: Constraint effect	0.12	0.17	0.73

Note. Significant effects are bolded.

Combined Analyses.

To directly test age-related differences in predictive processes during normal reading, two additional sets of analyses were conducted comparing the present data to the data of a sample of young adults who were a subset of Wong et al.'s (in revision; Experiment 2; *n*=57, M_{age} = 21.2 years, range: 17-32 years, 40 females) study which presented similar sentences as part of a connected two-sentence passage.[3] The two age groups showed no significant difference in mean comprehension scores, $t(99) = -0.20$, $p = 0.84$.

The first set of analyses compared the following global reading measures for each group: total sentence reading time, average fixation duration, number of fixations, number of regressions, average forward saccade length, and number of words skipped. The mean global reading measures for each group are presented in Table 4.4. The data were analyzed by (G)LMMs which included the fixed effect of age (older vs. younger), random intercepts for subjects and items, and a by-item random slope for the age effect.

[3] The young adults in Wong et al.'s (in revision) Experiment 2 read 76 pairs of two-sentence passages. The first sentence from a subset of 66 items that were virtually identical to the sentences presented in the current experiment were included in the combined analyses.

Compared to younger adults, older adults had significantly longer total sentence reading times (b = 2083.50, SE = 259.70, t = 8.02). There was no significant difference between the age groups in average fixation duration (t < 1); however, older readers made a higher number of fixations (b = 0.22, SE = 0.05, z = 4.59) and regressions (b = 0.52, SE = 0.11, z = 4.64) than younger readers. Older readers also made longer forward saccades on average than younger readers (b = 1.04, SE = 0.15, t = 7.16). There was no significant difference in number of words skipped between the age groups (z < 1). Thus, the present sample of older adults mostly showed the typical pattern of global reading behaviors that has been reported in the literature, which has been argued to reflect a contextually based risky reading strategy (e.g., Paterson et al., 2020; Rayner et al., 2006).

Table 4.4

Mean (and standard deviation) global reading measures for older and younger adults in Experiment 1

Global reading measure	Older adults	Younger adults
Total sentence reading time (ms)	4570 (2641)	2491 (1289)
Average fixation duration (ms)	199 (37)	195 (39)
Fixation count	15.57 (6.43)	12.52 (5.49)
Regression count	4.12 (2.75)	2.59 (2.45)
Average forward saccade length (letters)	11.41 (3.11)	8.43 (2.28)
Skip count	6.41 (2.31)	6.23 (2.38)

Note. Younger adults (n=57) from Wong et al. (in revision; Experiment 2)

The second set of analyses compared the following first-pass local reading measures on the target for each group: log-transformed first fixation and gaze duration, and the probability of skipping and regressions-out of the target.[4] Figure 4.1 presents older and younger adults' means across conditions on gaze duration, which showed the significant constraint effect for unrelated unpredictable targets for both age groups.

The data were analyzed by (G)LMMs which tested the fixed effect of age (older vs. younger) and constraint (strong vs. weak) nested under target type. Models that showed singular fits with the maximal random effects structure (i.e., by-subject and by-item random intercepts and slopes for the effect of constraint nested under target type, and a by-item random slope for the age effect) were simplified according to the same criteria as the analyses conducted on the older adults' data. Power analyses conducted with 100 Monte Carlo simulations demonstrated sufficient power (>.80) to detect Age x Constraint interactions for each target type of at least 14 ms effect size on first fixation duration and 20 ms effect size on gaze duration. A summary of the combined statistical analyses for the reading measures on the target is presented in Table 4.5.

The outcomes of the combined analyses averaged over age were identical to the outcomes of the analyses restricted to older adults. The main effect of age was only significant on the probability of skipping because target skipping was lower for older adults compared to younger adults (21% vs 28%; z = -2.61). Age did not interact with the effects of target predictability or relatedness ($|t/z|$s < 1.45), or with the constraint effect for each target type ($|t/z|$s < 1.22). Thus, as illustrated in Figure 4.1, both age groups showed similar

[4] The other local reading measures included in the analyses of the older adults' data (i.e., total fixation duration and the probability of regressions into the target) were not analyzed because they may have been influenced by reading of the follow-up sentence in Wong et al.'s (in revision) data.

patterns of predictability benefits and costs on the target, although older readers also showed lower rates of target skipping which is inconsistent with the risky reading hypothesis (e.g., Paterson et al., 2020; Rayner et al., 2006).

Table 4.5

Results for the (generalized) linear mixed effects models for reading measures on the target word for older and younger adults in Experiment 1

Measure	Fixed effect	*b*	*SE*	*t/z*
Skipping	**Intercept**	**-1.28**	**0.09**	**-13.53**
	Age	**-0.41**	**0.16**	**-2.61**
	Predictability	0.09	0.05	1.85
	Relatedness	-0.03	0.05	-0.57
	Predictable target: Constraint effect	**-0.35**	**0.09**	**-3.97**
	Related target: Constraint effect	**-0.23**	**0.09**	**-2.67**
	Unrelated target: Constraint effect	-0.02	0.08	-0.28
	Age x Predictability	-0.13	0.09	-1.37
	Age x Relatedness	0.05	0.11	0.49
	Age x Predictable target: Constraint effect	-0.11	0.15	-0.72
	Age x Related target: Constraint effect	-0.18	0.17	-1.10
	Age x Unrelated target: Constraint effect	-0.01	0.15	-0.09
First fixation	**Intercept**	**5.32**	**0.01**	**356.37**
	Age	-0.00	0.03	-0.07
	Predictability	**-0.06**	**0.01**	**-9.37**
	Relatedness	0.01	0.01	0.81
	Predictable target: Constraint effect	**0.03**	**0.01**	**2.21**
	Related target: Constraint effect	0.00	0.01	0.35
	Unrelated target: Constraint effect	-0.01	0.01	-0.97
	Age x Predictability	-0.00	0.01	-0.08
	Age x Relatedness	-0.01	0.01	-0.78
	Age x Predictable target: Constraint effect	0.03	0.02	1.21
	Age x Related target: Constraint effect	0.00	0.02	0.14
	Age x Unrelated target: Constraint effect	0.00	0.02	0.04
Gaze	**Intercept**	**5.39**	**0.02**	**300.53**
	Age	-0.00	0.03	-0.02
	Predictability	**-0.08**	**0.01**	**-10.12**
	Relatedness	0.02	0.01	1.75
	Predictable target: Constraint effect	0.03	0.02	1.81

	Related target: Constraint effect	-0.01	0.02	-0.52
	Unrelated target: Constraint effect	**-0.03**	**0.02**	**-2.09**
	Age x Predictability	0.00	0.01	-0.01
	Age x Relatedness	-0.02	0.02	-1.45
	Age x Predictable target: Constraint effect	-0.01	0.03	-0.40
	Age x Related target: Constraint effect	-0.02	0.03	-0.72
	Age x Unrelated target: Constraint effect	-0.03	0.03	-1.10
Regressions-out	**Intercept**	**-2.05**	**0.09**	**-22.02**
	Age	-0.17	0.17	-1.02
	Predictability	-0.06	0.06	-1.03
	Relatedness	0.03	0.07	0.44
	Predictable target: Constraint effect	**0.45**	**0.10**	**4.37**
	Related target: Constraint effect	0.22	0.12	1.82
	Unrelated target: Constraint effect	-0.10	0.16	-0.63
	Age x Predictability	0.01	0.12	0.05
	Age x Relatedness	-0.08	0.13	-0.60
	Age x Predictable target: Constraint effect	-0.23	0.19	-1.22
	Age x Related target: Constraint effect	0.09	0.19	0.50
	Age x Unrelated target: Constraint effect	-0.22	0.23	-0.97

Note. Significant effects are bolded.

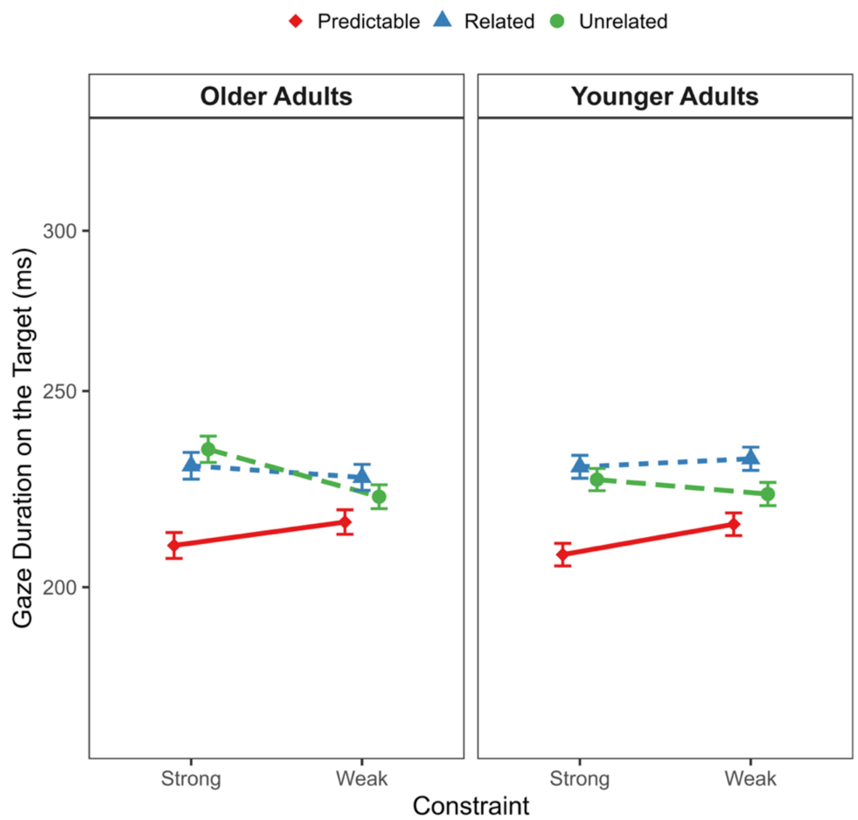

Figure 4.1 Mean log gaze durations for the target across conditions for older and younger readers in Experiment 1. Younger adults (*n*=57) from Wong et al. (in revision; Experiment 2).

4.4.3 Discussion.

The aim of this experiment was to assess eye-movement evidence of older adults' use of anticipatory prediction during online processing by investigating whether they demonstrate processing costs for incorrect predictions in a controlled experimental design. As expected, older readers in the current experiment processed predictable words more efficiently in strongly compared to weakly constraining contexts. However, unlike prior eye-movement investigations of predictability effects in this age group (e.g., Cheimariou et al., 2021; Choi et al., 2017; Kliegl et al., 2004; Veldre et al., 2022), these processing benefits emerged not only on the late measures of total fixation duration and the probability of regressions-out and -in but also on the early measures of skipping and first fixation duration. This suggests that older readers were facilitated in their processing of expected input not only because these items were easier to integrate into the preceding context, but because these items were also preactivated in advance of their presentation. The combined analyses of older and younger adults' first-pass reading data further revealed that these early-occurring benefits were of similar magnitude across the age groups, consistent with the preservation of predictability effects with age (e.g., Zhang et al., 2022).

Older readers also processed unpredictable words that were semantically related to the best completion more efficiently under conditions of strong compared to weak constraint. Like predictable completions, these processing benefits were evident on the late measures of total reading time and regressions-in, implying that these items were easier to integrate into the unfolding discourse representation because of their semantic overlap with the most expected candidate. However, these processing benefits also emerged on skipping rates – related unpredictable words were more likely to be skipped in strongly constraining contexts – indicating that older readers may have partially preactivated these items ahead of time, either due to spreading activation from the most predictable word (Collins & Loftus, 1975; Neely, 1977) or because the context activated multiple possible continuations based on the available semantic information (Andrews et al., 2022; Luke & Christianson, 2016). As indicated by the combined analyses, this early processing benefit did not differ between older and younger adults. Thus, evidence that processing benefits for the most predictable word extended to semantically related alternatives in older adults is consistent with previous findings in younger adults (e.g., Frisson et al., 2017; Wong et al., 2022), reflecting the fact that the organization of semantic knowledge remains relatively intact with age (e.g., Laver & Burke, 1993).

Importantly, older readers showed evidence of early processing costs for unexpected input that disconfirmed their expectations. Specifically, unpredictable words that were semantically unrelated to the best completion received longer gaze durations in strongly compared to weakly constraining contexts, suggesting that older readers had generated lexical predictions about the upcoming text, leading to an immediate processing disadvantage when there was a subsequent mismatch between their prediction and the word actually encountered. The combined analyses further revealed that the size of this prediction error cost was similar for older and younger adults. Thus, contrary to the findings of Andrews et al. (2022), older readers do appear to be sensitive to the consequences of prediction failure during reading like their younger counterparts. However, this finding may have been obscured in the earlier study because older readers were presented with a corpus of naturalistic texts in which highly predictable words were rare, limiting the opportunity for predictions to be disconfirmed.

The present findings are therefore consistent with existing observations of processing costs for unexpected input in young adults (Cevoli et al., 2022; Wong et al., in revision), suggesting that predictive processes remain relatively preserved across the lifespan. However, they challenge ERP findings of no prediction error costs in older adults (e.g., Federmeier et al., 2010; Wlotko et al., 2012), which could be attributed to the use of the unnatural RSVP paradigm that discourages effective use of context to generate predictions about upcoming text. To provide some insight into the source of the discrepancy between the two methodologies, Experiment 2 investigated the sensitivity of older adults' predictive processing to unnatural presentation methods.

4.5 Experiment 2

Experiment 2 presented the same stimuli as the previous experiment in a self-paced reading paradigm in which each word of a sentence appeared one at a time at the readers' own pace. Although this methodology uses a word-by-word presentation format, it allows readers to have control over the presentation rate which simulates normal reading more closely than fixed-pace RSVP reading. As such, if older readers do generate predictions about upcoming text during self-paced reading, their pattern of processing should replicate that of Experiment 1. However, if older readers do not make predictions about upcoming text during self-paced reading, predictable words should not yield larger processing benefits in strongly compared to weakly constraining contexts, while related unpredictable words should also be processed equivalently across the constraint conditions. Moreover, unrelated unpredictable words should yield no processing costs under conditions of strong compared to weak constraint given that no other lexical candidates would have been expected and subsequently disconfirmed. Evidence of a different pattern of processing compared to the previous experiment would suggest that the source of older adults' reduced predictive processing in ERP studies is the overall unnatural presentation method that discourages normal reading.

To directly test age-related differences in predictive processes during self-paced reading, Experiment 2 also compared older adults' processing pattern to that of a sample of younger adults. If older readers are more sensitive to unnatural presentation methods during online processing, they may show reduced use of anticipatory prediction compared to their younger counterparts.

4.5.1 Method.

Participants.

Thirty-nine healthy, cognitively intact older adults (M_{age} = 73.5 years, range: 62-89 years, 28 females) who were living independently in the community participated in return for cash reimbursement and sixty-seven undergraduate young adults from The University of Sydney (M_{age} = 19.70 years; range: 17-31; 44 females) participated in return for course credit. Most older adults had completed some form of post-secondary education and 69% had a college degree. All participants were native English speakers and had self-reported corrected-to-normal vision.[5]

[5] The data for a further seven older-adult and thirteen young-adult participants were excluded due to technical errors. The data for one young-adult participant was removed due to comprehension accuracy that was ~4 *SD* below average in the self-paced reading task.

Materials.

The critical stimuli were the same sentences as in Experiment 1.[6]

Procedure.

The SPR task was implemented in JavaScript using the *jspysch* library (de Leeuw, 2015) to allow participants to complete the task on a HTML web browser on their own computer or laptop device due to restrictions on laboratory-based data collection during the COVID-19 pandemic. Participants were instructed to read the sentences for meaning and to respond to comprehension questions which appeared after approximately a third of the trials. Older adults had significantly higher mean comprehension scores (M=95.7%) than young adults (M=92.3%; $t(104) = 3.45$, $p < .001$), although the high accuracy for both groups indicated that participants were reading for comprehension.

On each trial, participants first saw a fixation cross centrally for 1000 ms and then the sentence frame was presented with all non-space characters replaced by underscores. Participants pressed the spacebar to view each word of the sentence such that progressing to the next word replaced the previous words with underscores.

After three practice trials, participants were randomly assigned to one of three lists which were counterbalanced in the same way as Experiment 1. Following the task, participants were given the opportunity to report any technical difficulties experienced during the task.

[6] The young adults read 76 pairs of two-sentence passages of which a quarter included an unpredictable target that was semantically and syntactically anomalous within the first sentence. Trials that included an anomalous completion were removed and the first sentence from a subset of 66 items that were virtually identical to the sentences presented in the current experiment were included in the combined analyses reported.

4.5.2 Results.

Reading times were analyzed for the target word of each sentence to assess readers' use of anticipatory prediction during self-paced reading. To capture possible spill-over effects (Mitchell, 1984), reading times were also analyzed for the word following the target (*Target*+1). To confirm that effects at the target reflected manipulations of this word, reading times were also analyzed for the word preceding the target (*Target*-1). For both age groups, trials were excluded if data were missing (.8% of trials). After visual inspection of the data, reading times on any of the three regions of interest reflecting very fast (<80 ms) or very slow (>5000 ms) reaction times were removed (.05% of the data). Following Payne and Federmeier (2017), reading times on any of the three regions of interest that were more than three SD above each participants' condition mean were also removed (1.7% of the data). For older adults, these exclusions left 5,030 Target-1 data points (97.7% of the data), 5,029 target data points (97.7% of the data), and 5,015 Target+1 data points (97.5% of the data) for analysis. For younger adults, these exclusions left 6,521 Target-1 data points (98.2% of the data), 6,499 target data points (97.9% of the data), and 6,527 Target+1 data points (98.3% of the data) for analysis. The mean reading times on the regions of interest for each condition across the age groups are presented in Table 4.6.

The first set of analyses compared the global reading measure of total sentence reading time for each group. The data were analyzed by a LMM which included the same fixed and random effects as the combined global analyses in Experiment 1. Similar to the global eye-movement data, older adults had significantly longer total sentence reading times than younger adults (8184 vs 4520 ms; b = 3650.30, SE = 356.50, t = 10.24).

Table 4.6

Mean (and standard deviation) reading times on the regions of interest for each condition across the age groups in Experiment 2

	Older Adults						Young Adults					
	Predictable		Related		Unrelated		Predictable		Related		Unrelated	
	Strong constraint	Weak constraint	Strong constraint	Weak constraint	Strong constraint	Weak constraint	Strong constraint	Weak constraint	Strong constraint	Weak constraint	Strong constraint	Weak constraint
Target-1	495 (153)	483 (144)	487 (155)	485 (137)	497 (162)	484 (156)	287 (76)	282 (65)	292 (86)	281 (68)	285 (61)	287 (72)
Target	512 (181)	525 (201)	528 (220)	516 (184)	547 (246)	507 (188)	285 (76)	283 (69)	297 (116)	285 (81)	291 (74)	289 (77)
Target+1	498 (158)	504 (149)	525 (189)	514 (156)	556 (211)	504 (161)	284 (69)	290 (67)	300 (86)	299 (83)	313 (88)	300 (84)

The second set of analyses compared self-paced reading times at the three regions of interest for each group. Log-transformed reading times were analyzed by LMMs which included the same fixed and random effects as the combined local analyses in Experiment 1. To control for any differences in the lexical characteristics of the words before and after the target, the models for these two regions of interest also included word length and log HAL frequency (Lund & Burgess, 1996). Criteria for the random effects structures and significance thresholds were identical to the combined local analyses in Experiment 1. Power analyses conducted with 100 Monte Carlo simulations demonstrated sufficient power (>.80) to detect at least 14 ms constraint effects and 27 ms Age x Constraint interaction effects for each target type at each region of interest. A summary of the combined statistical analyses for the reading measures on the regions of interest is presented in Table 4.7. Figure 4.2 presents older and young adults' mean reading times across conditions on the target and the word following the target.

Target-1.

There was a significant main effect of age because older adults had longer reading times at the word preceding the target than younger adults (489 vs 286 ms; t = 11.72). There were no significant effects of target predictability or relatedness, or interactions with age on self-paced reading times at the word preceding the target ($|t|$s < 1).

The constraint effect for each target type, and interaction with age were not significant ($|t|$s < 1.18). Thus, there was an age-related difference in self-paced reading times at the word preceding the target that was not specific to manipulations of the target.

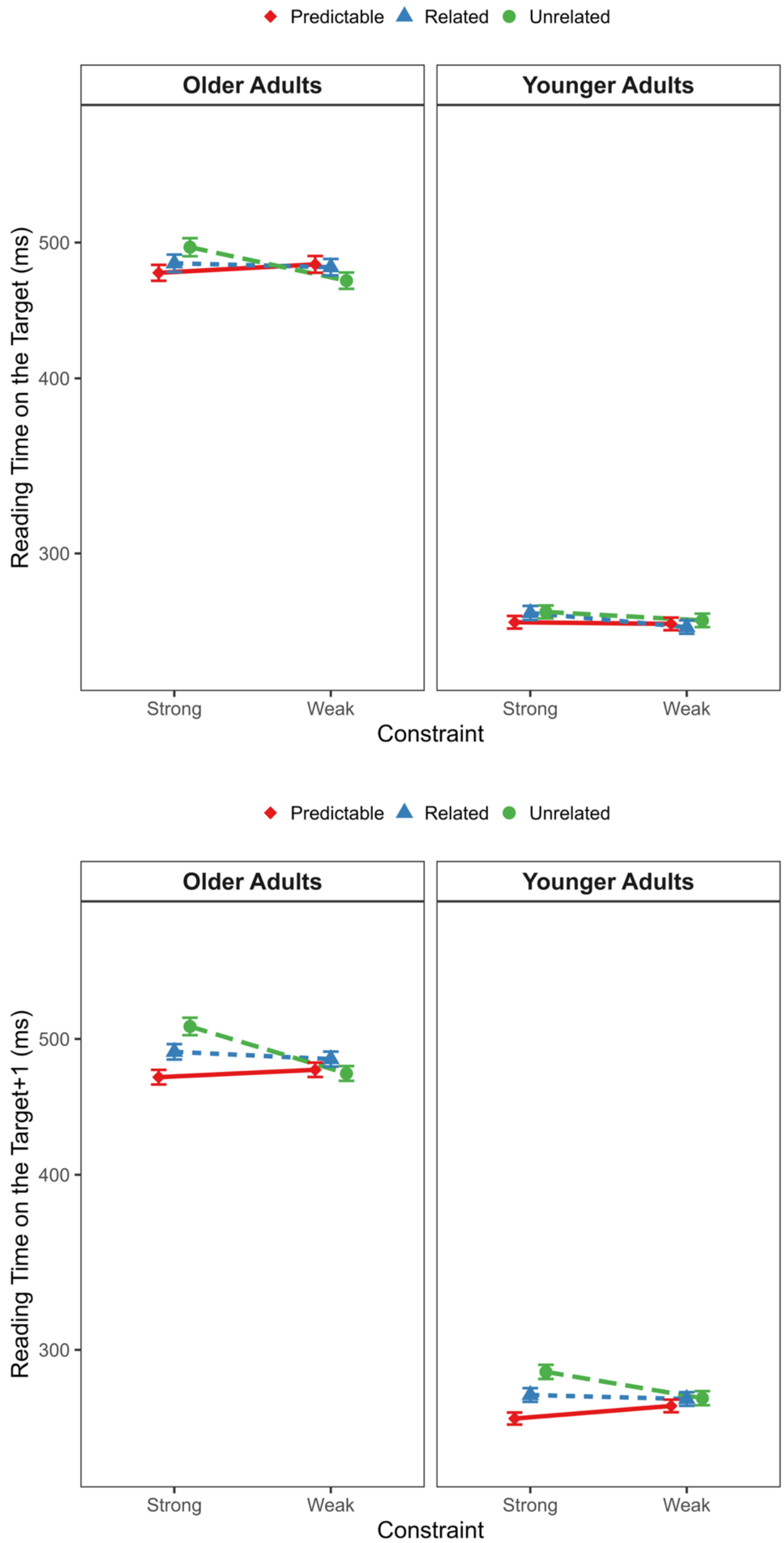

Figure 4.2 Mean log reading times for the target (upper panel) and the word following the target (lower panel) across conditions for older and younger readers in Experiment 2.

Target.

As illustrated in the upper panel of Figure 4.2, the main effect of age was significant because older adults spent longer reading the target compared to younger adults (523 vs 288 ms; t = 11.25). There were no significant effects of target predictability or relatedness, or interactions with age on self-paced reading times at the target ($|t|$s < 1.36).

For both predictable and related targets, the constraint effect was not significant on self-paced reading times ($|t|$s < 1.29) because, averaged over age, these words were processed equivalently in strongly and weakly constraining contexts. Age did not interact with the constraint effect for either of the targets ($|t|$s < 1) – follow-up analyses confirmed that, for both age groups, there were no constraint effects for predictable (older adults: b = 0.01, SE = 0.02, t = 0.88; younger adults: b = -0.00, SE = 0.01, t = -0.18) or related targets (older adults: b = -0.01, SE = 0.02, t = -0.48; younger adults: b = -0.02, SE = 0.02, t = -1.49). For unrelated targets, there was a significant effect of constraint on self-paced reading times (t = -2.68) because, averaged over age, these words received *longer* reading times in strongly compared to weakly constraining contexts. Age did not interact with the constraint effect for unrelated targets (t = 1.68), although separate group analyses revealed that this processing cost was significant for older (b = -0.05, SE = 0.02, t = -2.68) but not younger adults (b = -0.01, SE = 0.02, t = -0.93).

Thus, for the most part, both age groups showed equivalent self-paced reading times at the target across the constraint conditions – while there was no evidence of any processing benefits for predictable or related unpredictable completions under conditions of strong constraint, there was evidence of a processing cost when an unrelated unpredictable completion appeared instead.

Target+1.

Similar to the previous two regions, there was a significant main effect of age at the word following the target reflecting longer reading times for older than younger adults (517 vs 298 ms; t = 11.23). The effect of target predictability was significant on self-paced reading times at the word following the target (t = -6.20) because, averaged over constraint and age, reading times were shorter following predictable than unpredictable words. The effect of target relatedness was also significant on self-paced reading times at the word following the target (t = -2.61) because, averaged over constraint and age, shorter reading times followed related than unrelated words. There were no significant interactions between these effects and age ($|t|$s < 1).

For predictable targets, there was a significant effect of constraint on self-paced reading times (t = 2.09) because, averaged over age, reading times were shorter following these words in strongly compared to weakly constraining contexts. For related targets, the effect of constraint was not significant on self-paced reading times averaged over age (t < 1). For unrelated targets, there was a significant effect of constraint on self-paced reading times (t = -4.30) because, averaged over age, reading times were longer following these words under conditions of strong compared to weak constraint. There were no significant interactions between age and the constraint effect for any of the targets ($|t|$s < 1.21). Separate group analyses revealed that there were no constraint effects for predictable (older adults: b = 0.02, SE = 0.01, t = 1.56; younger adults: b = 0.02, SE = 0.01, t = 1.58) or related targets (older adults: b = -0.01, SE = 0.02, t = -0.84; younger adults: b = -0.00, SE = 0.02, t = -0.24) for either age groups; but, as illustrated in the lower panel of Figure 4.2, there was a similar delayed processing cost for unrelated targets for older (b = -0.07, SE = 0.02, t = -3.43) and younger adults (b = -0.04, SE = 0.02, t = -2.70).

Thus, both age groups showed similar patterns of processing at the spill-over region – a small processing benefit following predictable completions in strongly constraining contexts that did not extend to related unpredictable completions, but a processing cost following unrelated unpredictable completions under conditions of strong constraint.

Table 4.7

Results for the (generalized) linear mixed effects models for reading times on the regions of interest for older and younger adults in Experiment 2

Measure	Fixed effect	*b*	*SE*	*t/z*
Target – 1	**Intercept**	**5.86**	**0.02**	**252.55**
	Age	**0.54**	**0.05**	**11.72**
	Predictability	0.00	0.01	0.19
	Relatedness	-0.00	0.01	-0.42
	Length	**0.01**	**0.00**	**2.35**
	Frequency	-0.00	0.00	-0.46
	Predictable target: Constraint effect	-0.01	0.01	-0.84
	Related target: Constraint effect	-0.01	0.01	-0.77
	Unrelated target: Constraint effect	-0.01	0.01	-0.90
	Age x Predictability	0.00	0.01	0.47
	Age x Relatedness	0.00	0.01	0.18
	Age x Predictable target: Constraint effect	-0.01	0.02	-0.65
	Age x Related target: Constraint effect	0.02	0.02	1.18
	Age x Unrelated target: Constraint effect	-0.02	0.02	-1.13
Target	**Intercept**	**5.88**	**0.03**	**226.81**
	Age	**0.58**	**0.05**	**11.25**
	Predictability	-0.01	0.01	-1.36
	Relatedness	-0.01	0.01	-0.90
	Predictable target: Constraint effect	0.01	0.01	0.51
	Related target: Constraint effect	-0.02	0.01	-1.29

	Unrelated target: Constraint effect	**-0.03**	**0.01**	**-2.68**
	Age x Predictability	0.00	0.01	0.23
	Age x Relatedness	0.00	0.01	0.24
	Age x Predictable target: Constraint effect	0.02	0.02	0.85
	Age x Related target: Constraint effect	0.01	0.02	0.62
	Age x Unrelated target: Constraint effect	-0.04	0.02	-1.68
Target + 1	**Intercept**	**5.91**	**0.03**	**238.50**
	Age	**0.55**	**0.05**	**11.23**
	Predictability	**-0.03**	**0.01**	**-6.20**
	Relatedness	**-0.02**	**0.01**	**-2.61**
	Length	**0.01**	**0.00**	**3.04**
	Frequency	0.00	0.00	0.85
	Predictable target: Constraint effect	**0.02**	**0.01**	**2.09**
	Related target: Constraint effect	-0.01	0.01	-0.72
	Unrelated target: Constraint effect	**-0.06**	**0.01**	**-4.30**
	Age x Predictability	-0.00	0.01	-0.02
	Age x Relatedness	0.01	0.01	0.64
	Age x Predictable target: Constraint effect	-0.00	0.02	-0.19
	Age x Related target: Constraint effect	-0.01	0.02	-0.42
	Age x Unrelated target: Constraint effect	-0.03	0.02	-1.21

Note. Significant effects are bolded.

Supplementary Recognition Memory Task.

In order to gain some insight into the downstream consequences of encountering prediction error, older adults who completed the self-paced reading task also took part in a subsequent word recognition memory task comprising 238 items.[7] This included 132 *Presented Old* items – target words that were presented and either predictable or unpredictable in the self-paced reading task, 84 *Unpresented New* items – words that were never expected or presented in the self-paced reading task, and 22 *Unpresented Lure* items – words that were expected because they were the predictable word in the strongly

[7] The data for a further two participants were excluded as their responses indicated that they had misunderstood the instructions for the task.

constraining context but never presented in the self-paced reading task. Each word appeared for 3000 ms during which older adults were required to make a keyboard response indicating whether the item had appeared in the self-paced reading task. Recognition accuracy was 63.4% for Presented Old items and 62.6% for Unpresented New items, but only 38.1% for Unpresented Lure items. A GLMM revealed a significant main effect of presentation (b = 0.54, SE = 0.23, z = 2.33) and lure (b = -0.83, SE = 0.14, z = -5.86) – older adults were better at recognising presented compared to unpresented items on average because there was a higher rate of false alarms for lures compared to new items. This suggests that predicted input may not have been fully suppressed when disconfirmed by unexpected alternatives during the self-paced reading task, leading to lingering representations in older adults' memory (see Hubbard et al., 2019 for similar evidence in young adults).

4.5.3 Discussion.

The aim of this experiment was to assess the sensitivity of older adults' predictive processing to unnatural presentation methods by investigating whether they show evidence of processing costs for unexpected input in a self-paced reading task. The same stimuli as Experiment 1 were presented except that each word of a sentence appeared one at a time at the readers' own pace.

In contrast to Experiment 1, the combined analyses revealed that like younger adults, older adults did not process predictable words more efficiently in strongly compared to weakly constraining contexts. Instead, these items received equivalent reading times across both constraint conditions, suggesting that readers were not facilitated by the presence of the most expected candidate under conditions of strong constraint. But predictable words in strongly constraining contexts did lead to faster reading times on the following word, implying that this spill-over effect captured a time lag in readers' button presses rather than ongoing facilitation from the expected input. This delayed processing benefit though was small (6 ms effect) and not significant in the separate analyses of older and younger adults' data. Further contrary to the previous experiment, both age groups processed related unpredictable words equivalently across strongly and weakly constraining contexts, indicating that these items did not benefit from their semantic overlap with the most expected completion.

Despite the absence of strong processing benefits for expected input, both age groups showed an overall processing cost for unpredictable words that were semantically unrelated to the best completion. Specifically, these items yielded longer reading times in strongly constraining contexts that encouraged the preactivation of a more expected competitor but not in weakly constraining contexts that did not. Although this evidence of processing costs for unexpected input appeared to be driven by the older adult sample, the combined analyses revealed that the magnitude of this effect did not differ between the two age groups. This processing disadvantage also extended to the word following unrelated unpredictable targets regardless of age, suggesting that older and younger adults experienced similar ongoing disruption even after they had moved beyond the unexpected input. Thus, like their younger counterparts, older readers do appear to be sensitive to the consequences of prediction failure, implying that they had generated predictions about upcoming text in the first place.

