HANDWRITING IN HEALTHY PEOPLE
AGED 65 YEARS AND OVER

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Thesis submitted in fulfillment of the requirements for the degree of
Master of Applied Science
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The University of Sydney, Australia
March, 2010
Student Certification

I, Nadege van Drempt, hereby declare that this submission is my own work and that it contains no material previously published or written by another person except where acknowledged in the text. Nor does it contain material which has been accepted for the award of another degree.

In addition, ethical approval from the University of Sydney Human Research Ethics Committee was granted for the study presented in this thesis. Subjects were required to read a Participant Information Statement and informed consent was gained prior to data collection.

Name:  Nadege van Drempt

Signed  .................................................................

Date  .................................
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Abstract

**Background:** Handwriting is an important activity which is commonly affected after a stroke. Handwriting research has predominantly involved children. In adults, the focus of handwriting research has been identifying forgery, doctors’ handwriting legibility and the kinematics of writing strokes. There are no known studies which provide information on unimpaired adult handwriting in real situations to guide stroke rehabilitation therapists.

**Aim:** This study aims to describe the handwriting practices of 30 unimpaired adults aged 65 years and over to inform adult handwriting rehabilitation. **Methods:** This study used a cross-sectional observational design. Three data collection methods were used: self-report questionnaire, handwriting samples collected using a digital pen and a handwriting log. Following ethical approval, 30 older adults were recruited using snowball sampling. Data were analysed using descriptive statistics. **Results:** The median age of participants was 72 years. Three-quarters of participants scored less than 4 for legibility on a 4-point scale. A tripod pen grip was used by 97% of the sample. Variations in handwriting were evident in letter size, slant and spacing. Participants wrote very little, an average of three times per day ($SD = 1.5$) and a median of 18 words per occasion. Most handwriting (85%) involved self-generated, not copied or transcribed text. Participants stood whilst writing for 17% of handwriting occasions. The most common reasons for handwriting were taking notes (23%) and completing puzzles (22%). **Discussion:** Legibility in older adults may not depend exclusively on the handwriting script that a beginning writer was taught at school, but may be due to other factors, as a person ages. A comprehensive adult handwriting assessment and retraining program should consist of relevant handwriting activities, involve self-generated text and few words. **Conclusion:** Findings will contribute to the ongoing development of an ecologically valid adult handwriting assessment and help inform stroke rehabilitation practice.
Presentations

Parts of this thesis have been presented in the following forms:

**Conference Presentations**


**Poster Presentation**

Acknowledgements

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Chapter One

1.1 Background to adult handwriting

Adults use handwriting for creativity, communication and to aid memory. Handwriting is used to record information, ideas, telephone messages and shopping lists. Although handwriting is common across many cultures, it is a complex activity simultaneously involving motor control, cognitive and visual-perceptual processing (Bonney, 1992). If any of these processes are impaired by neurological conditions such as a stroke or traumatic brain injury, poor handwriting may result. Therefore, adult handwriting is of importance to rehabilitation therapists. Yet surprisingly little is known about the handwriting of healthy adults. The following section summarises the research in relation to adult handwriting parameters that can be measured, motor control, activities and personal factors, handwriting assessments and retraining.

Parameters of handwriting include features that can be measured from written text, such as legibility, pen pressure and error corrections. There is currently no consensus on the most suitable method of assessing legibility. Further, no normative data on adult handwriting legibility have been published. Variations in pen pressure within words and across a page appear to be normal, with increases in pressure occurring when people write text larger or faster (Wann & Nimmo-Smith, 1991). However, further investigation is required to determine the range of normal downward and lateral pen pressure for optimal handwriting performance. Error corrections appear to be normal (Hennessy, 1997), particularly as people age (Walton, 1996), however there are currently no normative data on error corrections made by unimpaired adults.
In the area of motor control for adult handwriting, pen grip, speed and handwriting movements have been the focus of limited studies. Studies suggest that grips other than the traditional dynamic tripod grip should be accepted as normal and functional. Pen grip is often one of the first characteristics of handwriting to be assessed during adult rehabilitation. However, research suggests that the time spent on trying to modify pen grip may be out of step with the incremental value that improving pen grip has on handwriting legibility (Bergmann, 1990; Stevens, 2008). Normative data have been published on the speed of adult handwriting. Adult handwriting speed reduces with age, particularly in older adults. These data are based on writing speed for a copied sentence and are over 27 years old (Agnew & Maas, 1982; Jebsen, Taylor, Trieschman, Trotter, & Howard, 1969). Handwriting movements appear to occur most at the shoulder and elbow joints for larger script size and between-word movements, and at the wrist, hand and finger joints for smaller intra-word movements. Further research is needed into normal movement patterns, and the relationship between distal and proximal muscles involved in real-life handwriting (as both are affected to varying degrees following a stroke).

Handwriting activities and the context under which text is written may change the processing demands when a person writes. Self-report data suggest that handwriting is performed by younger and older adults daily or almost daily (McMahon, 2008; Rosenblum & Werner, 2006). However, currently no information exists on the reasons for and contexts of writing in adults. It is unknown how often, and how much, adults write. Further, although handwriting appears to be valued by Australian adults (McMahon, 2008), the impact of technology use on handwriting frequency and quality warrants further investigation and monitoring over time.
Accurate assessment of handwriting performance is essential for developing appropriate intervention programs. Anecdotally, adult handwriting is often measured using adapted paediatric assessments. Several standardised adult assessments exist which include sub-tests that measure only one or two features of handwriting, such as speed or pen control (Carr, Shepherd, Nordholm, & Lynne, 1985; Fahn, Elton, & Members of the UPDRS Development Committee., 1987; Jebsen, et al., 1969). To overcome these limitations, a Handwriting Assessment Battery (HAB; McCluskey & Lannin, 2003) was developed for use with adults. The HAB measures pen manipulation, writing speed and legibility. While the HAB has good to excellent inter-rater reliability, the validity of test items requires further study (Faddy, McCluskey, & Lannin, 2008). Faddy and colleagues (2008) recommend that normative data on adult handwriting practices be collected across people from different age groups and occupations to inform the validity of the test. However, to date, no comprehensive validated adult handwriting assessment has been published.

Handwriting retraining is commonly addressed during adult rehabilitation. However no randomised controlled trials evaluating handwriting retraining programs for adults have been published. One small study involving a two-week handwriting retraining program was conducted with four adults with brain injury using a single system design (Beaudet, 2004). Further studies investigating adult handwriting interventions, preferably randomised controlled trials involving larger samples, are recommended.

There are still many knowledge gaps about the real-life handwriting practices of unimpaired adults. Information about the handwriting activities commonly performed by adults could inform tests such as the HAB. Normative data and information on unimpaired adult handwriting practices will help to determine whether the HAB in its current form is a
valid test, adequately representing contemporary handwriting. Further, a greater understanding of adult handwriting practices will help guide therapists during assessment and retraining.

1.2 Aim of the Study

This study aims to describe the handwriting practices, performance and factors associated with legibility of 30 unimpaired adults aged 65 years and over living in New South Wales (NSW).

1.3 Significance of the Study

The results of this study will address gaps in current knowledge about contemporary handwriting practices. Such information is necessary to determine the validity of future adult handwriting assessments. This information will provide a standard against which impaired adult handwriting may be measured, and inform retraining interventions for older people with neurological conditions such as stroke.

1.4 Scope of the Study

To address study aims, this study will describe features of handwriting as opposed to identifying the underlying neurological processes. While these processes will be reviewed in Chapter 2, key studies only will be included to provide an important, but brief background. The unique contribution of this thesis will be to describe the features of handwriting, and as such, the focus of the literature review will centre on studies which have investigated the features of handwriting to date.
When deciding upon the age-range of the study population, anecdotal and published evidence regarding adult handwriting revealed a number of key facts. First, the leading cause of disability in Australian adults is stroke (Australian Institute of Health and Welfare, 2006). Stroke is also the most common diagnostic population seen by occupational therapists and physiotherapists (Rijken & Dekker, 1998). Second, handwriting deficits are common amongst stroke survivors. A stroke may result in physical, sensory, visual-perceptual and cognitive deficits, all of which are important for handwriting (National Stroke Foundation, 1995). Third, the greatest incidence of stroke occurs in adults aged 65 years and over (Australian Institute of Health and Welfare, 2004). Since handwriting retraining is an important aspect of rehabilitation for this client group, the present study will involve adults aged 65 years of age and older as the population of investigation.

### 1.5 Key Terms

Terminology used in this thesis has been defined in the following glossary.

**Handwriting:** *Handwriting* is defined as “writing done by hand using a pen or pencil” (Forbes, Knight, & Turner, 1986, p. 209).

**Legibility:** Text which is *legible* is “clear enough to be deciphered, readable” (Forbes, et al., 1986, p. 162). *Legibility* refers to the features of written text that contribute to “readability” (Rosenblum, Weiss, & Parush, 2004).

**Digital pen:** A *digital pen* is a portable and commercially available pen which captures notes that have been handwritten on paper. Text and sketches are electronically
recorded in a memory unit, and can be downloaded via a universal serial bus (USB) cable provided with the pen (PLANiT OrganiZer, 2005).

1.6 Synopsis and Overview of the Thesis

This chapter has introduced some of the gaps in knowledge in adult handwriting. There is currently little scientific evidence upon which therapists can base their treatment decisions. Accordingly, there is a need for further research into the features of unimpaired adult handwriting, and the assessment and retraining of adult handwriting. The literature review will discuss the available relevant handwriting literature for children and adults, outline gaps in current knowledge and discuss how these gaps may impact on assessing adult handwriting deficits. The following chapter will outline study methods. Next, findings will be presented and discussed, and the implications for practice, education and research will be presented.
Chapter Two: Literature Review

2.1 Introduction

Handwriting is performed across many cultures in the world and is highly valued by Australian adults. Despite increasing technology, Australian adults still report using handwriting to record factual information and ideas, to communicate with others and for creative expression (McMahon, 2008). Handwriting is a complex functional activity, simultaneously involving motor skills, cognitive and visual-perceptual processing (Bonney, 1992; Cornhill & Case-Smith, 1996). In adults, the ability to handwrite can be affected or even lost following neurological events such as stroke. Thus, the clinical assessment and retraining of handwriting are important components of many adult rehabilitation programs. Despite research evidence that the ability to use handwriting everyday is highly valued by Australian adults, and anecdotal evidence that rehabilitation therapists assess and treat adult handwriting dysfunction, there is limited published literature on adult handwriting assessment and retraining programs. Little is known about why, when or how adults handwrite in real situations, and there is no information about the handwriting practices of older adults.

The majority of studies investigating handwriting have been undertaken with a paediatric population. The following section in this thesis will therefore summarise a number of studies pertaining to children’s handwriting, particularly where adult studies are lacking. To facilitate ease of understanding, available research will be grouped into the themes of a) handwriting parameters; b) motor and sensorimotor, cognitive and perceptual components of handwriting; c) handwriting activities and personal factors; d) handwriting assessments and e) handwriting retraining. Finally, the context for this study will be presented, with an overview of key handwriting research and the limitations of existing literature.
2.2 Search strategies

To identify relevant literature, research team members developed a list of topics relevant to handwriting. Using subject and medical subject headings (MeSH) including ‘handwriting’, ‘writing’, ‘legibility’, ‘speed’, ‘pen grip’ and ‘pressure’, the following bibliographic databases were last searched on April 19th 2009: the Cumulative Index to Nursing and Allied Health Literature (CINAHL), Allied and Complementary Medicine (AMED), Australian Bureau of Statistics (ABS), Embase, PubMed, EBM Reviews, Ovid MEDLINE(R), Education Resource Information Centre (ERIC) and PsycINFO. The OTseeker database (Occupational Therapy Systematic Evaluation of Evidence) was last searched on August 24th 2009.

Where searches resulted in a large number of citations, limits were placed including ‘English language’ and ‘year’ (from 1980). Keywords used to focus the search included: ‘adult’, ‘children’, ‘posture’, ‘graphology’, ‘forensic analysis,’ and ‘style’. Truncation symbols, such as ‘*’, were used where necessary to enable keywords with the same root to be searched. Relevant studies were also followed up through reference lists. All volumes of the International Graphonomics Society newsletter were searched for key researchers in the field and relevant articles.

Manual searches were conducted for articles not available electronically. A number of citations were excluded based upon a title/abstract which was irrelevant or outside the scope of this review (for example the process of word generation). One hundred and twenty three articles were included, with articles grouped under pre-identified themes and topics. Where a number of studies were located, studies that were more recent, more frequently cited or of
stronger methodological quality were included. Topics identified later in the study, such as handwriting fluency, were also included.

2.3 Handwriting Parameters

*Handwriting parameters* refer to the features of handwriting that can be measured from written text. These parameters include: legibility, pen pressure, handwriting style and error corrections.

**Legibility:** Legibility refers to the features of written text that contribute to ‘readability’ (Rosenblum, et al., 2004). Legibility is considered to be one of the most important aspects of handwriting performance (Feder & Majnemer, 2007). Over the years, two main approaches have been used to evaluate handwriting legibility: analytic evaluations and global evaluations (Rosenblum, et al., 2004).