However, these findings of processing costs for unexpected input could also be indicative of older adults' reliance on late integration processes, rather than early predictive processes, to guide online processing. While eye-tracking tasks yield several online reading measures that are thought to distinguish early and late stages of processing (e.g., the probability of skipping vs. regressions-in; Clifton et al., 2007; Vasishth et al., 2013), self-paced reading tasks yield one online reading measure – the amount of time taken by readers to process each word before they make a button press that reveals the next word. As such, this single measure potentially captures the effects of early processing stages including word identification and lexical access which are more likely to be influenced by predictive processes, but also the effects of late processing stages such as sentence- and discourse-level comprehension which are more likely to require integration processes. From this perspective, the longer reading times for unrelated unpredictable words under conditions of strong constraint could reflect the additional integration difficulty for items that are semantically incompatible with the broader discourse representation. At present, the single measure yielded by the self-paced reading paradigm makes it difficult to distinguish between these two accounts.

The present findings based on self-paced reading are therefore partly compatible with the findings of the previous experiment based on naturalistic reading. In particular, older adults demonstrated evidence of processing costs for unexpected input when semantically unrelated to the best completion across both methodologies, suggesting that the predictive processes engaged in normal reading also extended to self-paced reading by allowing readers to have control over the presentation rate despite the word-by-word presentation format. More generally, this pattern of processing emerged despite older adults' slower and more variable self-paced reading times across the entire sentence compared to their younger counterparts, consistent with the preservation of older readers' ability to use contextual information in a predictive manner (e.g., Zhang et al., 2022). Thus, the discrepant findings drawn from eye-movement and ERP literatures regarding the impact of aging on predictive processing could reflect the fact that ERP studies typically use a fixed-pace presentation rate that requires more resources to be allocated to lower-level processes like word identification and/or lexical access instead of higher-level processes like anticipatory prediction.

4.6 General Discussion

The overall aim of the present research was to investigate older adults' use of anticipatory prediction during online language comprehension. Although previous eye-movement studies have reported preserved, if not enhanced, predictability effects in older compared to younger adults (e.g., Andrews et al., 2022; Cheimariou et al., 2021; Choi et al., 2017; Kliegl et al., 2004; Rayner et al., 2006; Veldre et al., 2022; Zhang et al., 2022), evidence of the immediate processing costs that would be expected to accompany instances of prediction failure remains elusive. The only eye-movement study to examine this issue to date by Andrews et al. (2022) found that older adults did not make longer reading times for unexpected words presented in place of a more expected competitor. However, these findings could reflect the use of corpus-based analyses in which very few words were highly predictable. Similarly, prior ERP studies have noted that older adults fail to yield a late frontal positivity (e.g., Federmeier et al., 2010; Wlotko et al., 2012) which is thought to index the additional neural activity required to process unexpected words (see Van Petten & Luka, 2012 for a review). However, it remains unclear whether these findings generalize to normal sentence reading given the use of an unnatural presentation method and other task-specific factors. Thus, the primary goal of the current set of experiments was to assess whether older readers show evidence of processing costs for incorrect predictions in a controlled experimental design. A further goal was to determine whether older readers' predictive processing depends on the stimuli presentation method. To this end, older readers' eye-movements (Experiment 1) and self-paced reading times (Experiment 2) were recorded as they read strongly and weakly constraining sentences that were completed either by the predictable word for the strongly constraining context, or by a semantically related or unrelated alternative.

Across both experiments, older readers demonstrated evidence of processing costs for unexpected input that disconfirmed a more expected completion. In Experiment 1's eye-tracking task, unpredictable words that were semantically unrelated to the highest cloze completion received longer gaze durations in strongly compared to weakly constraining contexts, while in Experiment 2's self-paced reading task, these same items yielded longer self-paced reading times under conditions of strong constraint, not only at the target but also at the following word. However, older readers did not show similar evidence of processing costs for unpredictable completions that were semantically related to the best completion across both methodologies. Instead, in Experiment 1, related unpredictable completions received shorter total reading times and fewer regressions back to previous text in strongly compared to weakly constraining contexts, reflecting their facilitated integration into the unfolding discourse representation. These items were also more likely to be skipped under conditions of strong constraint, suggesting that they may have been partially preactivated ahead of time. In Experiment 2, on the other hand, related unpredictable completions were processed equivalently across both constraint conditions, i.e., these items generated no processing costs like the eye-movement data, but they also did not elicit any processing benefits which could reflect the fact that readers were unable to return to earlier parts of the sentence due to the word-by-word presentation format.

According to the present findings then, older readers do appear to be sensitive to the consequences of prediction failure during naturalistic and self-paced sentence reading, specifically when their expectations are disconfirmed by semantically unrelated alternatives. As such, this implies that older readers had generated lexical predictions about the upcoming text ahead of time, leading to disrupted processing when a mismatch was detected between their expectation and the word actually presented. This additional processing likely reflects the temporary suppression of the expected word and/or revision of the existing discourse representation so that the less expected input can be processed thoroughly. Evidence that older adults make use of anticipatory prediction during online language comprehension is consistent with the fact that linguistic experience via reading accumulates over one's lifespan (Payne et al., 2012; Ryskin et al., 2020), allowing more precise and refined predictions to be generated with age. Indeed, this pattern of processing costs exhibited by older readers across both methodologies did not differ from that of their younger counterparts, in line with previous observations that the use of linguistic prediction during online processing remains relatively preserved with age (e.g., Zhang et al., 2022).

Notably, however, the processing costs for prediction violations did not extend to semantically related alternatives, which instead received facilitated processing in the eye-movement record. This indicates that older readers not only generated "all-or-none" lexical predictions about upcoming text (DeLong et al., 2014b) but also graded predictions involving the partial preactivation of upcoming words in terms of their morphosyntactic, syntactic, and semantic attributes (Federmeier, 2021; Levy, 2008; Luke & Christianson, 2016; Staub, 2015; Staub et al., 2015). As such, multiple continuations were possible for each word of a sentence, allowing predictability effects to arise across a range of contextual constraints, including for less predictable words. The strongest support for this graded prediction account comes from the fact that related unpredictable completions in the eye-movement record not only elicited late processing benefits but also an early processing benefit on skipping in strongly constraining contexts, suggesting that older readers had broadly activated a set of words that were likely to appear in the input. A recent proposal by Federmeier (2022) posits that readers use both prediction strategies during online processing but that the transformation of graded predictions into lexical predictions can depend on a variety of factors including task demands and individual differences. This evidence that older adults are capable of lexical and graded prediction is consistent with prior findings in younger adults (e.g., Andrews et al., 2022), providing further evidence that predictive processes remain unchanged across the lifespan.

The current findings, particularly from Experiment 1's eye-tracking task, thus extend Andrews et al.'s (2022) study by demonstrating that older adults do show evidence of processing costs for incorrect predictions in a controlled experimental design. The discrepancy between the two eye-movement studies then could reflect older readers' sensitivity to predictive information in their broader linguistic environment (see Brothers et al., 2019; Brothers et al., 2017; Wong et al., in revision for similar evidence in young adults). That is, when there are weak or sparse predictive cues in the linguistic environment, such as in the naturalistic texts used in Andrews et al.'s corpus-based study, older readers may be more inclined to generate multiple possible continuations for upcoming words which are less likely to incur processing costs when disconfirmed by unexpected input. However, when there are strong or more predictive cues in the linguistic environment, such as in the present studies where half of the sentences were strongly constraining and completed by the most expected completion a third of the time, older readers may favor the prediction of a specific lexical candidate given its higher likelihood of turning out correct. This strategic modulation of predictive processes would be consistent with Federmeier's (2022) proposal that lexical and graded predictions are underpinned by the same processes, but that readers' use of either strategy depends on other factors. Indeed, prior research has found that older readers are more likely to recruit anticipatory prediction when they are cued by certain task demands (Federmeier et al., 2010) or explicit instructions (e.g., Dave et al., 2018), and/or when they have higher levels of verbal fluency (Federmeier et al., 2002). A flexible predictive strategy may be especially important for older readers to ensure optimization of their limited resources for successful online language comprehension (Huettig & Mani, 2016; Pickering & Gambi, 2018).

The current set of experiments also provide further insight into the discrepant findings between eye-movement and ERP studies regarding the impact of aging on predictive processes. Unlike eye-movement studies, data from ERP studies has been taken to suggest that older adults are less reliant on anticipatory prediction because they show reduced N400 effects and no late frontal positivity for prediction violations (see Payne & Silcox, 2019 for a review). However, these findings may not generalize to normal reading because they could reflect older adults' inability to adapt effectively to the unnatural RSVP paradigm in which each word of a sentence appears one at a time at a fixed pace controlled by the experimenter. Indeed, the present experiments revealed that older readers' processing patterns during normal reading in Experiment 1 were very similar to that during self-paced reading in Experiment 2, which also used a word-by-word presentation format but at the readers' own pace. These converging findings suggest then that older adults' failure to recruit predictive strategies in ERP studies is unlikely to be due to just the word-by-word presentation format that imposes constraints on key reading strategies including skipping words, re-reading text and extracting upcoming parafoveal information. Instead, the source of this decline could be the fixed-pace presentation rate which removes older readers' control over the rate of input and displays each word for a duration between 400 and 1000 ms – for example, in the ERP studies that have failed to elicit the late frontal positivity (e.g., Federmeier et al., 2010; Wlotko et al., 2012), older readers were presented each word for 200 ms with an interstimulus interval of 300 ms. These unnatural modifications may require older readers to allocate more resources to lower-level processes like word identification and/or lexical access in order to maintain an adequate level of comprehension, which could subsequently leave fewer resources available for higher-level processes like anticipatory prediction. Thus, older adults' predictive processing does appear to be sensitive to unnatural presentation methods, although it remains unclear the precise aspects of the RSVP paradigm that disrupt normal reading. Future research could provide further insight into the source of the discrepancy in age-related predictability effects between methodologies via the co-registration of eye movements and EEG during a sentence reading task (see Dimigen et al., 2011; Himmelstoss et al., 2020 for reviews).

There are several other noteworthy procedural factors that could have contributed to the mixed evidence of predictability effects in older readers between eye-movement and ERP studies. Unlike natural reading, ERP studies require readers to suppress their eye movements during RSVP reading. This unnatural processing demand may impose an additional cognitive load on older readers that not only diverts their attention away from word identification (e.g., Rayner & Morrison, 1981; Veldre et al., 2022) or comprehending the text being read (Castelhano & Muter, 2001; Rubin & Turano, 1992) but also impedes their ability to use contextual information in a predictive manner. Moreover, differing comprehension demands across the methodologies could play a role in older readers' propensity to engage predictive strategies during online processing. While eye-movement studies typically include occasional comprehension questions to encourage deeper processing of the text, ERP studies include either no task or a secondary task like a memory recognition test that requires little comprehension (e.g., Federmeier & Kutas, 2005; Wlotko & Federmeier, 2012, but see DeLong et al., 2012). As such, this may lead older readers in ERP studies to process text in a shallower, “good enough” manner (Ferreira et al., 2002) that does not draw upon higher-order processes like anticipatory prediction. Indeed, there is accumulating evidence across methodologies that readers’ processing strategies are modulated by comprehension demands (e.g., Andrews & Veldre, 2021; Andrews et al., 2022; Dave et al., 2018; Payne et al., 2019; Radach et al., 2008). Most notably, an ERP study by Dave et al. (2018) in which older and younger adults were instructed to predict passage-final words and report the accuracy of their predictions found that both age groups showed predictability benefits in the form of reduced N400 effects, as well as predictability costs in the form of the late frontal positivity, suggesting that, under certain explicit comprehension demands, older readers do predict upcoming words ahead of time and are sensitive to the consequences of prediction failure.

Although older readers’ processing of unexpected input across both experiments attests to their use of anticipatory prediction during online processing, evidence of the predictability benefit, indexed by comparing the processing of predictable completions in strongly and weakly constraining contexts, differed across the methodologies. In Experiment 1’s eye-tracking task, predictable completions yielded early and late processing benefits in strongly constraining contexts, consistent with facilitation arising from both predictive and integrative mechanisms. In Experiment 2’s self-paced reading task, however, predictable completions failed to yield any processing benefits under conditions of strong constraint, either at the target or the following word. This decreased sensitivity to the presence of confirmed predictions during self-paced reading is unlikely to be due to a weak manipulation of predictability – disconfirmed predictions, i.e., words replaced by unrelated unpredictable completions, in the same task yielded immediate processing costs, while the same predictable completions elicited processing benefits in the eye-tracking task. Instead, the absence of predictability benefits in Experiment 2 could reflect an upper limit on older readers' processing benefits for expected input. That is, older readers may have been unable to speed up their reading times, even when their expectations matched the word actually presented, either due to the cognitive demands of the word-by-word presentation format or the physical limitations of making continuous button-presses to progress through the sentence. Given that older readers were able to slow down their reading times in response to prediction failure, it appears that these limitations of the self-paced reading paradigm only affected whether older readers were able to optimize their reading strategies and not whether they were able to use predictive processes during online language comprehension. However, it should be noted that this discrepancy in processing of predictable words across the methodologies was also apparent in younger readers, which could indicate that the limitations of the self-paced reading paradigm extended to all ages.

Taken together then, the pattern of processing exhibited by older adults in both experiments, particularly Experiment 1's eye-tracking task, provides limited support for the idea that older readers adopt a risky reading strategy during online processing. According to this hypothesis (Rayner et al., 2006), older adults compensate for declines in their visual and motor processes by relying more heavily on contextual information which predicts that they should show higher skipping rates, longer forward saccades, and more regressions compared to their younger counterparts. Consistent with this, Experiment 1's global analysis of readers' eye movements revealed that older adults did have slower reading times across the entire sentence compared to younger adults, due to a higher number of fixations and regressions and longer forward saccades. However, inconsistent with the predictions of the risky reading hypothesis, there was no age-related difference in global skipping rates, while local skipping rates at the target word were in fact *lower* for older than younger adults. Furthermore, the local analysis of readers' eye movements revealed similar predictability benefits and costs at the target word for both age groups. Thus, older adults do not appear to rely on a contextually based risky reading strategy, in line with the conclusions that have begun to emerge from other recent eye-movement studies (e.g., Choi et al., 2017; Veldre et al., 2021, 2022; see Zhang et al., 2022 for a meta-analysis).

The current patterns of global and local reading behaviors observed across both experiments could be more compatible with an account in which older adults are more careful and motivated readers than younger adults due to their declines in visual acuity and other cognitive abilities (see Owsley, 2011; Verhaeghen, 2013 for reviews), especially under laboratory settings. Older adults who take part in research may feel more inclined to perform at their best which could encourage them to read more slowly and more carefully than normal. The present sample of older adults also received financial reimbursement for their time which could lead to differing levels of motivation compared to younger adults who received course credit instead.

The final contribution of the present research was towards the question of whether normal online reading processes are observable during self-paced reading given the latter's increasing popularity as an easy, low-cost methodology for investigating language comprehension processes (Marsden et al., 2018). Propitiously, older adults revealed evidence of processing costs in the form of longer reading times for unrelated unpredictable completions in strongly constraining contexts across both self-paced and naturalistic sentence reading. However, there were notable differences in older adults' processing of the other completions across the methodologies. As discussed above, predictable completions in strongly constraining contexts yielded processing benefits in the eye-movement but not self-paced reading task, regardless of age, which could reflect the latter's additional cognitive and physical demands due to the unnatural presentation and/or response method. Related unpredictable completions in strongly constraining contexts similarly elicited late integration benefits in the eye-movement record but little evidence of comparable benefits in the self-paced reading record, suggesting that the latter may also be insensitive to the full range of reading behaviors linked to later stages of processing, including re-reading and making regressions to previous parts of text, due to its word-by-word presentation format. These discrepancies suggest that there are several possible limitations associated with using the self-paced reading task which, notably, also only yields a single reading measure, unlike the several online reading measures that can be recorded by the eye-tracking task. The utility of self-paced reading paradigms then may be restricted to investigations of online processes that occur early in the time course of real-time language comprehension and that are robust to the cognitive and physical demands of the unnatural presentation and/or response method. The eye-tracking paradigm based on naturalistic reading thus appears to remain the more robust and advantageous methodology for examining the online processes underlying reading.

In summary, the present research extends what is known about predictive processes beyond that of skilled, young-adult readers. Like their younger counterparts, older adults appear to make use of anticipatory prediction during online processing, consistent with other language-related abilities that remain resilient to age-related decline. However, the current findings also suggest that older readers' propensity to engage predictive processes may depend on a variety of factors including the information in their broader linguistic environment and the stimuli presentation method. This is consistent with accumulating evidence in young adults that predictive processes are not ubiquitous but rather context-dependent and determined by the availability of cognitive resources (e.g., Huettig & Mani, 2016; Pickering & Gambi, 2018). Predictive processing then, regardless of age, may be an important but flexible strategy for successful online language comprehension.

CHAPTER 5: Summary, Conclusions, and Future Directions

It is well-accepted that one way in which real-time language comprehension is able to unfold as rapidly and effortlessly as it does is because readers predict upcoming linguistic content even before bottom-up input has been encountered. Evidence that prediction occurs during reading is demonstrated by robust predictability effects across a range of methodologies including eye-movement and ERP recordings (see Chapter 1; Kutas & Federmeier, 2011; Staub, 2015 for reviews). However, there remain several unresolved empirical issues relating to prediction processes which are critical for the broader question of whether prediction plays a fundamental role in real-time language comprehension as posited by several theoretical accounts (e.g., Ferreira & Chantavarin, 2018; Huettig, 2015; Kuperberg & Jaeger, 2016; Lupyan & Clark, 2015; Pickering & Gambi, 2018). These include whether there are processing costs for misprediction, what the contents of predictions are, and whether all readers engage in prediction to the same extent. The present thesis therefore aimed to systematically investigate these issues across six experiments. The primary methodology used was eye-movement recording given its ability to measure online processing during natural reading for comprehension. Self-paced reading was also used to assess the impact of stimuli presentation format on predictive processing. The final chapter of this thesis summarises the key findings of these experiments and discusses their implications in relation to the ongoing empirical challenges for understanding language prediction. This chapter concludes by considering the contributions of the present research to broader theories of prediction before outlining some potential future research directions.

5.1 Summary of empirical findings

Chapter 2 reported an eye-movement experiment which investigated the nature of prediction error costs and whether they depended on the source of constraint violation provided by the prior context. Readers' eye movements were recorded as they read predictable words and unpredictable alternatives that were either semantically related or unrelated in three-sentence passages. The source of constraint in these passages originated either from the global context which was designed to encourage higher-level discourse representations, the local context which was designed to activate lower-level lexicosemantic information, the combined global and local contexts, or none of the three sentences in the passage. The results revealed the classic processing benefits for predictable completions in the presence of any constraining context, although the relative contributions of global and local sources of constraint differed across the time course of word processing. Unpredictable completions, however, did not yield any processing costs regardless of the source of constraint, instead receiving immediate facilitated processing in the presence of any constraining context. The initial processing of related unpredictable completions was further enhanced by the provision of a supportive global context. Thus, these findings were taken to suggest that predictability benefits did not appear to be determined by cloze probability alone but also by the nature of the prior contextual constraint. However, predictability costs were not observable regardless of the source of constraint violation provided by the context preceding the misprediction.

Chapter 3 reported three eye-movement experiments which aimed to further explore the nature of prediction error costs by examining whether there were consequences of misprediction beyond online processing in the moment. In these studies, readers' eye movements were recorded as they read predictable words and unpredictable alternatives that were either semantically related or unrelated in strongly and weakly constraining sentences. Each sentence was presented within a connected two-sentence passage in which the second sentence contained the predictable word from the initial sentence. This allowed an assessment of whether readers' predictions had downstream consequences even when they did not materialise and were replaced by less expected input. The results at the initial target across all experiments revealed that predictable completions received the usual processing benefits in strongly constraining contexts although these effects on first-pass reading measures were somewhat weaker than expected. These processing benefits also extended to unpredictable completions that were semantically related, but only on late reading measures which index postlexical integration processes. However, unpredictable completions that were semantically unrelated to the best completion yielded immediate processing costs in strongly constraining contexts that were only evident when the stimuli were plausible, i.e., when no anomalous completions were presented in the broader linguistic environment. The results at the downstream target across all experiments further revealed minimal evidence that readers' initial predictions were observable downstream regardless of whether they had been subsequently confirmed or disconfirmed. Thus, these processing patterns at the initial and downstream targets were argued to suggest that the consequences of making an incorrect prediction were small, short-lived, and observable only during the immediate, and not downstream, processing of unexpected input.

Finally, Chapter 4 reported separate eye-movement and self-paced reading experiments which tested prediction in older adults to assess the extent to which readers other than young adults made use of prediction strategies during online processing. Older readers' eye movements were recorded as they read strongly and weakly constraining sentences containing a predictable word or unpredictable alternative that was semantically related or unrelated. To assess whether differences in stimuli presentation method impacted predictive processing, a separate group of older adults' self-paced reading times were collected for the same materials. The eye-movement results revealed that older readers showed the typical processing benefits for predictable completions in strongly constraining contexts which also extended to related unpredictable completions. Unrelated unpredictable completions, on the other hand, yielded immediate processing costs under conditions of strong constraint. The self-paced reading results did not reveal similar processing benefits for either predictable or related unpredictable completions, but there was evidence of processing costs for unrelated unpredictable completions. Notably, these processing patterns exhibited by older readers across both methodologies did not differ to that of a comparison sample of young readers. Thus, these findings were taken to suggest that predictive processes remained relatively preserved with age and, to a certain extent, regardless of the stimuli presentation method.

5.2 Implications for understanding language prediction

The findings of the current research are consistent with the large body of existing literature on predictability effects reviewed in Chapter 1 that has been taken as evidence of prediction processes during real-time language comprehension. Across all eye-movement experiments, predictable completions received facilitated processing on first-pass reading measures including skipping, first fixation and gaze duration when presented in constraining compared to non-constraining context conditions, indicating that readers had likely activated these items in advance of their presentation to affect the earliest stages of processing. These predictability benefits also extended to late reading measures including total fixation duration and the probability of regressions, suggesting that these items were also easier to integrate into unfolding discourse representations. These classic predictability benefits, however, were not replicated during self-paced reading in samples of older and younger readers, the implications of which are discussed in further detail later in this chapter.

The major implication of these findings is that predictability benefits do not appear to be determined by effects of cloze probability alone. Chapter 2 revealed that global and local contexts preceding predictable completions made independent contributions to the early stages of processing of these items even when cloze probability was controlled, suggesting that the source of contextual constraint also had an influence over readers' predictive strategies. Specifically, while an immediate local context was more likely to activate the expected completion based on lower-level lexicosemantic information, a prior global context was more likely to encourage higher-level discourse representations that propagated the most expected completion through multiple representational levels of a hierarchical network. These independent contributions, however, did not extend to the late stages of processing of these items, suggesting that the integration of predictable completions was more dependent on their degree of semantic fit as indexed by cloze probability. Chapter 3 revealed further evidence that predictability benefits were not determined by cloze probability alone – immediate processing benefits for high cloze continuations under conditions of strong constraint were weaker when some of the stimuli were implausible, suggesting that readers were more likely to prioritise incoming bottom-up input when a noticeable proportion of sentences were anomalous. That is, readers' use of top-down comprehension strategies including anticipatory prediction appeared to depend on the presence of a plausible linguistic environment.

Taken together, these findings related to expected input indicate that predictability effects are determined by a combination of cloze probability and other linguistic factors such as the nature of prior contextual constraint and information in the broader linguistic environment. This conclusion is consistent with the findings of previous studies such as Staub et al. (2015) who found that contextual constraint determined response times on a speeded cloze task when cloze probability was controlled, and Brothers et al. (2017) who found that the presence of more predictable filler sentences in a self-paced reading task led to shorter reading times for expected input. On the assumption that predictability effects index prediction processes during real-time language comprehension (Kutas et al., 2011), readers' use of lexical prediction appears to be a flexible rather than automatic strategy during online processing. This section now revisits several of the unresolved empirical issues identified in Chapter 1 in order to further assess whether prediction plays a fundamental role in real-time language comprehension. This section concludes by considering whether the language processor is truly a "prediction machine" (Clark, 2013).

5.2.1 Are there processing costs for misprediction?

If the language processor does routinely engage in prediction during online processing and receives processing benefits when its predictions turn out correct, there should be evidence of processing costs for the flipside of this equation, i.e., when its predictions turn out incorrect. Despite apparent inconsistencies in the literature as to whether readers are sensitive to the consequences of misprediction during real-time language comprehension (see Chapters 2-4 for reviews), the present research revealed evidence of immediate processing costs when readers' predictions were disconfirmed by unexpected input that was semantically unrelated. Specifically, in Chapter 3, two of the three eye-movement experiments showed that unrelated unpredictable completions yielded processing costs on first fixation and gaze duration when presented in contexts that constrained towards a more expected completion. A similar pattern of results was obtained in Chapter 4 across eye-movement and self-paced reading experiments assessing a combined sample of older and younger readers using similar sentence stimuli. As such, it appears that there are processing consequences for a mismatch between the word expected in a constraining context and the input actually encountered. This implies that readers do activate linguistic content and commit to their predictions ahead of time during online processing.

Notably, the consequences of misprediction experienced by readers were relatively small and short-lived. Firstly, the increase in processing times for unrelated unpredictable completions in strongly compared to weakly constraining contexts was 9 ms on gaze duration in Chapter 3's Experiment 2, 8 ms and 12 ms on first fixation and gaze duration, respectively, in Chapter 3's Experiment 3, and 15 ms on gaze duration in Chapter 4's Experiment 1. These effect sizes are relatively small, especially when compared to the average effect sizes of the processing benefits for predictable completions in strongly compared to weakly constraining contexts reported in eye-movement studies (e.g., 16 ms and 24 ms on first fixation and gaze duration, respectively, Frisson et al., 2017). This suggests that the disrupted processing arising from incorrect predictions may be weaker than the typical facilitated processing accompanying correct predictions during online processing. Secondly, Chapter 3 revealed across three experiments that readers' processing of previously expected completions was minimally disrupted even when these items had been disconfirmed earlier by a less expected alternative, implying that incorrect predictions were only temporarily suppressed at their initial point of processing. Indeed, the second experiment reported in Chapter 3 showed that while unrelated unpredictable completions yielded longer first-pass reading times under conditions of strong constraint, these items subsequently received *shorter* total reading times and *fewer* regressions-in, indicating that readers were able to quickly resolve their disconfirmed predictions via integration processes that were supported by information extracted from the rest of the sentence. These processing patterns, however, were not replicated in either Chapter 3's Experiment 3 or Chapter 4's Experiment 1 which both revealed evidence of immediate prediction error costs (but see Cevoli et al., 2022 for similar evidence of late processing benefits for unexpected input). Nonetheless, it appears that while predictions about upcoming text lead to processing benefits when they turn out correct, the violation of these expectations only leads to small and short-lived processing costs for the language processor.

These findings of prediction error costs, however, did not emerge for all unexpected input across all experiments. Firstly, there was no evidence of processing costs for unpredictable completions in strongly constraining contexts when semantically related to the best completion. This indicates that readers were minimally disrupted when their expectations were replaced by input that shared some semantic overlap (see also Andrews et al., 2022; Frisson et al., 2017; Luke & Christianson, 2016). Secondly, there was no evidence of processing costs for unexpected input in Chapter 2's experiment or in Chapter 3's Experiment 1. In Chapter 3's Experiment 1, the absence of processing costs may have been due to the inclusion of the anomalous target condition which could have disrupted readers' normal reading strategies (Braze et al., 2002; Rayner et al., 2004; Veldre et al., 2020). Indeed, there was no consistent numerical trend observed across any first-pass reading measures – processing times for unrelated unpredictable completions in strong versus weak contexts were longer on gaze duration but shorter on first fixation duration.

The exclusion of anomalies in the subsequent two experiments in Chapter 3 yielded evidence of prediction error costs, consistent with the idea mentioned earlier that readers' propensity to engage in anticipatory prediction depends on the presence of plausible stimuli in the broader linguistic environment. In Chapter 2's experiment, where readers would have been more likely to engage in normal reading strategies because they did process plausible stimuli, the reason for the lack of processing costs is less straightforward. In fact, there was a numerical trend towards shorter processing times on first fixation and gaze duration for unrelated unpredictable completions in globally constraining compared to globally non-constraining contexts, and in locally constraining compared to locally non-constraining contexts. However, the absence of processing costs in this experiment in Chapter 2 is unlikely to be due to a weak manipulation of predictability – cloze probability ratings were very high for predictable words in constraining contexts but very low for unpredictable words in the same contexts, indicating that the latter disconfirmed a highly probable completion in these contexts.

One potential explanation then for the failure to observe prediction error costs in Chapter 2's experiment could be related to the extended contexts preceding readers' mispredictions. Compared to the experiments in Chapters 3 and 4 which presented unexpected input in single sentences, Chapter 2's experiment presented unexpected input in the final sentence of three-sentence passages. These extended contexts may have provided more time and opportunity for readers to passively activate general morphosyntactic, syntactic, and semantic information about upcoming words as part of the natural reading process, meaning that multiple lexical candidates could have been partially preactivated ahead of time including those that are low in cloze probability. On the assumption that a broad range of completions have been preactivated, the presentation of less expected input is therefore unlikely to lead to processing costs and instead more likely to yield processing benefits especially when semantically related to the best completion. While this explanation seems counter-intuitive as one would expect three-sentence passages to contain enough information for readers to eventually activate a single lexical candidate (e.g., Brothers et al., 2020), it is also possible that these extended contexts encouraged readers to prioritise the preactivation of multiple lexical candidates because the presence of more prior context made it easier to integrate a wider set of items. This trade-off would account for similar null evidence of prediction error costs in previous eye-movement studies using extended passage contexts (e.g., Andrews et al., 2022; Luke & Christianson, 2016; but see Cevoli et al., 2022).

If it is the case that readers are less sensitive to the consequences of misprediction in extended contexts, the natural question that arises is why there *was* evidence of prediction error costs in the eye-movement experiments reported in Chapters 3 and 4 which presented unexpected input in single sentences. It is possible that the minimal contexts preceding readers' mispredictions provided less time and opportunity for the passive activation of information such that a broad range of low cloze continuations were unlikely to have been partially preactivated ahead of time. It is also possible that readers in these experiments were more likely to narrow down on a single lexical candidate because the presence of less prior context made it more difficult to effectively support the integration of a wider set of items. While these possibilities account for the differing outcomes observed across the present experiments, it does not fully account for why the current evidence of prediction error costs is contrary to the null findings of Frisson et al.'s (2017) study – the only other eye-movement study to investigate these effects using single sentence stimuli to date. Before speculating on some potential explanations for the prediction error costs observed in

Chapters 3 and 4, it is necessary to consider several factors that may appear to have contributed to the longer processing times on unrelated unpredictable completions in strongly constraining contexts.

One possibility is that the evidence of prediction error costs reflects intrinsic lexical characteristics of unrelated unpredictable completions, such as their frequency and length. It is well-established that lower frequency words increase reading times and the probability of fixations compared to higher frequency words (e.g., Drieghe et al., 2005; Inhoff & Rayner, 1986; Rayner & Duffy, 1986; Rayner & Raney, 1996). Similarly, longer words yield increased fixation durations and fewer skips compared to shorter words (e.g., Just & Carpenter, 1980; Rayner & McConkie, 1976). However, the current experiments always presented the same items in strongly and weakly constraining contexts, meaning that these lexical characteristics were perfectly matched across the two context conditions. As such, potential confounds like frequency and length are unlikely to have contributed to the evidence of prediction error costs observed in Chapters 3 and 4.

Another possibility is that the evidence of prediction error costs reflects the plausibility of unrelated unpredictable completions in strongly constraining contexts because these items received lower ratings in an offline plausibility judgement task. Specifically, across both Chapters 3 and 4, these items were rated 4.2 and 4.5, respectively, out of 5 in strongly constraining contexts, and 4.6 and 4.7, respectively, out of 5 in weakly constraining contexts based on a scale where 4 was "Slightly plausible" and 5 was "Highly plausible". Previous research has linked the presentation of highly implausible words to processing difficulties that typically arise early in the eye-movement record (e.g., Rayner et al., 2004; Staub et al., 2007; Veldre & Andrews, 2016; Veldre et al., 2020; Warren &

McConnell, 2007) and late in the ERP record in the form of a late posterior positivity (e.g., Brothers et al., 2020; Delong, Quante, & Kutas, 2014a; Kuperberg et al., 2020), although it should be noted that predictability was not always consistently controlled for in these studies. Supplementary analyses to address this potential confound in the present research removed items that were rated 3.5 or lower in plausibility, i.e., leaving items rated in between "Neither plausible nor implausible" (3) and "Slightly plausible" (4) or higher for analysis.[1] Evidence of prediction error costs on gaze duration remained in the expected direction in Chapter 3's Experiment 2 and Chapter 4's Experiment 1, i.e., significantly longer processing times for unrelated unpredictable completions in strongly compared to weakly constraining contexts.[2] Although evidence of prediction error costs on first-pass reading measures in Chapter 3's Experiment 3 were not significant in the supplementary analysis, the numerical trend was in the expected direction.[3] While these findings suggest that prediction error costs likely reflect consequences of the genuine violation of predictability rather than plausibility, they should be interpreted with some caution given that predictability and plausibility are generally correlated (see Nieuwland et al., 2020). As such, it can be difficult to disentangle their relative contributions during online and offline

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[1] For Chapter 3's Experiments 2 and 3, 24 items were removed leaving a subset of 52 items for analysis. Plausibility ratings for the unrelated unpredictable completions were 4.5 (*SD*=0.4) and 4.8 (*SD*=0.3) in strongly and weakly constraining contexts, respectively. For Chapter 4's Experiment 1, 6 items were removed leaving a subset of 60 items for analysis. Plausibility ratings for the unrelated unpredictable completions were 4.6 (*SD*=0.4) and 4.8 (*SD*=0.3) in strongly and weakly constraining contexts, respectively.

[2] For Chapter 3's Experiment 2, the mean gaze duration on unrelated unpredictable completions was 242 ms (*SD*=32) and 230 ms (*SD*=31) in strongly and weakly constraining contexts, respectively, (*b*=-0.05, *SE*=0.02, *t*=-2.08). For Chapter 4's Experiment 1, the mean gaze duration on unrelated unpredictable completions for older adults was 250 ms (*SD*=29) and 233 ms (*SD*=26) in strongly and weakly constraining contexts, respectively, (*b*=-0.06, *SE*=0.03, *t*=-2.23). The mean gaze duration on unrelated unpredictable completions for the combined sample of older and younger adults was 246 ms (*SD*=29) and 236 ms (*SD*=28) in strongly and weakly constraining contexts, respectively, (*b*=-0.04, *SE*=0.02, *t*=-2.32).

[3] The mean first fixation duration on unrelated unpredictable completions was 217 ms (*SD*=16) and 213 ms (*SD*=19) in strongly and weakly constraining contexts, respectively, (*b*=-0.02, *SE*=0.01, *t*=-1.13). The mean gaze duration on these same items was 238 ms (*SD*=24) and 233 ms (*SD*=22) in strongly and weakly constraining contexts, respectively, (*b*=-0.02, *SE*=0.02, *t*=-1.34).

language processing – readers are inherently more likely to rate an unpredictable word that is semantically unrelated to their expectations as more implausible even if it is a completely plausible continuation (see also Frisson et al., 2017). Furthermore, the average difference in plausibility for the unrelated unpredictable completions across both context conditions in the supplementary analyses was negligible (~4.6 vs 4.8), especially in comparison to previous studies of plausibility effects in which these differences are much larger (e.g., 1-2 vs. 4-5 based on a 5-point scale; Rayner et al., 2004; Staub et al., 2007; Veldre et al., 2020). Nonetheless, it appears that, to the extent that effects of plausibility are separable from predictability, the small differences in rated plausibility between unrelated unpredictable completions in strongly and weakly constraining contexts are unlikely to be responsible for the evidence of prediction error costs observed in Chapters 3 and 4.

Thus, the question remains as to why there was evidence of prediction error costs, which was observed most consistently on gaze duration, in the eye-movement experiments reported in Chapters 3 and 4. Given that the possible confounds of lexical (i.e., frequency and length) and contextual (i.e., plausibility) factors have been ruled out, the most plausible explanation is that readers did activate and commit to a single lexical candidate ahead of time because of the stimuli presented and perhaps, more importantly, because of their idiosyncratic characteristics as participants. However, as illustrated in Figure 5.1, not all readers showed evidence of prediction error costs on gaze duration even if individual experiments trended that way averaged over participants, suggesting that there was variability in the extent to which readers generated lexical predictions about upcoming text during online processing. Similarly, some participants in Chapter 3's Experiment 1 demonstrated evidence of prediction error costs on gaze duration even though this effect was not significant averaged over participants.

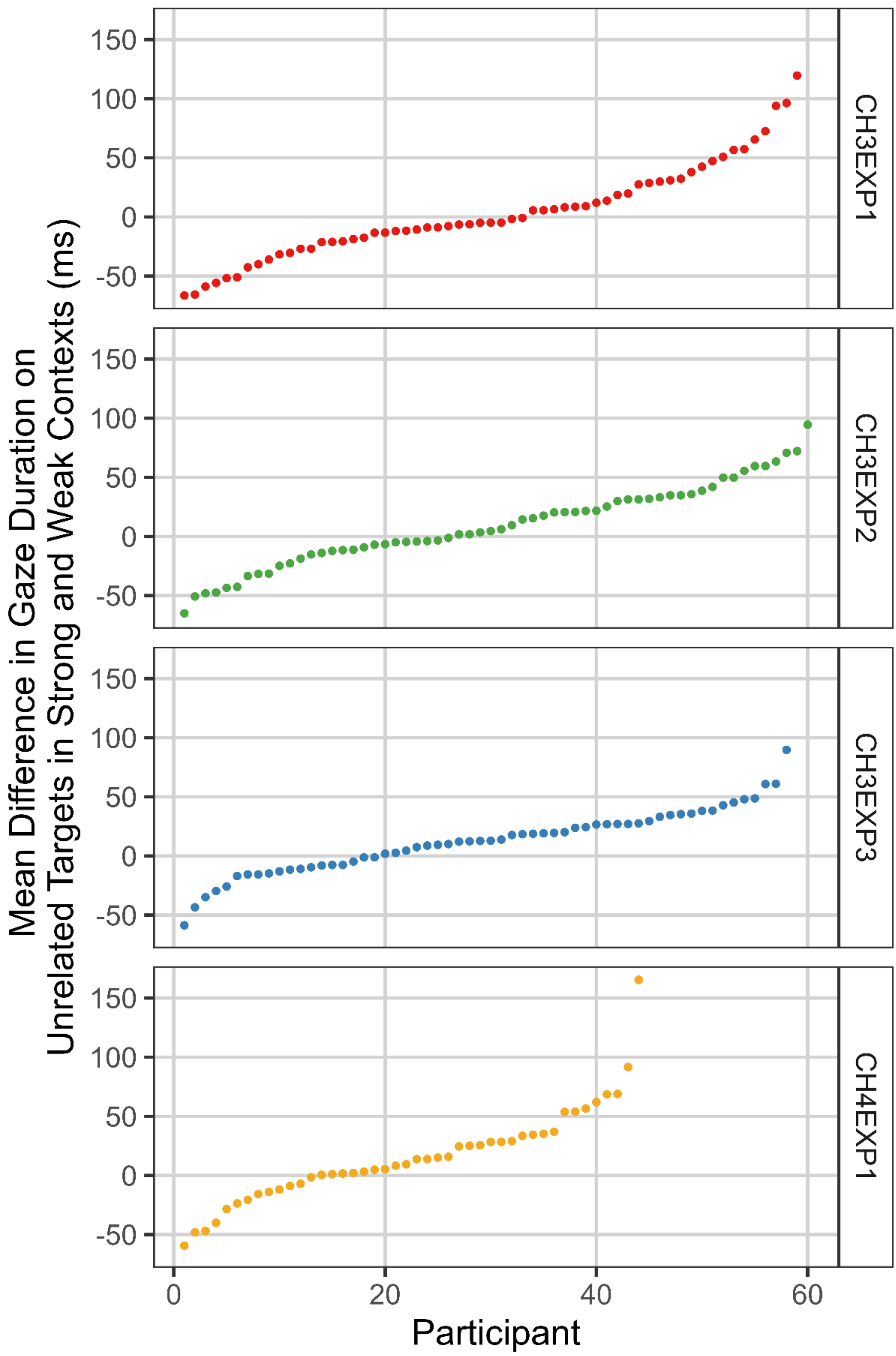

Figure 5.1 Mean difference in gaze duration on unrelated targets in strong and weak contexts for each participant in the eye-movement experiments using single sentence contexts. Positive mean differences reflect prediction error costs.

This variability in predictive processing is unsurprising when considering the fact that anticipatory prediction has been shown to be sensitive to a variety of factors that go beyond the linguistic content presented (see Huettig & Mani, 2016 for a review). For example, certain task demands and goals have been shown to increase the extent to which readers rely on lexical prediction, including explicit instructions to predict passage-final words and report the accuracy of these predictions (Brothers et al., 2015; Brothers et al., 2017; Dave et al., 2018), and tasks that involve proofreading for semantically incongruent words compared to reading for comprehension (Andrews et al., 2022; Schotter et al., 2014). As such, readers in the current experiments that revealed evidence of prediction error costs may have also generated stronger lexical predictions about upcoming text because, for reasons that remain unclear, it was beneficial or necessary for their current task demands and goals.

Another factor that has been shown to influence readers' use of lexical prediction is individual differences in language experience, with higher literacy skills linked to greater predictive abilities (e.g., Favier et al., 2021; Mishra et al., 2012; Ng et al., 2017). As such, the current samples of readers that showed evidence of processing costs for unexpected input may have also formed stronger lexical predictions because of their prior levels of language experience. Supplementary analyses tested this idea by examining the relationship between readers' gaze duration on unrelated unpredictable completions in strongly and weakly constraining contexts and their overall reading proficiency which was indexed by aggregating their performance on the *vocabulary* and *reading comprehension* subtests of the half-timed version of the Nelson-Denny Reading Test (Andrews et al., 2020; Brown et al., 1993).[4] There was no correlation between reading proficiency and the size of readers' mean difference in gaze duration on unrelated targets in strong and weak contexts, (*r*=-.09, *p*=.20), implying that reading proficiency was not associated with whether or not readers generated lexical predictions. However, as illustrated in Figure 5.2, there was a weak negative correlation between reading proficiency and the size of readers' prediction cost on gaze duration, as indexed by positive mean differences on unrelated targets in strong and weak contexts, (*r*=-.22, *p*=.01). This suggests that, among readers who committed to a lexical prediction, poorer readers were more disrupted by the presentation of unexpected input that disconfirmed a more expected completion. For these same individuals though, there was no correlation between reading proficiency and the size of readers' prediction benefit on gaze duration, as indexed by mean differences on predictable targets in strong and weak contexts, (*r*=-.02, *p*=.86). Additionally, there was no indication that reading speed, as indexed by the *reading rate* subtest of the Nelson-Denny Reading Test (Brown et al., 1993), correlated with the size of readers' mean difference on unrelated targets in strong and weak contexts, (*r*=.03, *p*=.65), or with the size of readers' prediction cost, (*r*=-.16, *p*=.08), on gaze duration, suggesting that the longer processing times on these targets under conditions of strong constraint were not because individuals were slower readers overall.[5] Thus, to the extent that these limited findings are interpretable, they suggest that even if individual differences in language experience are not directly related to whether or not readers

[4] Mean performance was 83% (*SD*=11) on the vocabulary subtest and 49% (*SD*=14) on the reading comprehension subtest, which were moderately correlated, (*r*=.50).

[5] Supplementary analyses were based on the eye-movement experiments using single sentence contexts (i.e., all three experiments reported in Chapter 3, and Chapter 4's Experiment 1; *N*=221); however, none of the results changed when based on the three eye-movement experiments that revealed evidence of prediction error costs (*N*=162).

generate lexical predictions during online processing, they may play a role in how well readers deal with the consequences of making incorrect predictions.

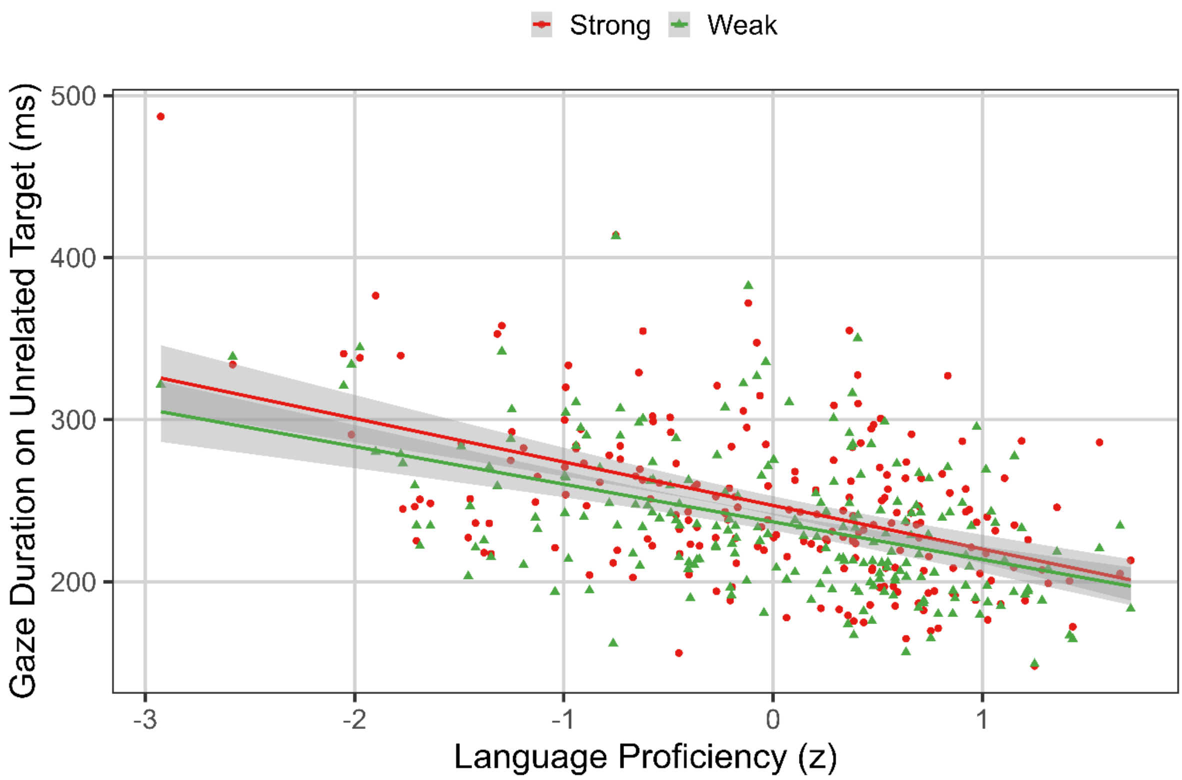

Figure 5.2 Mean gaze duration on unrelated targets in strong and weak contexts across levels of language proficiency.

More generally, another consideration that should be mentioned is that the present experiments had more statistical power than Frisson et al.'s (2017) study due to a larger number of participants and items per condition. There were 60 and 58 participants in Chapter 3's Experiment 2 and 3, respectively, compared to 48 in Frisson et al.'s experiment. There were also 25 and 38 items in each condition in Chapter 3's Experiment 2 and 3, respectively, and 22 items in each condition in Chapter 4's Experiment 1 compared to 20 items per condition in Frisson et al.'s experiment. Thus, observing costs of prediction error may also depend on an adequately powered experimental design to detect the relatively small and short-lived effects on early reading measures.

Finally, it should also be noted that while most eye-movement studies investigating predictability effects during reading have reported no evidence of prediction error costs (e.g., Andrews et al., 2022; Frisson et al., 2017; Luke & Christianson, 2016), a recent study by Cevoli et al. (2022) did find evidence of longer first fixation durations for unexpected input that replaced a more expected completion. Notably, their findings were derived from the Provo corpus – the same corpus of texts used in studies conducted by Luke and Christianson (2016) and Andrews et al. (2022) which reported *facilitatory* processing for unexpected completions that replaced high cloze continuations. The critical difference between these studies was the way in which predictability effects were operationalised – while the other two studies (Andrews et al., 2022; Luke & Christianson, 2016), like the current research, estimated predictability from cloze probability, Cevoli et al. used the metrics of surprisal and entropy derived from a language model which provide more fine-grained estimates of word predictability across the entire probability distribution. Although there are a number of limitations associated with using these information-theoretic metrics to estimate predictability (see Chapter 1 for a review), these findings provide further support for the idea that evidence of predictability costs may also depend on the methodological choices made by researchers.

To summarise, the current findings provide evidence of small, short-lived processing consequences on first-pass eye-movement measures when readers' predictions are disconfirmed by unexpected input. However, prediction error costs do not appear to depend only on the mismatch between the word expected in a constraining context and the input actually encountered. There is also a role for broader linguistic factors including the degree of semantic overlap between the mismatching inputs, the plausibility of stimuli in the broader linguistic environment, and the amount of context preceding the misprediction. More tentatively, there is also a potential role for non-linguistic factors including task demands and goals, individual differences in language experience and/or proficiency, and the methodological choices made by researchers; however, further research is clearly necessary to investigate these factors more systematically. What is evident from the present research though is that lexical prediction depends on a variety of linguistic and non-linguistic factors and is therefore not always an automatic strategy during real-time language comprehension.

5.2.2 What exactly do readers predict?

The question of whether the language processor makes use of prediction during online processing has typically focused on demonstrating evidence of *lexical prediction* which involves the activation of a specific lexical item in advance of its presentation (e.g., DeLong, Troyer, & Kutas, 2014b). This predictive process is assumed to yield processing benefits when readers' predictions turn out correct but processing costs when they turn out to be incorrect. As reviewed in the previous sections, the present experiments provided robust evidence of early and late processing benefits for readers' predictions that were confirmed by expected input. However, there was mixed evidence of the immediate processing costs that would be expected to accompany readers' predictions that were disconfirmed by less expected input. As such, it appears that while the language processor is capable of generating specific lexical predictions about upcoming text, it may not always rely on this predictive strategy during online processing.

More compelling evidence from the current research that readers may not engage in lexical prediction comes from the fact that the presence of a less expected competitor yielded *facilitatory* effects during online processing. Across all eye-movement experiments, unpredictable words that were semantically related to the best completion received processing benefits when presented in contexts that constrained towards a more predictable completion compared to those that did not. Although these processing benefits were observed more consistently on late reading measures including total fixation duration and the probability of regressions, suggesting that these items were easier to integrate due to their semantic overlap with the most expected completion, these processing benefits were also reported on the early reading measures of first fixation and gaze duration in Chapter 2 and skipping in Chapter 4 indicating that these items may have also been activated in advance of their presentation. While these first-pass effects could have been driven by spreading activation from the most predictable completion (Collins & Loftus, 1975; Neely, 1997), they could also reflect the partial preactivation of multiple lexical candidates based on the available semantic information (Andrews et al., 2022; Luke & Christianson, 2016). Indeed, Chapter 2 revealed that unpredictable words that were semantically *unrelated* to the best completion also received general processing facilitation across early and late measures when presented in any constraining context.

Thus, these eye-movement patterns indicate that prediction during real-time language comprehension does not only involve the activation of a single lexical candidate. Instead, as defined by *graded prediction*, it also involves the partial preactivation and rapid convergence of other types of information such as the morphosyntax, syntax, and semantics of upcoming words even if their full lexical identity cannot be predicted from the prior context (e.g., Brothers & Kuperberg, 2021; Federmeier, 2022; Luke & Christianson, 2016; Staub, 2015; Staub et al., 2015). This means that, as discussed in the previous section, the language processor is able to generate multiple lexical candidates for each upcoming word of a sentence, allowing processing benefits to arise across a range of contextual constraints including low cloze continuations. Moreover, because the language processor does not actively commit to any of these lexical candidates which could trigger suppression processes (Federmeier et al., 2007; Kutas, 1993; Ness & Meltzer-Asscher, 2018) or context-updating processes (Brothers et al., 2015; Brothers et al., 2020; DeLong et al., 2014b) when disconfirmed by less expected input, processing costs are also unlikely to arise in the event of misprediction. Although graded prediction may appear to operate independently of lexical prediction, these two prediction strategies could in fact unfold in succession as part of the same one-stage process, a possibility that is discussed in further detail later in this chapter.

5.2.3 Do all readers predict?

Evidence from the present research confirms that different populations of readers generate predictions about upcoming linguistic content before bottom-up input has even been encountered. Chapters 2 and 3 demonstrated that young readers made use of prediction during the online processing of sentence and passage contexts. More importantly, Chapter 4 revealed that older readers (60+ years) also relied on prediction and that their processing patterns were similar to a comparison sample of young readers (17-32 years) on both eye-movement and self-paced measures of reading. These findings are consistent with previous eye-movement studies that have revealed at least age-related equivalence in predictability effects during real-time language comprehension (see Zhang et al., 2022 for a review and meta-analysis).

The current findings therefore indicate that prediction processes do extend beyond skilled monolingual, young adults who are the typical population under investigation in psychological research. Moreover, they suggest that prediction processes remain relatively preserved across the lifespan despite the array of cognitive changes that usually accompany normal ageing. These include lower processing speed, reduced attention and executive control, and smaller working memory (see Verhaeghen, 2013 for a review) which could impact older readers’ ability to anticipate upcoming linguistic input. Instead, it appears that the language experience accumulated by older adults via reading over the course of their lifetime provides a buffer against these declines in cognitive functioning, allowing them to generate precise and fine-grained predictions like their younger counterparts (Payne et al., 2012; Ryskin et al., 2020).

Thus, all readers do appear to predict during real-time language comprehension given an adequate level of language experience and/or exposure. This aligns with evidence reviewed in Chapter 1 that suggests that readers with higher literacy skills show stronger predictive abilities than readers with lower literacy skills (e.g., Favier et al., 2021; Mishra et al., 2012; Ng et al., 2017). Even developing readers such as children (e.g., Borovsky et al., 2012; Mani & Huettig, 2012; 2014) and non-native adult speakers (e.g., Dussias et al., 2013; Hopp, 2013) demonstrate predictive abilities when they have some level of linguistic proficiency. However, at the same time, as discussed in the previous sections, the present research indicates that, even if all readers are capable of prediction, the influence of a range of linguistic and non-linguistic factors can also mediate their propensity to do so.

5.2.4 What is the impact of stimuli presentation method?

The final major empirical issue explored in the present thesis was whether differences in stimuli presentation method impact predictive processing. Chapter 4 which assessed older readers' use of prediction revealed consequences of misprediction on eye-movement measures during naturalistic reading. The critical finding was that there was also evidence of prediction error costs on response time measures during self-paced reading which uses an unnatural stimuli presentation format where words are presented one at a time at the readers' own pace. These comparable findings were taken to suggest that older readers do make use of similar prediction strategies during naturalistic and self-paced reading. Moreover, they also indicated that older readers' failure to recruit predictive strategies in previous ERP studies which typically use the RSVP paradigm (e.g., Federmeier et al., 2010; Wlotko et al., 2012) may not be due to the word-by-word presentation format which imposes constraints on key reading behaviours including skipping words, re-reading text, and extracting upcoming parafoveal information. Instead, the source of the age-related declines in predictive processing in ERP studies is more likely to be their fixed-pace presentation rate which removes older readers' control over the rate of input and typically displays each word for 200 ms with an interstimulus interval of 300 ms. These unnatural modifications may require older readers to allocate more resources to lower-level processes like word identification and/or lexical access instead of higher-level processes like anticipatory prediction.

More generally, while there was evidence of prediction error costs across both eye-movement and self-paced reading experiments reported in Chapter 4, evidence of the classic predictability benefits was only observable in the former experiment. This discrepancy suggests that the self-paced reading paradigm may have created an upper limit on older readers' ability to speed up their reading times when the word presented matched their expectations, either because of the cognitive demands of the word-by-word presentation format or the physical limitations of making continuous button-presses to progress through the sentence. Given that older readers were able to slow down their reading times in response to prediction failure, these limitations of the self-paced reading paradigm do not appear to have impacted their ability to form predictions about upcoming text. Instead, this unnatural stimuli presentation and/or response method only affected whether they were able to subsequently use these predictions to facilitate online processing.

These reading patterns on both predictable and unpredictable completions across both methodologies were also evident in a comparison sample of younger readers, although evidence of prediction error costs was delayed and emerged only on the word following unexpected input. Given that previous ERP studies of young readers have found that they make use of prediction during RSVP reading (see Kutas & Federmeier, 2011 for a review), the current findings provide further support for the idea that young readers may be minimally impacted by unnatural stimuli presentation methods compared to their older counterparts. Indeed, a number of ERP studies have shown that younger readers engage in anticipatory prediction even when words appear at slower presentation rates that do not simulate naturalistic reading (e.g., Dambacher et al., 2012; Ito et al., 2016; Wlotko & Federmeier, 2015). Taken together then, the present findings suggest that stimuli presentation method does have some impact on how readers make use of prediction processes, as well as reading comprehension processes more generally, although these effects appear to be more pronounced in older compared to younger readers.

5.2.5 Is the language processor a "prediction machine"?

These empirical issues that have been explored throughout the current thesis provide support for the idea that different groups of readers predict upcoming linguistic content even before bottom-up input has been encountered. The major contribution of the present findings is that prediction does not always entail the activation of a specific lexical item (e.g., DeLong et al., 2014b). Instead, it can also involve the partial preactivation of upcoming words in terms of their morphosyntactic, syntactic, and semantic features even if the precise word form cannot be predicted from the prior context (e.g., Brothers & Kuperberg, 2021; Federmeier, 2022; Luke & Christianson, 2016; Staub, 2015; Staub et al., 2015). As such, processing benefits for the highest cloze continuation of a given context can extend to more weakly activated candidates especially when semantically related, and processing costs for all unexpected input can be minimised. Importantly, the circumstances under which readers generate either or both lexical and graded predictions depend not only on cloze probability but also on a variety of factors. These include linguistic factors, such as the nature of prior contextual constraint and information in the broader linguistic environment, and non-linguistic factors such as task demands and goals, individual differences in language experience and/or proficiency, and stimuli presentation method. Thus, anticipatory prediction appears to play an important, but flexible, role in real-time language comprehension consistent with the idea that the language processor is a “prediction machine” as posited by general predictive accounts of cognitive functioning (Clark, 2013; Friston, 2010).

5.3 Implications for theories of prediction

The present findings are compatible with the growing realisation in the literature that prediction during real-time language comprehension is not a simple one-stage process whereby readers generate the best prediction they can manage about upcoming words given the prior context. Instead, prediction appears to be a dynamic process that involves the preactivation of multiple sources of information over different time courses (e.g., Burnsky et al., 2022; Federmeier, 2022; Huettig, 2015; Kuperberg, 2007; Pickering & Gambi, 2018; Szewczyk & Federmeier, 2022).

For example, Federmeier (2022) posits that language comprehension comprises two processing modes: *connecting* and *considering*. The first process, *connecting*, reflects the passive stage of language comprehension during which readers link incoming linguistic input with long-term semantic memory to activate information in a graded and parallel manner. Importantly, the language processor does not commit to any of these representations, allowing it to remain flexible enough to deal with uncertain linguistic environments, low probability events, and errors. The second phase, *connecting*, reflects the active stage of language comprehension during which readers make use of comprehension strategies like prediction to transform their initial graded semantic representations into more stable multidimensional representations. In other words, readers move away from simply understanding language towards being able to act upon it in task- and goal-specific ways. Importantly, according to Federmeier, this second stage is non-obligatory because it can depend on resources that are not always available to all readers or under all circumstances (e.g., age-related, individual differences, and hemispheric factors).

Pickering and Gambi (2018) similarly propose a two-systems account of prediction. Under this account, readers engage in an initial processing mechanism, *prediction-by-association*, which is characterised by spreading activation between related concepts (Collins & Loftus, 1975; Neely, 1997). However, because associative predictions tend to be short-lived and error prone (e.g., Kukona et al., 2011; McNamara, 2005), readers also engage in a second processing mechanism, *prediction-by-production*, which involves using the production system to covertly anticipate upcoming linguistic content (see also Dell & Chang, 2013; Huettig, 2015; Pickering & Garrod, 2004; 2013). Specifically, readers first covertly imitate what they have comprehended so far from the linguistic context, potentially using representations already activated by the prediction-by-association mechanism. They then derive the underlying intention based on shared background knowledge and other linguistic and non-linguistic information. Finally, by running the derived intention through their production system, readers are able to construct representations of their predictions. Notably, this prediction-by-production mechanism is also optional for real-time language comprehension because it can depend on readers having sufficient time (e.g., slower presentation rates, Dambacher et al., 2012; Ito et al., 2016; Wlotko & Federmeier, 2015) and cognitive resources (e.g., Huettig & Janse, 2016; Ito et al., 2018) to carry out all three stages of production.

Thus, across these different accounts, prediction is conceptualised as a dual-systems process during which an initial passive, but obligatory, stage of preactivation prepares the language processor for a subsequent active, but optional, stage of prediction. As such, at any given point in a sentence, readers may have either preactivated general semantic information or activated a more specific word form depending on their stage of processing. The current findings that readers generate both lexical and graded predictions about upcoming text provide further support for this notion that partly distinct, but interactive, processing modes contribute to real-time language comprehension. That is, graded predictions which are passively activated as part of the natural reading process have the potential to transform into lexical predictions given the right combination of linguistic and non-linguistic factors.

5.4 Is the language processor also an "integration machine"?

While the present research demonstrates that *forward-looking prediction* is an important characteristic of real-time language comprehension, there is also substantial evidence that the language processor engages in *backward-looking integration* during reading. Consistent with previous eye-movement studies investigating predictability effects (e.g., Andrews et al., 2022; Frisson et al., 2017; Luke & Christianson, 2016), predictable completions across all eye-movement experiments received processing benefits on late reading measures including total fixation duration and the probability of regressions in contexts that were constraining compared to non-constraining, reflecting the efficient postlexical integration of contextually appropriate words. These late integration benefits also extended to unpredictable completions in strongly constraining contexts, regardless of their semantic relatedness, suggesting that these items were also easier to integrate into semantically rich discourse contexts.

This idea that language comprehension is supported by integration processes is by no means new. Early theories of language comprehension placed a heavy emphasis on integration – the linking of new ideas and concepts to what was already known by the comprehender including general world knowledge and prior text information (Kintsch, 1988; Kintsch & van Dijk, 1978; Myers & O'Brien, 1998; O'Brien & Myers, 1999). For example, Kintsch's (1988) influential construction-integration model posited that text comprehension involved generating a propositional textbase using bottom-up input and the comprehender's knowledge base which was then integrated into an unfolding discourse representation via a spreading activation process. In the event that the current sentence being processed could not be integrated, readers were assumed to make backward inferences which involved looking back to previously processed text to determine a connection with the current sentence (Just & Carpenter, 1978; Singer & Ferreira, 1983). For example, understanding the second half of this sequence, "*He quickly threw his report in the fire. The ashes floated up the chimney"*, requires readers to make an inference that the report had burnt up in the first place (Singer & Ferreira, 1983).

Although current theories of language comprehension are dominated by the notion of prediction (e.g., Kuperberg & Jaeger, 2016; Lupyan & Clark, 2015; Pickering & Gambi, 2018), the past few years has seen an increasing emphasis on the potential concurrent role of integration (e.g., Brouwer et al., 2021; Ferreira & Chantavarin, 2018; Onnis et al., 2022). For example, Ferreira and Chantavarin (2018) reconciled these two mechanisms by positing that integration laid the groundwork for prediction. Specifically, they hypothesised that the integration of input with prior context and knowledge leads to the creation of rich semantic representations. It is then these representations of preceding discourse that prepare readers to receive new information and therefore make predictions about upcoming text. In other words, language comprehension involves the continuous updating of discourse representations through both bottom-up integration and top-down expectations.

Empirical evidence that real-time language comprehension involves integration comes from a recent study by Onnis et al. (2022) which assessed readers' sensitivity to prediction and integration in an eye-tracking reading task and two self-paced reading tasks. Using trigram probabilities to estimate prediction and integration, they found that backward conditional probability (i.e., the likelihood of prior context given the current word being processed), which was used to index integration, reduced reading effort on the current word more than forward conditional probability (i.e., the likelihood of the current word being processed given the prior context), which was used to index prediction. Although it remains debatable whether forward and backward conditional probabilities reflect true measures of prediction and integration, which can be difficult to disentangle empirically, these findings suggest that, while the role of prediction is important in real-time language comprehension, there may be too little emphasis on the complementary role of integration.

Thus, the findings of the present research provide further support for the case that future models of language comprehension should account for the role of backward-looking integration. In other words, the language processor may be as much of an "integration machine" as it is a "prediction machine" (Onnis et al., 2022).

5.5 Implications for models of eye-movement control

The robust predictability effects observed in the present research are consistent with the architectures of current models of eye-movement control such as E-Z Reader (Reichle et al., 1998; Reichle et al., 2009; Reichle et al., 2012) and SWIFT (Engbert et al., 2002; Engbert et al., 2005) which posit that a word's predictability guides where and when readers move their eyes. In particular, the fact that predictability effects emerge across the entire time course of processing reflects the influence of word predictability on the completion of both prelexical and lexical stages of processing.

However, the reliable effects of integration also observed across the present research suggest that current models of eye-movement control should be extended to include additional assumptions about postlexical stages of processing. E-Z Reader 10 (Reichle et al., 2009) introduced a postlexical integration stage (*I*) to account for the influence of integration on readers' eye movements. During this stage, postlexical integration difficulty causes the cancellation of planned forward saccades and the programming of regressions back to the source of comprehension difficulty. However, E-Z Reader does not otherwise make any deep assumptions about *how* readers identify or repair postlexical integration failure. Thus, a more detailed account of the information and processes underlying integration will contribute to understanding the full range of complexities underlying readers' eye movements during real-time language comprehension. It may also help resolve the long-standing difficulty of disentangling the effects of prediction from that of integration. More generally, it remains to be seen how other models of eye-movement control including those that assume parallel lexical processing of multiple words (e.g., SWIFT) would handle the distinction between lexical and postlexical stages of processing.

5.6 Limitations and future directions

The current thesis has presented a large body of evidence that the language processor generates predictions about upcoming text ahead of time. There are several potential directions for future research that could further clarify how readers make use of prediction during real-time language comprehension.