*Analytic evaluation scales* assume that a relationship exists between legibility and the quality of specific parameters (Rosenblum, et al., 2004). For example, letter formation has been found to contribute significantly to legibility (Graham, Weintraub, & Berninger, 2001), as have letter size, alignment and spacing (Graham, Struck, Santoro, & Berninger, 2006; Ziviani & Elkins, 1984). These parameters have been incorporated into children’s handwriting assessments, such as the *Evaluation Tool of Children’s Handwriting* (ETCH; Amundson, 1995) and the *Test of Legible Handwriting* (TOLH; Larsen & Hammill, 1989). Children’s handwriting has been compared against an ideal standard such as ‘copybook’ writing or the style of handwriting taught in schools, for example the Palmer and Zaner-Bloser manuscript and D’Nealian styles used in the *Minnesota Handwriting Test* (MHT) (Reisman, 1999). This approach to evaluating legibility is often used in paediatric...
standardised assessments such as the MHT (Reisman, 1999) and the ETCH (Amundson, 1995). Analytic scales are thought to be more objective and useful than global evaluation scales, however they may be less reliable (Dennis & Swinth, 2001; Ziviani & Elkins, 1984), time consuming to score, and results may not be comparable with those from other analytic scales (Rosenblum, et al., 2004).

In the adult population, analytic methods have primarily been used for the forensic examination of documents to help identify forgery (Ling, 2002). Although some data are available about letter formation, size and slant (Asicioglu & Turan, 2003; Astrom & Thorell, 2007), no normative data were located for the components of legibility (i.e., letter formation, size, spacing and slant) for English-writing adults. Relationships between each of the components of legibility and text legibility have not yet been researched in adults.

*Global evaluation scales* are used to form an overall judgement about the readability of text. Research into adult legibility has primarily focused on doctor’s handwriting and comparing legibility across professions (Berwick & Winickoff, 1996; Lyons, Payne, McCabe, & Fielder, 1998; Rodriguez-Vera, Marin, Sanchez, Borrachero, & Pujol, 2002). Doctors’ handwriting has mostly been evaluated using a four point legibility scale (Rodriguez-Vera, et al., 2002). With training, raters achieved high inter-rater reliability (kappa concordance coefficient = .85). In another study, a simpler four point legibility scale was used to rate handwriting samples as ‘poor’, ‘fair’, ‘good’ or ‘excellent’. Raters achieved fair to good inter-rater reliability (pairwise correlation coefficients = .60 to .76) (Berwick & Winickoff, 1996). Table 2.1 depicts the four point legibility scale descriptions and examples of handwriting samples for each category.
Table 2.1
A Four Point Legibility Scale * With Handwriting Samples

<table>
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<tr>
<td>1 = Illegible (most or all of words impossible to identify)</td>
<td><img src="image1" alt="Sample 1" /></td>
</tr>
<tr>
<td>2 = Most words illegible; meaning of the whole unclear</td>
<td><img src="image2" alt="Sample 2" /></td>
</tr>
<tr>
<td>3 = Some words illegible, but report can be understood by a clinician</td>
<td><img src="image3" alt="Sample 3" /></td>
</tr>
<tr>
<td>4 = Legible (all words clear)</td>
<td><img src="image4" alt="Sample 4" /></td>
</tr>
</tbody>
</table>

*Note.* *(Rodriguez-Vera, et al., 2002, p. 545)*

With technological advances, digital methods have more recently been used for computer analysis of legibility. Doctors’ handwriting has been compared with that of other health professionals and administrative staff, using a software package that translated scanned handwriting into computer text. Characters which were not easily recognised were counted and an error score was generated by the computer program (Lyons, et al., 1998). This method of assessing legibility was described as objective by the authors, but was not compared with any other method. While digital methods of analysis have advantages (i.e., less time consuming than manually scoring every letter/word), the accuracy and reliability needs further testing. The main limitation of using technology to evaluate handwriting legibility is the limited clinical utility that such a method would have in practice. Costs associated with
the technology, and extra time required to scan writing samples and run the program, limit the usefulness of such methods in a resource-limited, busy clinical environment.

When a global, analytic and digital method of analysis were compared, the global evaluation scale discriminated best between proficient and poor handwriters in children (Rosenblum, et al., 2004). The global legibility scale was scored on a four point Likert scale (1 = most legible and 4 = least legible). The analytic scale assessed letters that were erased, overwritten or unrecognisable and the spatial arrangement of written text. Both global and analytical measures were part of the Hebrew Handwriting Evaluation (HHE; Erez & Parush, 1999). Digital analysis, using samples obtained via a digital pen and digitising tablet, included variables such as in-air time, on-paper time, total time to complete the task and on-paper path length. As Hebrew text was evaluated, these results cannot be generalised to English text. However, global legibility was found to have higher inter-rater reliability than the letter legibility scores using the ETCH (Amundson, 1995) in another study involving English-writing children (Dennis & Swinth, 2001). These studies confirm the usefulness of global evaluation scales compared to other legibility measures.

The variability of scales used, features assessed and scoring methods highlight that no gold-standard legibility assessment for adult handwriting has yet been identified. Analytic evaluation scales assess every letter according to a standard. However, it has been suggested that a word may be recognised if the first and last letter are legible (Bouma, 1973). Given that legible handwriting is defined as writing that is ‘readable’, measuring letter legibility as opposed to overall word or text legibility may be unnecessary. Children’s handwriting legibility has received substantially more attention than adult handwriting legibility. Research needs to identify the features and range of normal adult handwriting and activities which will
assist in developing validated assessment techniques. These features will now be discussed, and include pressure, handwriting style and error corrections.

**Pressure:** Pressure during handwriting is exerted in two directions: laterally onto the barrel of the pen by the fingers and downwards through the pen tip onto the paper (Dooijes, 1983). Appropriate lateral pressure on the pen allows well coordinated movements, whereas excessive pressure restricts mobility (Selin, 2003).

Downward pen pressure has been measured during a range of writing tasks and conditions. Median downward pressure for six typically developing children (mean age = 6.7 years, SD = 0.6 years) was 0.70 Newtons (N) (SD = 0.29), and maximum downwards pressure was 1.5 N when writing was copied onto a digitising tablet (Chau, Ji, Tam, & Schwellnus, 2006). Mean downward pressure when writing a sentence on a digitising tablet was 1.5 N (SD not reported) in a study involving 11 adults (mean age = 37.7 years) (Baur, et al., 2006). In another study, the words ‘select’ and ‘delete’ were written under three different conditions by 11 adults (age range = 30 to 50 years) (Wann & Nimmo-Smith, 1991). The conditions were writing at a normal pace, writing twice as large and writing ‘in a hurry’. For normally paced writing, mean pressure was 1.4 N and 1.5 N for ‘select’ and ‘delete’ respectively. Mean pressure increased with larger script (1.6 N for ‘select’, p < 0.01, 1.6 N for ‘delete’, p < 0.05). Mean pressure increased even more when participants wrote at a fast pace (1.6 N for ‘select’, p < 0.025, 1.7 N for ‘delete’, p < 0.056) (Wann & Nimmo-Smith, 1991). Downward pressure measured in these studies ranged from 1.4 to 1.7 N. Pressure was found to increase throughout the writing task, a finding supported by others (Dooijes, 1983; Kao, 1983). One study has reported reduced pressure for words with more letters (van der Plaats & Van Galen, 1990). Collectively, these studies indicate that downward pen pressure
varies amongst healthy adults according to the writing task and conditions, with pressure increasing when text is written quickly or more largely.

The relationship between downward pen pressure and handwriting performance has not been widely studied. No correlation was found between pen pressure and legibility in an older study of 144 boys and girls in Grades 4, 6 and 10 (Harris & Rarick, 1959). The type of writing task performed, however, may be related to variations in pen pressure. In undergraduate students, pressure was found to be higher when letters were written free-hand compared to symbols that were traced (Kao, 1983). Further, increased task complexity was associated with higher pen pressure (correlation coefficients not reported) (Kao, 1983).

Excessive finger pressure on the barrel of a pen has been reported in clinical settings based on hyper-extended joints or white knuckles. These observations were used to classify grip as being ‘with pressure’ in one study of 61 Finnish students (Selin, 2003). No statistically significant differences in legibility were found between students using ‘pen grips with pressure’ versus those using ‘pen grips with ease’ (Selin, 2003). The sample size in that study was small and involved Finnish students. Generalisability of results to an Australian population may be limited. Excessive pressure on the barrel of the pen is thought to increase fatigue and pain, and inadequate pressure may lead to poor pen control. However, while small in sample size and possibly underpowered, results of the study by Selin (2003) do suggest an absence of relationship between pressure on the pen and legibility. Handwriting endurance was not studied. No published studies investigating lateral pen pressure and handwriting legibility in adults were located.
In summary, the normal range for downward pen pressure when writing has been explored during non-functional laboratory handwriting tasks and with small sample sizes. No normative data exists on pen pressures used by adults of various ages. Whilst some pressure variations appear to be normal within words and across the paper, correlational studies to date have provided limited information about the relationship between pen pressure and handwriting quality. Pen pressure has been measured in different units including Newtons (e.g., Baur, et al., 2006; Chau, et al., 2006; Wann & Nimmo-Smith, 1991), grams (Kao, 1983) and the amount of vertical displacement in millimeters measured by a strain gauge system built into a table (Harris & Rarick, 1959). Use of different units to measure pressure makes comparison of various studies difficult. Moreover, no published studies of clinical observation methods for assessing downward pen pressure were located (such as categorizing the indent in the paper from the pen). Such a technique would be beneficial in a rehabilitation setting. Even fewer studies have investigated the relationships between pressure exerted by the fingers on the pen, handwriting legibility and endurance. No such published studies involving adults were located. An understanding of the optimum ranges of downward pressure and pressure on the barrel of the pen for quality of handwriting and endurance is required for correct training in these aspects of handwriting.

**Handwriting style:** Handwriting style is another parameter which refers to whether the text has been written in printed text (manuscript), cursive text or a mixture of the two (refer to Figures 3.4 to 3.6). Various writing styles are used by both unimpaired children and adults. A mixed style was used by almost 40% of students in a study of 600 children (Grades 4 to 9) (Graham, Weintraub, & Berninger, 1998b). These students were three times more likely to use printed text than write in any other style. Students who used a combination of printed text and cursive text copied text faster than those who used either cursive text (effect
size = .48) or printed text (effect size = .40) exclusively. Findings also demonstrated that the legibility of mixed text (as measure using the TOLH; Larsen & Hammill, 1989) was either equivalent, or superior, to both printed text and cursive text alone \((p < .05)\) (Graham, et al., 1998b). Mixed style was most commonly \((44\%)\) used in a study of 66 university students (mean age = 20 years, range = 18 to 39 years) (Summers & Catarro, 2003). In that study, writing style was not associated with the amount of words written during a two-hour examination. The legibility of text written in the different styles was not compared.

Although these were the only two studies located which investigated handwriting styles, results suggest that handwriting assessments should not, as a general rule, compare handwriting against a cursive standard. However, further research on handwriting styles used by children and adults of different ages is required. As handwriting appears to change considerably from childhood to young adulthood (Hamstra-Bletz & Blote, 1990), adult handwriting assessments may need to consider an even greater range of handwriting styles. In order to develop an assessment that can accommodate a range of handwriting styles, further information about adult handwriting styles and variations is required.

**Error correction:** A fourth handwriting parameter, error correction, refers to retouching, overwriting or crossing out letters. Error correction appears to increase with age. One third of unimpaired middle-aged adults \((% \text{ not reported})\) and two thirds of unimpaired older adults made errors, particularly spelling mistakes and adding extra capitals, in a longitudinal study of adults aged 39 to 91 years (Walton, 1996). Extra capital letters \((\text{range} = 3 \text{ to } 5)\) were added by 18\% of older controls whilst writing a dictated sentence. Some of the older writers made mistakes when starting a word, or made a stroke in the wrong direction, which they then corrected. They also tended to form some characters incorrectly or poorly.
(Walton, 1996). The error correction rate (for example, errors corrected per 100 words) was not reported.

A number of error corrections were noted in a self-report study of 73 participants aged 20 to 70 years (Hennessy, 1997). A high percentage (89%) reported that they corrected errors through touch-ups and by inserting omitted letters when handwriting. Reasons for correcting errors included trying to write with increased speed ($n = 46$), spelling mistakes ($n = 29$), pen or surface problems ($n = 29$), carelessness ($n = 26$), lapses in concentration ($n = 15$) and external distractions ($n = 15$) (Hennessy, 1997). That study had a number of limitations, most significantly that the results were based on self-report, and that error corrections were not observed.

In summary, error corrections produced in the handwriting samples of unimpaired populations have largely been overlooked, with only two published studies located. Findings suggest that a certain percentage of errors made and corrected by adults can be considered normal. The proportion of error corrections appears to be greater with increasing age. Normative data on error corrections in adults aged 65 years and older would help to provide a baseline against which to compare adults with handwriting deficits. Availability of norms for error corrections amongst unimpaired adults would ensure that therapists do not misinterpret a small number of error corrections as a sign of handwriting impairment.

In the area of handwriting parameters, the majority of research has involved children. Further research on unimpaired adult handwriting is required to inform the ecological validity of a handwriting assessment measuring legibility. The range of downward pen pressure appears to be 1.4 N to 1.7 N. Research is recommended to validate a clinically useful method.
for categorizing downward pen pressure and for determining optimum downward and lateral pressure ranges. A mixed handwriting style, although likely to be penalised in a formal assessment, appears to be both a common and useful handwriting adaptation. Similarly, a small amount of error corrections appears to be common in unimpaired adult handwriting. Normative data on error corrections are required to prevent unnecessary penalty on the writer during handwriting assessment and retraining. The following section details research on the motor control aspects of handwriting.

2.4 Motor Control

Motor control refers to the coordination of muscle movements (McCluskey, Lannin, & Schurr, 2009). In relation to producing handwritten text, this section provides a summary of research on pen grip, in-hand manipulation, speed, fluency, handwriting movements and posture.