Firstly, it remains an open question as to how exactly graded predictions transform into lexical predictions during real-time language comprehension. The preliminary conclusion that has been drawn from the present research is that readers' use of either or both lexical and graded predictions depends on the interplay between linguistic factors such as cloze probability, the nature of prior contextual constraint, and the information in the broader linguistic environment, and non-linguistic factors such as task demands and goals, individual differences in language experience and/or proficiency, and stimuli presentation method. While linguistic factors such as those just mentioned have been investigated relatively extensively in the literature; as discussed earlier in this chapter, the impact of non-linguistic factors on prediction has received far less attention. Indeed, in addition to the potential roles of the non-linguistic factors already discussed, predictive processing may also depend on motivational states (Payne & Silcox, 2019), and individual differences in cognitive resources (e.g., Huettig & Janse, 2016; Ito et al., 2018). Thus, future research should investigate non-linguistic factors more systematically to determine whether and how they work in conjunction with linguistic factors to encourage different types of anticipatory prediction during online processing.

Secondly, while the present research has demonstrated mixed evidence of prediction error costs on eye-movement measures during naturalistic reading, studies using ERPs have revealed consistent evidence of neural processing costs for unexpected input in the form of a late frontal positivity (see Van Petten & Luka, 2012 for a review). The most obvious difference between these paradigms is that ERP studies typically present stimuli in a RSVP format which does not reflect normal reading in many aspects – readers are unable to make use of natural eye-movement behaviour including skipping words, re-reading text, and extracting upcoming information from the parafovea. As such, the findings of ERP studies that use RSVP reading may not reflect the genuine online processes underlying normal reading. Another possible difference between these paradigms is that their online processing measures capture different underlying functions. The late frontal positivity that emerges in response to disconfirmed predictions occurs 500-1000 ms poststimulus onset which is relatively late in the time course of normal reading given that the typical fixation lasts 200-250 ms. Moreover, this ERP waveform has also been observed in response to unexpected input that appears in weakly to moderately constraining contexts where the most expected completion is unlikely to have been activated and therefore disconfirmed (e.g., Brothers et al., 2015; Federmeier & Kutas, 2005; Freunberger & Roehm, 2016; Thornhill & Van Petten, 2012; Zirnstein et al., 2018). As such, it is possible that the late frontal positivity observed in ERP studies reflects different processes (e.g., suppression; Federmeier et al., 2007; Kutas, 1993; Ness & Meltzer-Asscher, 2018; context-updating; Brothers et al., 2015; Brothers et al., 2020; DeLong et al., 2014b) for which there may be no reliable behavioural correlates. While the current research explored the impact of different stimuli presentation methods on predictive processing by comparing eye-movement and self-paced reading records, it is clear that further research using neural recording methods is necessary to address this issue. One potential avenue is by investigating predictability effects via the co-registration paradigm which simultaneously records eye movements and EEG (see Dimigen et al., 2011; Himmelstoss et al., 2020 for reviews). As mentioned briefly in Chapter 1, the few studies to date to have explored the nature of predictability effects using co-registration have revealed evidence of the classic predictability benefits for expected input across both methodologies (e.g., Bianchi et al., 2023; Burnsky et al., 2022; Kretzschmar et al., 2015). However, none of these studies examined the consequences of misprediction by comparing unexpected input in strongly and weakly constraining contexts. As such, future research using co-registration should focus on investigating predictability benefits and costs within a more controlled experimental design in order to provide further insights into the source of the discrepancy in predictability effects between eye-movement and ERP literatures.

Thirdly, it remains an ongoing debate as to which eye-tracking reading measures can be taken to index genuine prediction processes. Although it is assumed in the literature that early reading measures including skipping and first fixation duration reflect early stages of processing (e.g., prediction; Vasishth et al., 2013) while late reading measures including total reading time and regressions reflect late stages of processing (e.g., integration; Clifton et al., 2007), this distinction has received little empirical investigation and therefore may not be as robust as most researchers assume. One reason for this uncertainty is that early and late reading measures are generally highly correlated, so processing effects on late reading measures could reflect the impact of early stages of processing and vice versa (see Veldre et al., 2020 for E-Z Reader simulations showing that skipping effects can be due to postlexical integration). Another reason is that early reading measures could also reflect the impact of spill-over processing from preceding words, which could weaken the assumption that they reflect prediction processes especially if the precritical region has not been kept identical across experimental conditions. As such, while early and late reading measures have the potential to inform different stages of processing, it is important for future research to provide further converging evidence of these mappings by using different methodologies.

Finally, it should be noted that almost all evidence of predictability effects across the current and previous research comes from prediction-encouraging experimental set-ups. That is, the stimuli presented to readers in studies of reading have been designed to be highly constraining such that only a single word can be predicted. As such, these studies of reading may encourage readers to engage in prediction processes to a greater degree than they would during normal reading (Huettig, 2015). Indeed, predictable words are relatively rare in naturally occurring texts in which contexts are typically only weakly to moderately constraining (e.g., Luke & Christianson, 2016). One way in which researchers could address this limitation is by investigating predictability effects in more naturalistic texts such as text corpora (e.g., Andrews et al., 2022; Cevoli et al., 2022; Kliegl et al., 2004; Luke & Christianson, 2016). However, text corpora also have their disadvantages because of the lack of experimental control –words may vary on multiple uncontrolled dimensions that influence the predictor of interest (Angele et al., 2015; Rayner et al., 2007), which could necessitate additional statistical control (e.g., Bianchi et al., 2019). Another possible way is by investigating predictability effects using only low to medium cloze continuations. If prediction is pervasive during real-time language comprehension, there should be evidence of predictability effects across the entire probability distribution. However, given the difficulties of estimating predictability effects at the lower end of the probability distribution using cloze probability, future research may need to use information-theoretic metrics like surprisal and entropy to explore this issue in further detail. Demonstrating that predictability effects arise across a range of different experimental set-ups is necessary to confirm the widespread role of anticipatory prediction during real-time language comprehension.

5.7 Final conclusions

Successful real-time language comprehension is a complex process that unfolds within hundreds of milliseconds with little conscious effort. One explanation for how readers are able to achieve this feat so quickly and effortlessly lies in the idea of prediction. The current thesis provides further compelling evidence that prediction plays an important, but flexible, role during online language processing for different groups of readers, consistent with the idea that the brain functions as a "prediction machine". The major contribution of the present research is the finding that prediction does not just involve the activation of specific lexical candidates in accordance with their cloze probability, which appears to be an optional strategy that depends on the influence of a range of linguistic and non-linguistic factors. Instead, prediction also involves the passive activation of general morphosyntactic, syntactic, and semantic information about upcoming words, leading to the partial preactivation of a broad range of potential lexical candidates. These findings therefore enhance theories of prediction by providing strong support for the growing realisation that prediction involves two distinct, but interactive, processing mechanisms during real-time language comprehension – an initial passive, but obligatory, stage of preactivation that prepares the language processor for a subsequent active, but optional, stage of comprehension where it might just be able to predict what comes next.

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Appendix A: Stimulus Materials

Sentences used in Chapter 2 Experiment

For each item set, the constraint for the sentence passages is in the order: (a) Global+Local context, (b) Global Only context, (c) Local Only context, and (d) Weak context. The target words are bolded in the order: predictable target, unpredictable related target, and unpredictable unrelated target.

1. (a) The family wanted to leave Mexico for a better life in America. They travelled north for days towards the area that divided the two countries. The immigrants left Mexico by crossing the **border/roadblock/waterfall** into the United States.
   (b) The family wanted to leave Mexico for a better life in America. They travelled north for days towards the area that divided the two countries. At last, the family arrived at the **border/roadblock/waterfall** which led into California.
   (c) The sun was shining brightly on the first day of the calendar year. There wasn't a single cloud seen hanging in the clear blue sky. The immigrants left Mexico by crossing the **border/roadblock/waterfall** into the United States.
   (d) The sun was shining brightly on the first day of the calendar year. There wasn't a single cloud seen hanging in the clear blue sky. At last, the family arrived at the **border/roadblock/waterfall** which led into California.
2. (a) The waiter had to stir the thick brown sauce before he could add it to the roast. It was still too lumpy. The roast beef was served with the **thick gravy/soup/serviette** a few moments later.
   (b) The waiter had to stir the thick brown sauce before he could add it to the roast. It was still too lumpy. Finally, he was able to add the **gravy/soup/serviette** to the plate and serve it.
   (c) Mitch was a bit unhappy with how his hard work was being presented. He tried to quickly adjust some parts of it. The roast beef was served with the thick **gravy/soup/serviette** a few moments later.
   (d) Mitch was a bit unhappy with how his hard work was being presented. He tried to quickly adjust some parts of it. Finally, he was able to add the **gravy/soup/serviette** to the plate and serve it.
3. (a) Sophie needed to wet the far side of the yard. She uncoiled the tube and turned on the tap. She sprayed the seedlings using the garden **hose/pipe/mitts** that belonged to her nephew.
   (b) Sophie needed to wet the far side of the yard. She uncoiled the tube and turned on the tap. It was her first time using the **hose/pipe/mitts** that she got for Christmas.
   (c) The afterglow of the pink sunset was fading into a night sky. Ella was excited about her final chore. She sprayed the seedlings using the garden **hose/pipe/mitts** that belonged to her nephew.

(d) The afterglow of the pink sunset was fading into a night sky. Ella was excited about her final chore. It was her first time using the **hose/pipe/mitts** that she got for Christmas.

4. (a) Climbing up Mount Whitney was beautiful but challenging. Julia was looking forward to what she knew awaited her at the top. Finally, she stood at the summit and admired the breathtaking **view/scenery/birds** that surrounded her.
(b) Climbing up Mount Whitney was beautiful but challenging. Julia was looking forward to what she knew awaited her at the top. But her imagination did not prepare her for the magnificent **view/scenery/birds** all around her.
(c) The final challenge was formidable but Julia felt optimistic. She had spent a long time preparing for this day to arrive. Finally, she stood at the summit and admired the breathtaking **view/scenery/birds** that surrounded her.
(d) The final challenge was formidable but Julia felt optimistic. She had spent a long time preparing for this day to arrive. But her imagination did not prepare her for the magnificent **view/scenery/birds** all around her.
5. (a) Someone armed was on the run. The police warned that he could shoot if provoked. The criminal with the loaded **gun/pistol/trolley** of ammunition was just down the road.
(b) Someone armed was on the run. The police warned that he could shoot if provoked. The young individual with the **gun/pistol/trolley** filled with bullets was somewhere close by.
(c) Amber finished watching the news broadcast. She picked up her phone to contact her parents. The criminal with the loaded **gun/pistol/trolley** of ammunition was just down the road.
(d) Amber finished watching the news broadcast. She picked up her phone to contact her parents. The young individual with the **gun/pistol/trolley** filled with bullets was somewhere close by.
6. (a) The man caught a whiff of the woman's sweet floral scent as she walked by. He could smell hints of vanilla and lavender. The scent of her expensive **perfume/fragrance/detergent** was quite strong.
(b) The man caught a whiff of the woman's sweet floral scent as she walked by. He could smell hints of vanilla and lavender. He somehow recognised the cheap **perfume/fragrance/detergent** that she used.
(c) The man counted his losses at the table. He couldn't help but take a glance at the person who had somehow beaten him. The scent of her expensive **perfume/fragrance/detergent** was quite strong.
(d) The man counted his losses at the table. He couldn't help but take a glance at the person who had somehow beaten him. He somehow recognised the cheap **perfume/fragrance/detergent** that she used.
7. (a) The man wearing a balaclava wasn't kidding about blowing up the aircraft. Everyone could see what he had in his backpack. The terrorist threatened to detonate the **bomb/explosive/fireworks** if he wasn't obeyed.
(b) The man wearing a balaclava wasn't kidding about blowing up the aircraft. Everyone could see what he had in his backpack. He had shown them his homemade **bomb/explosive/fireworks** which could kill them.

(c) The man provided Susanna and her sister with some clear instructions to follow. They couldn't help but hesitate for a moment. The terrorist threatened to detonate the **bomb/explosive/fireworks** if he wasn't obeyed.
(d) The man provided Susanna and her sister with some clear instructions to follow. They couldn't help but hesitate for a moment. He had shown them his homemade **bomb/explosive/fireworks** which could kill them.

8. (a) The boy's palms were sticky from building the model airplane. There were so many little pieces that he had to join together. He stuck on the final piece of wood with some **glue/paste/effort** and proudly admired his work.
(b) The boy's palms were sticky from building the model airplane. There were so many little pieces that he had to join together. The whole project required him to use a lot of **glue/paste/effort** and took until almost midnight.
(c) The little boy followed the final part of the tutorial video carefully. He didn't want to mess up and start everything again. He stuck on the final piece of wood with some **glue/paste/effort** and proudly admired his work.
(d) The little boy followed the final part of the tutorial video carefully. He didn't want to mess up and start everything again. The whole project required him to use a lot of **glue/paste/effort** and took until almost midnight.
9. (a) The young star wanted to know if he had been nominated for an Oscar. He had worked hard on his last role. Henry received an Oscar nomination for best **actor/director/hairdresser** to his absolute delight.
(b) The young star wanted to know if he had been nominated for an Oscar. He had worked hard on his last role. He wanted to be recognised as a good **actor/director/hairdresser** amongst his fellow peers.
(c) Henry was fixated on the television screen mounted on the wall. He did not want to miss any part of the broadcast. Henry received an Oscar nomination for best **actor/director/hairdresser** to his absolute delight.
(d) Henry was fixated on the television screen mounted on the wall. He did not want to miss any part of the broadcast. He wanted to be recognised as a good **actor/director/hairdresser** amongst his fellow peers.
10. (a) Santa was grateful for his green and red clad helpers. They helped him maintain the North Pole all year round. All the toys in Santa's workshop were made by the **elves/dwarves/widows** who were very hard-working.
(b) Santa was grateful for his green and red clad helpers. They helped him maintain the North Pole all year round. He knew that he would be lost without all the **elves/dwarves/widows** who worked for him nonstop.
(c) The only thing Frank had to do was ensure things ran smoothly. Otherwise, he didn't have much else to do. All the toys in Santa's workshop were made by the **elves/dwarves/widows** who were very hard-working.
(d) The only thing Frank had to do was ensure things ran smoothly. Otherwise, he didn't have much else to do. He knew that he would be lost without all the **elves/dwarves/widows** who worked for him nonstop.
11. (a) The task force had already come up with several good proposals. They continued to rack their brains for some more. They brainstormed until they were out of **ideas/answers/biscuits** before taking a break.

(b) The task force had already come up with several good proposals. They continued to rack their brains for some more. But they were completely out of **ideas/answers/biscuits** and decided to give up.
(c) The young husband and wife were almost free to leave. They stared at the final obstacle in front of them. They brainstormed until they were out of **ideas/answers/biscuits** before taking a break.
(d) The young husband and wife were almost free to leave. They stared at the final obstacle in front of them. But they were completely out of **ideas/answers/biscuits** and decided to give up.

12. (a) The musician played the keyboard quite rigidly. It looked like she was injured. The stiffness in the pianist's right **hand/thumb/bracelet** was slowing her down.
(b) The musician played the keyboard quite rigidly. It looked like she was injured. Unfortunately, the problem with her **hand/thumb/bracelet** was too obvious.
(c) Louise groaned as she sat through the session. She ordered everyone to stop. The stiffness in the pianist's right **hand/thumb/bracelet** was slowing her down.
(d) Louise groaned as she sat through the session. She ordered everyone to stop. Unfortunately, the problem with her **hand/thumb/bracelet** was too obvious.
13. (a) The food critic was excited about eating at the hotel restaurant. He was friends with the head of the kitchen. The main course prepared by the world-renowned **chef/cook/photographer** exceeded all his expectations.
(b) The food critic was excited about eating at the hotel restaurant. He was friends with the head of the kitchen. Afterwards, he went to thank the **chef/cook/photographer** for his outstanding work.
(c) The night was finally drawing to a close. Carlos had enjoyed it more than he dared to admit to himself. The main course prepared by the world-renowned **chef/cook/photographer** exceeded all his expectations.
(d) The night was finally drawing to a close. Carlos had enjoyed it more than he dared to admit to himself. Afterwards, he went to thank the **chef/cook/photographer** for his outstanding work.
14. (a) Zoe's shirt was full of wrinkles that had to be removed. She needed a flat heated tool to smooth them out. She pressed her creased shirt with a warm **iron/steamer/skillet** before putting it on.
(b) Zoe's shirt was full of wrinkles that had to be removed. She needed a flat heated tool to smooth them out. She looked in the cupboard for her mum's **iron/steamer/skillet** that would do the job.
(c) It was nearly time for Zoe's online job interview with the prestigious firm. She just had one last thing to do. She pressed her creased shirt with a warm **iron/steamer/skillet** before putting it on.
(d) It was nearly time for Zoe's online job interview with the prestigious firm. She just had one last thing to do. She looked in the cupboard for her mum's **iron/steamer/skillet** that would do the job.
15. (a) The little girl was scolded for eating her sundae with her fingers. Her father pointed to her cutlery. She ate her sundae with a **spoon/fork/cherry** in a more sensible manner.
(b) The little girl was scolded for eating her sundae with her fingers. Her father pointed to her cutlery. She paused before picking up the **spoon/fork/cherry** on the plate next to her.

(c) Katherine wanted to make her father proud. She wanted to prove to him that she was grown up. She ate her sundae with a **spoon/fork/cherry** in a more sensible manner.
(d) Katherine wanted to make her father proud. She wanted to prove to him that she was grown up. She paused before picking up the **spoon/fork/cherry** on the plate next to her.

16. (a) Ian worried about getting a puncture while driving. He didn't want to be stranded in the middle of nowhere. In the car boot, he always kept a spare **tyre/wheel/stool** just in case he needed it.
(b) Ian worried about getting a puncture while driving. He didn't want to be stranded in the middle of nowhere. He always knew to keep an extra **tyre/wheel/stool** in the back of his ute.
(c) Craig swore out loud as soon as he realised what he had done. Fortunately, he had a temporary solution. In the car boot, he always kept a spare **tyre/wheel/stool** just in case he needed it.
(d) Craig swore out loud as soon as he realised what he had done. Fortunately, he had a temporary solution. He always knew to keep an extra **tyre/wheel/stool** in the back of his ute.
17. (a) Maria was conscious about saving electricity. It was constantly dark in her house. She always dimmed the **lights/lamps/computers** if she used them.
(b) Maria was conscious about saving electricity. It was constantly dark in her house. She rarely used the **lights/lamps/computers** unless absolutely necessary.
(c) Vincent was proud of his child. She had finally learned some good habits. She always dimmed the **lights/lamps/computers** if she used them.
(d) Vincent was proud of his child. She had finally learned some good habits. She rarely used the **lights/lamps/computers** unless absolutely necessary.
18. (a) Anne's dog loved to sit and gnaw away at anything hard. He hated when anyone took away whatever he was chewing. The dog began to bury his **bone/stick/sock** away so that it could not be stolen.
(b) Anne's dog loved to sit and gnaw away at anything hard. He hated when anyone took away whatever he was chewing. He decided to hide away his **bone/stick/sock** so that no one could find it.
(c) The front door of the house creaked open before slamming shut loudly. The little boy was finally back home from school. The dog began to bury his **bone/stick/sock** away so that it could not be stolen.
(d) The front door of the house creaked open before slamming shut loudly. The little boy was finally back home from school. He decided to hide away his **bone/stick/sock** so that no one could find it.
19. (a) Ted was scared of black hairy creatures with lots of legs. He hated how fast they could crawl around. He screamed when he saw the black hairy **spider/caterpillar/crab** appear out of nowhere.
(b) Ted was scared of black hairy creatures with lots of legs. He hated how fast they could crawl around. He stepped back when he saw the **spider/caterpillar/crab** appear out of nowhere.
(c) Bill placed vines at the base of the wooden poles. He hoped they would create shade as they grew. He screamed when he saw the black hairy **spider/caterpillar/crab** appear out of nowhere.

(d) Bill placed vines at the base of the wooden poles. He hoped they would create shade as they grew. He stepped back when he saw the **spider/caterpillar/crab** appear out of nowhere.

20. (a) The pollen was triggering Lea's hayfever allergies. She could not stop sneezing and sniffling. Her nose began to run again so she reached for another **tissue/napkin/aspirin** in her pocket.
    (b) The pollen was triggering Lea's hayfever allergies. She could not stop sneezing and sniffling. She apologised to the people nearby as she reached for the **tissue/napkin/aspirin** on the table.
    (c) Juliana finally appeared in the cafeteria. She had made a pitstop along the way. Her nose began to run again so she reached for another **tissue/napkin/aspirin** in her pocket.
    (d) Juliana finally appeared in the cafeteria. She had made a pitstop along the way. She apologised to the people nearby as she reached for the **tissue/napkin/aspirin** on the table.
21. (a) My son's loud bulldog kept me up all of last night. The ferocious thunderstorm was making it anxious. The loud dog wouldn't stop **barking/growling/sprinting** out the back door when thunder struck.
    (b) My son's loud bulldog kept me up all of last night. The ferocious thunderstorm was making it anxious. All I could hear was constant **barking/growling/sprinting** near the back door of the house.
    (c) I lay down the beanie that I was crocheting with some exasperation. I was struggling to keep going. The loud dog wouldn't stop **barking/growling/sprinting** out the back door when thunder struck.
    (d) I lay down the beanie that I was crocheting with some exasperation. I was struggling to keep going. All I could hear was constant **barking/growling/sprinting** near the back door of the house.
22. (a) The recital in the hall drew a large audience. The instrument's black and white keys had even been polished. The pianist sat down in front of the **piano/organ/camera** and began to play.
    (b) The recital in the hall drew a large audience. The instrument's black and white keys had even been polished. The girl sat down in front of the **piano/organ/camera** and began to sing.
    (c) The empty space echoed with silence. It was quiet now that the rowdy high school students had gone home. The pianist sat down in front of the **piano/organ/camera** and began to play.
    (d) The empty space echoed with silence. It was quiet now that the rowdy high school students had gone home. The girl sat down in front of the **piano/organ/camera** and began to sing.
23. (a) The farmer had been toiling in the muddy barn all day. He was exhausted and completely covered in grime and soil. The dirty man had to have a quick **shower/rinse/smoke** as soon as he got home.
    (b) The farmer had been toiling in the muddy barn all day. He was exhausted and completely covered in grime and soil. He had no choice but to have a **shower/rinse/smoke** before he could go to bed.

(c) William let out another annoyed groan after checking that he was alone. He was unimpressed by the day's events. The dirty man had to have a quick **shower/rinse/smoke** as soon as he got home.
(d) William let out another annoyed groan after checking that he was alone. He was unimpressed by the day's events. He had no choice but to have a **shower/rinse/smoke** before he could go to bed.

24. (a) Valerie was a vain and self-conscious person. She constantly checked her appearance. She stared at her reflection in the **mirror/rearview/creek** every morning filled with pride.
(b) Valerie was a vain and self-conscious person. She constantly checked her appearance. Whenever she could, she used the **mirror/rearview/creek** to stare at her own reflection.
(c) The seamstress disliked her job. The work was sometimes demanding and unpredictable. She stared at her reflection in the **mirror/rearview/creek** every morning filled with dread.
(d) The seamstress disliked her job. The work was sometimes demanding and unpredictable. Whenever she could, she used the **mirror/rearview/creek** to vent at her own reflection.
25. (a) Ricky knelt against the pew and said a prayer. He had been moved by the religious service. Afterwards, he spoke to the priest outside the **church/chapel/basement** and thanked him.
(b) Ricky knelt against the pew and said a prayer. He had been moved by the religious service. Afterwards, he stayed behind by himself inside the **church/chapel/basement** to admire the statues.
(c) The job was finally done. Justin directed his workers to box and load everything into the van. Afterwards, he spoke to the priest outside the **church/chapel/basement** and thanked him.
(d) The job was finally done. Justin directed his workers to box and load everything into the van. Afterwards, he stayed behind by himself inside the **church/chapel/basement** to admire the statues.
26. (a) Irene wasn't very tall. She always had to stand on a chair to reach the top shelves. The child couldn't reach anything because she was too **short/petite/sore** to get it on her own.
(b) Irene wasn't very tall. She always had to stand on a chair to reach the top shelves. She hated the fact that she was just too **short/petite/sore** to reach things by herself.
(c) Irene's dad pressed pause on the show that he was watching. He wondered why Irene was yelling. The child couldn't reach anything because she was too **short/petite/sore** to get it on her own.
(d) Irene's dad pressed pause on the show that he was watching. He wondered why Irene was yelling. She hated the fact that she was just too **short/petite/sore** to reach things by herself.
27. (a) Sam's mother arranged the icing on top of his birthday surprise. She had spent all day in the kitchen yesterday. She had baked him a birthday **cake/cookie/pretzel** in the shape of a heart.
(b) Sam's mother arranged the icing on top of his birthday surprise. She had spent all day in the kitchen yesterday. She was excited to show him the **cake/cookie/pretzel** that she had made for him.

(c) Joshua and Alexis only became acquainted a few months ago. But he could tell that she fancied him a lot. She had baked him a birthday **cake/cookie/pretzel** in the shape of a heart.
(d) Joshua and Alexis only became acquainted a few months ago. But he could tell that she fancied him a lot. She was excited to show him the **cake/cookie/pretzel** that she had made for him.

28. (a) Eloise tasted the slice of fruit and immediately puckered up her lips. She couldn't help but wrinkle her face. The raw lemon was too **sour/bitter/bland** but she had to pretend to chew it.
(b) Eloise tasted the slice of fruit and immediately puckered up her lips. She couldn't help but wrinkle her face. Her piece was a bit too **sour/bitter/bland** but she couldn't spit it out just yet.
(c) Justine smiled and thanked the woman for her offering. She didn't want to appear rude in front of everyone. The raw lemon was too **sour/bitter/bland** but she had to pretend to chew it.
(d) Justine smiled and thanked the woman for her offering. She didn't want to appear rude in front of everyone. Her piece was a bit too **sour/bitter/bland** but she couldn't spit it out just yet.
29. (a) David dreaded his economics test next week. He had barely passed the last assignment. David never studied and was definitely going to **fail/flop/pray** on the day of the test.
(b) David dreaded his economics test next week. He had barely passed the last assignment. He already knew that he was going to **fail/flop/pray** on the day of the test.
(c) David muted his friends in the chat. Their uninteresting conversation did not concern him. David never studied and was definitely going to **fail/flop/pray** on the day of the test.
(d) David muted his friends in the chat. Their uninteresting conversation did not concern him. He already knew that he was going to **fail/flop/pray** on the day of the test.
30. (a) We began to smell honey as we approached the hive. We didn't want to be stung so we stayed at a distance. The beekeeper had warned that the **bees/wasps/shrubs** could hurt us.
(b) We began to smell honey as we approached the hive. We didn't want to be stung so we stayed at a distance. We were both worried that the **bees/wasps/shrubs** were quite dangerous.
(c) The homemade setup was impressive. Despite our curiosity, we knew it was best to stand back as we had been asked to. The beekeeper had warned that the **bees/wasps/shrubs** could hurt us.
(d) The homemade setup was impressive. Despite our curiosity, we knew it was best to stand back as we had been asked to. We were both worried that the **bees/wasps/shrubs** were quite dangerous.
31. (a) The comedy man at the gig was hilarious. All his punchlines were executed perfectly. The audience couldn't stop laughing at his funny **joke/skit/protest** which was directed towards the government.

(b) The comedy man at the gig was hilarious. All his punchlines were executed perfectly. He was even asked to repeat his **joke/skit/protest** which was directed at the big corporations.
(c) Nicholas breathed a sigh of relief when he finished. He knew he had succeeded. The audience couldn't stop laughing at his funny **joke/skit/protest** which was directed towards the government.
(d) Nicholas breathed a sigh of relief when he finished. He knew he had succeeded. He was even asked to repeat his **joke/skit/protest** which was directed at the big corporations.

32. (a) The wild elephants on the savannah were being hunted unlawfully. The animals were very popular with illegal traders. The poachers killed the elephants for their **tusks/ivory/offspring** which were worth a fortune.
(b) The wild elephants on the savannah were being hunted unlawfully. The animals were very popular with illegal traders. The men just wanted to sell their **tusks/ivory/offspring** to very shady merchants.
(c) Zoe was astonished by the footage. She had never seen the beautiful creatures being treated like this before. The poachers killed the elephants for their **tusks/ivory/offspring** which were worth a fortune.
(d) Zoe was astonished by the footage. She had never seen the beautiful creatures being treated like this before. The men just wanted to sell their **tusks/ivory/offspring** to very shady merchants.
33. (a) Everyone was appalled by the lead's recent theatrical performance. They expressed their anger by shouting and booing. The actress stepped off the **stage/scene/ferry** before things got more awkward.
(b) Everyone was appalled by the lead's recent theatrical performance. They expressed their anger by shouting and booing. She quickly left the **stage/scene/ferry** before things turned more ugly.
(c) Katherine looked around with tears forming in her eyes. There was nothing that she could do now. The actress stepped off the **stage/scene/ferry** before things got more awkward.
(d) Katherine looked around with tears forming in her eyes. There was nothing that she could do now. She quickly left the **stage/scene/ferry** before things turned more ugly.
34. (a) Steven was going to ask his girlfriend to marry him. He hid the special box so that it remained a surprise. He proposed to Amy with a beautiful **ring/diamond/banner** a few days later.
(b) Steven was going to ask his girlfriend to marry him. He hid the special box so that it remained a surprise. He didn't want Amy to see the **ring/diamond/banner** before the special day.
(c) Dan had to stop thinking about all the worst case scenarios that could happen. He got up quickly from his chair. He proposed to Amy with a beautiful **ring/diamond/banner** and she said yes.
(d) Dan had to stop thinking about all the worst case scenarios that could happen. He got up quickly from his chair. He didn't want Amy to see the **ring/diamond/banner** before the special day.

35. (a) The emergency personnel were on their way. Dan didn't need to see their flashing red and blue colours to know. He could hear the ambulance's **siren/alarm/engine** heading his way.
(b) The emergency personnel were on their way. Dan didn't need to see their flashing red and blue colours to know. He could hear a loud **siren/alarm/engine** screeching towards him.
(c) Elliot decided to read a bit more of his historical fiction novel while he waited. He paused a moment later. He could hear the ambulance's **siren/alarm/engine** heading his way.
(d) Elliot decided to read a bit more of his historical fiction novel while he waited. He paused a moment later. He could hear a loud **siren/alarm/engine** screeching towards him.
36. (a) Sylvia licked her ice cream as it started to melt. She didn't want it to go all over her fingers. Her ice cream was served in a **cone/tray/crepe** that was too small.
(b) Sylvia licked her ice cream as it started to melt. She didn't want it to go all over her fingers. It continued to drip down the **cone/tray/crepe** to her dismay.
(c) The little girl was too tired to say anything. She looked down once more at the thing she had picked. Her ice cream was served in a **cone/tray/crepe** that was too small.
(d) The little girl was too tired to say anything. She looked down once more at the thing she had picked. It continued to drip down the **cone/tray/crepe** to her dismay.
37. (a) Jan wanted to have cereal for breakfast. She looked in the dishwasher for something clean to use. She poured some cornflakes into her **bowl/flask/yoghurt** before going back to her room.
(b) Jan wanted to have cereal for breakfast. She looked in the dishwasher for something clean to use. She quickly reached for her favourite **bowl/flask/yoghurt** before sitting down on the sofa.
(c) George's grandmother was ignoring him today. She didn't look like she was in a fantastic mood. She poured some cornflakes into her **bowl/flask/yoghurt** before going back to her room.
(d) George's grandmother was ignoring him today. She didn't look like she was in a fantastic mood. She quickly reached for her favourite **bowl/flask/yoghurt** before sitting down on the sofa.
38. (a) Laura was visiting the dental clinic for a check up. It was important for her to have a nice white smile. The dentist checked each of her **teeth/molars/charts** before calling for her father.
(b) Laura was visiting the dental clinic for a check up. It was important for her to have a nice white smile. The intern checked each of her **teeth/molars/charts** before letting her go.
(c) The little girl sat with her feet crossed awkwardly at her ankles. She stared out the window in front of her. The dentist checked each of her **teeth/molars/charts** before calling for her father.
(d) The little girl sat with her feet crossed awkwardly at her ankles. She stared out the window in front of her. The intern checked each of her **teeth/molars/charts** before letting her go.

39. (a) The autumn trees were starting to look bare. Every step that Alison took crunched underneath her feet. She finished raking up the **leaves/branches/confetti** in the yard and returned inside.
(b) The autumn trees were starting to look bare. Every step that Alison took crunched underneath her feet. There was a huge pile of **leaves/branches/confetti** that needed to be cleaned up.
(c) Charlotte looked around and realised that she was all alone. She sighed loudly before resuming her work. She finished raking up the **leaves/branches/confetti** in the yard and returned inside.
(d) Charlotte looked around and realised that she was all alone. She sighed loudly before resuming her work. There was a huge pile of **leaves/branches/confetti** that needed to be cleaned up.
40. (a) The man was caught going several kilometres over the limit in a school zone. The punishment was going to be severe. The officer gave the speeding driver a big **fine/warning/scowl** before letting him go.
(b) The man was caught going several kilometres over the limit in a school zone. The punishment was going to be severe. Moments later, he was given a big **fine/warning/scowl** from the unimpressed policeman.
(c) The gentleman sat stiffly upright in his seat. He was too frightened say anything in case he made the situation worse. The officer gave the speeding driver a big **fine/warning/scowl** before letting him go.
(d) The gentleman sat stiffly upright in his seat. He was too frightened say anything in case he made the situation worse. Moments later, he was given a big **fine/warning/scowl** from the unimpressed policeman.
41. (a) The lieutenant knew that it was time to quit. He hoped that the general would still respect him. The soldier quit his place in the **army/navy/marathon** not long after.
(b) The lieutenant knew that it was time to quit. He hoped that the general would still respect him. Not longer after, he withdrew from the **army/navy/marathon** and returned home.
(c) Eric wondered what his true goal in life was. The question made him feel quite confused and helpless. The soldier quit his place in the **army/navy/marathon** not long after.
(d) Eric wondered what his true goal in life was. The question made him feel quite confused and helpless. Not longer after, he withdrew from the **army/navy/marathon** and returned home.
42. (a) The cricket pitch was manicured in time for the match. The green surface was just flat enough to play on. The gardener inspected the freshly cut **grass/turf/wound** near his foot before beckoning his assistant over.
(b) The cricket pitch was manicured in time for the match. The green surface was just flat enough to play on. The worker went to feel the **grass/turf/wound** near his foot before getting his colleague's help.
(c) The secluded area overlooking the steep valley was eerily quiet. It felt like the whole world was still fast asleep. The gardener inspected the freshly cut **grass/turf/wound** near his foot before beckoning his assistant over.

(d) The secluded area overlooking the steep valley was eerily quiet. It felt like the whole world was still fast asleep. The worker went to feel the **grass/turf/wound** near his foot before getting his colleague's help.

43. (a) The princess was disappointed to receive the bunch of red roses. She hated their colour and smell. A rose was her least favourite **flower/bloom/signal** to receive from an admirer.
(b) The princess was disappointed to receive the bunch of red roses. She hated their colour and smell. She would have preferred any other **flower/bloom/signal** from her secret lover.
(c) Nate lay in bed awake ruminating. He didn't know what to do about the lady next door. A rose was her least favourite **flower/bloom/signal** to receive from an admirer.
(d) Nate lay in bed awake ruminating. He didn't know what to do about the lady next door. She would have preferred any other **flower/bloom/signal** from her secret lover.
44. (a) The huge suitcase weighed more than fifty kilograms. It was well over the weight limit. Mary couldn't carry her luggage because it was too **heavy/bulky/embarrassing** for her to do it alone.
(b) The huge suitcase weighed more than fifty kilograms. It was well over the weight limit. Jake had already warned Mary that her thing was too **heavy/bulky/embarrassing** to carry onto the busy train.
(c) Mary was angry and refused to talk to anyone. She hated when her brother was right. Mary couldn't carry her luggage because it was too **heavy/bulky/embarrassing** for her to do it alone.
(d) Mary was angry and refused to talk to anyone. She hated when her brother was right. Jake had already warned Mary that her thing was too **heavy/bulky/embarrassing** to carry onto the busy train.
45. (a) All aircraft were stuck on the tarmac due to the bad weather. Nothing was allowed to fly out of the airport. The frustrated airline travellers just wanted to get on the **plane/flight/internet** inside the terminal.
(b) All aircraft were stuck on the tarmac due to the bad weather. Nothing was allowed to fly out of the airport. The family of five just wanted to get on the **plane/flight/internet** inside the terminal.
(c) The male employee sent a message for backup when no one was looking. He wasn't sure about what to do next. The frustrated airline travellers just wanted to get on the **plane/flight/internet** inside the terminal.
(d) The male employee sent a message for backup when no one was looking. He wasn't sure about what to do next. The family of five just wanted to get on the **plane/flight/internet** inside the terminal.
46. (a) Victor was starving by dinnertime because he hadn't eaten all day. He didn't have anything for breakfast. The schoolboy's mother had then forgotten to pack his **lunch/sandwich/allowance** into his backpack.
(b) Victor was starving by dinnertime because he hadn't eaten all day. He didn't have anything for breakfast. He had also somehow forgotten to bring his **lunch/sandwich/allowance** to school.

(c) Daniel had a disastrous morning. He had accidentally dropped his late aunt's antique collection of porcelain teapots. The schoolboy's mother had then forgotten to pack his **lunch/sandwich/allowance** into his backpack.
(d) Daniel had a disastrous morning. He had accidentally dropped his late aunt's antique collection of porcelain teapots. He had also somehow forgotten to bring his **lunch/sandwich/allowance** to school.

47. (a) The enraged board member decided to take the matter to court. He expected to win the case against his former employee. The defendant hired himself a good **lawyer/barrister/caravan** before cutting off all contact.
(b) The enraged board member decided to take the matter to court. He expected to win the case against his former employee. Chloe immediately got herself a good **lawyer/barrister/caravan** before making a quick getaway.
(c) Time was beginning to run out for something practical to be done. There was not much point in waiting another day. The defendant hired himself a good **lawyer/barrister/caravan** before cutting off all contact.
(d) Time was beginning to run out for something practical to be done. There was not much point in waiting another day. Chloe immediately got herself a good **lawyer/barrister/caravan** before making a quick getaway.
48. (a) The magic wand was under the witch's control. She could make anything happen by chanting the right words. The witch cast a terrible **spell/curse/odour** over the girl while she napped.
(b) The magic wand was under the witch's control. She could make anything happen by chanting the right words. The woman quickly put a nasty **spell/curse/odour** over the girl while she slept.
(c) The dark gloomy night was devoid of moonlight and even stars. There was no one around for kilometres. The witch cast a terrible **spell/curse/odour** over the girl while she napped.
(d) The dark gloomy night was devoid of moonlight and even stars. There was no one around for kilometres. The woman quickly put a nasty **spell/curse/odour** over the girl while she slept.
49. (a) The two children always asked their father to read to them before bed. Usually, he picked something off their bookshelf. Tonight, he read them a bedtime **story/tale/hymn** until they fell asleep.
(b) The two children always asked their father to read to them before bed. Usually, he picked something off their bookshelf. Tonight, he came up with his own **story/tale/hymn** which made them laugh.
(c) The creative father was constantly trying new things. He wanted to make every day interesting and unique for his children. Tonight, he read them a bedtime **story/tale/hymn** until they fell asleep.
(d) The creative father was constantly trying new things. He wanted to make every day interesting and unique for his children. Tonight, he came up with his own **story/tale/hymn** which made them laugh.
50. (a) Rita's father was starting to get shortsighted. His vision was often very blurry. He had trouble seeing without his **glasses/spectacles/daughter** to help him out.
(b) Rita's father was starting to get shortsighted. His vision was often very blurry. He couldn't do anything without his **glasses/spectacles/daughter** to help him out.

(c) Ron leaned back into his brown swivel armchair. He sighed to himself miserably. He had trouble seeing without his **glasses/spectacles/daughter** to help him out.
(d) Ron leaned back into his brown swivel armchair. He sighed to himself miserably. He couldn't do anything without his **glasses/spectacles/daughter** to help him out.

51. (a) The shepherd polished his brand new electric clippers. It was time for his sheep to be shorn. All his sheep had grown a thick coat of **wool/fleece/lic**e that needed to be removed.
(b) The shepherd polished his brand new electric clippers. It was time for his sheep to be shorn. He wanted to get rid of all the **wool/fleece/lice** before the inspectors arrived.
(c) Winston finally recovered from his broken leg. He had lots of work to catch up on now. All his sheep had grown a thick coat of **wool/fleece/lice** that needed to be removed.
(d) Winston finally recovered from his broken leg. He had lots of work to catch up on now. He wanted to get rid of all the **wool/fleece/lice** before the inspectors arrived.
52. (a) Bill suddenly remembered the book that he had borrowed two months ago. He had kept it longer than he meant to. He quickly returned his overdue book to the **library/museum/relative** that had lent it to him.
(b) Bill suddenly remembered the book that he had borrowed two months ago. He had kept it longer than he meant to. He quickly made his way over to the **library/museum/relative** that had sent him a reminder.
(c) The little boy suddenly remembered the errand that he had to run before school. He had an hour of spare time. He quickly returned his overdue book to the **library/museum/relative** that had lent it to him.
(d) The little boy suddenly remembered the errand that he had to run before school. He had an hour of spare time. He quickly made his way over to the **library/museum/relative** that had sent him a reminder.
53. (a) The queen wrote urgently to the duchess. She sealed the envelope and passed it to her servant. He quickly mailed the handwritten **letter/note/recipe** before it was too late.
(b) The queen wrote urgently to the duchess. She sealed the envelope and passed it to her servant. He took the important **letter/note/recipe** and rode into the night.
(c) Daniel already had two strikes against his record. He did not want to disappoint Patricia any further. He quickly mailed the handwritten **letter/note/recipe** before it was too late.
(d) Daniel already had two strikes against his record. He did not want to disappoint Patricia any further. He took the important **letter/note/recipe** and rode into the night.
54. (a) The talented drummer wanted to write tracks with other musicians. He was getting tired of playing by himself. The drummer decided to join the jazz **band/group/quiz** at the nearby bar to meet people.
(b) The talented drummer wanted to write tracks with other musicians. He was getting tired of playing by himself. The man decided to put together a **band/group/quiz** at the local pub to make friends.
(c) The bustling city was a wonderful place to explore. There was something interesting to see on every corner. The drummer decided to join the jazz **band/group/quiz** at the nearby bar to meet people.

(d) The bustling city was a wonderful place to explore. There was something interesting to see on every corner. The man decided to put together a **band/group/quiz** at the local pub to make friends.

55. (a) The boss groaned when he saw the bold, childish typeface used for the text. He couldn't bring himself to read it. He hated Comic Sans and wanted to change the **font/print/booklet** to something different immediately.
(b) The boss groaned when he saw the bold, childish typeface used for the text. He couldn't bring himself to read it. He politely asked his new secretary to change the **font/print/booklet** to another style immediately.
(c) The new manager was wary of upsetting any of his workers. But today he felt like he had no other choice. He hated Comic Sans and wanted to change the **font/print/booklet** to something different immediately.
(d) The new manager was wary of upsetting any of his workers. But today he felt like he had no other choice. He politely asked his new secretary to change the **font/print/booklet** to another style immediately.
56. (a) The power was suddenly cut last night. We had to generate some brightness the old fashioned way. During the outage, we lit some **candles/lanterns/haystacks** that we found in the shed.
(b) The power was suddenly cut last night. We had to generate some brightness the old fashioned way. We decided to use some spare **candles/lanterns/haystacks** in the barn to start a bonfire.
(c) As soon as we were alone, Holly began to despair. But Mum was unfazed by the situation. During the outage, we lit some **candles/lanterns/haystacks** that we found in the shed.
(d) As soon as we were alone, Holly began to despair. But Mum was unfazed by the situation. We decided to use some spare **candles/lanterns/haystacks** in the barn to start a bonfire.
57. (a) The hypochondriac was worried about the state of his health. He was being troubled by some unfamiliar symptoms recently. He was prescribed medicine by his **doctor/physician/uncle** whom he trusted.
(b) The hypochondriac was worried about the state of his health. He was being troubled by some unfamiliar symptoms recently. He decided to speak to his **doctor/physician/uncle** about his issues.
(c) Danny was feeling rather uneasy. He disliked the strange and unusual predicament that he had somehow found himself in. He was prescribed medicine by his **doctor/physician/uncle** whom he trusted.
(d) Danny was feeling rather uneasy. He disliked the strange and unusual predicament that he had somehow found himself in. He decided to speak to his **doctor/physician/uncle** about his issues.
58. (a) Jared dreamed of becoming a famous bodybuilder. He started eating more protein and going to the gym. The skinny teenager wanted to build more **muscle/strength/friendships** before the end of the year.
(b) Jared dreamed of becoming a famous bodybuilder. He started eating more protein and going to the gym. He was desperate to get some more **muscle/strength/friendships** over the next couple of months.

(c) It was time for everyone to share their new year resolutions. Jared offered to say his first. The skinny teenager wanted to build more **muscle/strength/friendships** before the end of the year.
(d) It was time for everyone to share their new year resolutions. Jared offered to say his first. He was desperate to get some more **muscle/strength/friendships** over the next couple of months.

59. (a) The criminal court case was about to begin. Several high profile individuals were due to give evidence on the opening day. The prosecution called its first **witness/juror/recess** after the opening statements.
(b) The criminal court case was about to begin. Several high profile individuals were due to give evidence on the opening day. They first called up a **witness/juror/recess** after the judge spoke.
(c) Contrary to my expectations, everyone in the room seemed very polite. This made me feel more at ease with the situation. The prosecution called its first **witness/juror/recess** after the opening statements.
(d) Contrary to my expectations, everyone in the room seemed very polite. This made me feel more at ease with the situation. They first called up a **witness/juror/recess** after the judge spoke.
60. (a) No one ever believed anything that Peter said. He couldn't be honest with the truth about anything. He was a pathological **liar/storyteller/narcissist** that couldn't be trusted.
(b) No one ever believed anything that Peter said. He couldn't be honest with the truth about anything. Everyone called him a **liar/storyteller/narcissist** behind his back.
(c) Annie felt quite confused. She looked over at her brother who was standing by the vending machine. He was a pathological **liar/storyteller/narcissist** that couldn't be trusted.
(d) Annie felt quite confused. She looked over at her brother who was standing by the vending machine. Everyone called him a **liar/storyteller/narcissist** behind his back.
61. (a) Mike was walking through dense vegetation when something slithered by his foot. He screamed because he didn't want to be bitten. The jungle was full of venomous **snakes/vipers/plants** which really scared him.
(b) Mike was walking through dense vegetation when something slithered by his foot. He screamed because he didn't want to be bitten. He had already come across a few **snakes/vipers/plants** which looked quite dangerous.
(c) Mike followed his colleagues who were walking ahead of him. He was glad they had agreed to accompany him on the trip. The jungle was full of venomous **snakes/vipers/plants** which really scared him.
(d) Mike followed his colleagues who were walking ahead of him. He was glad they had agreed to accompany him on the trip. He had already come across a few **snakes/vipers/plants** which looked quite dangerous.
62. (a) There was a report of sharks right by the coast. The primary concern was to prevent any incidents in the sea. The lifeguards had to caution the inexperienced **swimmers/divers/backpackers** in the area about the news.

(b) There was a report of sharks right by the coast. The primary concern was to prevent any incidents in the sea. Everyone was concerned about the inexperienced **swimmers/divers/backpackers** who were oblivious to the danger.
(c) All of a sudden, everyone's phone started to buzz loudly with calls and messages. A sense of urgency filled the air. The lifeguards had to caution the inexperienced **swimmers/divers/backpackers** in the area about the news.
(d) All of a sudden, everyone's phone started to buzz loudly with calls and messages. A sense of urgency filled the air. Everyone was concerned about the inexperienced **swimmers/divers/backpackers** who were oblivious to the danger.

63. (a) The thick stew had been simmering away in the kitchen for hours. The babysitter was afraid that the children would scald themselves accidentally. The burning hot pan sitting on top of the **stove/fire/coaster** was very dangerous.
(b) The thick stew had been simmering away in the kitchen for hours. The babysitter was afraid that the children would scald themselves accidentally. She carefully removed it from the top of the **stove/fire/coaster** to somewhere safer.
(c) Everyone was curious to see how the project turned out. But the instructor with the dark blonde hair insisted that they stay seated. The burning hot pan sitting on top of the **stove/fire/coaster** was very dangerous.
(d) Everyone was curious to see how the project turned out. But the instructor with the dark blonde hair insisted that they stay seated. She carefully removed it from the top of the **stove/fire/coaster** to somewhere safer.
64. (a) The sorcerer planned to incapacitate the prince over dinner. One mouthful would do the job. The prince was killed with a drop of **poison/cyanide/mould** just a few days later.
(b) The sorcerer planned to incapacitate the prince over dinner. One mouthful would do the job. He slowly placed a small amount of **poison/cyanide/mould** into the prince's cup before fleeing.
(c) Christopher stopped abruptly in the middle of the empty room. He had to leave now. The prince was killed with a drop of **poison/cyanide/mould** just a few days ago.
(d) Christopher stopped abruptly in the middle of the empty room. He had to leave now. He slowly placed a small amount of **poison/cyanide/mould** into the prince's cup before fleeing.
65. (a) The zoologist entered the large rock chamber that extended deep below ground. He was searching for an endangered species of bats. He eventually found the bats hanging in the underground **cave/tunnel/drain** just beneath the opening.
(b) The zoologist entered the large rock chamber that extended deep below ground. He was searching for an endangered species of bats. As he had suspected, they were all in the **cave/tunnel/drain** just beyond the entrance.
(c) Paul was looking for something using a second-hand compass that he had owned for years. He checked his coordinates once more. He eventually found the bats hanging in the underground **cave/tunnel/drain** just beneath the opening.
(d) Paul was looking for something using a second-hand compass that he had owned for years. He checked his coordinates once more. As he had suspected, they were all in the **cave/tunnel/drain** just beyond the entrance.

66. (a) Matt always remembers to bring a facecloth when he works out. He gets very hot and smelly when he exercises. He always finishes the gym drenched in **sweat/perspiration/cologne** which can be unpleasant.
(b) Matt always remembers to bring a facecloth when he works out. He gets very hot and smelly when he exercises. His shirt is always dotted with **sweat/perspiration/cologne** when he finishes at the gym.
(c) Theo's girlfriend of three years isn't very happy with him. She can't pretend to ignore the problem for any longer. He always finishes the gym drenched in **sweat/perspiration/cologne** which can be unpleasant.
(d) Theo's girlfriend of three years isn't very happy with him. She can't pretend to ignore the problem for any longer. His shirt is always dotted with **sweat/perspiration/cologne** when he finishes at the gym.
67. (a) The woman who sang soprano cleared her throat. She was excited for her event tomorrow night. The singer had a beautiful **voice/song/estate** that she wanted to showcase.
(b) The woman who sang soprano cleared her throat. She was excited for her event tomorrow night. She had a very lovely **voice/song/estate** that she wanted everyone to know about.
(c) Colette worked hard to overcome her low self-esteem. For once, she felt very proud of herself. The singer had a beautiful **voice/song/estate** that she wanted to showcase.
(d) Colette worked hard to overcome her low self-esteem. For once, she felt very proud of herself. She had a very lovely **voice/song/estate** that she wanted everyone to know about.
68. (a) Ross gasped when he saw the tropical location. He had never seen such white sand in his life before. The palm trees on the **beach/resort/pamphlet** also looked very beautiful.
(b) Ross gasped when he saw the tropical location. He had never seen such white sand in his life before. He took a photo of the **beach/resort/pamphlet** and showed his wife.
(c) Max glanced around and felt very pleased with himself. He was certain that he had made the right choice. The palm trees on the **beach/resort/pamphlet** looked very beautiful.
(d) Max glanced around and felt very pleased with himself. He was certain that he had made the right choice. He took a photo of the **beach/resort/pamphlet** and showed his wife.
69. (a) George hasn't been able to walk properly all week. He had several large blisters on his feet. The podiatrist asked him to remove his muddy **shoes/socks/umbrella** as soon as she saw him.
(b) George hasn't been able to walk properly all week. He had several large blisters on his feet. The assistant asked him to remove his **shoes/socks/umbrella** as soon as he entered her office.
(c) Timothy couldn't help but bite into his nails with some nervousness. He was going to be next. The podiatrist asked him to remove his muddy **shoes/socks/umbrella** as soon as she saw him.

(d) Timothy couldn't help but bite into his nails with some nervousness. He was going to be next. The assistant asked him to remove his **shoes/socks/umbrella** as soon as he entered her office.

70. (a) The place was too dirty to walk around in barefoot. The cleaner went to grab a spare broom. He swept and then mopped the **floor/tiles/lift** to his boss' satisfaction.
(b) The place was too dirty to walk around in barefoot. The cleaner went to grab a spare broom. He felt obliged to clean the **floor/tiles/lift** until it was perfect.
(c) Brian wanted to unwind with his friends at the local pub. He had one last thing to finish. He swept and then mopped the **floor/tiles/lift** to his boss' satisfaction.
(d) Brian wanted to unwind with his friends at the local pub. He had one last thing to finish. He felt obliged to clean the **floor/tiles/lift** until it was perfect.
71. (a) The oven in the bakery was preheating. The flour and liquid had been combined nicely. Martha was ready to knead the **dough/bread/clay** when her phone rang.
(b) The oven in the bakery was preheating. The flour and liquid had been combined nicely. Martha was ready to work the **dough/bread/clay** when the door buzzed.
(c) Martha had nothing to do when she arrived. Her things had already been set up. Martha was ready to knead the **dough/bread/clay** when her phone rang.
(d) Martha had nothing to do when she arrived. Her things had already been set up. Martha was ready to work the **dough/bread/clay** when the door buzzed.
72. (a) Katie wanted to display her beautiful tulips. She found a small ornamental container. She quickly arranged her tulips in the **vase/jars/sink** until she found something bigger.
(b) Katie wanted to display her beautiful tulips. She found a small ornamental container. She quickly placed everything in the **vase/jars/sink** until she found something bigger.
(c) Vanessa was exhausted from running errands. She needed to take a quick break. She quickly arranged her tulips in the **vase/jars/sink** before laying on the couch.
(d) Vanessa was exhausted from running errands. She needed to take a quick break. She quickly placed everything in the **vase/jars/sink** before laying on the couch.
73. (a) The liquid in Erin's bath was no longer hot. She needed to dry herself before she caught a cold. She dried herself with a clean **towel/cloth/scarf** as she got out of the tub.
(b) The liquid in Erin's bath was no longer hot. She needed to dry herself before she caught a cold. She quickly reached for her grey **towel/cloth/scarf** as she stepped out of the spa.
(c) Amy didn't know why she was in such an irritable mood. She hoped that it would not last long. She dried herself with a clean **towel/cloth/scarf** as she stepped out of the spa.
(d) Amy didn't know why she was in such an irritable mood. She hoped that it would not last long. She quickly reached for her grey **towel/cloth/scarf** as she stepped out of the spa.
74. (a) Remy wanted to take a daytime nap. She just had to block out the sunshine coming in through the window. Before sleeping, she pulled down her **blinds/shutters/braids** before turning off her phone.
(b) Remy wanted to take a daytime nap. She just had to block out the sunshine coming in through the window. She went to pull down her **blinds/shutters/braids** before crawling into bed.

(c) Minnie was taking her driving test the next morning. Her insides were in a big knot because of her nerves. Before sleeping, she pulled down her **blinds/shutters/braids** before turning off her phone.
(d) Minnie was taking her driving test the next morning. Her insides were in a big knot because of her nerves. She went to pull down her **blinds/shutters/braids** before crawling into bed.

75. (a) The student stayed up late studying. She wanted to finish reading as many books as possible. The freshman didn't feel ready for her final **exam/assessment/surgery** tomorrow and was worried.
(b) The student stayed up late studying. She wanted to finish reading as many books as possible. She was about to have her last **exam/assessment/surgery** which was happening tomorrow.
(c) Josie was speaking with her boyfriend over the phone. Her father overheard parts of their conversation. The freshman didn't feel ready for her final **exam/assessment/surgery** tomorrow and was worried.
(d) Josie was speaking with her boyfriend over the phone. Her father overheard parts of their conversation. She was about to have her last **exam/assessment/surgery** which was happening tomorrow.
76. (a) The retired CEO was looking for a new source of income. He just needed some investors to get started. The entrepreneur wanted to start a small **business/company/flock** on his private property.
(b) The retired CEO was looking for a new source of income. He just needed some investors to get started. He wanted to have his own **business/company/flock** on his farm soon.
(c) Janet liked what she was hearing. She continued to listen carefully to the person sitting in front of her. The entrepreneur wanted to start a small **business/company/flock** on his private property.
(d) Janet liked what she was hearing. She continued to listen carefully to the person sitting in front of her. He wanted to have his own **business/company/flock** on his farm soon.
77. (a) Natalie heard the minute hand strike the hour. Three loud bells rang out to indicate the time. She checked the time on her **watch/clock/email** and realised that her assignment was almost due.
(b) Natalie heard the minute hand strike the hour. Three loud bells rang out to indicate the time. She looked down at her **watch/clock/email** and realised that her assignment was already late.
(c) Jessica read the article several times. She wasn't sure if it was worth including in her essay. She checked the time on her **watch/clock/email** and realised that her assignment was almost due.
(d) Jessica read the article several times. She wasn't sure if it was worth including in her essay. She looked down at her **watch/clock/email** and realised that her assignment was already late.
78. (a) The woman quickly put her money away to avoid being noticed by opportunists. But she had already been seen. The robber snatched the woman's **purse/wallet/blazer** a minute later.

(b) The woman quickly put her money away to avoid being noticed by opportunists. But she had already been seen. The bald man took her black **purse/wallet/blazer** a moment later.
(c) The woman looked around her with a bewildered expression on her face. Everyone around her was yelling so loudly. The robber snatched the woman's **purse/wallet/blazer** a minute later.
(d) The woman looked around her with a bewildered expression on her face. Everyone around her was yelling so loudly. The bald man took her black **purse/wallet/blazer** a moment later.

79. (a) The insects flew close to my burger before landing on it. I was horrified. I swatted the two little **flies/beetles/shadows** on my food immediately.
(b) The insects flew close to my burger before landing on it. I was horrified. The two little black **flies/beetles/shadows** looked quite revolting.
(c) I glanced down at the item in front of me. My jaw dropped opened. I swatted the two little **flies/beetles/shadows** on my food immediately.
(d) I glanced down at the item in front of me. My jaw dropped opened. The two little black **flies/beetles/shadows** looked quite revolting.
80. (a) Jason had no plans to get married. He did not want to settle down with a wife anytime soon. The single man wanted to remain a **bachelor/player/pessimist** who didn't believe in love.
(b) Jason had no plans to get married. He did not want to settle down with a wife anytime soon. He was proud to be known as a **bachelor/player/pessimist** amongst all the ladies.
(c) Janice was kept wide awake that night by her thoughts. She couldn't figure out what to do about Tim. The single man wanted to remain a **bachelor/player/pessimist** who didn't believe in love.
(d) Janice was kept wide awake that night by her thoughts. She couldn't figure out what to do about Tim. He was proud to be known as a **bachelor/player/pessimist** amongst all the ladies.
81. (a) There was only one way to cross over the treacherous currents. The rusty metal structure was swaying but Becky had to use it. Becky crossed over the river on the shaky **bridge/overpass/bike** with caution.
(b) There was only one way to cross over the treacherous currents. The rusty metal structure was swaying but Becky had to use it. Becky stepped very carefully onto the old **bridge/overpass/bike** with caution.
(c) Becky's elderly father was suddenly nowhere to be seen. She tried to call out after him but she heard nothing back in response. Becky crossed over the river on the shaky **bridge/overpass/bike** to find him.
(d) Becky's elderly father was suddenly nowhere to be seen. She tried to call out after him but she heard nothing back in response. Becky stepped very carefully onto the old **bridge/overpass/bike** to find him.
82. (a) Amanda disliked celebrating her birthday. She hated when people wasted money buying her things. Her parents always gave her several birthday **presents/cards/hugs** whenever they came to visit.
(b) Amanda disliked celebrating her birthday. She hated when people wasted money buying her things. Her parents still gave her several **presents/cards/hugs** whenever they could.

(c) Samantha could not help but feel very lonely. Nonetheless she decided not to complain. Her parents always gave her several birthday **presents/cards/hugs** whenever they came to visit.
(d) Samantha could not help but feel very lonely. Nonetheless she decided not to complain. Her parents still gave her several **presents/cards/hugs** whenever they could.

83. (a) Tammy admired her make up look. Her lips did look pale but otherwise she was satisfied. She puckered her lips as she put on the red **lipstick/blush/pendant** completed her look.
(b) Tammy admired her make up look. Her lips did look pale but otherwise she was satisfied. After a bit more thought, she reached for the red **lipstick/blush/pendant** on the stand.
(c) It was a lovely warm summer evening. Charlotte was feeling very relaxed after her spa session. She puckered her lips as she put on the red **lipstick/blush/pendant** completed her look.
(d) It was a lovely warm summer evening. Charlotte was feeling very relaxed after her spa session. After a bit more thought, she reached for the red **lipstick/blush/pendant** on the stand.
84. (a) We patiently waited our turn to enter the gallery to see the new exhibit. There were many people ahead of us. We stood in a very long **line/queue/corridor** for almost two hours.
(b) We patiently waited our turn to enter the gallery to see the new exhibit. There were many people ahead of us. In the end, we waited in the **line/queue/corridor** for hours before entering the gallery.
(c) The day we were waiting for had finally come. We were all on our very best behaviour even without being asked. We stood in a very long **line/queue/corridor** for almost two hours.
(d) The day we were waiting for had finally come. We were all on our very best behaviour even without being asked. In the end, we waited in the **line/queue/corridor** for hours before entering the gallery.
85. (a) The queen's niece was a talented equestrian. She had been riding since she was a little girl. The princess skilfully mounted the **horse/camel/steps** as the crowd cheered.
(b) The queen's niece was a talented equestrian. She had been riding since she was a little girl. She stood proudly next to the **horse/camel/steps** as she received her trophy.
(c) Everyone in town already knew about the talented young lady. But this was her first public appearance. The princess skilfully mounted the **horse/camel/steps** as the crowd cheered.
(d) Everyone in town already knew about the talented young lady. But this was her first public appearance. She stood proudly next to the **horse/camel/steps** as she received her trophy.
86. (a) Lea's family was overwhelmed with grief following her sudden death last week. They were planning to farewell her today. Many mourners attended the solemn **funeral/burial/parade** held in her honour.

(b) Lea's family was overwhelmed with grief following her sudden death last week. They were planning to farewell her today. Many people turned up at the **funeral/burial/parade** held in her honour.
(c) The torrential downpour of rain caught everyone by surprise. It did not look like slowing down any time soon. Many mourners attended the solemn **funeral/burial/parade** despite the wet weather.
(d) The torrential downpour of rain caught everyone by surprise. It did not look like slowing down any time soon. Many people turned up at the **funeral/burial/parade** despite the wet weather.

87. (a) The travellers had enjoyed their trans-Atlantic cruise adventure. They were now delighted to be back on dry land. Their journey sailing across an entire **ocean/gulf/cyclone** with a faulty radio was challenging.
(b) The travellers had enjoyed their trans-Atlantic cruise adventure. They were now delighted to be back on dry land. Their experience crossing an entire **ocean/gulf/cyclone** with a broken propeller was frightening.
(c) The mother was pleased with her two children. They had handled the situation exceptionally well for their age. Their journey sailing across an entire **ocean/gulf/cyclone** with a faulty radio was challenging.
(d) The mother was pleased with her two children. They had handled the situation exceptionally well for their age. Their experience crossing an entire **ocean/gulf/cyclone** with a broken propeller was frightening.
88. (a) Seamus could only eat something green and healthy for dinner. He was trying hard to lose weight. He had lettuce and dressing and made a **salad/wrap/decision** that he soon abandoned.
(b) Seamus could only eat something green and healthy for dinner. He was trying hard to lose weight. He got some things prepared and then made a **salad/wrap/decision** that he instantly regretted.
(c) Rory rummaged through a few of his boxes on the bench. He didn't have anything particularly interesting. He had lettuce and dressing and made a **salad/wrap/decision** that he soon abandoned.
(d) Rory rummaged through a few of his boxes on the bench. He didn't have anything particularly interesting. He got some things prepared and then made a **salad/wrap/decision** that he instantly regretted.
89. (a) Kenneth hated his very uninteresting job. It made him want to fall asleep. The repetitive work was so **boring/tedious/humiliating** for him.
(b) Kenneth hated his very uninteresting job. It made him want to fall asleep. He wished it was less **boring/tedious/humiliating** for him.
(c) Ben got ready slowly. He somewhat regretted his offer to help his mother. The repetitive work was so **boring/tedious/humiliating** for him.
(d) Ben got ready slowly. He somewhat regretted his offer to help his mother. He wished it was less **boring/tedious/humiliating** for him.
90. (a) Tia wondered why she hadn't sorted out her toothache sooner. She only saw a dentist when brushing became impossible. The anaesthetic reduced her sharp **pain/discomfort/annoyance** a few seconds later.
(b) Tia wondered why she hadn't sorted out her toothache sooner. She only saw a dentist when brushing became impossible. She had never experienced such **pain/discomfort/annoyance** in her life before.

(c) Michelle didn't feel like talking to the strangers in the room. She concentrated on playing with her scraggly dolls. The anaesthetic reduced her sharp **pain/discomfort/annoyance** a few seconds later.
(d) Michelle didn't feel like talking to the strangers in the room. She concentrated on playing with her scraggly dolls. She had never experienced such **pain/discomfort/annoyance** in her life before.

91. (a) Sarah forgot to apply sunblocker when she went outside yesterday. She had tanned in the sun for hours. After being outdoors, her fair skin was terribly **burnt/scorched/itchy** and swollen the next day.
(b) Sarah forgot to apply sunblocker when she went outside yesterday. She had tanned in the sun for hours. She wasn't surprised when she ended up quite **burnt/scorched/itchy** on her legs the next day.
(c) Sarah awoke with a sudden jolt. She had somehow fallen asleep next to her dogs on the verandah. After being outdoors, her fair skin was terribly **burnt/scorched/itchy** and swollen the next day.
(d) Sarah awoke with a sudden jolt. She had somehow fallen asleep next to her dogs on the verandah. She wasn't surprised when she ended up quite **burnt/scorched/itchy** on her legs the next day.

92. (a) The farmer always tends to his dairy cattle at dawn. Their udders become swollen and red if he ever forgot. His cows always produced lots of **milk/fluid/noise** in the mornings to remind him.
(b) The farmer always tends to his dairy cattle at dawn. Their udders become swollen and red if he ever forgot. They always produced a lot of **milk/fluid/noise** in the mornings to remind him.
(c) Andrew wondered where his son had gone. He needed some extra help with the creatures that he was dealing with. His cows always produced lots of **milk/fluid/noise** in the evenings without any reason.
(d) Andrew wondered where his son had gone. He needed some extra help with the creatures that he was dealing with. They always produced a lot of **milk/fluid/noise** in the evenings without any reason.