**Pen grip:** Pen grip refers to how the pen is held, or the configuration of finger placement on the barrel of the writing implement (Sassoon, Nimmo-Smith, & Wing, 1986). Pen grips can be classified according to descriptors such as the degree of index finger flexion, forearm pronation and supination, the number of fingers used on the pen shaft, and thumb and index finger opposition (Ziviani, 1983). Alternatively, classification may be according to pen grip types. Several classification systems for pen/pencil grip types have been developed, based on studies of children aged up to seven years (Selin, 2003). Developmental progression of pencil and crayon grip types were classified by Schneck and Henderson (1990) on the basis of a literature review and a cross-sectional sample of 320 children without handwriting difficulties, aged 3 to 7 years. Although other pen grip types have been presented (e.g., Selin, 2003), Schneck and Henderson’s classifications have been used or built upon by several other
researchers (Bergmann, 1990; Rosenblum, Goldstand, & Parush, 2006; Tseng, 1998). These classifications will therefore be described in more detail below and some common pen grips are shown in Figure 2.1.

**Figure 2.1. Common Pen Grips.**

Schneck and Henderson (1990) categorised observed grips as *primitive, transitional* and *mature* grips. Primitive grips refer to the pencil being grasped in the palm of the hand. Transitional grips are where the pencil is grasped between the thumb and fingers, with the forearm on the table (such as the cross thumb, static tripod and four fingers grasps). The two mature grips, dynamic tripod and lateral tripod (see Figure 2.1), build upon the transitional grips and involve intrinsic muscle control. This developmental progression was observed by way of an increasing proportion of children at each age level who used mature grips. The proportions of children using mature grips ranged from 7.5% in the youngest children to 95% in the older children (Schneck & Henderson, 1990). Increased use of the traditional dynamic tripod grip was also demonstrated in children of increasing age in a study of 287 Australian children aged 7 to 14 years (Ziviani, 1983). Maturation of grip towards the dynamic tripod grip was most commonly observed at approximately 10 years of age (Ziviani, 1983). In that study, the percentage of alternative grips to the dynamic tripod were not reported.
The dynamic tripod grip is frequently observed and typically taught by therapists and teachers (Schneck & Henderson, 1990). Professionals assume that the dynamic tripod grip is conducive to greater speed and legibility, and less pain and fatigue during writing, and that other grips negatively affect handwriting (Tseng & Cermak, 1993). However, there are little or no empirical data to support these assumptions (Selin, 2003; Tseng & Cermak, 1993).

Handwriting speed and legibility were not negatively affected by pencil grasp in a number of studies involving children aged between 7 and 16 years (e.g., Rosenblum, Goldstand, et al., 2006; Ziviani & Elkins, 1986). Use of a dynamic tripod grip did not result in significant differences in speed or legibility when compared with use of an alternative grip in a study of 282 Australian children aged 8 to 14 years (Ziviani & Elkins, 1986) and in a study of 100 Israeli students aged 8 to 9 years (Rosenblum, Goldstand, et al., 2006). Consistent with those findings, another study of 46 students aged 9 to 10 years found no significant differences in legibility between students using the dynamic tripod grip versus those using alternative grips when copying short and long passages (Dennis & Swinth, 2001). The limitations of the study by Dennis and Swinth (2001) are that the sample size was small, and the difference between the short and long tasks was only 4 to 6 sentences. The rating for legibility involved only parts of the longer task, which may have affected the results. The authors also noted the difficulty of consistently evaluating handwriting legibility (measured using the ETCH) (Amundson, 1995; Dennis & Swinth, 2001).

Previous studies have focused on children aged 7 to 16 years. There have been limited studies of pen grip involving adults. In one study of 447 right handed adults, 64 (14.3%) used alternative grips (Bergmann, 1990), particularly the lateral tripod grip (9.3%) (refer to Figure...
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2.1. The author suggested that the lateral tripod grip should be considered acceptable for use by adults. While these results provide interesting data on the range and proportion of pen grips used by adults, the results do not provide information about the relationship between pen grips and fatigue, speed or legibility.

The association between pen grip, speed and fatigue has been explored in two studies involving adults. University students \((N = 66)\) using a dynamic tripod grip or a four finger quadrupod grip wrote slightly faster \((M = 38.7\) words per minute\) during the three-minute \textit{Handwriting Speed Test} (HST; Wallen, Bonney, & Lennox, 1996) than students using lateral grips \((M = 35.5\) words per minute\) \((p = .014)\). There were no significant differences between the groups during a two-hour written examination \((p = .379)\). Speed differences between tripod and quadrupod grips were not analysed. A more rapid onset of fatigue was associated with the lateral tripod grip than other grip types when writing for up to one hour in a study of 102 subjects (mean age = 36.3 years) (Stevens, 2008). In that study, the most common grips were the dynamic tripod (51\%) and the lateral tripod (20\%) (Stevens, 2008). The authors postulated that the difference in writing endurance may be due to thumb position. However, as there was no significant difference between groups for the number of words written, the lateral tripod grip may be as functional as other grips for writing tasks of around 30 minutes duration. Further, the selected handwriting task involved copying ‘the quick brown fox jumps over the lazy dog’ repeatedly until cessation was required due to fatigue. Although providing useful information on various pen grips in a continuous handwriting situation, the study handwriting task is not likely to be performed in real-life context. The impact of various pen grips on fatigue, legibility and speed of adults for extended handwriting tasks such as copying recipes, writing a letter or writing in a journal is not known.
In summary, pen grip is one aspect of motor control involved in handwriting. Most studies investigating the relationship between pen grip and handwriting legibility or speed have involved children with only a few investigating adult pen grips. Overall, these studies suggest that grips other than the traditional tripod grip, such as the lateral tripod grip and other more atypical grips should be considered acceptable when used by children and adults. However, studies involving children to date have had methodological limitations, particularly the brevity of the handwriting tasks assessed which do not consider the effects of fatigue on pen grip during extended writing tasks. The study by Dennis and Swinth (2001) which did compare short handwriting tasks with longer tasks did not find any significant differences regarding grip types. Studies involving adults suggest a small advantage associated with the dynamic tripod grip. Nevertheless, the non-functional handwriting tasks used and heterogeneous results of studies investigating the relationship between pen grip types and handwriting performance make it difficult to draw conclusions. A major implication for therapists of existing pen grip research is that trying to change a person’s pen grip may not be necessary and indeed may be misdirected.

In-hand manipulation: Another factor which contributes to motor control during handwriting is in-hand manipulation. This term refers to the manipulation of an object between the fingers and thumb and within the hand after grasp (Exner, 1989). The definition of in-hand manipulation is often based upon Exner’s description (1989) of five types of in-hand manipulation: finger-to-palm translation, palm-to-finger translation, shift, simple rotation and complex rotation, as well as that of Elliott and Connolly (1984). These classifications have recently been questioned and a modified classification published (see Pont, Wallen, Bundy, & Case-Smith, 2008). However, as previous research has used Exner’s definition of in-hand manipulation (e.g., 1989), that definition will be used in this review.
Skilled in-hand manipulation has been associated with better letter formation when measured using the MHT (Reisman, 1993) in a study of 48 first grade students (Cornhill & Case-Smith, 1996). The ability to quickly move pegs between the fingers accounted for 63.7% of the variance between good handwriters and poor handwriters ($M = 35.1$ seconds and 59.2 seconds respectively). A limitation of that study was that the examiners were not blinded to the children’s handwriting classification, which may have biased scoring. In-hand translation (moving an object between the fingers and palm of the hand) accounted for the largest variation (18%) in handwriting speed in another study involving 69 first grade children (Feder, Majnemer, Bourbonnais, Blayney, & Morin, 2007). Another study of children aged 6 to 11 years found that those with handwriting dysfunction, on average, scored lower on the In-Hand Manipulation (IHM; Pehoski, Henderson, & Tickle-Degnen, 1997a, 1997b) than proficient writers (Denton, Cope, & Moser, 2006; Pehoski, Henderson, & Tickle-Degnen, 1997a, 1997b). The results of that study suggest that handwriting difficulties and in-hand manipulation deficits co-exist, but do not support a causal relationship (Denton, et al., 2006).

In summary, the ability to manipulate a writing implement appears to be important for successful handwriting (Cornhill & Case-Smith, 1996), however, studies examining the relationship between in-hand manipulation and handwriting are limited. No studies on the in-hand manipulation of writing implements for adults were located.

**Speed:** Speed is another aspect of motor control and is an important measure of handwriting performance. Writing needs to be completed in a reasonable time-frame (Graham, et al., 1998; Rosenblum, Weiss, & Parush, 2003). Handwriting speed is commonly measured as the average number of letters written per minute or the amount of text.
reproduced within a specific time period (Graham, Berninger, Weintraub, & Schafer, 1998; Rosenblum, et al., 2004). Kinematic studies provide information on the velocity of letter strokes (e.g., Plamondon, 1993). These studies are not reviewed here due to the limited usefulness of the technology for measuring writing speed clinically.

In children, handwriting speed increases with increasing age (Hamstra-Bletz & Blote, 1990). Girls were found to write faster than boys of the same age in the majority of studies (Graham, et al., 1998; Wallen, et al., 1996; Ziviani & Elkins, 1984), however one study reported that boys’ handwriting speed overtook that of girls’ at age 11 years (Ziviani & Watson-Will, 1998). Table 2.2 summarises studies of handwriting speed in children. The variation in children’s handwriting speeds across different studies may be due to the variety of methods used during the normative studies. Although many studies used large samples, a variety of writing activities, instructions, test duration and outcome measures were used. For example, one study required 1365 children in the USA to copy text for 2 minutes at their usual pace, and included children from resource (education support) classes (Phelps, 1985). Another study involved 1292 children from Australia who were instructed to write “the quick brown fox jumped over the lazy dog” as quickly but as neatly as they could for 3 minutes (Wallen, et al., 1996). Yet another study involved 127 children copying text in Dutch for five minutes in their usual style (Hamstra-Bletz & Blote, 1990). Ziviani and Watson-Will (1998) reported handwriting speeds according to children’s ages and not grades as previous studies had done. It is therefore difficult to pool data and make comparisons between findings from existing studies.

Adult handwriting speed normative values are available for the Jebsen-Taylor Hand Function Test for both the North American and Australian populations, with 300 and 382
people in each sample respectively, (Agnew & Maas, 1982; Jebsen, et al., 1969). Table 2.3 presents normative speed data for a 24 letter copied sentence written as fast as possible (Jebsen, et al., 1969). Females wrote faster than males in each age group, however the female participants’ handwriting speed decreased from age 26 years. Males aged 16 to 25 years wrote more slowly than their slightly older counterparts, then handwriting speed decreased after 36 years of age. The slowest handwriting was produced by older participants of both genders aged over 65 years. Both studies had relatively small sample sizes and were conducted over 20 years ago, therefore results may not be representative.

Handwriting speed and legibility do not appear to be strongly correlated. An Australian study of 372 children aged 7 to 14 years found only a low correlation existed between faster speed and legibility ($r = .23, p > .05$) (Ziviani & Watson-Will, 1998). A larger scale study conducted with 900 school-age children had similar results (Graham, et al., 1998), indicating that factors other than speed appear to influence legibility.

In summary, whilst Australian normative data for children’s handwriting speed have been relatively recently published, adult data are 27 years old. Further, adult normative values were collected while participants copied a sentence. Rather than collecting normative data on speed while adults copy a sentence, researchers need to first identify the most common modes of handwriting, that is, whether text is most often self-generated, copied, transcribed from spoken messages or a combination of each.
### Table 2.2

*Mean Handwriting Speed (Letters Written per Minute) in Previous Studies, Modified From Feder and Majnemer (2007)*

<table>
<thead>
<tr>
<th>Grade</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hamstra-Bletz &amp; Blote (1990) <em>&lt;sup&gt;a&lt;/sup&gt;</em>(N = 127)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group 1</td>
<td>-</td>
<td>24</td>
<td>35</td>
<td>46</td>
<td>54</td>
<td>66</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
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<tr>
<td>Group 2</td>
<td>-</td>
<td>25</td>
<td>34</td>
<td>42</td>
<td>59</td>
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<td>-</td>
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<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Group 3</td>
<td>-</td>
<td>25</td>
<td>39</td>
<td>49</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Phelps, et al., (1985) <em>(N = 1365)</em></td>
<td>Boys</td>
<td>-</td>
<td>-</td>
<td>23</td>
<td>35</td>
<td>46</td>
<td>54</td>
<td>58</td>
<td>70</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Girls</td>
<td>28</td>
<td>39</td>
<td>48</td>
<td>60</td>
<td>66</td>
<td>75</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Ziviani &amp; Elkins, 1984 <em>(N = 575)</em></td>
<td>Boys and girls</td>
<td>-</td>
<td>-</td>
<td>33</td>
<td>34</td>
<td>38</td>
<td>46</td>
<td>52</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Girls</td>
<td>55</td>
<td>58</td>
<td>67</td>
<td>86</td>
<td>98</td>
<td>104</td>
<td>119</td>
<td>119</td>
<td>125</td>
<td>134</td>
<td>-</td>
</tr>
<tr>
<td>Graham, et al., (1998) <em>(N = 900)</em></td>
<td>Boys</td>
<td>17</td>
<td>32</td>
<td>45</td>
<td>61</td>
<td>71</td>
<td>78</td>
<td>91</td>
<td>112</td>
<td>114</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Girls</td>
<td>21</td>
<td>37</td>
<td>50</td>
<td>66</td>
<td>75</td>
<td>91</td>
<td>109</td>
<td>118</td>
<td>121</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Ziviani &amp; Watson-Will (1998) <em>(N = 372)</em></td>
<td>Boys</td>
<td>35</td>
<td>46</td>
<td>67</td>
<td>73</td>
<td>89</td>
<td>110</td>
<td>-</td>
<td>-</td>
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<td>-</td>
</tr>
<tr>
<td></td>
<td>Girls</td>
<td>39</td>
<td>56</td>
<td>70</td>
<td>83</td>
<td>83</td>
<td>85</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

*Note.* *<sup>a</sup>Gr 1 = Group 2 to 6 (2 classes followed up for 5 years, *N* = 63), Gr 2 = Group 2 to 5 (2 classes followed up for 4 years, *N* = 29) and Gr 3 = Group 2 to 4 (2 classes followed up for 3 years, *N* = 35).*

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### Table 2.3
**Normative Data on Handwriting Speed in Adults Using a Sub-Test from the Jebsen-Taylor Hand Function Test**

<table>
<thead>
<tr>
<th>Age Group (in years)</th>
<th>16 to 25</th>
<th>26 to 35</th>
<th>36 to 45</th>
<th>46 to 55</th>
<th>56 to 65</th>
<th>66 to 90</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agnew &amp; Maas (1982)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(N = 382)</td>
<td>Males</td>
<td>12.8 (6.1)</td>
<td>10.1 (2.4)</td>
<td>11.2 (3.3)</td>
<td>12.5 (4.3)</td>
<td>15.1 (8.8)</td>
</tr>
<tr>
<td></td>
<td>Females</td>
<td>9.6 (2.0)</td>
<td>10.1 (2.6)</td>
<td>10.4 (3.0)</td>
<td>10.9 (2.9)</td>
<td>11.3 (3.1)</td>
</tr>
<tr>
<td>Letters per minute</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Agnew &amp; Maas (1982)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Males</td>
<td>112.5</td>
<td>142.6</td>
<td>128.6</td>
<td>115.2</td>
<td>95.4</td>
</tr>
<tr>
<td></td>
<td>Females</td>
<td>150.0</td>
<td>142.6</td>
<td>138.5</td>
<td>132.1</td>
<td>127.4</td>
</tr>
<tr>
<td>Jebsen, et al. (1969)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(N = 300)</td>
<td>Males</td>
<td>12.2 (3.5)</td>
<td></td>
<td></td>
<td></td>
<td>19.5 (7.5)</td>
</tr>
<tr>
<td></td>
<td>Females</td>
<td>11.7 (2.1)</td>
<td></td>
<td></td>
<td></td>
<td>15.7 (4.7)</td>
</tr>
<tr>
<td>Letters per minute</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jebsen, et al. (1969)</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Males</td>
<td>118.03</td>
<td></td>
<td></td>
<td></td>
<td>73.85</td>
</tr>
<tr>
<td></td>
<td>Females</td>
<td>123.08</td>
<td></td>
<td></td>
<td></td>
<td>91.72</td>
</tr>
</tbody>
</table>

**Note.** SD = Standard deviation; a Jebsen, Taylor, Treischmann, Trotter & Howard, 1969 (non-disabled subjects, USA). Results are for age groups 20 to 59 years and 60 to 94 years, for the writing speed sub-test, time taken (in seconds) to copy a 24 letter sentence with the dominant hand. b Agnew & Maas, 1982 (non-disabled subjects, Australia). Age groups as tabulated. c Letters per minute calculated from raw data from Jebsen and colleagues (1969).
Handwriting fluency: Fluency refers to the ability to write without pausing (Rosenblum, Goldstand, et al., 2006). Fluency is measured by calculating the number of times the pen is lifted off the paper, and therefore contributes to speed. Poor fluency (as measured by increased pauses or pen lift) has been associated with less proficient handwriting in a study comparing 15 proficient and 15 non-proficient handwriters aged 8 to 9 years (Rosenblum, Chevion, & Weiss, 2006). Proficient writers mostly lifted the pen from the paper only when necessary, at the end of words or lines. Non-proficient writers often lifted the pen from the paper during words, such as to correct errors. A greater number of pen lifts resulted in increased in-air time, where the pen was not in contact with the paper.

Fluency and global legibility are related ($r = .55, p < .01$), as are fluency and unrecognisable letters ($r = .53, p < .01$) (Rosenblum, Goldstand, et al., 2006). In that study, fluency was significantly better for 50 proficient writers (mean pen lifts = 1.12) than for 50 non-proficient handwriters (mean pen lifts = 2.98, $p = .001$). That is, fluent writers had higher legibility scores and wrote more legible letters. Fluency was also moderately correlated with total writing time ($r = .69; p < .01$) using a computerised system, indicating that poorer fluency was associated with slower writing speed (Rosenblum, Goldstand, et al., 2006).

In summary, while fluency may be important for quality handwriting, there are limited studies on the relationship between fluency, speed and legibility for children’s handwriting. No published studies involving adults were identified. Further research into the handwriting fluency of children and adults is required.

Handwriting movements: Handwriting movements in the proposed study refer to the movements or motor control required to form letters, move across words, sentences and lines.
The range of handwriting movements involves activation of the muscles of the shoulder girdle, elbow, forearm, wrist, hand, fingers and thumb (see Table 2.4). Kinematic studies (e.g., Dounskaia, Van Gemmert, & Stelmach, 2000; Thomassen & Meulenbroek, 1997) have established the contribution of multiple upper limb joints. During handwriting in adults, small horizontal (intra-word) movements result from wrist deviation when the forearm is stabilised on the table (Dooijes, 1983). In that study, pen angle varied from 45° to 90° across participants and during a sentence for individual subjects, suggesting varying degrees of forearm supination. Proximal and distal interphalangeal joint flexion and extension of the index were shown to be responsible for small vertical movements (Dooijes, 1983). Findings from that study were consistent with those from a study where 20 subjects performed strokes in different orientations. Vertical strokes involved primarily the finger joints, horizontal strokes were performed primarily using the wrist joint, and oblique strokes required a combination of finger and wrist movements (Contreras-Vidal, Teulings, & Stelmach, 1998).

Inter-word movements are primarily performed using shoulder abduction, external rotation, supination/pronation and wrist extension in kindergarten children (Blote, Zielstra, & Zoetewey, 1987). Although the degree of supination/pronation is thought to change around 10 years of age (Ziviani, 1983), the same muscle groups used by children for inter-word movements are likely to be used by adults. While no empirical data were located, task analysis of handwriting provides support for the assumption that common muscle groups are used by children and adults for inter-word movements.
Table 2.4
Upper Limb Movements Used in Picking up and Using a Pen or Pencil

<table>
<thead>
<tr>
<th>Movement</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conjoint rotation of individual fingers towards thumb (opposition/cupping), IP flexion of thumb, IP flexion of all fingers, wrist extension (^a)</td>
<td>Used to grip the pen</td>
</tr>
<tr>
<td>Shoulder abduction, external rotation, elbow flexion/extension, forearm supination/pronation and wrist extension (^{b, f})</td>
<td>Inter-word movements and larger script size</td>
</tr>
<tr>
<td>Forearm supination (^c)</td>
<td>Adjustment of pen angle</td>
</tr>
<tr>
<td>Wrist deviation and extension (^{d, e})</td>
<td>Small horizontal (intra-word and letter) movements</td>
</tr>
<tr>
<td>Proximal and distal IP joint flexion and extension of the index and middle fingers, thumb MCP and IP joints (^{c, d, e, f})</td>
<td>Small vertical intra-word movements</td>
</tr>
</tbody>
</table>

Note. Upper limb movements were analysed using the analysis approach as outlined by Bukowski (2000), \(^a\) (Bukowski, 2000), \(^b\) (Blote et al., 1987), \(^c\) (Dooijes, 1983), \(^d\) (Contreras-Vidal et al., 1998), \(^e\) (Elliott & Connolly, 1984), \(^f\) (Lacquaniti, Ferrigno, Pedotti, Soechting, & Terzuolo, 1987). IP = interphalangeal; MCP = metacarpalphalangeal.

Larger script size (i.e., larger letters) appears to involve greater shoulder and elbow movements (Lacquaniti, et al., 1987). In that study, markers placed on shoulder, elbow, wrist and MCP joints were used to measure movement via a television digitised image and opto-electronic system. The distance from the second MCP joint to the pen tip was measured to estimate the angular changes of the thumb MCP and IP joints. Three experiments (50 trials) revealed that the amount of angular motion at the shoulder and elbow joints increased proportionally with increased script size, but wrist and finger movements remained small irrespective of script size (Lacquaniti, et al., 1987). These results suggest that smaller handwriting movements are performed by the wrist and fingers, and remain fairly constant, while increases in script size are largely due to increased shoulder and elbow movements.
The type of pen grip is also thought to affect the pattern of writing movements. Average script size (measured as average total path on paper) increased from 267 mm when a sample of 11 adults used their habitual (tripod) grips, to 316 mm when using a modified grip (see Figure 2.2B) \( p = .006 \) (Baur, et al., 2006). The authors proposed that the increased script size was due to increased proximal joint involvement with the distal joints more immobilised by the modified grip. In other words, restricting finger movements resulted in increased movements in proximal joints such as the shoulder and elbow. No studies directly investigating the effect of pen grip types on proximal joint movements were located.

![Figure 2.2. (A) Habitual and (B) modified grip as described by Baur et al. (2006).](image)

In summary, upper limb joints appear to differ in their contribution to handwriting movements. Proximal joints appear to be primarily responsible for larger between-word movements and larger script size. Distal joints appear to be responsible for smaller intra-word movements and these movements remain fairly constant regardless of the movement at the shoulder or elbow. Handwriting movements have been the focus of a few studies, primarily involving laboratory handwriting tasks. A greater understanding of normal movement patterns and the relationship between distal and proximal muscles and handwriting performance in real handwriting situations is needed for accurate assessment and retraining of
handwriting deficits. Further studies involving larger samples of English-writing adults are recommended.

**Posture:** Another aspect of motor control which is thought to affect handwriting performance is posture. Posture of the body refers to the position of the trunk and limbs. Correct posture is often emphasised during handwriting instruction (Graham & Weintraub, 1996). “Optimum positioning” has been described as 90° hip flexion, feet positioned flat on the floor, and the table height conducive to 90° elbow flexion (Smith-Zuzovsky & Exner, 2004). This optimum posture is generally considered to be associated with better handwriting performance (Feder & Majnemer, 2007).

The effect of optimal body positioning on hand function has been investigated in children (Smith-Zuzovsky & Exner, 2004). In that study, 40 children aged 6 to 7 years were randomly assigned to an optimal positioning or sub-optimal positioning group (desk and chair height not adjusted for the child) while they performed the quality of skills section of the *In-Hand Manipulation Test* (IMT-Q; Exner, 1997). Optimally positioned children scored a mean of 145.4 out of 165 (88.1%) compared with the sub-optimally positioned children, who scored 135.0 out of 165 (81.8%) \( p < .01 \). Thus, children seated in the optimum position performed better at in-hand manipulation, particularly complex tasks requiring stabilisation of an object in the hand whilst manipulating another, than children with poor posture. Assessors (not blinded, thus introducing possible bias) noted that children in the optimal position moved less during testing compared with the sub-optimally positioned children. The authors also suggested that attention to task may have been negatively affected by frequent postural changes (Smith-Zuzovsky & Exner, 2004). While that study did not specifically measure handwriting, better posture was associated with better in-hand manipulation, and in-hand
manipulation is associated with improved letter formation (Cornhill & Case-Smith, 1996) and handwriting speed (Feder, et al., 2007). Results therefore suggest a possible relationship between posture and handwriting performance. Further research is required before conclusions can be drawn.

Large variations in posture have been observed in kindergarten children during writing (Blote, et al., 1987). Only 50% to 60% of the children sat in the ‘optimum position’ to write (Blote, et al., 1987). The impact of shifting posture on handwriting performance was not reported in this study. However, another study found upper limb steadiness to be associated with better letter legibility in first grade children (Feder, et al., 2007). Only a weak correlation (Pearson Correlation Coefficient = -.37, \( p < .05 \)) was found, suggesting other factors most likely impact on legibility.

Body posture was one of several biomechanical factors investigated in an Israeli cross-sectional study comparing handwriting performance in 50 proficient and 50 non-proficient students aged 8 to 9 years (Rosenblum, Goldstand, et al., 2006). Moderate to low correlations were found between poor body posture and lower legibility scores, worse letter appearance and spatial arrangement as assessed by the HHE (Erez & Parush, 1999). Computerised temporal and spatial outcome measures were also collected while the children wrote on a digitising tablet. Temporal measures included total time spent writing, on-paper time and in-air time. Spatial measures included total path length of all characters written, on-paper length and in-air length. A moderate correlation was found \( (r = .60) \) between poor body posture and greater in-air time. Greater total time, on-paper time and total path length were associated to a lesser extent with low body posture scores. These modest correlations suggest that although
ergonomic biomechanical factors may contribute to poor handwriting performance, these factors alone do not explain the differences between proficient and non-proficient writers.

In summary, a review of studies on body posture and handwriting suggests that poor posture may contribute to poor handwriting. The absence of strong correlations (i.e., >.60) suggests other factors contribute to writing performance. Nevertheless, teaching good postural habits to young writers may be advantageous. No studies were found on the effects of posture in adult handwriting or on the range of postures assumed by adults during handwriting tasks. Anecdotally, adults can be observed to write at times while sitting, standing and stooping. Further research into the range of postures assumed by adults during handwriting and the relationships between posture, handwriting movements and performance would be beneficial in retraining adult writers.