93. (a) The airplane was acting strangely and making loud beeping sounds. The control panel was not performing as it should. The air traffic controller warned the **pilot/crew/spectators** about the disturbing situation.
(b) The airplane was acting strangely and making loud beeping sounds. The control panel was not performing as it should. This caused some worry for the **pilot/crew/spectators** who felt helpless.
(c) Unexpectedly, the system required some extra time to start up completely. There was nothing left to do but wait. The air traffic controller warned the **pilot/crew/spectators** about the disturbing situation.
(d) Unexpectedly, the system required some extra time to start up completely. There was nothing left to do but wait. This caused some worry for the **pilot/crew/spectators** who felt helpless.

94. (a) The dead body was gruesomely discovered in the man's house. The police finally had the evidence to arrest him. The killer was charged with the **murder/manslaughter/embezzlement** of the elderly man soon after.

(b) The dead body was gruesomely discovered in the man's house. The police finally had the evidence to arrest him. The man responsible for the **murder/manslaughter/embezzlement** of the young woman remained silent.
(c) After a few unexpected delays, the important meeting was finally underway. Loud conversation slowly began to fill the room. The killer was charged with the **murder/manslaughter/embezzlement** of the elderly man soon after.
(d) After a few unexpected delays, the important meeting was finally underway. Loud conversation slowly began to fill the room. The man responsible for the **murder/manslaughter/embezzlement** of the young woman remained silent.

95. (a) Pete hit the jackpot. The money in his bank account increased by almost tenfold overnight. Winning the lotto made him instantly **rich/wealthy/attractive** in the eyes of many people.
(b) Pete hit the jackpot. The money in his bank account increased by almost tenfold overnight. All of a sudden, he became **rich/wealthy/attractive** in the eyes of his neighbours.
(c) Harrison was a simple man. He loved living by the quiet seaside with his labrador. Winning the lotto made him instantly **rich/wealthy/attractive** in the eyes of many people.
(d) Harrison was a simple man. He loved living by the quiet seaside with his labrador. All of a sudden, he became **rich/wealthy/attractive** in the eyes of his neighbours.

96. (a) Haley's little bunny never ate anything soft like lettuce. He always preferred something crunchier. Her rabbit loved munching on **carrots/celery/cicadas** by her side.
(b) Haley's little bunny never ate anything soft like lettuce. He always preferred something crunchier. His favourite snack was always **carrots/celery/cicadas** from her garden.
(c) Georgina felt relieved. Her golden retriever appeared to be settling into his new home. Her rabbit loved munching on **carrots/celery/cicadas** by his side.
(d) Georgina felt relieved. Her golden retriever appeared to be settling into his new home. His favourite snack was always **carrots/celery/cicadas** from her garden.

97. (a) Paulette pulled again at the stubborn door. Then she realised that she was doing it the wrong way. She stopped pulling at the door that clearly said to **push/knock/donate** in order to access the foyer.
(b) Paulette pulled again at the stubborn door. Then she realised that she was doing it the wrong way. She did not know that she actually needed to **push/knock/donate** in order to enter the building.
(c) Megan was usually a very bright person. But she found it quite difficult to think straight this morning. She stopped pulling at the door that clearly said to **push/knock/donate** in order to access the foyer.
(d) Megan was usually a very bright person. But she found it quite difficult to think straight this morning. She did not know that she actually needed to **push/knock/donate** in order to enter the building.

98. (a) The couple's belongings were being blown all over the place. It was the strong southerly change that the weatherman had warned about. Their tent was being battered by the wild **winds/gusts/locusts** from all sides.

(b) The couple's belongings were being blown all over the place. It was the strong southerly change that the weatherman had warned about. They were surprised by the strength of the **winds/gusts/locusts** that had just arrived.
(c) Jim rested a gentle arm around his wife's shoulder. The first day of their honeymoon wasn't turning out as they had expected. Their tent was being battered by the wild **winds/gusts/locusts** from all sides.
(d) Jim rested a gentle arm around his wife's shoulder. The first day of their honeymoon wasn't turning out as they had expected. They were surprised by the strength of the **winds/gusts/locusts** that had just arrived.

99. (a) Alex loved playing acoustic string instruments. But he had grown tired of the ukulele and wanted to try something different. He slowly strummed the **guitar/violin/racket** and pretended to sing.
(b) Alex loved playing acoustic string instruments. But he had grown tired of the ukulele and wanted to try something different. He bought himself a **guitar/violin/racket** to see how it felt.
(c) Alex was finally comfortable enough to relax himself. He felt like there were no more expectations weighing him down now. He slowly strummed the **guitar/violin/racket** and pretended to sing.
(d) Alex was finally comfortable enough to relax himself. He felt like there were no more expectations weighing him down now. He bought himself a **guitar/violin/racket** to see how it felt.

100. (a) The pregnant mother suddenly went into labour. She desperately needed a ride to the hospital. She quickly hailed a **taxi/tram/bartender** for some help.
(b) The pregnant mother suddenly went into labour. She desperately needed a ride to the hospital. She quickly stopped a **taxi/tram/bartender** for some help.
(c) Marie didn't know what to do. She wanted to follow her heart even if it made no sense. She quickly hailed a **taxi/tram/bartender** for some help.
(d) Marie didn't know what to do. She wanted to follow her heart even if it made no sense. She quickly stopped a **taxi/tram/bartender** for some help.

101. (a) The children had been building sandcastles at the beach all day. They wanted to cool off before going home. The lifeguard watched them splash around in the shallow **water/waves/cavern** just outside the flags.
(b) The children had been building sandcastles at the beach all day. They wanted to cool off before going home. Their parents finally gave them permission to go into the **water/waves/cavern** for a few minutes.
(c) It was impossible to separate the two boys. They refused to do anything unless they could do it together. The lifeguard watched them splash around in the shallow **water/waves/cavern** just outside the flags.
(d) It was impossible to separate the two boys. They refused to do anything unless they could do it together. Their parents finally gave them permission to go into the **water/waves/cavern** for a few minutes.

102. (a) After their vows, the couple prepared to release something into the sky. They hoped it would symbolise their new married life together. The newlyweds released some white **doves/pigeons/balloons** as everyone clapped.
(b) After their vows, the couple prepared to release something into the sky. They hoped it would symbolise their new married life together. Everyone watched as they released some **doves/pigeons/balloons** into the sky.

(c) The couple took a big step back before turning simultaneously to face each other. They knew what they had to do next. The newlyweds released some white **doves/pigeons/balloons** as everyone clapped.
(d) The couple took a big step back before turning simultaneously to face each other. They knew what they had to do next. Everyone watched as they released some **doves/pigeons/balloons** into the sky.

103. (a) The sailors began to despair when they realised they had run aground. They needed to deploy the lifeboat. The captain decided to stay with the sinking **ship/vessel/coffin** in hopes of salvaging it.
(b) The sailors began to despair when they realised they had run aground. They needed to deploy the lifeboat. Only one of the men stayed with the damaged **ship/vessel/coffin** as it disappeared underwater.
(c) The sun had finished setting in the distance. A bleak darkness was beginning to sweep across the horizon. The captain decided to stay with the sinking **ship/vessel/coffin** in hopes of salvaging it.
(d) The sun had finished setting in the distance. A bleak darkness was beginning to sweep across the horizon. Only one of the men stayed with the damaged **ship/vessel/coffin** as it disappeared underwater.

104. (a) Jenny felt prepared for tomorrow's test. She even remembered that she wasn't allowed to use pen. The student sharpened all her **pencils/crayons/scalpels** before going to bed.
(b) Jenny felt prepared for tomorrow's test. She even remembered that she wasn't allowed to use pen. She lined up several of her **pencils/crayons/scalpels** before going to bed.
(c) Jenny sat right by the telephone. She was waiting on an important call to come through. The student sharpened all her **pencils/crayons/scalpels** as she waited nervously.
(d) Jenny sat right by the telephone. She was waiting on an important call to come through. She lined up several of her **pencils/crayons/scalpels** as she waited nervously.

105. (a) We watched the wild feline in the distance hunt for prey on the open African savannah. Its impressive mane encircled its head. Suddenly, the ferocious roar of the **lion/hyena/truck** gave us a huge fright.
(b) We watched the wild feline in the distance hunt for prey on the open African savannah. Its impressive mane encircled its head. Suddenly behind us, we noticed another **lion/hyena/truck** approaching us very slowly.
(c) The first day of our trip had been an eye-opening experience. Everyone was keen to get some rest before the next day. Suddenly, the ferocious roar of the **lion/hyena/truck** gave us a huge fright.
(d) The first day of our trip had been an eye-opening experience. Everyone was keen to get some rest before the next day. Suddenly behind us, we noticed another **lion/hyena/truck** approaching us very slowly.

106. (a) The monkey in the enclosure stared at the piece of food that Jennifer was holding. She looked down at the yellow fruit before throwing it over. The monkey peeled the **banana/mango/label** before biting into it.

(b) The monkey in the enclosure stared at the piece of food that Jennifer was holding. She looked down at the yellow fruit before throwing it over. It prodded at the **banana/mango/label** before taking a sniff.
(c) The woman carried out the medical test in a quiet room at the back of the building. Nothing seemed wrong with the animal at first glance. The monkey peeled the **banana/mango/label** before biting into it.
(d) The woman carried out the medical test in a quiet room at the back of the building. Nothing seemed wrong with the animal at first glance. It prodded at the **banana/mango/label** before taking a sniff.

107. (a) The classified files on the server were taken without authorisation. Someone had broken into the system. The passwords which were stolen by the online **hacker/scammer/comedian** were very important.
(b) The classified files on the server were taken without authorisation. Someone had broken into the system. No one could recognise the name of the **hacker/scammer/comedian** who was responsible.
(c) The entire team was working overtime on the problem. They hadn't made much progress since yesterday. The passwords which were stolen by the online **hacker/scammer/comedian** were very important.
(d) The entire team was working overtime on the problem. They hadn't made much progress since yesterday. No one could recognise the name of the **hacker/scammer/comedian** who was responsible.
108. (a) Ken checked the red meat options on the menu. He craved a cut that was juicy and tender. He wanted the medium rare **steak/cutlets/combo** on the specials board.
(b) Ken checked the red meat options on the menu. He craved a cut that was juicy and tender. He liked the look of the **steak/cutlets/combo** on the front page.
(c) Bob looked over at his wife who was sat next to him. He had already settled on something. He wanted the medium rare **steak/cutlets/combo** on the specials board.
(d) Bob looked over at his wife who was sat next to him. He had already settled on something. He liked the look of the **steak/cutlets/combo** on the front page.
109. (a) The colourful mural on the wall was almost finished. It just needed a bit more red to even it out. The **paint/varnish/beer** and continued his work.
(b) The colourful mural on the wall was almost finished. It just needed a bit more red to even it out. Sam got out a little bit more **paint/varnish/beer** and got down to work.
(c) At last, the old windows were pried open. There was finally a nice cool breeze entering the room. The **paint/varnish/beer** and continued his work.
(d) At last, the old windows were pried open. There was finally a nice cool breeze entering the room. Sam got out a little bit more **paint/varnish/beer** and got down to work.
110. (a) The couple were driving around aimlessly looking for their destination. They had misplaced their map hours ago. The lost couple stopped to ask for some **directions/information/sunscreen** from a random stranger.
(b) The couple were driving around aimlessly looking for their destination. They had misplaced their map hours ago. After a while, they agreed to ask for some **directions/information/sunscreen** before continuing their trip.

(c) Stephanie was in an irritable mood. Benedict didn't want to do anything that would upset her further. The lost couple stopped to ask for some **directions/information/sunscreen** from a random stranger.
(d) Stephanie was in an irritable mood. Benedict didn't want to do anything that would upset her further. After a while, they agreed to ask for some **directions/information/sunscreen** before continuing their trip.

111. (a) The costumed children were excited to trick or treat. It was the only time of the year that they were allowed sugary foods. Halloween always meant getting lots of **candy/chocolate/attention** from the neighbours.
(b) The costumed children were excited to trick or treat. It was the only time of the year that they were allowed sugary foods. They were ready to get some **candy/chocolate/attention** from their parents.
(c) The twins awoke from their nap at about the same time. They rolled out of bed and got ready in matching outfits quickly. Halloween always meant getting lots of **candy/chocolate/attention** from the neighbours.
(d) The twins awoke from their nap at about the same time. They rolled out of bed and got ready in matching outfits quickly. They were ready to get some **candy/chocolate/attention** from their parents.
112. (a) Delia sometimes passes out in response to triggering stimuli. It is something that she can't control. The sight of blood causes her to **faint/collapse/retch** almost immediately.
(b) Delia sometimes passes out in response to triggering stimuli. It is something that she can't control. People sometimes worry when they see her **faint/collapse/retch** very abruptly.
(c) Christie walked over to the instructor. She had to explain the situation before it was too late. The sight of blood causes her to **faint/collapse/retch** almost immediately.
(d) Christie walked over to the instructor. She had to explain the situation before it was too late. People sometimes worry when they see her **faint/collapse/retch** very abruptly.
113. (a) The council planned to chop down the dying tree beside our house. They offered to remove the log too. Most of our dangerous tree was felled, leaving behind a small **stump/hole/plaque** in its place.
(b) The council planned to chop down the dying tree beside our house. They offered to remove the log too. When everything was done, all that remained was a small **stump/hole/plaque** in the yard.
(c) Our two friendly neighbours saw us struggling with our job behind the house. They offered to help us out. Most of our dangerous tree was felled, leaving behind a small **stump/hole/plaque** in its place.
(d) Our two friendly neighbours saw us struggling with our job behind the house. They offered to help us out. When everything was done, all that remained was a small **stump/hole/plaque** in the yard.
114. (a) Luke was dehydrated after running so many kilometres in the sun. He felt very parched. The thirsty runner just wanted a cold **drink/juice/compress** from the fridge.
(b) Luke was dehydrated after running so many kilometres in the sun. He felt very parched. He immediately went to buy himself a **drink/juice/compress** to cool down.

(c) Michael wondered why his request was taking so long. He decided to do it himself. The thirsty runner just wanted a cold **drink/juice/compress** from the fridge.
(d) Michael wondered why his request was taking so long. He decided to do it himself. He immediately went to buy himself a **drink/juice/compress** to cool down.

115. (a) The firefighter was recognised for his heroic work. He had saved the woman's life without hesitation. He received a shiny bravery **medal/award/sticker** from the mayor for his hard work.
(b) The firefighter was recognised for his heroic work. He had saved the woman's life without hesitation. Afterwards, he admired his shiny **medal/award/sticker** from his boss with pride.
(c) Benjamin endured a busy day at work. He was relieved when his shift was finally over. He received a shiny bravery **medal/award/sticker** from the mayor for his hard work.
(d) Benjamin endured a busy day at work. He was relieved when his shift was finally over. Afterwards, he admired his shiny **medal/award/sticker** from his boss with pride.

116. (a) Anthony didn't like how long his new wig was. He wanted it slightly shorter. The barber gave him a nice **haircut/trim/deal** which cheered him up.
(b) Anthony didn't like how long his new wig was. He wanted it slightly shorter. His mate gave him a nice **haircut/trim/deal** which made his day.
(c) Jim's morning started off terribly. His mood only began to improve in the afternoon. The barber gave him a nice **haircut/trim/deal** which cheered him up.
(d) Jim's morning started off terribly. His mood only began to improve in the afternoon. His mate gave him a nice **haircut/trim/deal** which made his day.

Sentences used in Chapter 3 Experiments 1 and 2

For each pair, the strongly constraining context appears first (a), followed by the weakly constraining context (b). The initial target is bolded in the order: predictable target, unpredictable related target, unpredictable unrelated target, unpredictable anomalous target (which did not appear in Experiment 2). The downstream target is underlined.

1 (a) The comedian's witty jokes made the audience **laugh/smile/groan/apple** awkwardly for a second. It was easy for him to laugh at his own jokes but not for other people.
(b) Jane made her nephew **laugh/smile/groan/apple** by tickling him. Usually, he would laugh at almost anything she did.

2 (a) In the centre of the cobweb were two big black **spiders/flies/buttons/become** that were not moving at all. The little spiders on the wall started crawling towards them in curiosity.
(b) The little girl looked up to see some **spiders/flies/buttons/become** on the roof. She did not notice the large spiders crawling near her foot.

3 (a) The waiter thought everything was ready when he put the salt and **pepper/chilli/spoons/betray** down onto the table. He ran off again when he realised the pepper shaker was actually empty.
(b) Alice paused before grabbing the **pepper/chilli/spoons/betray** from the supermarket shelf. The last thing she needed now was a new pepper grinder from the next aisle.

4 (a) After dinner was finished, the maid washed the **dishes/stove/window/played** with water and soap. She often left the dishes to last because they always took the longest.
(b) Mum looked at the **dishes/stove/window/played** as she thought about what to do next. There were not enough dishes left so she decided to do the washing up first.

5 (a) As soon as the war broke out, Nathan decided to join the **army/navy/spies/sees** who were defending the country. Unfortunately, this required army training first.
(b) Unexpectedly, the **army/navy/spies/sees** snatched complete control of the troubled country from the government. It would not be long before the army also started killing people.

6 (a) I was lucky to visit my favourite aunt and **uncle/niece/puppy/fixes** over the Christmas break. Usually, my uncle does not get leave at that time of year.
(b) I was excited to see my **uncle/niece/puppy/fixes** after his surgery on the weekend. I knew that my uncle would have bought lots of food to celebrate.

7 (a) Liam is a grouch in the morning until he has had a **coffee/drink/shower/droops** and either read or watched the news. Either way, a coffee will always come first for him.
(b) A single voucher for a free **coffee/drink/shower/droops** was the pathetic compensation for my cancelled flight. I needed a strong coffee to get me through the ordeal.

8 (a) The family dog liked to bury his **bone/toys/food/asks** under the rose bushes in the backyard. Every week or so, a <u>bone</u> of his would go missing like this.
(b) I gingerly picked up the **bone/toys/food/asks** from under the dining table. Such a <u>bone</u> could only have been left by the family dog.
9 (a) The renowned baker prepared his delicious three layered **cake/tart/plan/seek** for the wedding. He was also the best <u>cake</u> decorator in the industry.
(b) The mother could picture the perfect **cake/tart/plan/seek** for her son's birthday. Fortunately, she knew a great <u>cake</u> maker to help her with it.
10 (a) The young actress rehearsed the lines for her new blockbuster **movie/show/role/nags** until the early hours of the morning. The last <u>movie</u> that she had been part of had also been a hit.
(b) George did not know anything about the new **movie/show/role/nags** at the cinema. He decided to ask about it on <u>movie</u> night later that week.
11 (a) At the zoo, the distant but loud roar of the **lion/bear/siren/tore** made the schoolgirl jump. She had just walked past the <u>lion</u> compound so she felt nervous.
(b) The zookeeper was unsure if the noise came from a **lion/bear/siren/tore** or an elephant. He checked the <u>lion</u> enclosure though to make sure they weren't responsible for the sound.
12 (a) The farmer gets some of his fresh milk from the **cows/sheep/store/goes** on his farm. Often, he finds that the <u>cows</u> do not produce enough for his whole family to drink.
(b) Harry was surprised when the **cows/sheep/store/goes** on his farm began to attract a lot of visitors. He decided that the <u>cows</u> needed to move to another field to avoid the crowds.
13 (a) To fix the tear, Catherine used a needle and **thread/string/button/depend** from her sewing kit. There was not much <u>thread</u> left by the time she was done.
(b) The little girl used an orange **thread/string/button/depend** to make the doll's nose. Next, she looked for some gold <u>thread</u> to give it a necklace.
14 (a) Jack comforted his inconsolable sister before entering the church for the **funeral/service/concert/imagine** that he had organised. Last week, the <u>funeral</u> of her friend had also been held here.
(b) Fiona didn't pay attention to the **funeral/service/concert/imagine** that was unfolding on the television. Her mind was on the <u>funeral</u> of her mother that she had to attend today.
15 (a) The thirsty runner was handed an ice cold **drink/juice/towel/knelt** straight after the race. He put his last <u>drink</u> in the bin so he could take it.
(b) I asked for a **drink/juice/towel/knelt** from room service as soon as I arrived at the hotel. I was disappointed that there was not a single <u>drink</u> in the mini bar.
16 (a) The handyman pounded the nail into the wall with a **hammer/wrench/brick/darken** before hanging up the painting. He grabbed the <u>hammer</u> again when he realised it wasn't level.
(b) Last weekend, Dad dropped a **hammer/wrench/brick/darken** on his toe. Fortunately, it was not the massive <u>hammer</u> we usually keep in the garage.
17 (a) The flock of birds flew south for the **winter/season/coast/listen** earlier than they did last year. This year's <u>winter</u> was unusually cold by weather standards.
(b) The girl was surprised by how much she enjoyed the **winter/season/coast/listen** during her time in Russia. She did not expect <u>winter</u> to be so warm.

18 (a) The pianist with a classical background sat down to play the **piano/organ/radio/reach** for a while. She was waiting for the second hand piano she had just bought to be delivered.
(b) It was time to throw out the old **piano/organ/radio/reach** owned by our family for many years. We needed more space for the new piano we had just bought.

19 (a) After watching a waiter sneeze into someone's dinner, I demanded to speak with the **manager/director/customer/consider** about the incident. Even though the manager apologised, I was still disgusted.
(b) The power failure meant that the **manager/director/customer/consider** was trapped inside the lift of the department store. Frantically, the manager tried to call someone to get it working.

20 (a) Jim decided to vote for his usual political **party/group/roots/prove** at the election. Like many others, his party preferences had been passed down from his parents.
(b) The large **party/group/roots/prove** in the garden was broken up by the big storm. Just yesterday, the weather had been lovely for the party I had planned for my sister.

21 (a) Alex hoped that the brain training would make him **smarter/better/richer/please** than before. He had a smarter brother that he needed to beat.
(b) The new company director was definitely **smarter/better/richer/please** than the previous one. In fact, we've never had a smarter leader than him before.

22 (a) Frank was tired of the children next door throwing stones and breaking his **windows/chimney/bicycle/removes** all the time. One time, they had also broken the windows of the nearby corner store.
(b) Owen watched the **windows/chimney/bicycle/removes** of his neighbours being vandalised by graffiti. His bedroom windows gave him a perfect view of the perpetrators.

23 (a) The cat ran around the house trying to catch the **mouse/shrew/light/learn** but it was simply too fast. Before long, the cat stopped to play with its toy mouse in the living room.
(b) The video showed a **mouse/shrew/light/learn** moving across the screen. In a moment, a mouse double its size would catch up to it.

24 (a) At the park, three homeless men were sitting on the **bench/seats/grass/teach** next to the metal gate arguing loudly. I saw a bench next to them but decided not to sit there.
(b) The bird flew near the **bench/seats/grass/teach** where a couple sat eating some hot chips. The nearby bench was covered in bread crumbs but it was not interested.

25 (a) My favourite zoo exhibit were the flightless **birds/ducks/wasps/cried** from New Zealand. My best friend enjoyed seeing the birds of prey area the most.
(b) Often, there are **birds/ducks/wasps/cried** that come through the back door of our house by accident. Our family birds would always squawk very loudly when that happened.

26 (a) The greedy businessman has been obsessed with **money/coins/rugby/stood** since a young age. His wife is worried that all his money will be lost because of it one day.
(b) I used to think that **money/coins/rugby/stood** and girls were the most important things to me. I know now that money can't buy happiness.

27 (a) My favourite place to skate in winter is the ice **rink/park/zone/stun** at the local mall. The kids <u>rink</u> is also right next to it.
(b) The council will open a new **rink/park/zone/stun** for hockey players next week. There isn't a <u>rink</u> better in the whole state.
28 (a) As part of his Halloween costume, my son wore a scary **mask/hood/sign/sits** and fake bloody teeth. In all honesty, I found his <u>mask</u> the most frightening.
(b) Out of nowhere, a **mask/hood/sign/sits** fell from the doorway of the haunted house. Its design reminded me of a certain <u>mask</u> from my childhood nightmares.
29 (a) The princess felt confident as she skilfully mounted the **horse/camel/steps/ought** in front of her. The suitor with a <u>horse</u> watched on in awe.
(b) The young man couldn't manage the **horse/camel/steps/ought** after having too many drinks. A nearby policeman on <u>horse</u> came over to help.
30 (a) Rebecca lit the fire with a **match/lighter/stake/greet** but it immediately went out. She picked up the <u>match</u> box on the counter to try again.
(b) The scout leader could not see the **match/lighter/stake/greet** in the dark. Instead, he tried to feel around for the <u>match</u> so that he could make a fire.
31 (a) The chef couldn't help crying as he chopped up the **onion/food/plank/occur** to vent his anger. The horrible <u>onion</u> farmer had just conned him out of all his savings.
(b) James threw out the old **onion/food/plank/occur** that had been sitting in his kitchen since last week. This left more space for him to make an <u>onion</u> soup for dinner that night.
32 (a) The large cut on the boy's forehead meant that he needed **stitches/bandages/checking/happened** as soon as possible. Fortunately, the required <u>stitches</u> would not cause permanent scarring.
(b) There was a lack of **stitches/bandages/checking/happened** at the hospital. Even though my son needed <u>stitches</u> urgently, he was turned away for not being a serious case.
33 (a) In the art class, Matthew went to sharpen his **pencil/rubber/dagger/wished** for the important task. He wanted to do a <u>pencil</u> drawing of all his toy weapons.
(b) My aunty gave me a limited edition **pencil/rubber/dagger/wished** for my birthday. This was to make up for the big <u>pencil</u> set she couldn't afford to buy me.
34 (a) David was a promising football player until he was **injured/wounded/burgled/problem** several years ago. His poor <u>injured</u> foot has never been the same since then.
(b) I did not expect to be **injured/wounded/burgled/problem** on my holiday overseas. My badly <u>injured</u> arm meant that I had to return home early.
35 (a) When I can't sleep, I close my eyes and count **sheep/goats/beans/begin** in my head. I think that <u>sheep</u> counting is overrated because it doesn't always work for me.
(b) Dale watched the **sheep/goats/beans/begin** on the neighbouring farm absentmindedly. The sound of his <u>sheep</u> turned his attention back to his farm.
36 (a) Just before the minister began the service, the sound of the church **bells/chime/phone/avoid** echoed around the room. The noise reminded me of the <u>bells</u> at school that used to ring before lunch.
(b) I could hear the **bells/chime/phone/avoid** ring clearly from the next room. It sounded like someone banging <u>bells</u> together with all their strength.
37 (a) The opera singer has meticulously trained her **voice/sound/child/lacks** for a number of years. Nothing compared to having the <u>voice</u> of an angel in her opinion.

(b) Mary tried to ignore the **voice/sound/child/lacks** as best as she could. But the <u>voice</u> of a screaming toddler is very hard to block out.

38 (a) The nervous parachutist jumped out of the **plane/train/chair/reads** as soon as he heard the announcement. There was a <u>plane</u> filled with explosives on course to hit them.

(b) The tired movie maker was fast asleep in the **plane/train/chair/reads** on his way to the premiere. At the same moment, the <u>plane</u> of his leading actress also touched down in the country.

39 (a) Denise felt that the sauna room was too **hot/humid/loud/bled** for her to be comfortable. Apparently, it was not <u>hot</u> enough for her friend though.

(b) The hotel room was **hot/humid/loud/bled** which made it hard for me to nap. It was also too <u>hot</u> when I tried sitting out on the balcony.

40 (a) It was hard to sleep with the fluorescent **light/glare/sign/frees** of the neighbouring shop streaming into the room. Even the <u>light</u> from the moon was strong that night.

(b) Tammy couldn't see the **light/glare/sign/frees** on the computer screen without her glasses. She switched the <u>light</u> on to help her see better.

41 (a) To change the colour of his walls, Dave bought some glossy **paint/spray/paper/yelps** from the hardware store. He needed to get the <u>paint</u> currently in his house stripped before starting anything though.

(b) I found some **paint/spray/paper/yelps** in different metallic colours in the garage. They were stored in the oldest looking <u>paint</u> cans I'd ever seen.

42 (a) The cleaner warned her manager about the slippery **floor/ground/handle/called** just as he was about to open the door. She was on her way from the <u>floor</u> above to clean it up.

(b) Sarah didn't realise that the **floor/ground/handle/called** was a bit sticky. But soon enough, she would notice that the <u>floor</u> of her bedroom was completely covered in blood.

43 (a) The lifeguard kept an eye on the children playing in the shallow **water/pools/caves/bless** by the beach. He didn't want the <u>water</u> to suddenly sweep them away.

(b) Summer days spent in the **water/pools/caves/bless** swimming makes me happy. There is nothing like the <u>water</u> to keep you cool on those days.

44 (a) Rick was a good comedian who could make his friends laugh with a funny **joke/tale/move/pays** within seconds. He could make a <u>joke</u> out of absolutely anything.

(b) The inconsiderate **joke/tale/move/pays** ruined the entire night for Bradley. One should never <u>joke</u> about another's marriage breakdown.

45 (a) The beautiful lady wearing a lovely fragrant **perfume/scent/garland/sustain** entered the hotel lobby. For some reason, I was reminded of the <u>perfume</u> my mother used to wear.

(b) The woman needed a **perfume/scent/garland/sustain** for the dinner. A nice <u>perfume</u> was all that she was now missing from her outfit.

46 (a) I screamed as I dropped the boiling **water/broth/beans/kills** onto the floor. I had been trying to move the <u>water</u> bottle out of the way with one hand.

(b) Tracey went to get some **water/broth/beans/kills** from the fridge in the kitchen. That's when she saw that the <u>water</u> in the saucepan had almost boiled dry.

47 (a) Irene and her husband travelled by boat to the tropical **island/resort/garden/seeing** for their honeymoon. It was close to the island they had chosen for their wedding.
(b) Today we visited a beautiful **island/resort/garden/seeing** famous for exotic birds. Tomorrow, we will go to the island where the capital is located.

48 (a) I took the forks and knives outside to set the **table/bench/scene/stank** in the garden for lunch. I left the ice for the drinks on the table inside because it was a hot day.
(b) I was very excited as the **table/bench/scene/stank** from my favourite movie came into shot. It was the table where the sitting couple were about to be engaged.

49 (a) Everyone in the court rose to their feet when the **judge/jury/queen/poach** entered the room. The now disgraced judge was about to receive his sentencing.
(b) Even with extra time, the **judge/jury/queen/poach** could not reach a decision about the case. It was decided another judge should take over.

50 (a) For their parents' anniversary, Linda and Samuel organised a big **party/dance/crowd/smelt** to celebrate. Linda knew the best party planner for the occasion.
(b) Betty did not want to join the **party/dance/crowd/smelt** at the beach. There was a party nearly every weekend so she would not be missing much if she did not go.

51 (a) Mark decided that the best time to speak to the priest would be on Sunday inside the **church/chapel/garden/weaken** after the service. He hoped that the church goers would have all left by then.
(b) I waited outside the **church/chapel/garden/weaken** for my mother. She had been speaking with the church ministers for at least an hour now.

52 (a) Rhonda washed her mug because it was a little **dirty/grimy/brown/abort** from her morning coffee. She made sure not to use the dirty sponge in the sink.
(b) Emily was happy that her old **dirty/grimy/brown/abort** ballet shoes were finally replaced with a new pair. There were always dirty footprints in the house when she used to wear them.

53 (a) It took the skilled gardener nearly two hours to pull out all the **weeds/roots/bones/began** in the front yard. Next, he would need to do the weeds behind the house.
(b) There were **weeds/roots/bones/began** covering the driveway of the old and run down house. It was mainly the weeds problem that made the place difficult to sell.

54 (a) The dangerous criminal flaunting a sharp **knife/blade/style/enjoy** entered the shopping centre. Because his knife was not well hidden, the nearest person immediately screamed.
(b) The cook's **knife/blade/style/enjoy** captured everyone's attention in the kitchen. I had never seen a knife slice through raw salmon with such precision.

55 (a) Edward's sister was home last night and played loud **music/tunes/games/refer** until midnight. Even worse, she had music from the eighties playing which he hated.
(b) I still had to finalise the **music/tunes/games/refer** and food for tomorrow's party. The only thing I had decided on was that music would be the theme.

56 (a) The manager reminded us all to work as a **team/crew/cook/pray** for the rest of the week. As everyone was a team player, I knew we would get the job done.
(b) My brother needed a **team/crew/cook/pray** to help cater his party. Fortunately, the best team for it was his own family.

57 (a) Because Valerie was going away, she asked a friend to come water her **plants/garden/rabbit/reckon** whenever they could. She hoped they would also be able to feed her plants when necessary.
(b) The painting of the **plants/garden/rabbit/reckon** was beautiful. The gallery decided to hang it amongst the plants in the foyer to let it blend in.

58 (a) The parents cried when they found out their child had been born with a rare **disease/illness/swelling/suggest** of the liver. Fortunately, the disease could be controlled with ongoing medication.
(b) Samuel hoped the **disease/illness/swelling/suggest** in his eye would not flare up on the last day of school. He did not want the disease to be how he was remembered.

59 (a) The teacher marked the students' work with a red **pen/biro/line/fled** during the lunch break. When her pen ran out of ink, she used an orange one instead.
(b) I could barely see the **pen/biro/line/fled** marking on the piece of paper I was given. I wished that a proper pen had been used to mark out my medication.