Motor control is a key component of handwriting performance. This section has reviewed studies on pen grip, in-hand manipulation, speed, fluency, handwriting movements and posture. Again, the majority of research into these areas has involved children. Pen grips other than the dynamic tripod grip are common in adults (Bergmann, 1990). In children, pen/pencil grip and handwriting performance do not appear to be associated. Further research is required which involves real-life handwriting activities.

In-hand manipulation has been associated with better handwriting performance in children, although research involving adults is lacking. Normative data exist for handwriting speed in children and adults. Up-to-date data involving a larger sample of adults and self-generated text is recommended. Handwriting fluency has received little attention and requires further investigation. Handwriting movements are performed primarily by the shoulder and
elbow joints for between-words movements and increasing script size and by distal joints for smaller, intra-word movements. Posture appears to have weak to moderate correlations with handwriting performance. In addition to motor control, a number of other neurological processes are necessary for successful handwriting. The following section reviews the research on some of the sensorimotor, perceptual and cognitive processes involved in handwriting.

2.5 Sensorimotor, Perceptual and Cognitive Processes Involved in Handwriting

Handwriting is a complex activity, simultaneously involving motor skills, cognitive and visual-perceptual processing (Bonney, 1992). Performance components involved in children’s handwriting have been identified in a number of correlational studies. The specific processes involved in handwriting are outside the scope of the study, so a significant body of studies addressing these processes will not be reviewed here. Instead, key studies and reviews (Cornhill & Case-Smith, 1996; Tseng & Cermak, 1993) have been outlined to describe the role of some commonly reported factors in children’s handwriting: kinesthesia, visual-perception, visual-motor integration (VMI) and motor planning (praxis).

Kinesthesia: Kinesthesia refers to the “awareness of weight of an object (and of limb) and the directionality of joint and limb movement” (Cornhill & Case-Smith, 1996, p. 733). Kinesthetic feedback provides information about arm movement, and assists with monitoring errors and motor learning (Laszlo & Bairstow, 1983). A study investigating kinesthetic training on drawing tasks in children aged 6 to 8 years (N = 24) found improvements in the treatment group, however no between-group comparisons were made with the control group (Laszlo & Bairstow, 1983). First grade children (N = 30) with handwriting difficulties had low grip scores and lower scores for kinesthesia on a drawing task when compared with
children without handwriting difficulties ($N = 30$) (Schneck, 1991). It was suggested that children may compensate for impaired kinesthetic feedback by adapting their pencil grip to increase the pressure on the pencil (Schneck, 1991).

Few studies have investigated the relationship between kinesthesia and handwriting performance. Kinesthesia, age and academic ability accounted for 71% of the variability of letter formation in a study of 34 children (aged 6.2 to 13.4 years) with spina bifida (Ziviani, Hayes, & Chant, 1990). In contrast, another study of 143 Chinese children (Grades 3 to 5) did not find any correlation between kinesthesia and handwriting legibility ($r = .11, p > .05$) (Tseng & Murray, 1994). Similarly, a randomised controlled trial of 45 first grade children identified as having handwriting and kinesthetic deficits reported no significant differences between groups receiving kinesthetic training or therapeutic handwriting practice (Sudsawad, Trombly, Hendersen, & Tickle-Degnen, 2002). This finding suggests that kinesthetic training had no effect on handwriting performance. Further, a study of 60 first grade children identified as good or poor handwriters found no relationship between handwriting quality and kinesthesia (Copley & Ziviani, 1990). Overall, it appears that there is no strong relationship between kinesthesia and handwriting performance in children.

**Visual perception:** Visual perception refers to the ability to interpret or make sense of visual information (Gardner, 1996). The role of visual perception and handwriting, as investigated in correlational studies, was reviewed by Tseng and Cermak (1993). In that review, no significant correlations were found between visual perception and handwriting ability based on one study involving 60 first grade children (Yost & Lesiak, 1980). In contrast, another study involving 354 first grade children found a ‘slight’ relationship between incidence of letter formation errors and visual perception (Lewis & Lewis, 1965). Similarly, a
small, positive relationship between visual perception and reversal errors was found in a study of 151 children aged 7 to 8 years (correlation coefficient not reported, \( p < .05 \)) (Chapman & Wedell, 1972). Limitations of these studies have been reported (Tseng & Murray, 1993). Visual perception was measured by Yost and Lesiak (1980) using a motor response. Impaired motor skills may have negatively impacted upon visual perception scores (Denton, et al., 2006). Lewis and Lewis (1965) did not report their data analysis or statistics pertaining to visual perception in their study. Chapman and Wedell (1972) investigated the relationship between visual perception and reversal errors, which is only one aspect of handwriting (Tseng & Cermak, 1993).

Visual perception has also been studied more recently. A significant difference in visual perception scores was found between children with good and poor handwriting \( (p = .0001) \) (Tseng & Murray, 1994). Handwriting legibility was assessed using a 7 point scale \( (1 = \text{poorest} \text{ and } 7 = \text{best}) \). In that study, stepwise multiple regression analysis of good handwriters who scored above 4.5 out of 7 for legibility, showed visual perception to be the only predictor of legibility score, accounting for 14% of variance \( (p = .02) \). However, visual perception was not a predictor of the poorer handwriting scores (below 3.6 out of 7, \( n = 45 \)), or of the total sample. Another study found that 75% of children \( (N = 38) \) with handwriting dysfunction scored below average in a visual-perceptual test, involving a motor-reduced response (Denton, et al., 2006). However that randomised controlled trial did not find any association between visual perception and handwriting performance (Denton, et al., 2006). The role of visual perception in handwriting thus remains unclear (Feder & Majnemer, 2003).

**Visual-motor integration:** Visual-motor integration refers to the ability to execute a movement based on visual information (Levine, 1987). Visual-motor integration is therefore
considered important for copying figures (Tseng & Cermak, 1993). While one study found only a weak, non-significant relationship between VMI and word legibility (Pearson Correlation Coefficient = .29, \( p = .06 \)) (Feder, et al., 2007), the majority of studies located found moderate correlations between VMI and handwriting performance. Visual-motor integration and ability to copy letters legibly were moderately correlated \((r = .47, p < .001)\) in a study of 59 kindergarten children aged 64 to 75 months (Weil & Cunningham Amundson, 1994) and in a study of 40 children (mean age 10 years) \((r = .49)\) (Rubin & Henderson, 1982). Visual-motor integration scores were moderately correlated with handwriting quality (Pearson Correlation Coefficient = 0.52, \( p < .01 \)) for 49 Dutch children aged 88 to 100 months (Volman, van Schendel, & Jongmans, 2006). Similarly, VMI had the strongest correlation with legibility \((r = .55, p < .001)\) in the study by Tseng and Murray (1994). Visual-motor integration was the best predictor of legibility, accounting for 30.5\% of the variance between the handwriting legibility scores (from 1 to 7) of the total sample of handwriters \((N = 143)\) (Tseng & Murray, 1994). Children aged 8 to 13 years with low VMI \((n = 19)\) made significantly greater total errors, particularly in spacing letters and words than children without VMI deficits \((n = 18)\) in a more recent study (Barnhardt, Borsting, Deland, Pham, & Vu, 2005). Overall, these studies indicate a relationship between visual-motor integration and handwriting performance in children, however moderate correlations suggest factors other than the ability to copy affect legibility.

**Motor planning:** Motor planning refers to the ability to plan how to perform unfamiliar movements (Cornhill & Case-Smith, 1996). Motor planning may therefore impact on handwriting, particularly when children are learning to write (Cornhill & Case-Smith, 1996). No relationship was found between motor planning (as measured by the Motor Accuracy Test; Ayres, 1980) and legibility in a study by Ziviani and colleagues (1990). As
this study included children with spina bifida, motor deficits related to their diagnosis may have affected results (Tseng & Cermak, 1993). Further, although the Motor Accuracy Test includes a component of motor planning, it is primarily a test of eye-hand co-ordination (Tseng & Murray, 1994). In contrast, motor planning was found to be the only predictor of legibility in poor writers who scored below 3.6 out of 7 for legibility in the study by Tseng and Murray (1994). Motor planning accounted for 10.3% of the variance in legibility scores. However, motor planning was not a predictor of the good handwriting scores or of the total sample. In that study, motor planning was measured using the Finger Position Imitation Test, which at the time was considered an experimental test (Tseng & Murray, 1994). Further investigation into the role of motor planning in handwriting is required for unimpaired, English-speaking children. It is not known to what extent motor planning is required in adult handwriting, although by definition, as handwriting is more automatic in adults (Olive & Kellog, 2002) motor planning may play a lesser role in adult handwriters.

There are many factors associated with handwriting and deficits in one area alone may not result in poor handwriting. In correlational studies involving perception, it is difficult to reduce the impact of variables such as cognitive processing. However, there appears to be an association between VMI and handwriting performance in children. No studies investigating the role of perception in adult handwriting have been found. Most of the studies reviewed have involved children aged between 5 to 11 years. Particularly during the earlier years, children’s pencil grips and handwriting styles are evolving. It is likely that perceptual processes have a greater role in children when handwriting is developing, than in adults, who have fully developed neurological systems and for whom handwriting is a more automated activity.
A number of other processes contribute to the complex task of handwriting and a review of these is outside the scope of this chapter. Handwriting involves processing of sensory information (e.g., Ebeid, Kemp, & Frostick, 2004) and vision (e.g., Smyth & Silvers, 1987; Van Doorn & Keuss, 1992). Cognitive functions including planning and working memory have been associated with handwriting (Olive, 2004; Peverly, 2006; Volman, et al., 2006), as has attention on handwriting speed (Tseng & Chow, 2000). Based on these findings, it is clinically assumed that the context under which the handwriting is being performed may change the demands of handwriting. Simply speaking, self-generated text involves generation of ideas followed by production of written text via language-specific processes (Jones & Christensen, 1999), copying requires processing of visual information and transcribing text from a spoken message requires processing of auditory information (Volman, et al., 2006).

This chapter has reviewed the parameters that can be measured from handwriting samples, and aspects of motor control that appear to be important for handwriting. This section has described key studies commonly reported in paediatric literature for kinesthesia, visual-perception, visual-motor integration and motor planning. Other underlying skills are certainly involved in handwriting, such as cognition, vision and sensation. However the contributions of neurological processes to handwriting performance are very complex, interrelated and not yet fully understood (Jones & Christensen, 1999). Further research is required to determine the role of specific processes involved in handwriting and their impact on handwriting performance in both children and adults. Neurological processes are likely to vary across different handwriting tasks and situations, and be affected by personal factors. Handwriting activities and personal factors and how these may impact upon handwriting performance are discussed in the following section.
2.6  **Handwriting Activities and Personal Factors**

Modes of handwriting, reasons for handwriting, length and frequency of handwriting occasions, writing implement and technology use may affect handwriting behaviour and performance. Additionally, the writer’s age, hand preference, socio-economic status and gender may also impact upon handwriting. Each will now be discussed in turn.

**Modes of handwriting:** Modes of handwriting refer to whether information is self-generated by the writer, copied from another source or transcribed from a spoken message (see Table 2.5 for examples of each mode).

Differences in writing parameters have been found for various handwriting modes. Copied writing was more legible, as measured by the TOLH (Larsen & Hammill, 1989), than self-generated writing in students from Grades 1 to 6 \( (p < .01) \) (Graham, et al., 1998). For students in Grades 7 to 9, self-generated samples were rated slightly higher for legibility although this finding did not reach statistical significance (Graham, et al., 1998). Another study of first and second grade children \( (N = 200) \) found that with self-generated writing tasks, letters were more crowded and smaller, less aligned with the baseline and more slanted than letters produced for a copying task (Graham, et al., 2006). These results support the assumption that self-generating text is more complex than copying.
Table 2.5
Examples of Modes of Handwriting

<table>
<thead>
<tr>
<th>Mode</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Self-generated text</td>
<td>Writing a letter, card, message or shopping list</td>
</tr>
<tr>
<td></td>
<td>Answering Bible study questions</td>
</tr>
<tr>
<td>Copied text</td>
<td>Copying an address onto an envelope</td>
</tr>
<tr>
<td></td>
<td>Copying a recipe</td>
</tr>
<tr>
<td>Transcribed text from a spoken message</td>
<td>Writing down a telephone message or a news item heard on the television or radio</td>
</tr>
</tbody>
</table>

Due to the various neurological pathways involved, studies comparing different modes are required to better understand their impact on handwriting. Programs aimed at measuring and retraining handwriting need to consider each mode (self-generated, copied and transcribed text). A greater understanding of the applications of each mode of handwriting by adults would assist in the development of an ecologically valid handwriting assessment and retraining program.

**Reasons for handwriting:** A common reason for pen and paper tasks including handwriting in children is for educational purposes (McHale & Cermak, 1992). While handwriting is commonly performed by most adults in a variety of settings and situations, very little is known about the range of everyday handwriting activities undertaken. The most common handwriting activities completed within the previous three days as reported in a recent Australian survey were: writing a signature (88.3%), ideas (85.6%), reminders (74.2%) or to-do lists (69.0%). That survey included 523 respondents aged 18 to 54 years (McMahon, 2008). Working-aged adults may be required to write as part of their employment. In post-retirement years, handwriting may be used more for writing letters and keeping lists, however
little data have been published on this topic. There is a need for research to identify the reasons for and context of writing in older adults. As self-report relies on memory, methods such as observation or digital pens may be used to gather objective data.

**Length and frequency of handwriting occasions:** Primary school children spend 30% to 60% of the school day performing fine motor tasks, the majority of which are pencil and paper tasks (McHale & Cermak, 1992). The frequency with which adults write or the proportion of time spent writing has not been widely studied. Even in research investigating the daily activities of older people, handwriting is rarely included in self-report questionnaires (Dixon, Kurzman, & Friesen, 1993). In one study, the majority (94.3%) of 52 participants aged 60 years and over, reported writing ‘daily’ or ‘almost daily’, suggesting that handwriting is a regular activity for older adults (Rosenblum & Werner, 2006). In another survey, 88.3% of working-aged respondents reported having written their signature within the past three days (McMahon, 2008). Although respondents reported writing daily or almost daily, data in these two studies were collected using self-report, rather than by objective methods such as direct observation. In addition, nothing is currently known about the number of words or the time of day that adults commonly write. Further research, objectively exploring the frequency and amount of handwriting per episode, may deepen our understanding of the duration of handwriting tasks required in an adult handwriting assessment and retraining program.

**Characteristics of the writing implement:** Characteristics of a pen or pencil include the weight, length, balance, grip diameter and texture (Gross, Lloyd, & Tabler, 1996). These characteristics are thought to have an impact on children’s handwriting performance, however studies have not provided empirical support for this assumption. A study of 48 preschoolers found no significant differences between smaller and larger pencil diameter and handwriting...
performance for drawing, tracing and writing name (Carlson & Cunningham, 1990). Similarly, a larger study of first grade children \((N = 525)\) found no significant differences in legibility of the different implement groups (large primary pencil, small primary pencil, triangular grip pencil and felt-tip pen) by gender or handedness (Lamme & Ayris, 1983). A more recent study involving 126 kindergarten children supported the findings of previous studies (Oehler, et al., 2000).

In adults, few studies exist to guide writing implement selection. The traditional biro was reported as being the most commonly used pen \((94.3\%)\), followed by the lead pencil \((72.1\%)\) and the fluorescent highlighter \((72.1\%)\) in the self-report survey study of 523 respondents (McMahon, 2008). Reasons given for the choice of writing implement were availability \((57\%)\), suitability for the task \((54\%)\), ease of use \((44\%)\), convenience \((37\%)\) and comfort \((36\%)\) (McMahon, 2008). These results support those of an older study where 30 university students indicated preference for ballpoint pens in terms of legibility and comfort qualities, followed by lead pencils then fountain pens (Kao, 1976).

The effect of different pens on perceived comfort and thenar muscle activity was studied by Gross and colleagues (1996) during a 68-word writing task. The pen types used in the study were the ErgoPen, Mont Blanc ball-point, Bic Round Stic, Papermate Flexgrip fine and Pilot V Ball extra fine. After each pen was used for the writing task, a questionnaire was completed by participants \((8\) men and \(5\) women, mean age \(= 34.5\) years). Each participant rated design features of the five pens according to their comfort. Preferred pen characteristics were found to be associated with hand size. People with larger hands scored the thicker ErgoPen more favourably for pen length, balance, grip diameter, texture and to a lesser extent ease of writing. People with smaller hands favoured the smaller Pilot V Ball pen for grip.
diameter, texture, ease of writing and, to a lesser extent, length \((p = .0004)\) (Gross, et al., 1996). Therefore, participants with small hands preferred the smallest pen, while participants with larger hands preferred the largest pen. Thenar electromyography (EMG) activity was similar across all pen types (average EMG ranged from 18.3 to 23.3\% of maximum voluntary contractions, \(p = 0.8\)), indicating that pen size did not significantly affect thenar muscle activity (Gross, et al., 1996). That study used a small sample size \((n=13)\), so results cannot be generalised to the population.

Research into writing implements with larger samples is recommended to further investigate the relationship between pen design and anthropometric characteristics of the writer. A longer handwriting task may help to determine whether pen characteristics are associated with handwriting endurance. Evidence suggests that people often select their writing implement based on what is readily available, and not necessarily according to the most suitable pen for them (McMahon, 2008). Research may be used by pen companies to market ‘best fit’ pens for different hand sizes. Certainly, having a range of available pens, and perceived comfort should be considered when retraining handwriting difficulties, particularly with those adults who have weak or static pen grips.

**Use of technology:** In an age of continuously developing technology, it is clinically assumed that other modes of communication may impact upon the frequency and use of handwriting. Computers, mobile telephones, email, internet, personal digital assistants (PDAs) and dictaphones all replace what used to be typically handwriting activities, such as writing letters and writing in diaries. The replacement of handwriting tasks with technology, however, is assumed to depend on the age of the person.
Working-aged adults \((N = 523)\) reported frequent use of technology to communicate. Almost three quarters of respondents \((n = 383)\) reported that they mostly used technology to communicate, but sometimes liked to handwrite. Only 3.6\% \((n = 19)\) of respondents stated that they preferred handwriting as a method of communication but sometimes used technology (McMahon, 2008). Regression analysis found being aged between 18 and 25 years to be predictive of greater technology use than people aged over 25 years \((p = .0001)\).

Older adults report relatively low levels of internet use (Horrigan, 2007). Only 17\% of adults aged 65 years and over reported being frequent internet users in a telephone survey of 4001 Americans in 2006 (Horrigan, 2007). Half of respondents were not connected to the internet, compared with 8\% of 18 to 29 year olds. In another study, only around one fifth of respondents aged over 60 years \((N = 352)\) reported using a computer within the previous 12 months when surveyed (aged 21 to 96 years) (Selwyn, Gorard, Furlong, & Madden, 2003). Word processing was reported as the most common reason for computer use, whilst the internet and email had only been used by 15.1\% of respondents \((n = 53)\) (Selwyn, et al., 2003).

Technology is more frequently used for activities that were previously handwritten, such as writing a letter. Nonetheless, daily or almost daily handwriting appears to be common in adults aged 65 years and over (Rosenblum & Werner, 2006). Little is currently known about the impact of alternative modes of communication on handwriting, especially in terms of frequency and endurance. The investigation of changes in the frequency of handwriting over time related to technology use is warranted.
**Age:** Handwriting changes from childhood to early adulthood have been documented. One longitudinal study involved a cohort of 127 students starting from Grade 2. Copied text samples were evaluated yearly over 3 to 5 years (Hamstra-Bletz & Blote, 1990). Over time, handwriting became smoother, letter formation and spacing deteriorated and script writing was less frequently used as older students developed their personal writing style (Hamstra-Bletz & Blote, 1990). It is during young adulthood that experimentation results in a writing style and grip which seems the most efficient. Significant differences in letter formation were found between children in Grades 7 and 9, in a study of 134 Israeli children (Weintraub, Drory-Asayag, Dekel, Jokobovits, & Parush, 2007). Older children had a greater number of poorly formed letters for both the copying task \( p = .008 \) and the dictation task \( p = .006 \) (Weintraub, et al., 2007). It appears that findings from children’s studies cannot be translated to adults, although this frequently occurs due to a paucity of literature on the handwriting of middle-aged and older adults.

A number of differences between middle-aged and older adults were identified in a study comparing the handwriting of people with Parkinson’s disease with age-matched unimpaired adults (Walton, 1996). Participants wrote a dictated sentence, then five years later, wrote the same sentence. Participants completed both handwriting samples. Few changes were found in the handwriting of middle-aged controls over the five year period. In contrast, the later handwriting samples of older controls had larger letter size and greater spacing than those written five years earlier. Approximately half of the older controls produced characters with irregular slopes and sizes. Two-thirds of older controls compared with one third of middle-aged controls produced errors. Pen pressure tended to be more uniformly heavy in some parts of the sentence, compared with the lighter upstrokes and heavier downstrokes of the younger group. Poorer fluency was found in older subjects (mean
age = 75 years, mean pen lifts = 6.0) compared with younger subjects (mean age = 57 years, mean pen lifts = 2.7). The younger group formed predominantly curved strokes, compared with the combination of curved and angular strokes of the older group. The author suggested differences may result from vision changes and some loss of muscle control (Walton, 1996). Although demonstrating some interesting differences, this study was not primarily designed to investigate the handwriting of the control groups. It is therefore uncertain whether this study design is able to compare the handwriting of middle aged and older people.

Legibility and speed differences have been found between younger and older adults. Legibility was rated more poorly for 70 professionals aged over 40 years (6.7 out of 13) than that of their 139 younger counterparts (8.1 out of 13, $p = .0011$) in the study by Berwick and Winickoff (1996). The mean score for handwriting samples overall was 7.1 out of 13. However, the primary aim of that study was to compare the legibility of doctors’ handwriting with that of other professionals, not to compare age groups. Further, due to the questionable inter-rater reliability of the scale and the artificial nature of the dictated sentence where participants were stopped after 10 seconds, results should be interpreted with caution.

The kinematic characteristics of the handwriting of 53 unimpaired Israeli people aged 60 years and over were analysed in a recent study (Rosenblum & Werner, 2006). Participants performed eight functional handwriting tasks on a digitised tablet. Five copying tasks did not involve memory, including copying the alphabet. Three tasks were memory-related, including dictated handwriting tasks and writing the alphabet. Specialised software was used to quantify the ‘in-air’ and ‘on-paper’ time, speed and pen pressure. Greater in-air and on-paper times were associated with higher ages. Significantly less downward pressure was also used by older participants for 4 out of 7 tasks. Reduced grip strength was proposed as an
explanation for reduced downward pen pressure by the older participants (Rosenblum & Werner, 2006). Reducing grip strength with increased age has been previously demonstrated (Agnew & Maas, 1982), and is not surprising. Also consistent with previous studies (Agnew & Maas, 1982; Dixon, et al., 1993; Jebsen, et al., 1969), lower speed was associated with higher age, with correlations ranging from -0.33 to -0.40 across tasks (Rosenblum & Werner, 2006). A limitation of this study is that the handwriting tasks, although functional, were pre-determined by the research team. Further, as the study was conducted in Israel, results cannot be applied to an English-writing population. No studies have yet provided information on unimpaired older adult English handwriting in real situations and environments.

In summary, ageing results in the decline of physiological and cognitive functions (Bonder & Goodman, 1995). The emerging picture is that aspects of handwriting performance also decline with increasing age, particularly over 65 years (Walton, 1996). Each of the studies discussed compared the handwriting of older subjects with that of younger subjects. A large, longitudinal study involving healthy older adults would provide data on handwriting changes over time, and enable more accurate relationships between handwriting features and ageing to be identified. Further, there is currently no information on the handwriting of unimpaired older adults in the context of their daily lives. Analysis of the features of real-life handwriting samples may provide more valid information of normal older adult handwriting than simulated activities.

**Hand preference:** Hand preference while handwriting refers to the hand used to write, irrespective of hand dominance for other activities. In a study of 504 Finnish children aged 6 to 12 years, 10% were left-handed. Similarly, in a study of 900 American children, 9% of children in Grades 1 to 3 were left-handed, 10% in Grades 4 to 6 and 8% in Grades 7 to
9 (Graham, et al., 1998). In the American study, right-handed writers wrote faster than left-handed writers ($M = 73$ vs $65$ letters per minute, respectively) (Graham, et al., 1998). Another study reported that right-handers (RH) wrote faster than left-handers (LH), although data were not presented (Phelps, 1985). In contrast, no differences were found in handwriting speed between LH and RH in an Australian study involving a sample of 212 children from Grades 3 to 6, with 14% of left-handed writers (RH = 69.8 letters/min, LH = 67.1 letters/min; $p = .61$) (Wallen & Mackay, 1999).

The hand preference of adults was investigated in a large study which collected data using an on-line survey ($N = 255,100$, ages 10 to 71 years) (Peters, Reimers, & Manning, 2006). Of the 112,572 white males and 102,080 white females who responded, 12.8% responded writing with their left hand. Of the 170 respondents from China, 10.3% of males and 4.4% of females reported writing with their left hands. The authors suggested that gender differences may be due to culture or environment (Peters, et al., 2006).

Functionally, left-handedness is often believed to be associated with awkward writing postures, including a hooked wrist (Selin, 2003). Only 8% of left-handers and 3% of right-handers demonstrated a hooked wrist in a study by Selin (2003). No significant differences were found in terms of pen lifts, slant, and stroke efficiency between three groups: a) 5 males and 5 females, RH with non-inverted wrist, b) 5 males and 5 females, LH with an inverted (hooked) wrist and c) 2 males and 5 females LH with non-inverted wrist (Meulenbroek & Van Galen, 1989). Findings suggested a slight advantage towards right handed writers, but also that the hooked wrist is a functional position for left-handed writers. The impact over a longer duration handwriting task was not assessed.
Significant gaps in knowledge about adult handwriting have been identified in this review and substantially more again for this left-handed minority group. Studies comparing the handwriting performance of left-handed and right-handed writers are inconclusive, and report primarily speed. Little is known about the legibility and endurance of left-handed writers.

**Socio-economic status:** A relationship between low socio-economic status and poor handwriting in children has been suggested. Children from three schools in England (N = 34, aged 9 to 11 years) were categorised as ‘achievers’ or ‘underachievers’ by their teachers and then rated using Intelligence Quotient (I.Q.) tests (Lee-Corbin & Evans, 1996). The two groups were compared in terms of their parents’ socio-economic status and handwriting, amongst other factors. Children identified as achievers were more likely to have a primary wage earning parent who performed non-manual work than children identified as underachievers (67% compared with 31%, \( p < .05 \)). That study also found that 75% of the underachievers had poor handwriting (rated by the children’s teachers) compared with just 5.5% of the achievers (\( p < .05 \)) (Lee-Corbin & Evans, 1996).