60 (a) After three attempts, I was ecstatic to finally get my driver's **licence/permit/plates/annoys** on the weekend. My brother's licence had not taken as long.
(b) I left my car **licence/permit/plates/annoys** on the kitchen counter in my hurry to leave. I hoped that my licence points would not be deducted if I were caught without them.

61 (a) Rita stepped out of the shower and dried her hair with a **towel/cloth/dryer/spend** that she had packed with her. The hotel towel smelt funny so she didn't use it.
(b) I moved the **towel/cloth/dryer/spend** out of the way and onto the floor. I was planning to install a towel rack in my bathroom.

62 (a) The graceful ballerina pulled some muscles in her **legs/back/show/wore** that caused a lot of pain. She recently had an operation on her legs that should have fixed the problem.
(b) I watched the **legs/back/show/wore** of the lions prowling in amazement. The zoo exhibit also let my legs take a rest from walking for a moment.

63 (a) The careless thieves set off the loud **alarm/alert/puppy/gives** and the owners immediately woke up. They knew that the alarm system would notify the police so they tried to stay calm.
(b) The sound of the **alarm/alert/puppy/gives** rattled my bedroom windows. Even though my alarm wasn't set to go off for another hour, I got up to see what was wrong.

64 (a) At my grandmother's funeral, my mother gave a very moving **speech/sermon/dance/arrive** in her honour. This was followed by another speech by my aunt.
(b) The first day started with a great **speech/sermon/dance/arrive** by the conference director which captivated the audience. I was nervous for my speech to follow such an amazing start.

65 (a) When we went fishing, we always took a bucket of worms to use as **bait/food/help/grow** to catch the fish. If the bait was getting low, we knew that it was time to go home.

(b) It was useless without **bait/food/help/grow** to try and catch the rat in our house. I needed to buy cheese <u>bait</u> from the shops tomorrow.

66 (a) The dentist carelessly let the extracted tooth slip from the tweezers into the patient's **mouth/face/shirt/cling** for a second. The nurse's <u>mouth</u> dropped open in shock.

(b) The physiotherapist asked me to move my **mouth/face/shirt/cling** to one side. He wanted to check my <u>mouth</u> and overall head movements.

67 (a) Because Mary needs to see a doctor again, she will arrange for another **appointment/consultation/babysitter/articulates** later today. She hoped that the <u>appointment</u> would not be difficult to arrange.

(b) I was annoyed to find out that my **appointment/consultation/babysitter/articulates** was delayed. I did not want to be late for my <u>appointment</u> with my hairdresser.

68 (a) After accidentally falling into the deep end of the pool, Daniel was rescued by the **lifeguard/attendant/gentleman/pretended** sitting nearby. He was taken to the <u>lifeguard</u> room immediately for a check up.

(b) In the distance, I could see the **lifeguard/attendant/gentleman/pretended** strolling along the beach. He was closely monitoring the new <u>lifeguard</u> in training.

69 (a) The bank customers froze when they noticed the men armed with **guns/axes/cash/went** running towards them. Minutes later, several <u>guns</u> were fired by the police outside as a warning to surrender.

(b) It was hard to overlook the pile of **guns/axes/cash/went** sitting on the counter. The shop which was famous for its <u>guns</u> was clearly making a lot of money.

70 (a) The romantic dinner was accompanied by a nice red **wine/drink/meat/earn** and brightly lit candles. I was pleased to find out that the <u>wine</u> was also complimentary.

(b) I went to check that there was still enough **wine/drink/meat/earn** at the party for everyone. Then I returned with my <u>wine</u> to my spot by the fireplace.

71 (a) After the blizzard, the children spent the whole day building a **snowman/figurine/hideout/believe** in the snow. There were already several <u>snowman</u> bodies lining their street.

(b) My annoying brother made me watch over his **snowman/figurine/hideout/believe** in the garden while he went to the bathroom. All I wanted to do was make my <u>snowman</u> at the end of the yard.

72 (a) As soon as Chris arrived home, his mother told him to remove his muddy **shoes/socks/balls/thank** from the house that she had just cleaned. He got his <u>shoes</u> and did as he was told.

(b) The brown **shoes/socks/balls/thank** camouflaged by the front door almost tripped me over. I used my <u>shoes</u> to clear the way a little.

73 (a) The shepherd spent all day looking for his lost **sheep/cows/tools/bring** in the rain. He first looked in the field where he had wandered with his <u>sheep</u> earlier in the day.

(b) The farmer reported some **sheep/cows/tools/bring** missing to the police. Only last week, the authorities had heard about some <u>sheep</u> being transported suspiciously in the countryside.

74 (a) Bill was distracted at the intersection and didn't notice the lights go **green/amber/crazy/hunts** for a few seconds. He didn't wait for the <u>green</u> to return before he crossed.

(b) Audrey was on her way to purchase some **green/amber/crazy/hunts** looking plants for her new apartment. She wanted a nice and interesting green space for her visitors.

75 (a) After many hours of hiking in the wilderness, we were glad to finally set up **camp/base/home/lose** for the night. There was a proper camp site nearby in case anything happened.

(b) The foreigner was glad to be at the **camp/base/home/lose** of the allied soldiers. Unfortunately, his camp was many hundreds of kilometres away.

76 (a) Evan couldn't change the television channel in the waiting room because he couldn't find the **remote/device/person/retire** to do it. Eventually, the remote turned up under a couch.

(b) I went to the shops to buy a little toy **remote/device/person/retire** for my brother. It was for the remote controlled car that he had received for his birthday.

Sentences used in Chapter 3 Experiment 3

For each quartet: (a) strongly constraining context, related initial target, previously predictable or unrelated downstream target, (b) strongly constraining context, unrelated initial target, previously predictable or related downstream target, (c) weakly constraining context, related initial target, previously predictable or unrelated downstream target, (d) weakly constraining context, unrelated initial target, previously predictable or related downstream target. The target word is bolded and the downstream word is underlined.

1 (a) The comedian's witty jokes made the audience **smile** awkwardly for a second. Then a <u>laugh/groan</u> drew the comedian's attention to the back of the crowd.
(b) The comedian's witty jokes made the audience **groan** awkwardly for a second. Then a <u>laugh/smile</u> drew the comedian's attention to the back of the crowd.
(c) Jane made her nephew **smile** by tickling him. He had to <u>laugh/groan</u> immediately afterwards because he couldn't help it.
(d) Jane made her nephew **groan** by tickling him. He had to <u>laugh/smile</u> immediately afterwards because he couldn't help it.

2 (a) In the centre of the cobweb were two big black **flies** that were almost hidden. I thought they were <u>spiders/buttons</u> at first because they were so huge.
(b) In the centre of the cobweb were two big black **buttons** that were almost hidden. I thought they were <u>spiders/flies</u> at first because they were so huge.
(c) The girl touched the **flies** with her index finger. They reminded her of <u>spiders/buttons</u> because of their roundness.
(d) The girl touched the **buttons** with her index finger. They reminded her of <u>spiders/flies</u> because of their roundness.

3 (a) The waiter thought everything was ready when he put the salt and **chilli** down onto the table. But the lady wanted extra <u>pepper/spoons</u> so he had to run off again.
(b) The waiter thought everything was ready when he put the salt and **spoons** down onto the table. But the lady wanted extra <u>pepper/chilli</u> so he had to run off again.
(c) Alice quickly grabbed the **chilli** from the supermarket shelf. She also had to remember the <u>pepper/spoons</u> her husband wanted.
(d) Alice quickly grabbed the **spoons** from the supermarket shelf. She also had to remember the <u>pepper/chilli</u> her husband wanted.

4 (a) After dinner was finished, the maid washed the **stove** with water and soap. At the same time, the <u>dishes/window</u> were cleaned by the other servant.
(b) After dinner was finished, the maid washed the **window** with water and soap. At the same time, the <u>dishes/stove</u> were cleaned by the other servant.
(c) Mum looked at the **stove** as she thought about what to do next. She decided that the <u>dishes/window</u> had to be cleaned before Dad got home.
(d) Mum looked at the **window** as she thought about what to do next. She decided that the <u>dishes/stove</u> had to be cleaned before Dad got home.

5 (a) As soon as the war broke out, Nathan decided to join the **navy** to help out. Along with the army/spies, they would defend the country as best as they could.
(b) As soon as the war broke out, Nathan decided to join the **spies** to help out. Along with the army/navy, they would defend the country as best as they could.
(c) Without any warning, the **navy** snatched control of the troubled country from the government. Just last week, the army/spies had unsuccessfully tried to do the same thing.
(d) Without any warning, the **spies** snatched control of the troubled country from the government. Just last week, the army/navy had unsuccessfully tried to do the same thing.

6 (a) I was lucky to visit my favourite aunt and **niece** over the Christmas break. They were taking care of an uncle/puppy who was very sick.
(b) I was lucky to visit my favourite aunt and **puppy** over the Christmas break. They were taking care of an uncle/niece who was very sick.
(c) I was looking forward to seeing my **niece** after her surgery on the weekend. I knew that my uncle/puppy in particular would be extremely excited.
(d) I was looking forward to seeing my **puppy** after her surgery on the weekend. I knew that my uncle/niece in particular would be extremely excited.

7 (a) Liam is a grouch in the morning until he has had a **drink** to wake him up. But sometimes a coffee/shower is the only thing that does the trick.
(b) Liam is a grouch in the morning until he has had a **shower** to wake him up. But sometimes a coffee/drink is the only thing that does the trick.
(c) Daniel had a quick **drink** when he got home even though he was in a hurry. He almost had a coffee/shower too but decided against it.
(d) Daniel had a quick **shower** when he got home even though he was in a hurry. He almost had a coffee/drink too but decided against it.

8 (a) The family dog liked to bury his **toys** under the rose bushes in the backyard. Often, he would use his bone/food to mark the spot.
(b) The family dog liked to bury his **food** under the rose bushes in the backyard. Often, he would use his bone/toys to mark the spot.
(c) I had to pick up all the **toys** from the floor before I could start vacuuming. There was even some bone/food left by the dog in the pile.
(d) I had to pick up all the **food** from the floor before I could start vacuuming. There was even some bone/toys left by the dog in the pile.

9 (a) The renowned baker prepared his delicious three layered **tart** for the wedding. The couple changed the cake/plan they wanted at the last minute.
(b) The renowned baker prepared his delicious three layered **plan** for the wedding. The couple changed the cake/tart they wanted at the last minute.
(c) The mother could picture the perfect **tart** for her son's birthday. Because the cake/plan for his last party had been a disaster, she was desperate to make amends.
(d) The mother could picture the perfect **plan** for her son's birthday. Because the cake/tart for his last party had been a disaster, she was desperate to make amends.

10 (a) The young actress rehearsed the lines for her new blockbuster **show** until she could remember them. She hoped that the movie/role would make her famous.
(b) The young actress rehearsed the lines for her new blockbuster **role** until she could remember them. She hoped that the movie/show would make her famous.

(c) George knew nothing about the new **show** by his favourite actress. But the last movie/role she had done was his favourite.
(d) George knew nothing about the new **role** by his favourite actress. But the last movie/show she had done was his favourite.

11 (a) At the zoo, the distant but loud roar of the **bear** made the schoolgirl jump. There was a lion/siren nearby that was already making her nervous.
(b) At the zoo, the distant but loud roar of the **siren** made the schoolgirl jump. There was a lion/bear nearby that was already making her nervous.
(c) The zookeeper was unsure if the noise came from a **bear** or something else. If it was a lion/siren, the whole zoo would need to go into lockdown.
(d) The zookeeper was unsure if the noise came from a **siren** or something else. If it was a lion/bear, the whole zoo would need to go into lockdown.

12 (a) The farmer gets most of his fresh milk from the **sheep** on his farm. Occasionally he goes to the cows/store when he needs more.
(b) The farmer gets most of his fresh milk from the **store** on his farm. Occasionally he goes to the cows/sheep when he needs more.
(c) Harry had a lot of people visit the **sheep** on his farm over the summer. Most of them would also stop to see his cows/store in the next field.
(d) Harry had a lot of people visit the **store** on his farm over the summer. Most of them would also stop to see his cows/sheep in the next field.

13 (a) To fix the tear, Helena used a needle and **string** from her sewing kit. Part of the thread/button along the zip of her skirt had come loose.
(b) To fix the tear, Helena used a needle and **button** from her sewing kit. Part of the thread/string along the zip of her skirt had come loose.
(c) The little girl only had a black **string** left to make the doll's nose. She had a thread/button of gold colour somewhere but she couldn't find it.
(d) The little girl only had a black **button** left to make the doll's nose. She had a thread/string of gold colour somewhere but she couldn't find it.

14 (a) Jack comforted his inconsolable sister before entering the church for the **service** that had just begun. Only last week, her friend's funeral/concert had been held there.
(b) Jack comforted his inconsolable sister before entering the church for the **concert** that had just begun. Only last week, her friend's funeral/service had been held there.
(c) Fiona didn't pay attention to the **service** that was unfolding on the television. Her mind was on the funeral/concert that she had to finish organising.
(d) Fiona didn't pay attention to the **concert** that was unfolding on the television. Her mind was on the funeral/service that she had to finish organising.

15 (a) The thirsty runner was handed an ice cold **juice** straight after the race. She really wanted a drink/towel instead though.
(b) The thirsty runner was handed an ice cold **towel** straight after the race. She really wanted a drink/juice instead though.
(c) I phoned for a **juice** from room service as soon as I arrived at the hotel. I had to call again for an extra drink/towel later that night.
(d) I phoned for a **towel** from room service as soon as I arrived at the hotel. I had to call again for an extra drink/juice later that night.

16 (a) The handyman pounded the nail into the wall with a **wrench** before hanging up the painting. He had a hammer/brick too but it was useless at the job.

(b) The handyman pounded the nail into the wall with a **brick** before hanging up the painting. He had a hammer/wrench too but it was useless at the job.
(c) Last weekend, Dad dropped a **wrench** onto his toe while cleaning. Fortunately, it was not the massive hammer/brick he had moved just beforehand.
(d) Last weekend, Dad dropped a **brick** onto his toe while cleaning. Fortunately, it was not the massive hammer/wrench he had moved just beforehand.

17 (a) The flock of birds flew south for the **season** earlier than they did last year. As soon as the winter/coast here was warm again, they would return.
(b) The flock of birds flew south for the **coast** earlier than they did last year. As soon as the winter/season here was warm again, they would return.
(c) The girl was surprised by how much the **season** had changed since her last visit. She remembered that the winter/coast last year had been much colder.
(d) The girl was surprised by how much the **coast** had changed since her last visit. She remembered that the winter/season last year had been much colder.

18 (a) The classical musician sat down and played the **organ** for a while. She was waiting for the piano/radio that she had ordered to arrive.
(b) The classical musician sat down and played the **radio** for a while. She was waiting for the piano/organ that she had ordered to arrive.
(c) It was time for the **organ** at the church to be replaced after thirty years. It was decided that a piano/radio would be more useful when we needed music.
(d) It was time for the **radio** at the church to be replaced after thirty years. It was decided that a piano/organ would be more useful when we needed music.

19 (a) After watching a waiter sneeze into someone's dinner, I demanded to speak with the **director** about it. Although the manager/customer seemed unfazed, I was disgusted.
(b) After watching a waiter sneeze into someone's dinner, I demanded to speak with the **customer** about it. Although the manager/director seemed unfazed, I was disgusted.
(c) The power failure meant that the **director** was trapped inside the store lift. Immediately, the manager/customer nearby raised the alarm.
(d) The power failure meant that the **customer** was trapped inside the store lift. Immediately, the manager/director nearby raised the alarm.

20 (a) Jim decided to vote for his usual political **group** at the election. He had to give his party/roots the support it needed.
(b) Jim decided to vote for his usual political **roots** at the election. He had to give his party/group the support it needed.
(c) Peter thought about the **group** that had made him into the person he was today. He had to be loyal to the party/roots that had shaped his character.
(d) Peter thought about the **roots** that had made him into the person he was today. He had to be loyal to the party/group that had shaped his character.

21 (a) Alex hoped that the brain training would make him **better** than before. He wanted to end up smarter/richer than his brother who always teased him.
(b) Alex hoped that the brain training would make him **richer** than before. He wanted to end up smarter/better than his brother who always teased him.
(c) The new company director was definitely **better** than we expected. On top of that, he was a smarter/richer leader than the one we had before.

(d) The new company director was definitely **richer** than we expected. On top of that, he was a <u>smarter/better</u> leader than the one we had before.

22 (a) Frank was tired of the children next door throwing stones and breaking his **chimney** all the time. Last night, his <u>windows/bicycle</u> had also been damaged.
(b) Frank was tired of the children next door throwing stones and breaking his **bicycle** all the time. Last night, his <u>windows/chimney</u> had also been damaged.
(c) Owen decided that his **chimney** needed to be repainted. After doing his <u>windows/bicycle</u>, he still had some left over paint.
(d) Owen decided that his **bicycle** needed to be repainted. After doing his <u>windows/chimney</u>, he still had some left over paint.

23 (a) The cat ran around the house trying to catch the **shrew** but it was simply too fast. I tried to distract it with a toy <u>mouse/light</u> but unsuccessfully.
(b) The cat ran around the house trying to catch the **light** but it was simply too fast. I tried to distract it with a toy <u>mouse/shrew</u> but unsuccessfully.
(c) I watched as the **shrew** moved from one side of the room to the other. It was like a <u>mouse/light</u> but almost faster.
(d) I watched as the **light** moved from one side of the room to the other. It was like a <u>mouse/shrew</u> but almost faster.

24 (a) At the park, three homeless men were sitting on the **seats** talking quietly. Soon, they walked over to the <u>bench/grass</u> near the bike path where there was more shade.
(b) At the park, three homeless men were sitting on the **grass** talking quietly. Soon, they walked over to the <u>bench/seats</u> near the bike path where there was more shade.
(c) The bird flew near the **seats** where a couple sat eating some hot chips. The nearby <u>bench/grass</u> was covered in bread crumbs but it was not interested.
(d) The bird flew near the **grass** where a couple sat eating some hot chips. The nearby <u>bench/seats</u> was covered in bread crumbs but it was not interested.

25 (a) My favourite zoo exhibit was the flightless **ducks** which I had never seen before. My best friend liked seeing the baby <u>birds/wasps</u> the most.
(b) My favourite zoo exhibit was the flightless **wasps** which I had never seen before. My best friend liked seeing the baby <u>birds/ducks</u> the most.
(c) We always get **ducks** in the house if we forget to close our back door. We also get <u>birds/wasps</u> straying in from time to time too.
(d) We always get **wasps** in the house if we forget to close our back door. We also get <u>birds/ducks</u> straying in from time to time too.

26 (a) The greedy businessman has been obsessed with **coins** since a young age. Apart from <u>money/rugby</u>, it was the only thing he invested his time in.
(b) The greedy businessman has been obsessed with **rugby** since a young age. Apart from <u>money/coins</u>, it was the only thing he invested his time in.
(c) Dad's main hobby was **coins** since I could remember. But he was also writing a book on <u>money/rugby</u> during his spare time.
(d) Dad's main hobby was **rugby** since I could remember. But he was also writing a book on <u>money/coins</u> during his spare time.

27 (a) My favourite place to skate in winter is the ice **park** at the local mall. They have a <u>rink/zone</u> just for beginners which suits me well.

(b) My favourite place to skate in winter is the ice **zone** at the local mall. They have a rink/park just for beginners which suits me well.
(c) The council will open a new **park** for ice hockey players next week. Sadly, the rink/zone where they used to practice had to be closed down last year.
(d) The council will open a new **zone** for ice hockey players next week. Sadly, the rink/park where they used to practice had to be closed down last year.

28 (a) As part of his Halloween costume, my son wore a scary **hood** around the neighbourhood. He had a mask/sign to go with it too.
(b) As part of his Halloween costume, my son wore a scary **sign** around the neighbourhood. He had a mask/hood to go with it too.
(c) While using a **hood** to cover his face, the offender ran out of the courthouse. His mother had a mask/sign for hiding her face too.
(d) While using a **sign** to cover his face, the offender ran out of the courthouse. His mother had a mask/hood for hiding her face too.

29 (a) The princess felt confident as she skilfully mounted the **camel** in front of her. On the horse/steps behind, the suitor watched on in awe.
(b) The princess felt confident as she skilfully mounted the **steps** in front of her. On the horse/camel behind, the suitor watched on in awe.
(c) The young man couldn't manage his **camel** after one too many drinks. Fortunately, a policeman on the horse/steps nearby came to help.
(d) The young man couldn't manage his **steps** after one too many drinks. Fortunately, a policeman on the horse/camel nearby came to help.

30 (a) Rebecca lit the fire with a **lighter** but it immediately went out. She had a match/stake as well but it would not light.
(b) Rebecca lit the fire with a **stake** but it immediately went out. She had a match/lighter as well but it would not light.
(c) The scout leader packed a **lighter** into his bag as the final thing. He also remembered a match/stake for back up just in case.
(d) The scout leader packed a **stake** into his bag as the final thing. He also remembered a match/lighter for back up just in case.

31 (a) The chef couldn't help crying as he chopped up the **food** to vent his anger. He was ready to throw the nearby onion/plank at the rude customer.
(b) The chef couldn't help crying as he chopped up the **plank** to vent his anger. He was ready to throw the nearby onion/food at the rude customer.
(c) James threw out the old **food** that he had chopped but never used. He needed more space to prepare the onion/plank for the wood fired oven.
(d) James threw out the old **plank** that he had chopped but never used. He needed more space to prepare the onion/food for the wood fired oven.

32 (a) The large cut on the boy's forehead meant that he needed **bandages** at the hospital. The nurse who did the stitches/checking was very nice.
(b) The large cut on the boy's forehead meant that he needed **checking** at the hospital. The nurse who did the stitches/bandages was very nice.
(c) The doctor asked the intern to do the **bandages** for the man who had just come in. It was because he needed to finish the stitches/checking of another patient.
(d) The doctor asked the intern to do the **checking** for the man who had just come in. It was because he needed to finish the stitches/bandages of another patient.

33 (a) In the art class, Matthew tried to sharpen his **rubber** which he wasn't supposed to. The teacher told him to focus on drawing the pencil/dagger in front of him.
(b) In the art class, Matthew tried to sharpen his **dagger** which he wasn't supposed to. The teacher told him to focus on drawing the pencil/rubber in front of him.
(c) My little brother took a **rubber** to school for show and tell. He was deciding between that and the pencil/dagger he got for Christmas.
(d) My little brother took a **dagger** to school for show and tell. He was deciding between that and the pencil/rubber he got for Christmas.

34 (a) David was a promising football player until he was **wounded** several years ago. He never recovered from being injured/burgled by those three men.
(b) David was a promising football player until he was **burgled** several years ago. He never recovered from being injured/wounded by those three men.
(c) I did not expect to be **wounded** on holiday overseas. Because being injured/burgled was covered by insurance, my hospital visit was free.
(d) I did not expect to be **burgled** on holiday overseas. Because being injured/wounded was covered by insurance, my hospital visit was free.

35 (a) When I can't sleep, I close my eyes and count **goats** in my head. I previously tried using sheep/beans but they got a bit boring.
(b) When I can't sleep, I close my eyes and count **beans** in my head. I previously tried using sheep/goats but they got a bit boring.
(c) For a living, Dale sold **goats** from his farm to other farmers. It made more money than the sheep/beans he used to sell.
(d) For a living, Dale sold **beans** from his farm to other farmers. It made more money than the sheep/goats he used to sell.

36 (a) Just as the minister began the service, the sound of the church **chime** echoed throughout. It was much louder than the bells/phone that rang out at the same time.
(b) Just as the minister began the service, the sound of the church **phone** echoed throughout. It was much louder than the bells/chime that rang out at the same time.
(c) Everyone thought it was rude that a **chime** would ring out during the wedding ceremony. But it was just some bells/phone that were malfunctioning.
(d) Everyone thought it was rude that a **phone** would ring out during the wedding ceremony. But it was just some bells/chime that were malfunctioning.

37 (a) The opera singer has meticulously trained her **sound** for a number of years. Apart from her voice/child, there was nothing else she cared more about.
(b) The opera singer has meticulously trained her **child** for a number of years. Apart from her voice/sound, there was nothing else she cared more about.
(c) All night, the **sound** next door interrupted Amy's sleep. Occasionally another voice/child would contribute to the raucous noise.
(d) All night, the **child** next door interrupted Amy's sleep. Occasionally another voice/sound would contribute to the raucous noise.

38 (a) The nervous parachutist jumped out of the **train** after he heard the news. There was a plane/chair nearby filled with explosives that was about to explode.
(b) The nervous parachutist jumped out of the **chair** after he heard the news. There was a plane/train nearby filled with explosives that was about to explode.
(c) The tired movie maker was fast asleep in the **train** when his phone rang. After being in a plane/chair for twenty hours, he was exhausted.

(d) The tired movie maker was fast asleep in the **chair** when his phone rang. After being in a plane/train for twenty hours, he was exhausted.

39 (a) Denise felt that the sauna room was too **humid** for her liking. The room was so hot/noisy as well that she wasn't used to it.
(b) Denise felt that the sauna room was too **noisy** for her liking. The room was so hot/humid as well that she wasn't used to it.
(c) The hotel room was **humid** and uncomfortable to sit in. And it was also too hot/noisy out on the balcony as well.
(d) The hotel room was **noisy** and uncomfortable to sit in. And it was also too hot/humid out on the balcony as well.

40 (a) It was hard to sleep with the fluorescent **glare** of the neighbouring shop streaming into the room. If only the light/sign could be switched off in the evenings.
(b) It was hard to sleep with the fluorescent **sign** of the neighbouring shop streaming into the room. If only the light/glare could be switched off in the evenings.
(c) Tammy couldn't see anything because the **glare** was blocking her view. She sighed before noticing a strange light/sign to her left.
(d) Tammy couldn't see anything because the **sign** was blocking her view. She sighed before noticing a strange light/glare to her left.

41 (a) To change the colour of his walls, Dave bought some glossy **spray** from the hardware store. He had wanted paint/paper too but they had run out.
(b) To change the colour of his walls, Dave bought some glossy **paper** from the hardware store. He had wanted paint/spray too but they had run out.
(c) The schoolboy used some **spray** that he found in the garage to start his crafts project. Then he decided to use some paint/paper for the next part.
(d) The schoolboy used some **paper** that he found in the garage to start his crafts project. Then he decided to use some paint/spray for the next part.

42 (a) The cleaner warned her manager about the slippery **ground** near the bathroom door. She had been cleaning the floor/handle when she noticed it.
(b) The cleaner warned her manager about the slippery **handle** near the bathroom door. She had been cleaning the floor/ground when she noticed it.
(c) Sarah didn't like the colour of the **ground** in her kitchen. It matched poorly with the floor/handle nearby which was brown.
(d) Sarah didn't like the colour of the **handle** in her kitchen. It matched poorly with the floor/ground nearby which was brown.

43 (a) The lifeguard kept an eye on the children playing in the shallow **pools** by the beach. The nearby water/caves was off limits so he had to make sure they didn't wander off.
(b) The lifeguard kept an eye on the children playing in the shallow **caves** by the beach. The nearby water/pools was off limits so he had to make sure they didn't wander off.
(c) The guide recommended the **pools** by the ocean for swimming. There was also the water/caves by the lake if we wanted something different.
(d) The guide recommended the **caves** by the ocean for swimming. There was also the water/pools by the lake if we wanted something different.

44 (a) Rick was a good comedian who could make his friends laugh with a funny **tale** within seconds. He had a joke/move for almost everything.

(b) Rick was a good comedian who could make his friends laugh with a funny **move** within seconds. He had a <u>joke/tale</u> for almost everything.
(c) His friend's unexpectedly nasty **tale** ruined the entire night for Bradley. It was a <u>joke/move</u> he found completely unnecessary.
(d) His friend's unexpectedly nasty **move** ruined the entire night for Bradley. It was a <u>joke/tale</u> he found completely unnecessary.

45 (a) The beautiful lady wearing a lovely fragrant **scent** entered the hotel lobby. Out of nowhere, I was reminded of the <u>perfume/garland</u> my mother used to wear.
(b) The beautiful lady wearing a lovely fragrant **garland** entered the hotel lobby. Out of nowhere, I was reminded of the <u>perfume/scent</u> my mother used to wear.
(c) The woman chose a **scent** to wear to the formal dinner. She had also been given a <u>perfume/garland</u> to wear by the organisers but she did not like it at all.
(d) The woman chose a **garland** to wear to the charity dinner. She had also been given a <u>perfume/scent</u> to wear by the organisers but she did not like it at all.

46 (a) I screamed as I dropped the boiling **broth** in the pot onto the floor. I probably needed to put more <u>water/beans</u> into the pot again.
(b) I screamed as I dropped the boiling **beans** in the pot onto the floor. I probably needed to put more <u>water/broth</u> into the pot again.
(c) Tracey went to get some **broth** from the fridge in the kitchen. That's when she saw that the <u>water/beans</u> in the saucepan had almost boiled dry.
(d) Tracey went to get some **beans** from the fridge in the kitchen. That's when she saw that the <u>water/broth</u> in the saucepan had almost boiled dry.

47 (a) Irene and her husband travelled by boat to the tropical **resort** for their honeymoon. It was close to the <u>island/garden</u> they had chosen for their wedding.
(b) Irene and her husband travelled by boat to the tropical **garden** for their honeymoon. It was close to the <u>island/resort</u> they had chosen for their wedding.
(c) Today we visited a beautiful **resort** full of exotic birds. Tomorrow we will go to the <u>island/garden</u> where we will spend the last few days of our holiday.
(d) Today we visited a beautiful **garden** full of exotic birds. Tomorrow we will go to the <u>island/resort</u> where we will spend the last few days of our holiday.

48 (a) I took the forks and knives outside to set the **bench** in the garden for lunch. Once I was done, the <u>table/scene</u> looked absolutely perfect.
(b) I took the forks and knives outside to set the **scene** in the garden for lunch. Once I was done, the <u>table/bench</u> looked absolutely perfect.
(c) The movie opened with a **bench** overlooking a city. Next it moved to a <u>table/scene</u> inside someone's backyard.
(d) The movie opened with a **scene** overlooking a city. Next it moved to a <u>table/bench</u> inside someone's backyard.

49 (a) Everyone in the court rose to their feet when the **jury** entered the room. They waited until the <u>judge/queen</u> arrived before sitting.
(b) Everyone in the court rose to their feet when the **queen** entered the room. They waited until the <u>judge/jury</u> arrived before sitting.
(c) After two weeks, the **jury** still had not reached a decision about the case. It was decided that the <u>judge/queen</u> would take over.
(d) After two weeks, the **queen** still had not reached a decision about the case. It was decided that the <u>judge/jury</u> would take over.

50 (a) For their parents' anniversary, Linda and Samuel organised a big **dance** to celebrate. In the end, the party/crowd was much bigger than they expected.
(b) For their parents' anniversary, Linda and Samuel organised a big **crowd** to celebrate. In the end, the party/dance was much bigger than they expected.
(c) Betty's friend wanted to take a closer look at the **dance** down on the beach. But Betty was afraid that the party/crowd would be full of people on drugs.
(d) Betty's friend wanted to take a closer look at the **crowd** down on the beach. But Betty was afraid that the party/dance would be full of people on drugs.

51 (a) Mark decided to speak to the priest on Sunday inside the **chapel** after the service. He had an issue with the church/garden that he needed to discuss.
(b) Mark decided to speak to the priest on Sunday inside the **garden** after the service. He had an issue with the church/chapel that he needed to discuss.
(c) I waited for my mother outside the **chapel** where she would pray. I went to the church/garden to look for her when she didn't come out after a while.
(d) I waited for my mother outside the **garden** where she would pray. I went to the church/chapel to look for her when she didn't come out after a while.

52 (a) Rhonda washed her mug because it was a little **grimy** from her morning coffee. She made sure not to use the dirty/brown sponge in the sink.
(b) Rhonda washed her mug because it was a little **brown** from her morning coffee. She made sure not to use the dirty/grimy sponge in the sink.
(c) Emily finally replaced her old **grimy** ballet shoes with a new pair. There were always dirty/brown footprints left behind when she wore them.
(d) Emily finally replaced her old **brown** ballet shoes with a new pair. There were always dirty/grimy footprints left behind when she wore them.

53 (a) It took the skilled gardener nearly two hours to pull out all the **roots** in front of the haunted house. The owner wanted the weeds/bones behind the house removed too.
(b) It took the skilled gardener nearly two hours to pull out all the **bones** in front of the haunted house. The owner wanted the weeds/roots behind the house removed too.
(c) The landlord was surprised to find **roots** under his house. He thought there would only be weeds/bones down there.
(d) The landlord was surprised to find **bones** under his house. He thought there would only be weeds/roots down there.

54 (a) The dangerous criminal flaunting a sharp **blade** entered the shopping centre. Immediately, his knife/style drew the attention of shoppers who started to run away.
(b) The dangerous criminal flaunting a sharp **style** entered the shopping centre. Immediately, his knife/blade drew the attention of shoppers who started to run away.
(c) The cook's **blade** captured everyone's attention in the kitchen. I had never seen a knife/style like his before.
(d) The cook's **style** captured everyone's attention in the kitchen. I had never seen a knife/blade like his before.

55 (a) Edward's sister was home last night and played loud **tunes** until midnight. He just wanted to enjoy his music/games in peace and quiet.

(b) Edward's sister was home last night and played loud **games** until midnight. He just wanted to enjoy his music/tunes in peace and quiet.
(c) I still had some **tunes** to choose before tomorrow night's Halloween party. There was going to be music/games to scare people as soon as they arrived.
(d) I still had some **games** to choose before tomorrow night's Halloween party. There was going to be music/tunes to scare people as soon as they arrived.

56 (a) The manager always reminded us to work as a **crew** when we were short staffed. Once in a while though, the team/cook would let him down.
(b) The manager always reminded us to work as a **cook** when we were short staffed. Once in a while though, the team/crew would let him down.
(c) I couldn't help but disagree with the **crew** on their decision. I needed the team/cook to do as I said.
(d) I couldn't help but disagree with the **cook** on their decision. I needed the team/crew to do as I said.

57 (a) Because Valerie was going away, she asked a friend to water her **garden** whenever they could. She hoped they would also check on her plants/rabbit if they had time.
(b) Because Valerie was going away, she asked a friend to water her **rabbit** whenever they could. She hoped they would also check on her plants/garden if they had time.
(c) The painting of the **garden** was unique and beautiful. The gallery decided to hang it with the painting of the plants/rabbit by the same artist.
(d) The painting of the **rabbit** was unique and beautiful. The gallery decided to hang it with the painting of the plants/garden by the same artist.

58 (a) The parents cried when they found out their child had been born with a rare **illness** of the liver. They were relieved to hear that the disease/swelling could be controlled with medication.
(b) The parents cried when they found out their child had been born with a rare **swelling** of the liver. They were relieved to hear that the disease/illness could be controlled with medication.
(c) Samuel hoped the **illness** in his eye would not flare up on the last day of school. He did not want the disease/swelling to be how he was remembered.
(d) Samuel hoped the **swelling** in his eye would not flare up on the last day of school. He did not want the disease/illness to be how he was remembered.

59 (a) The teacher marked her students' work with a red **biro** during the lunch break. She would use a pen/line of a different colour occasionally.
(b) The teacher marked her students' work with a red **line** during the lunch break. She would use a pen/biro of a different colour occasionally.
(c) I could hardly see the **biro** used by my doctor to indicate my medication. Since the pen/line wasn't clear, I decided to ring up to check.
(d) I could hardly see the **line** used by my doctor to indicate my medication. Since the pen/biro wasn't clear, I decided to ring up to check.

60 (a) After three attempts, I was ecstatic to finally get my driver's **permit** on the weekend. Having the licence/plates to my own car felt liberating.
(b) After three attempts, I was ecstatic to finally get my driver's **plates** on the weekend. Having the licence/permit to my own car felt liberating.
(c) I copied the details of the **permit** for my car into my notebook. I wanted to get my licence/plates renewed today.

(d) I copied the details of the **plates** for my car into my notebook. I wanted to get my <u>licence/permit</u> renewed today.

61 (a) Rita stepped out of the shower and dried her hair with a **cloth** that she had packed. The hotel <u>towel/dryer</u> smelt funny so she didn't want to use it.
(b) Rita stepped out of the shower and dried her hair with a **dryer** that she had packed. The hotel <u>towel/cloth</u> smelt funny so she didn't want to use it.
(c) I made sure to put the **cloth** back in its spot after I finished using it. I did not see the cockroach hiding under the <u>towel/dryer</u> right next to it.
(d) I made sure to put the **dryer** back in its spot after I finished using it. I did not see the cockroach hiding under the <u>towel/cloth</u> right next to it.

62 (a) The graceful ballerina pulled some muscles in her **back** that caused a lot of pain. She hoped that the pain would not affect her <u>legs/show</u> when she danced.
(b) The graceful ballerina pulled some muscles in her **show** that caused a lot of pain. She hoped that the pain would not affect her <u>legs/back</u> when she danced.
(c) Grace was glad that her **back** was cleared by the doctor after her stunt injury. She hoped that her <u>legs/show</u> would be back to normal again soon too.
(d) Grace was glad that her **show** was cleared by the doctor after her stunt injury. She hoped that her <u>legs/back</u> would be back to normal again soon too.

63 (a) The careless thieves set off the loud **alert** and the owners immediately woke up. Suddenly, the <u>alarm/puppy</u> next door started going off as well.
(b) The careless thieves set off the loud **puppy** and the owners immediately woke up. Suddenly, the <u>alarm/alert</u> next door started going off as well.
(c) Because it was in the next room, the **alert** was too soft for me to hear. Sometimes even an <u>alarm/puppy</u> at full volume doesn't wake me up.
(d) Because it was in the next room, the **puppy** was too soft for me to hear. Sometimes even an <u>alarm/alert</u> at full volume doesn't wake me up.

64 (a) At my grandmother's funeral, my mother gave a very moving **sermon** in her honour. This was followed by a <u>speech/dance</u> by my cousins.
(b) At my grandmother's funeral, my mother gave a very moving **dance** in her honour. This was followed by a <u>speech/sermon</u> by my cousins.
(c) I arrived at the hall just as the **sermon** began to start. I had missed the <u>speech/dance</u> which had opened the ceremony.
(d) I arrived at the hall just as the **dance** began to start. I had missed the <u>speech/sermon</u> which had opened the ceremony.

65 (a) When we went fishing, we always took a bucket of worms to use as **food** to catch the fish. We would always get <u>bait/help</u> from the local shop beforehand.
(b) When we went fishing, we always took a bucket of worms to use as **help** to catch the fish. We would always get <u>bait/food</u> from the local shop beforehand.
(c) We quickly realised that we would need **food** to catch the rat in our house. We planned to return with some <u>bait/help</u> to catch it.
(d) We quickly realised that we would need **help** to catch the rat in our house. We planned to return with some <u>bait/food</u> to catch it.

66 (a) The dentist carelessly let the extracted tooth slip from the tweezers into the patient's **face** for a second. It also touched their <u>mouth/shirt</u> which left a bit of blood.

(b) The dentist carelessly let the extracted tooth slip from the tweezers into the patient's **shirt** for a second. It also touched their mouth/face which left a bit of blood.
(c) After working out at the gym, my **face** was dripping with sweat. But it was my mouth/shirt that felt the most unpleasant.
(d) After working out at the gym, my **shirt** was dripping with sweat. But it was my mouth/face that felt the most unpleasant.

67 (a) Because the mother needs to see a doctor again, she will arrange for another **consultation** later today. She hoped the appointment/babysitter would be easy to arrange.
(b) Because the mother needs to see a doctor again, she will arrange for another **babysitter** later today. She hoped the appointment/consultation would be easy to arrange.
(c) I was annoyed to find out that my **consultation** was delayed. I had to cancel my appointment/babysitter because of it.
(d) I was annoyed to find out that my **babysitter** was delayed. I had to cancel my appointment/consultation because of it.

68 (a) After accidentally falling into the deep end of the pool, Daniel was rescued by the **attendant** sitting nearby. It was the lifeguard/gentleman at the other end who raised the alarm.
(b) After accidentally falling into the deep end of the pool, Daniel was rescued by the **gentleman** sitting nearby. It was the lifeguard/attendant at the other end who raised the alarm.
(c) In the distance, I could see the **attendant** walking along the beach. They were with a lifeguard/gentleman who looked familiar.
(d) In the distance, I could see the **gentleman** walking along the beach. They were with a lifeguard/attendant who looked familiar.

69 (a) The bank customers froze when they noticed the men armed with **axes** enter the building. They could see guns/cash sticking out of their bags as they came past.
(b) The bank customers froze when they noticed the men armed with **cash** enter the building. They could see guns/axes sticking out of their bags as they came past.
(c) The huge pile of **axes** that the police found during their raid was a record. There were also some guns/cash seized from the same property.
(d) The huge pile of **cash** that the police found during their raid was a record. There were also some guns/axes seized from the same property.

70 (a) The romantic dinner was accompanied by a nice red **drink** and brightly lit candles. We ordered an extra wine/meat which was also great.
(b) The romantic dinner was accompanied by a nice red **meat** and brightly lit candles. We ordered an extra wine/drink which was also great.
(c) It was too late when I realised that the **drink** I had ordered was more expensive than I had expected. I should've chosen a wine/meat instead of it.
(d) It was too late when I realised that the **meat** I had ordered was more expensive than I had expected. I should've chosen a wine/drink instead of it.

71 (a) After the blizzard, the children spent the whole day building a **figurine** in the snow. They had finished a whole snowman/hideout just yesterday.
(b) After the blizzard, the children spent the whole day building a **hideout** in the snow. They had finished a whole snowman/figurine just yesterday.

(c) My brother asked me to watch his **figurine** in the yard while he went inside for a second. I had to stop building my snowman/hideout for a few minutes.
(d) My brother asked me to watch his **hideout** in the yard while he went inside for a second. I had to stop building my snowman/figurine for a few minutes.

72 (a) As soon as Chris arrived home, his mother told him to remove his muddy **socks** from the house she had just cleaned. Luckily, he left his shoes/balls outside which were even dirtier.
(b) As soon as Chris arrived home, his mother told him to remove his muddy **balls** from the house she had just cleaned. Luckily, he left his shoes/socks outside which were even dirtier.
(c) Tommy had no idea where his **socks** from yesterday were. Eventually he found them with his shoes/balls by the front door.
(d) Tommy had no idea where his **balls** from yesterday were. Eventually he found them with his shoes/socks by the front door.

73 (a) The shepherd spent all day looking for his lost **cows** in the rain. He took his sheep/tools with him as he looked.
(b) The shepherd spent all day looking for his lost **tools** in the rain. He took his sheep/cows with him as he looked.
(c) The farmer reported some **cows** missing to the police. He suspected the person who had come to buy his sheep/tools the week before.
(d) The farmer reported some **tools** missing to the police. He suspected the person who had come to buy his sheep/cows the week before.

74 (a) Bill was stopped at the intersection but didn't notice the lights go **amber** for a few seconds. He also missed the green/crazy car in front driving erratically.
(b) Bill was stopped at the intersection but didn't notice the lights go **crazy** for a few seconds. He also missed the green/amber car in front driving erratically.
(c) Audrey could see the **amber** sunset every evening from the top floor of her apartment. Everything looked so green/crazy from up there.
(d) Audrey could see the **crazy** sunset every evening from the top floor of her apartment. Everything looked so green/amber from up there.

75 (a) After many hours of hiking in the wilderness, we were glad to finally set up **base** for the night. We were too far from camp/home to make it before sunset.
(b) After many hours of hiking in the wilderness, we were glad to finally set up **home** for the night. We were too far from camp/base to make it before sunset.
(c) The foreigner was glad to be at the **base** of the allied soldiers. It was too bad his camp/home was hundreds of kilometres away.
(d) The foreigner was glad to be at the **home** of the allied soldiers. It was too bad his camp/base was hundreds of kilometres away.

76 (a) Evan couldn't change the tv channel in the waiting room because he couldn't find the **device** to do it. Eventually, he got a remote/person from the front desk.
(b) Evan couldn't change the tv channel in the waiting room because he couldn't find the **person** to do it. Eventually, he got a remote/device from the front desk.
(c) I went to the shops to buy a toy **device** for my younger brother. I picked one that came with a remote/person for him to play with.
(d) I went to the shops to buy a toy **person** for my younger brother. I picked one that came with a remote/device for him to play with.

Sentences used in Chapter 4 Experiments

For each pair, the strongly constraining context appears first (a), followed by the weakly constraining context (b). The target is bolded in the order: predictable target, unpredictable related target, and unpredictable unrelated target.

1 (a) The comedian's witty jokes made the audience **laugh/smile/groan** awkwardly for a few seconds.
(b) Jane made her nephew **laugh/smile/groan** by tickling him on his tummy.
2 (a) At the zoo, the distant but loud roar of the **lion/bear/siren** made the schoolgirl jump suddenly.
(b) The noise that came from the **lion/bear/siren** was deafening to the ears.
3 (a) To fix the tear, Wendy used a needle and **thread/string/button** from her trusty sewing kit.
(b) The little girl used an orange **thread/string/button** to make the doll's nose.
4 (a) After the woman's death, her family held a **funeral/service/concert** at the small local temple.
(b) Fiona didn't pay attention to the **funeral/service/concert** that was unfolding on the television.
5 (a) The handyman pounded the nail into the wall with a **hammer/wrench/brick** before hanging up the picture.
(b) Last weekend, Dad dropped a **hammer/wrench/brick** on his foot by accident.
6 (a) The flock of geese flew south for the **winter/season/coast** earlier than they did last year.
(b) The girl was surprised by how much she enjoyed the **winter/season/coast** during her time in Russia.
7 (a) After watching a waiter sneeze into someone's dinner, I demanded to speak with the **manager/director/customer** immediately about the nasty incident.
(b) No one knew that the **manager/director/customer** was trapped inside the lift of the department store following the power failure.
8 (a) In the centre of the cobweb were two big black **spiders/flies/sticks** that were swaying with the wind.
(b) The little girl looked up to see some **spiders/flies/sticks** on the roof of the house.
9 (a) Jim decided to vote for his usual political **party/group/roots** at the next government election.
(b) The large **party/group/roots** in the yard was broken up by the big storm.
10 (a) Alex hoped that the brain exercises would make him **smarter/better/richer** over the next few months.
(b) The new company executive was definitely **smarter/better/richer** than the previous one we had.
11 (a) Frank was tired of the teenagers in the neighbourhood throwing stones and breaking his **windows/chimney/bicycle** whenever they felt like it.
(b) Owen noticed the **windows/chimney/bicycle** of his neighbours had been vandalised by graffiti.

12 (a) The cat ran around the room trying to catch the **mouse/shrew/ball** but she was simply too slow.
(b) The infant watched as the **mouse/shrew/ball** moved slowly across the room.
13 (a) At the playground, three homeless men were sitting on the **bench/seats/grass** next to the metal gate arguing loudly.
(b) The pigeon flew near the **bench/seats/grass** where a couple sat eating some fried chips.
14 (a) My favourite zoo exhibit were the flightless **birds/ducks/wasps** that were native to New Zealand.
(b) Often, there are **birds/ducks/wasps** that come through the front of our house by accident.
15 (a) The greedy businessman has been obsessed with **money/coins/rugby** since he was a young boy.
(b) I used to think that **money/coins/rugby** was the most important thing to me.
16 (a) My favourite place to skate indoors is the ice **rink/park/zone** across from the local mall.
(b) There will be a new **rink/park/zone** for hockey players opened by the council next week.
17 (a) The princess felt confident as she skilfully mounted the **horse/camel/steps** that was in front of her.
(b) The young man couldn't manage the **horse/camel/steps** after consuming too much alcohol.
18 (a) The waiter thought everything was ready when he put the salt and **pepper/chilli/spoons** down in front of the couple.
(b) Alice paused before grabbing the **pepper/chilli/spoons** from the supermarket top shelf.
19 (a) Rebecca lit the fire with a **match/lighter/stake** but it immediately went out.
(b) The scout leader could not see the **match/lighter/stake** because it was too dark.
20 (a) The chef couldn't stop crying as he chopped up the **onion/bread/plank** to let out his anger.
(b) James threw out the old **onion/bread/plank** that had been sitting on his kitchen counter since last week.
21 (a) The large cut on the boy's forehead meant that he needed **stitches/bandages/checking** as soon as it was possible.
(b) There was a lack of **stitches/bandages/checking** at the new local hospital.
22 (a) In the art class, Matthew went to sharpen his **pencil/rubber/dagger** before the important task.
(b) My aunty gave me a limited edition **pencil/rubber/dagger** that she had found online.
23 (a) David was a promising football player until he was **injured/wounded/burgled** several years ago in an incident.
(b) I did not expect to be **injured/wounded/burgled** while I was on my holiday.
24 (a) Just before the minister began the reading, the peal of the cathedral **bells/chime/phone** echoed loudly around the room.
(b) I could hear the **bells/chime/phone** ringing clearly from the next room.
25 (a) The opera singer has meticulously trained her **voice/sound/child** for a number of years.

(b) Mary tried to ignore the **voice/sound/child** as best as she could.

26 (a) The nervous parachutist jumped out of the **plane/train/chair** as soon as he heard the announcement.
(b) The tired movie maker was fast asleep in the **plane/train/chair** on his way to the premiere.

27 (a) Denise felt that the sauna room was too **hot/humid/dusty** for her to be comfortable.
(b) The hotel room was **hot/humid/dusty** which made it hard for me to nap.

28 (a) After dinner was finished, the maid washed the **dishes/stove/clothes** with some soap by hand.
(b) Mum looked at the **dishes/stove/clothes** as she thought about what to do next.

29 (a) It was hard to sleep with the fluorescent **light/glare/sign** of the neighbouring shop streaming into the room.
(b) Tammy couldn't see the **light/glare/sign** properly without her prescription glasses.

30 (a) To change the colour of his walls, Dave bought some glossy **paint/spray/paper** from the hardware store across town.
(b) I found some **paint/spray/paper** in different metallic colours in the garage.

31 (a) The cleaner warned her supervisor about the slippery **floor/ground/handle** just as he was about to enter the room.
(b) Sarah didn't realise that the **floor/ground/handle** was covered in blood until it was too late.

32 (a) The beautiful lady wearing a lovely fragrant **perfume/scent/dress** entered the lavish hotel lobby.
(b) The woman needed a **perfume/scent/dress** to wear to the dinner.

33 (a) I screamed as I dropped the boiling **water/soup/eggs** onto the white kitchen tiles.
(b) Tracey went to get some **water/soup/eggs** from the fridge in the kitchen.

34 (a) Irene and her husband travelled by boat to the tropical **island/resort/forest** for their honeymoon after the wedding.
(b) Today we visited a beautiful **island/resort/forest** with our local tour guide.

35 (a) I took the forks and knives outside to set the **table/stand/scene** on the patio for lunch.
(b) Anna pointed to the **table/stand/scene** where the actor would deliver the final words of the play.

36 (a) Everyone in the court rose to their feet when the **judge/jury/queen** entered the room without a word.
(b) Even with extra time, the **judge/jury/queen** could not reach a decision about the case.

37 (a) As soon as the war broke out, Nathan decided to join the **army/navy/spies** who were defending the country.
(b) Unexpectedly, the **army/navy/spies** snatched complete control of the troubled country from the government.

38 (a) Mark decided that the best time to speak to the priest would be on Sunday inside the **church/chapel/garden** after the ceremony had finished.
(b) I waited outside the **church/chapel/garden** for my mother who was late.

39 (a) Rhonda washed her mug because it was a little **dirty/grimy/brown** from the tea she had in the morning.

(b) Emily was happy that her old **dirty/grimy/brown** ballet slippers were finally replaced with a new pair.

40 (a) It took the skilled gardener nearly two hours to pull out all the **weeds/vines/gnomes** in the front yard by hand.
(b) There were **weeds/vines/gnomes** covering the driveway of the old and run down house.

41 (a) The dangerous criminal flaunting a sharp **knife/blade/style** entered the suburban shopping centre.
(b) The chef's **knife/blade/style** captured everyone's attention in the kitchen.

42 (a) Edward's sister was around last night and played loud **music/tunes/games** until the early hours of the morning.
(b) I still had to decide on the **music/tunes/games** and snacks for tomorrow night's gathering.

43 (a) The leader reminded us all to work as a **team/crew/cook** for the rest of the week.
(b) My brother needed a **team/crew/cook** to organise his work function.

44 (a) The parents cried when they found out their daughter had been born with a rare **disease/illness/swelling** affecting both of her kidneys.
(b) Samuel hoped the **disease/illness/swelling** in his eye would not flare up on the last day of school.

45 (a) The teacher marked the students' work with a red **pen/biro/line** during her short lunch break.
(b) I could barely see the **pen/biro/line** marking on the form I was given.

46 (a) I was lucky to visit my favourite aunt and **uncle/niece/puppy** over the extended Christmas break.
(b) I was excited to see my **uncle/niece/puppy** after his surgery on the weekend.

47 (a) After three attempts, I was ecstatic to finally get my driver's **licence/permit/plates** over the long weekend.
(b) I left my car **licence/permit/plates** on the kitchen counter in my hurry to leave.

48 (a) Rita stepped out of the bathtub and dried her hair with a **towel/cloth/dryer** that she had packed with her.
(b) I moved the **towel/cloth/dryer** out of the way and into the cupboard.

49 (a) The graceful ballerina pulled some muscles in her **legs/back/show** that caused a lot of discomfort.
(b) I watched the **legs/back/show** of the cheetahs in awe.

50 (a) The careless thieves set off the loud **alarm/alert/door** behind the house and the owners immediately woke up.
(b) We wondered why the **alarm/alert/door** was set off by our movements.

51 (a) At my grandmother's burial, my mother gave a very moving **speech/sermon/dance** which made us all cry.
(b) The first day began with a great **speech/sermon/dance** by the conference coordinator which captivated the audience.

52 (a) When we went fishing, we always took a bucket of worms to use as **bait/food/help** to catch as many fish as we could.
(b) It was useless without **bait/food/help** to try and catch the rat in our house.

53 (a) The dentist carelessly let the extracted tooth slip from the tweezers into the patient's **mouth/face/shirt** for the second time in a day.

(b) Because the man's **mouth/face/shirt** was covered in blood, Rick asked if he needed some assistance.

54 (a) Because Mary needs to see a doctor again, she will arrange for another **appointment/consultation/babysitter** for later in the day.
(b) I was annoyed to find out that my **appointment/consultation/babysitter** was delayed by a whole hour.

55 (a) After accidentally falling into the deep end of the pool, Daniel was rescued by the **lifeguard/attendant/gentleman** who was sitting in the shade.
(b) In the distance, I could see the **lifeguard/attendant/gentleman** strolling along the beach which was packed with people.

56 (a) The bank employees froze when they noticed the men armed with **guns/axes/cash** running towards them at full speed.
(b) It was hard to overlook the pile of **guns/axes/cash** sitting on the counter by the side.

57 (a) Liam is a grouch in the morning until he has had a **coffee/juice/shower** and read the daily newspaper.
(b) A single voucher for a free **coffee/juice/shower** was the pathetic compensation for my cancelled flight.

58 (a) The romantic dinner was accompanied by a nice red **wine/drink/meat** and some brightly lit candles.
(b) Mia went to see if there was still enough **wine/drink/meat** at the dinner for everyone.

59 (a) After the blizzard, the kids spent the whole day building a **snowman/figurine/hideout** in the piles of snow.
(b) My annoying brother made me watch over his **snowman/figurine/hideout** in the yard while he went to the bathroom.

60 (a) As soon as Chris arrived at the house, his mother told him to remove his muddy **shoes/socks/boxes** from the house that she had just cleaned.
(b) The grey **shoes/socks/boxes** camouflaged by the front gate almost tripped me over.

61 (a) The shepherd spent all day looking for his lost **sheep/cows/tools** in the fields despite the rain.
(b) The farmer reported that some **sheep/cows/tools** had been stolen from his property.

62 (a) Bill was distracted at the intersection and didn't notice the traffic signal go **green/amber/crazy** for at least a few seconds.
(b) Audrey was on her way to purchase some **green/amber/crazy** artwork for her new apartment.

63 (a) After many hours of hiking in the wilderness, we were glad to finally set up **camp/base/home** for the cold night ahead.
(b) The foreigner was glad to be at the **camp/base/home** of the friendly allied soldiers.

64 (a) Evan couldn't change the television channel in the waiting room because he couldn't find the **remote/device/person** to do it anywhere nearby.
(b) My little brother lost the **remote/device/person** that came with his miniature car.

65 (a) The family dog liked to bury his **bone/toys/bowl** under the rose bushes in the backyard.
(b) Charlie gingerly picked up the **bone/toys/bowl** that was covered in his son's saliva.

66 (a) The renowned baker prepared his delicious three layered **cake/tart/plan for** the couple's upcoming wedding.
(b) The mother could picture the perfect **cake/tart/plan** for her son's birthday next week.

Appendix B: Supplemental Materials

Analysis of Downstream Target in Chapter 3 Experiment 3

The downstream target in Chapter 3 Experiment 3 was either the predictable, but never presented, completion from the strongly constraining sentence or the other plausible, unpredictable completion (see Table B.1 for an example item pair).

Data handling was identical to the experiments reported in Chapter 3. Trials were removed either due to track loss or blinks on the region of interest (2.2% of trials). Fixations on the downstream targets below 80ms, first fixation durations above 800 ms, gaze durations above 1200 ms, and total durations above 2000 ms were also excluded (1.7% of trials). These exclusions left 8473 downstream target data points (96.1% of the data) for analysis. The average reading measures on the downstream target for each condition are presented in Table B.2.

As in the previous experiments in Chapter 3, (G)LMMs tested the fixed effect of constraint nested under condition which returned estimates of the main effect of condition and the constraint effect separately for the four types of downstream targets (previously predictable downstream targets following related initial targets, previously unrelated downstream words following related initial targets, previously predictable downstream words following unrelated initial targets, and previously related downstream words following unrelated initial targets). Condition was coded as a set of three orthogonal contrasts which tested: (1) the initial target type effect – the difference between the related and unrelated initial target conditions, (2) the downstream effect following related initial targets – the difference between the previously predictable and unrelated downstream words following related initial target conditions, and (3) the downstream effect following unrelated initial targets – the difference between the previously predictable and related downstream words following unrelated initial target conditions. Criteria for the maximal random-effects structures and significance thresholds were identical to the previous experiments in Chapter 3. A summary of the statistical analyses for the downstream target is presented in Table B.3.

The initial target type effect was not significant on any reading measures at the downstream target ($|t/z|$s < 1.29). The downstream effect following related targets was significant on gaze duration, total fixation duration, and regressions-in ($|t/z|$s > 3.08) – downstream targets following related initial words received shorter reading times and fewer regressions-in when they were the previously predictable versus unrelated word. The downstream effect following unrelated targets was significant on total fixation duration and regressions-in (t/zs > 4.08) – downstream targets following unrelated initial words received shorter reading times and fewer regressions-in when they were the previously predictable versus related word. The effect of constraint was not significant on any of the reading measures at the downstream target regardless of the completion that appeared in the first sentence ($|t/z|$s < 1.47). Thus, consistent with the previous experiments reported in Chapter 3, there was no indication that readers' lexical predictions were observable downstream from their initial point of activation.

Table B.1

Example set of items and mean (and standard deviation) stimulus characteristics in Chapter 3 Experiment 3

Condition	Example item (Initial target bolded; Downstream target underlined)	Cloze probability Initial target	 Expected word
Strongly constraining context			
Related initial target, Previously predictable downstream target	Irene and her husband travelled by boat to the tropical **resort** for their honeymoon. It was close to the island they had chosen for their wedding	.01 (.03)	.83 (.13)
Related initial target, Previously unrelated downstream target	Irene and her husband travelled by boat to the tropical **resort** for their honeymoon. It was close to the garden they had chosen for their wedding	.01 (.03)	.83 (.13)
Unrelated initial target, Previously predictable downstream target	Irene and her husband travelled by boat to the tropical **garden** for their honeymoon. It was close to the island they had chosen for their wedding	.00 (.02)	.83 (.13)
Unrelated initial target, Previously related downstream target	Irene and her husband travelled by boat to the tropical **garden** for their honeymoon. It was close to the resort they had chosen for their wedding	.00 (.02)	.83 (.13)
Weakly constraining context			
Related initial target, Previously predictable downstream target	Today we visited a beautiful **resort** full of exotic birds. Tomorrow we will go to the island where we will spend the last few days of our holiday.	.01 (.03)	.01 (.03)
Related initial target, Previously unrelated downstream target	Today we visited a beautiful **resort** full of exotic birds. Tomorrow we will go to the garden where we will spend the last few days of our holiday.	.01 (.03)	.01 (.03)
Unrelated initial target, Previously predictable downstream target	Today we visited a beautiful **garden** full of exotic birds. Tomorrow we will go to the island where we will spend the last few days of our holiday.	.01 (.05)	.01 (.03)
Unrelated initial target, Previously related downstream target	Today we visited a beautiful **garden** full of exotic birds. Tomorrow we will go to the resort where we will spend the last few days of our holiday.	.01 (.05)	.01 (.03)

Table B.2

Mean (and standard deviation) reading measures on the downstream target word for each condition in Chapter 3 Experiment 3

	Strongly constraining context				Weakly constraining context			
Reading measure	Related initial target-Previously predictable downstream target	Related initial target-Previously unrelated downstream target	Unrelated initial target-Previously predictable downstream target	Unrelated initial target-Previously related downstream target	Related initial target-Previously predictable downstream target	Related initial target-Previously unrelated downstream target	Unrelated initial target-Previously predictable downstream target	Unrelated initial target-Previously related downstream target
Skipping (%)	28 (12)	26 (10)	28 (12)	27 (11)	29 (10)	28 (10)	25 (9)	27 (10)
First fixation (ms)	192 (18)	193 (17)	192 (16)	195 (16)	189 (19)	193 (18)	191 (18)	190 (18)
Gaze (ms)	206 (24)	212 (24)	207 (22)	212 (24)	203 (21)	215 (24)	212 (22)	213 (28)
Total fixation (ms)	282 (42)	287 (32)	270 (41)	298 (38)	270 (39)	300 (39)	286 (31)	299 (38)
Regressions out (%)	25 (11)	27 (11)	25 (10)	25 (12)	26 (10)	27 (10)	26 (9)	28 (9)
Regressions in (%)	19 (8)	23 (11)	17 (9)	23 (10)	19 (10)	24 (9)	19 (10)	22 (9)

Table B.3

Results for the nested linear mixed effects models for log-transformed fixation duration measures and generalised linear mixed effects models for fixation probability measures on the downstream target word in Chapter 3 Experiment 3

Measure	Fixed effect	*b*	*SE*	*t/z*
Skipping	**Intercept**	**-1.09**	**0.10**	**-11.09**
	Initial target type	0.05	0.05	1.02
	Related initial target: Downstream effect	0.12	0.07	1.67
	Unrelated initial target: Downstream effect	-0.02	0.07	-0.29
	Related initial target-Previously Predictable downstream: Constraint effect	0.02	0.13	0.12
	Related initial target-Previously Unrelated downstream: Constraint effect	0.13	0.15	0.88
	Unrelated initial target-Previously Predictable downstream: Constraint effect	-0.13	0.13	-1.07
	Unrelated initial target-Previously Related downstream: Constraint effect	0.02	0.12	0.13
First fixation	**Intercept**	**5.19**	**0.02**	**301.24**
	Initial target type	0.00	0.01	0.21
	Related initial target: Downstream effect	-0.02	0.01	-1.56
	Unrelated initial target: Downstream effect	0.00	0.01	0.02
	Related initial target-Previously Predictable downstream: Constraint effect	-0.03	0.03	-1.30
	Related initial target-Previously Unrelated downstream: Constraint effect	-0.00	0.02	-0.20
	Unrelated initial target-Previously Predictable downstream: Constraint effect	-0.01	0.02	-0.38
	Unrelated initial target-Previously Related downstream: Constraint effect	-0.02	0.02	-0.81
Gaze	**Intercept**	**5.27**	**0.02**	**279.85**
	Initial target type	-0.00	0.01	-0.50
	Related initial target: Downstream effect	**-0.04**	**0.01**	**-3.08**
	Unrelated initial target: Downstream effect	-0.00	0.01	-0.29

	Related initial target-Previously Predictable downstream: Constraint effect	-0.02	0.03	-0.64
	Related initial target-Previously Unrelated downstream: Constraint effect	0.01	0.03	0.46
	Unrelated initial target-Previously Predictable downstream: Constraint effect	0.02	0.03	0.55
	Unrelated initial target-Previously Related downstream: Constraint effect	-0.00	0.03	-0.01
Total fixation	**Intercept**	**5.52**	**0.02**	**226.17**
	Initial target type	-0.01	0.01	-0.97
	Related initial target: Downstream effect	**-0.07**	**0.02**	**-4.23**
	Unrelated initial target: Downstream effect	**-0.06**	**0.02**	**-4.08**
	Related initial target-Previously Predictable downstream: Constraint effect	-0.04	0.03	-1.28
	Related initial target-Previously Unrelated downstream: Constraint effect	0.03	0.03	1.18
	Unrelated initial target-Previously Predictable downstream: Constraint effect	0.05	0.03	1.47
	Unrelated initial target-Previously Related downstream: Constraint effect	0.00	0.03	0.12
Regressions out	**Intercept**	**-1.19**	**0.10**	**-11.96**
	Initial target type	0.02	0.05	0.31
	Related initial target: Downstream effect	-0.06	0.08	-0.85
	Unrelated initial target: Downstream effect	-0.09	0.08	-1.13
	Related initial target-Previously Predictable downstream: Constraint effect	0.09	0.18	0.52
	Related initial target-Previously Unrelated downstream: Constraint effect	-0.05	0.18	-0.29
	Unrelated initial target-Previously Predictable downstream: Constraint effect	0.08	0.18	0.44
	Unrelated initial target-Previously Related downstream: Constraint effect	0.14	0.18	0.76
Regressions in	**Intercept**	**-1.56**	**0.12**	**-13.48**
	Initial target type	0.08	0.06	1.29
	Related initial target: Downstream effect	**-0.35**	**0.08**	**-4.29**
	Unrelated initial target: Downstream effect	**-0.34**	**0.08**	**-4.09**
	Related initial target-Previously Predictable downstream: Constraint effect	-0.02	0.20	-0.13
	Related initial target-Previously Unrelated downstream: Constraint effect	0.04	0.16	0.28

Unrelated initial target-Previously Predictable downstream: Constraint effect	0.15	0.18	0.84
Unrelated initial target-Previously Related downstream: Constraint effect	-0.12	0.17	-0.72

Note. Significant effects are bolded.