Another study compared the handwriting speed of Irish children (N = 1224, aged 7.7 to 19.6 years), from 24 regular schools with children from 8 ‘disadvantaged schools’ (O’Mahoney, Dempsey, & Killeen, 2008). Children from ‘disadvantaged schools’ wrote more slowly than children from regular schools (\( p \leq .05 \)), with the mean difference ranging from 5.6 to 13.9 letters per minute. In the English study, the relationship between socio-economic status and handwriting was not the primary purpose of the study. In the Irish study, the backgrounds of individual students were not assessed, rather children from the ‘disadvantaged schools’ were assumed to have poorer socio-economic backgrounds. Based on these studies,
a relationship between low socio-economic status and poor handwriting performance in children seems likely. However, studies directly investigating the relationship between socio-economic status and handwriting performance are required before conclusions may be drawn.

Studies comparing the handwriting of adults from different socio-economic backgrounds are also limited. The legibility of doctors’ handwriting has been studied, due to the serious health and medico-legal implications of poor handwriting legibility in this population (Berwick & Winickoff, 1996; Lyons, et al., 1998; Rodriguez-Vera, et al., 2002). Two studies found doctors’ handwriting to be significantly less legible than that of other hospital staff (Lyons, et al., 1998; Rodriguez-Vera, et al., 2002). In contrast, another study did not find significant differences between the handwriting legibility of doctors compared with non-doctors (Berwick & Winickoff, 1996). In that study, executives scored on average 2.9 points less out of 13 points for legibility compared to non-executives (4.7 out of 13 vs 7.6 out of 13 respectively, $p < .0001$) (Berwick & Winickoff, 1996). Differences in findings across these studies may have been due to the various methods for rating handwriting legibility, and further highlights the challenges in assessing handwriting legibility. These study findings do not suggest that better handwriting quality is associated with higher socio-economic status, however these studies compared doctors’ handwriting with that of other skilled or executive professionals.

In summary, only one published study was found directly investigating the differences in handwriting between children from different socio-economic backgrounds. Doctors’ handwriting was found to be less legible than that of non-doctors in more recent studies, however no published studies directly investigating the handwriting of adults from different socio-economic backgrounds were found. Further research comparing the handwriting of
people from high and low socio-economic backgrounds is required before any conclusions can be drawn.

**Gender:** Differences in the handwriting of males and females have been found. During Grades 2 to 6 boys continued to write a joined script, whereas girls stopped writing joins in Grades 5 and 6 in the study by Hamstra-Bletz & Blote (1990). The small script size was adopted by nearly 70% of Grade 2 girls as opposed to 35% of Grade 2 boys. No significant differences in speed were identified between boys and girls in that study. Another study found that the writing speed of boys caught up to the speed of girls around the age of 11 (Ziviani & Watson-Will, 1998). In contrast, a number of larger studies have found that girls write faster than boys at various grades (Graham, et al., 1998; Phelps, 1985; Wallen, et al., 1996). A possible explanation for the differences in handwriting speed between genders is that girls write significantly smaller than boys ($p = .001$) from Grades 3 to 6 (Ziviani & Elkins, 1984). Smaller script size has been associated with faster handwriting speed (Wann & Nimmo-Smith, 1991).

Gender has also been associated with legibility. Girls scored significantly higher for legibility (on a scale of 1 to 7, 1 = *poor legibility*, 7 = *good legibility*) than boys ($M = 4.2$ and 3.5 respectively, $p < .0001$) in a study of 372 children aged 7 to 14 years (Ziviani & Watson-Will, 1998). Similarly, boys in first grade scored more poorly than girls for word legibility ($t = -2.45, p = .017$) and letter legibility ($t = -2.36, p = .021$) when letters were rated using the ETCH (Amundson, 1995; Feder, et al., 2007). For adults, in a study of 209 hospital staff, females wrote more legibly than males, scoring 8.6 out of 13 compared with 6.3 out of 13 respectively ($p < .0001$), when text was rated using a four point scale of *poor, fair, good or excellent* (Berwick & Winickoff, 1996).
For older adults, gender was not significantly associated with any kinematic variables in the study by Rosenblum and Werner (2006). However, normative data on writing speed collected over 20 years ago, found that females aged over 60 years wrote faster than their male counterparts in Australia and North America (Agnew & Maas, 1982; Jebsen, et al., 1969). No comparable studies have been published investigating the handwriting legibility of older adult men and women. A number of studies show that females of all ages write faster than males. Less conclusively, it appears that during childhood and middle adulthood at least, overall females may write more legibly than males. However further research is required. Again, a larger scale study involving English-writing men and women from different age groups would provide further information regarding whether there are any significant differences between men and women’s handwriting.

The context with which text is written influences the mode of handwriting, the reasons for handwriting, the implement used and the frequency and length of handwriting episodes. This section has highlighted the paucity of research into real-life handwriting activities and practices of adults and older adults. Other personal factors may also impact upon handwriting performance, such as technology use, age and gender. Whether socio-economic status affects handwriting performance has not yet been proven. Further research is required into the real-life handwriting behaviours of adult males and females of varying ages and occupations, using objective methods so that we can have a greater understanding of the reasons why they handwrite, how often, how many words per occasion and in what contexts they write. These data will inform the development of an ecologically valid adult handwriting assessment, which is the first step in the rehabilitation of people who have had a stroke, prior to retraining their handwriting. Adult handwriting tests which contain sub-tests relevant to handwriting,
have been referred to in the introduction. The strengths and limitations of these instruments will now be presented.

2.7 Handwriting Assessments

There are a number of children’s handwriting assessments which have been developed and researched (refer to Rosenblum, Weiss & Parush, 2003 for a review of children’s handwriting assessments). A number of hand function tests or rating scales for adults do contain at least one item that measures features of handwriting. Such tests include the Jebsen-Taylor Hand Function Test (Jebsen, et al., 1969), the Motor Assessment Scale (Carr, et al., 1985), and the Unified Parkinson’s Disease Rating Scale (Fahn, et al., 1987).

The Jebsen-Taylor Hand Function Test (JTHFT), an assessment of functional upper limb activities for adults, includes a handwriting speed sub-test as one of 7 sub-tests. The JTHFT is standardised and includes normative data for copying a 24 letter sentence for 300 unimpaired North American adults aged 16 to 94 years (Jebsen, et al., 1969). The data for adults aged 20 to 59 years were collapsed into one category as the authors reported a lack of significant differences in performance for adults aged less than 60 years. Normative data were later collected using the JTHFT from 382 unimpaired Australian men and women (Agnew & Maas, 1982) and presented across 6 age groups. The JTHFT demonstrates good discriminate validity, with 33 adults with stable hand impairments (hemiplegia, spinal cord injury and rheumatoid arthritis) scoring a mean of greater than two standard deviations from normative reference values (Jebsen, et al., 1969). Test-retest reliability with unimpaired people has been found to be moderate to high ($r = .60$ to $.99, p < .01$). However, test-retest reliability of each sub-test was evaluated with 26 people with stable hand impairments being tested using the JTHFT on two occasions. The writing sub-test (with dominant hand), scored
the second-worst test-retest reliability ($r = .67$) (Jebsen, et al., 1969). The writing sub-test was also shown to have poorer test-retest reliability ($p < .05$) than most of the other sub-tests for 20 adults writing free handed or with orthoses (Stern, 1992). Further limitations of this assessment are that normative data only relate to copied text, do not provide information about the range of normal handwriting legibility and are now over 27 years old.

The Motor Assessment Scale (MAS) (Carr, et al., 1985) was designed to assess eight areas of motor function post-stroke. The MAS includes one sub-test - Advanced Hand Activities - that evaluates a range of motor skills including pen control. As part of this sub-test, participants are asked to: 1) pick up a pen top and put it down again; 2) draw 10 horizontal lines in 20 seconds, with at least five stopping and starting at a vertical line and 3) making 10 consecutive dots on a page in 5 seconds. Each activity is scored as ‘pass’ or ‘fail’, with a score from ‘0’ to ‘6’ awarded if all activities can be performed. The MAS is standardised, and the 8 MAS subtest items have been shown to have high test-retest reliability ($r = .87$ to $1.00$, $M = .98$) and inter-rater reliability ($r = .89$ to $.99$, $M = .95$) (Carr, et al., 1985). The test has also been demonstrated to retain both validity and reliability when the upper limb subtests are administered in isolation (Lannin, 2004; Poole & Whitney, 1988). Administration of the relevant pencil and paper tasks of the MAS may therefore hold promise for valid handwriting assessment tasks. However, a limitation of this assessment in terms of its ability to assess handwriting is that it only measures pen control. There is no measure of handwriting performance such as legibility and the tasks do not involve actual handwriting tasks. Administration of the MAS in its entirety is therefore not suitable as an adult handwriting assessment.
The *Unified Parkinson’s Disease Rating Scale* (UPDRS) is a rating scale used to follow the longitudinal course of Parkinson’s disease (Fahn & Elton 1987). The scale consists of 42 sub-items under the domains of 1) mentation, behavior and mood, 2) activities of daily living, 3) motor examination, 4) complications of therapy, 5) Modified Hoehn and Yahr Staging and 6) Schwab and England Activities of Daily Living Scale. The UPDRS is administered by interview and clinical observation for the motor examination. The ‘activities of daily living’ domain includes one handwriting item. Handwriting is rated as 0 = normal, 1 = slightly slow or small, 2 = moderately slow or small, all words are legible, 3 = severely affected, not all words are legible and 4 = the majority of words are not legible. The UPDRS has moderate to excellent inter-rater reliability for most sections of the motor examination (ICC = .49 to .92), except poor agreement for speech and facial mobility (Richards, Marder, Cote, & Mayeux, 1994). For the handwriting question (administered via a patient interview), concordance rate is 75%, (Kw = .80), indicating excellent inter-rater reliability between patient report and physician administered UPDRS (Louis, Lynch, Marder, & Fahn, 1996).

Limitations of the assessment are that the handwriting question relies on the patient’s self-report evaluation of their handwriting performance without any objective assessment of the handwriting, and that it only considers handwriting size and legibility. Further, the UPDRS has only been validated for use with people who have Parkinson’s disease, and therefore is not advised to be used with people with other neurological conditions.

A recent battery of relevant tasks, the *Handwriting Assessment Battery* (HAB) (McCluskey & Lannin, 2003), has been developed in Australia to measure adult handwriting (see Appendix A). Activities and skills thought to be important for overall handwriting performance - pen manipulation, writing speed and legibility - are included as sub-tests of the HAB. The HAB included eight sub-tests. Two sub-tests are based on the MAS (Carr, et al.,
1985) and require participants to draw lines and dots on a page in a specified time, testing pen control. A third sub-test is derived from the JTHFT (Jebsen, et al., 1969), requiring participants to copy a 24 letter sentence as quickly and clearly as possible, testing writing speed. The remaining five sub-tests are derived from a children’s test, the ETCH (Amundson, 1995) and measure legibility. Participants write the alphabet in lower and upper case, numbers 1 to 12 and compose then write a sentence. The HAB had good to excellent inter-rater reliability, when completed writing samples were scored by two trained raters (Faddy, et al., 2008). The inter-rater reliability has been found to be excellent (k = 1.0, p = .010) and very good (k = 0.80, p = .002) for the horizontal line and dot subtest scores, respectively. For the writing speed scores, inter-rater reliability was excellent (ICC = 1.00, p = .0001). For the legibility section ICC values ranged from 0.71 (Sentence Composition-Letters) to 0.83 (Numeral Legibility) (Faddy, et al., 2008). The HAB does not include functional handwriting activities such as writing a message or a shopping list. Therefore the validity of test items requires further study. Faddy and colleagues recommended that data on unimpaired adult handwriting practices be collected across different age groups and occupations. These data will help to determine whether the HAB in its current form adequately represents contemporary handwriting.

Currently no clinically useful, validated adult handwriting assessment exists although the HAB (McCluskey & Lannin, 2003) is under development. Clinically, assessments of adult handwriting deficits are often non-standardised and based upon children’s handwriting assessments. Use of adapted paediatric assessments for measuring adult handwriting is problematic both because children’s handwriting assessments have methodological limitations (see Rosenblum et al., 2003), but also because adult handwriting cannot be compared with that of children. An adult handwriting assessment needs to consider the major features of
handwriting (such as legibility and speed), the variability of individuals’ handwriting and the
range and contexts of most common handwriting activities. Again however, little data exists
on handwriting in unimpaired adults. It is likely that the variability of handwriting is even
greater in adults than children, with years of habits leading to adopting styles differing from
the cursive script taught in schools (Hamstra-Bletz & Blote, 1990). Information on the
characteristics of unimpaired adult handwriting, across various age groups, is essential if adult
handwriting assessment tools such as the HAB are to be validated.

Assessments are an important part of the rehabilitation process for people who have
had a stroke. Accurate measurement at baseline enables an appropriate and effective
retraining program to be developed. Reassessment allows reliable and accurate measurement
of the outcome of intervention. In the area of handwriting, firstly, research is required into the
real-life handwriting of unimpaired adults to validate an adult handwriting assessment.
Secondly, a comprehensive and ecologically validated assessment needs to be developed to
enable accurate measurement and assessment of the handwriting of adults who have had a
stroke or other neurological conditions. Normative data will enable comparisons between the
client’s handwriting with the writing of age-matched unimpaired people. Lastly, a greater
understanding of adult handwriting practices and a psychometrically sound assessment tool,
based on scientific data, will lay the foundations for the development of a retraining program,
to assist the client in achieving the best possible handwriting outcomes. The next section
summarises studies investigating the effectiveness of handwriting interventions.

2.8 Handwriting Retraining

In children, handwriting problems are a common reason for referral to occupational
therapy (Marr & Dimeo, 2006). A telephone survey of 50 experienced paediatric
occupational therapists found that an eclectic approach was used for remediating handwriting difficulties (Feder, Majnemer, & Synnes, 2000). A sensorimotor approach was most commonly reported (90%), followed by perceptual-motor (74%) and motor learning (68%). Cognitive training (64%), biomechanical (64%), sensory-integrative (50%) and neurodevelopmental (42%) approaches were also used. Intervention programs for children’s handwriting have been studied in at least five randomised controlled trials involving a range of treatment approaches. Clinical trials have been summarised in Table 2.6.

A number of experimental studies exist on the effectiveness of interventions on children’s handwriting. However, as handwriting intervention is common for children, the number of randomised controlled trials is surprisingly small. With most studies having been published in the last seven years, it appears that research in children’s handwriting interventions will continue to expand. For adults however, no randomised controlled trials investigating the impact of interventions on handwriting in adults were found. In fact only one study was located. That study used a single-subject design on four participants to investigate the effectiveness of a two-week handwriting retraining program (6 sessions at home) for adults with brain injury, based upon motor learning theory (Beaudet, 2004). Participants improved in legibility following task-specific handwriting training and practice, however due to the small sample size, results cannot be generalised. Difficulties were encountered in conducting this pilot study, including the time to administer the assessment (Handwriting Assessment Battery; McCluskey & Lannin, 2003), ceiling effects and the reliability for scoring legibility. These difficulties highlighted the challenges inherent in assessing handwriting in adults. Further studies involving larger and varied samples, and preferably randomised controlled trials, are required to determine effective handwriting retraining approaches for adults.
There is currently little scientific information to guide therapists working with adults with handwriting deficits. Accurate measurement and assessment of handwriting performance is a necessary pre-requisite for developing appropriate intervention programs and measuring the outcome of interventions. As has been repeatedly highlighted in this summary, we still do not know enough about usual handwriting in adults to guide therapists in the assessment, measurement and retraining of adult handwriting. Objective methods such as observation and use of a digital pen may be used to obtain information about the handwriting practices of adults. The next section will discuss possible research methods to collect handwriting data.
### Table 2.6

**Summary of Clinical Trials Evaluating the Effectiveness of Interventions to Improve Children’s Handwriting**

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<th>Authors</th>
<th>Groups</th>
<th>Intervention</th>
<th>Frequency</th>
<th>Results</th>
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| Berninger, et al. (1997) | First grade students ($N = 144$) who were identified as being at risk of handwriting problems were randomly assigned to one of six treatment conditions. Design: randomised controlled trial. | 1) Motor imitation: imitation of motor acts for letter strokes.  
2) Visual cues: producing letters following numbered arrows for the strokes used in the letter formation.  
3) Memory retrieval: writing letters from memory, after having looked at the letter.  
4) Visual cues and memory retrieval: looking at numbered arrows, and then writing the letter from memory.  
5) Copying written letters.  
6) Contact control: phonological awareness training (focusing on syllables and phonemes) which is not thought to be directly related with learning to handwrite. After ten minutes of the intervention, all students composed text on a given topic then read their text to the group. | Two sessions per week (20 minute duration) to complete 24 lessons. Students were treated in groups of three. | Combining visual cues with memory retrieval was the most effective intervention (resulting in significant improvements in all tasks: alphabet task; quick brown fox copy task; text copy task; dictation task and WJ-R Compositional Fluency subtest). The contact control group had the poorest outcome for all outcome measures except speed. |
<p>| Graham, Harris, &amp; Fink (2000) | First grade students ($N = 38$) with ID were randomly allocated to an IG and contact control group. Design: randomised controlled trial. | IG received handwriting instruction: naming letters; tracing letters with numbered arrows to guide letter formation, verbalising stroke sequence and evaluation of handwritten letters/words, copying words containing target letters and feedback from instructors regarding errors. Another task, copying a sentence, was designed to increase handwriting fluency. Contact control group (see Berninger et al., 1997). | 27 lessons (15 minute duration), 3 times per week. | The IG improved more in all measures, evaluating both handwriting and writing skills (e.g., compositional fluency). Statistically significant differences were reached in favour of the IG for 3/8 tasks: alphabet production in 15 seconds ($p &lt; .001$), total number of alphabet letters written correctly ($p &lt; .001$), and total number of letters copied correctly per minute ($p &lt; .007$). Effects were less pronounced at 6 month follow-up. Findings indicate that the handwriting instruction method was more effective for improving handwriting speed and quality than phonological awareness training. |</p>
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<td>Case-Smith (2002)</td>
<td>Students (Grades 2 to 4) with ID. IG: n = 31; comparison group: n = 9 (non-randomised). 29 children from IG completed beginning and end-of-year testing. Data on intervention for 4 students were lost. Design: non-randomised comparison group design</td>
<td>Occupational therapists treating IG participated in interviews about their intervention. Handwriting activities were implemented in 77% of sessions and visual-motor activities in 72% of sessions. Other interventions were reported, therefore, an eclectic approach was used. The comparison sample did not receive intervention.</td>
<td>IG: 12 intervention sessions (mean duration 32 minutes over a mean of 16 sessions). Mean total intervention time per student = 528 minutes (SD 155; range 312 to 836), almost 9 hours.</td>
<td>There were no significant differences between IG and the comparison group for ETCH legibility scores and speed. IG maintained or improved performance on visual-motor (p &lt; .004), visual perceptual (p &gt; .05) and manipulation (p &lt; .008) tests. Adjustments were made for maturation over the year, and for the small comparison group size. The eclectic approach appears to have produced positive results; although it is unknown which components of therapy were most effective.</td>
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<td>Jongmans, Linthorst-Bakker, Westenberg, &amp; Smits-Engelsman (2003), Study 1</td>
<td>ID group (N = 7; mean age = 7.9 years). Comparison group: 7 children (TD, mean age = 8.6 years). Design: pre-post test. Small sample.</td>
<td>Task-specific self-instruction method. Systematic reflection followed exercises to assist the child to identify problem areas and improve planning the exercise the next time. Training addressed knowledge of the exercise letter shapes, movement sequences and force level and tempo of motor execution. Subjects identified best effort for the letter and how to improve. Next, the exercise letter was written in a pair, to train connective strokes. Lastly, the letter was identified within text and the subject reflects upon the letter quality.</td>
<td>Both groups received the same intervention consisting of 18 twice-weekly lessons on a one-to-one basis (30 minutes duration each).</td>
<td>Mean BHK total scores (speed and quality) for ID group increased by 7.7 (SD = 9.1) points compared with a decrease by 0.43 points (SD = 9.2) for the comparison group. No between-group differences at item level for the 13 quality of writing items. Indicates improvement in ID group in overall handwriting quality compared with comparison group of TD children.</td>
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<tr>
<td>Study 2</td>
<td>Grade 2 to 6 children attending special education with ID (N = 24). 18 received intervention, 6 did not. Comparison group: TD children without handwriting difficulties (N = 36). 18 received intervention and 18 did not. Of the groups receiving intervention, the TD group was older (p = .00001). Design: quasi-experimental case-control (non-randomised).</td>
<td>Intervention was provided in a group setting, for 6 months, twice per week for 30 minutes.</td>
<td>Mean BHK total scores (speed and quality): significant differences between most groups (p &lt; .00001) including between children with ID receiving intervention compared with children with ID who did not. No differences between children with ID who did not receive intervention and control children who did receive interventions (even when adjustments made for age differences). No significant differences for speed were found. Quality of writing at the level of item scores: significant differences between groups for 5/13 items (p ≤ .002). Results suggest intervention improved handwriting quality for children with ID.</td>
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<td>Authors</td>
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<td>Sudsawad, Trombly, Henderson, &amp; Tickle-Degnen (2002)</td>
<td>First grade children (N = 45) with ID and kinesthetic deficit randomly allocated to KT group, TP group and CG (N = 15 each). One participant was lost and replaced. Design: randomised controlled trial.</td>
<td>KT: Runway task training – differentiation of angle of two table-top ‘runways’ with vision occluded. Pattern task training – reorienting (back to original position) of stencil patterns (up to 6, presented from least to most complex), with vision occluded. TP: Copying of letters, words and sentences, with verbal and visual feedback for size, spacing and alignment.</td>
<td>KT and TP groups: received 30 minutes of intervention daily for 6 consecutive school days. CG: attended regular school activities.</td>
<td>No significant differences were found between groups for KST, ETCH, teachers’ ratings of handwriting or speed.</td>
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<td>Peterson &amp; Nelson (2003)</td>
<td>First grade children (N = 59; mean age 7.1 years) from lower socioeconomic backgrounds randomly assigned to an OT IG (N = 30) or CG (N = 29). Design: randomised controlled trial.</td>
<td>OT intervention consisted of BM, SM and teaching-learning approaches. Gross motor games for 5 minutes. Activities targeting motor planning, motor memory, self monitoring, use of sensory modalities and strategies for letter size, spacing and line use for 20 minutes. Then handwriting practice for 5 minutes, with imagery to assist with memorising letter formations.</td>
<td>IG: 20 sessions of 30 minute duration over 10 weeks. CG: received no intervention.</td>
<td>CG: no significant changes at post-test from pre-test. IG: large effect sizes for space (d = .88, p &lt; .01) and size (d = 1.3, p &lt; .01), and medium effect sizes for line use (d = .73, p &lt; .01) and legibility (d = .67, p = .0129) compared with CG. Speed was not significantly different between groups (p = .157). It is unknown which components of therapy were the most effective</td>
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<td>Denton, Cope, &amp; Moser (2006)</td>
<td>Random allocation of 38 children (aged 6 to 11 years) to SM group (N = 14), TP group (N = 15) and CG (N = 9). Design: randomised controlled trial.</td>
<td>SM protocol: activities for sensorimotor components (visual perception, visual-motor integration, proprioception/kinesthesia and in-hand manipulation). TP protocol: handwriting practice involving worksheets, real-life writing and writing for fun.</td>
<td>IG: received 30 minutes of intervention 4 times per week for 5 weeks. CG: received no intervention and attended to regular classroom activities.</td>
<td>CG: No change from baseline scores. SM group improved in SM component scores, however declined in handwriting performance (THS) scores. TP group did not change significantly in SM scores. Trend towards improvement in handwriting performance (NS). SM and TP groups not statistically significantly different from control group. Relatively small sample size.</td>
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Table 2.6 (Continued).

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<th>Authors</th>
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<td>Zwicker &amp; Hadwin</td>
<td>Students (Grades 1 and 2) randomised to a C intervention group, MS group and CG (N = 24 for each group). Design: randomised controlled trial.</td>
<td>C intervention: emphasis was placed on the “metacognitive awareness of letter formation” (p. 43), and involved the students verbalising letter formation. Activities included alphabet warm-up to identify and name letters, modeling by therapists to demonstrate and described how to form letters on cards with numbered arrows and then imitation, involving the child tracing the letter whilst describing how to form it. MS: writing letters in various sensory mediums such as on a chalkboard, a tray of sand, over bumpy glue letters and then onto paper.</td>
<td>IG: received 30 minute weekly sessions over 10 weeks. CG: received no intervention.</td>
<td>Grade 1 students all improved in ETCH legibility scores, no significant differences between groups. MS groups achieved slightly higher legibility scores, (NS). Grade 2 students: MS intervention group scored similarly to the CG with 4/9 scoring more poorly in legibility at post-test than at the pre-test. C intervention group all achieved better scores at post-test, although these results were not statistically significantly different from the other groups. No significant improvements in legibility regardless of group, although trend towards intervention groups. Intervention may not have been sufficiently intensive.</td>
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<td>McGarrigle &amp; Nelson</td>
<td>Comparison group: N = 5 (received intervention after IG; then results pooled with IG and compared with comparison group). IG: N = 8 (+5), Grade 1 Indigenous students. Design: pilot study, non-random allocation, small convenience sample.</td>
<td>Intervention consisted of SM, BM and teaching-learning approaches used to address handwriting, scissor use, visual motor coordination and classroom behaviour. Included gross motor activities, sensory activities such as writing in sand or shaving cream, posture, handwriting practice and scissor skills.</td>
<td>IG: received 6 weekly sessions, 80 minutes duration Comparison group: attended regular schooling.</td>
<td>Between-group differences showed a statistically significant in Writing Skills 2 (non-standardised assessment developed for this study consisting of tracing and copying pre-writing patterns, writing name, letters of the alphabet and copying a 3 word sentence) (p = .037).</td>
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Note. Test of Handwriting Skills (THS; M. Gardner, 1998); Evaluation Tool of Children’s Handwriting (ETCH; Amundson, 1995), Kinesthetic Sensitivity Test (KST – sum of Runway and Pattern Task z scores), Concise Assessment Scale of Children’s Handwriting (BHK; Hamstra-Bletz, de Bie, & den Brinker, 1987); Woodcock-Johnson Psycho-Educational Battery – Revised (WJ-R; Woodcock & Johnson, 1990). ID = Identified handwriting difficulties, TD = Typically developing. CG = Control group, IG = Intervention group. Sensorimotor (SM), multisensory (MS), kinaesthetic training (KT), cognitive (C), biomechanical (BM), therapeutic handwriting practice (TP). NS = Not significant.
2.9 Methods for Collecting Handwriting Data

A range of data collection methods could be used to collect data on adult handwriting. These methods include use of a digital pen, observation, self-monitoring, surveys and interviews. The following section summarises and critiques data collection methods that were considered when designing the current study.

**Digital Pen:** A digital pen is an objective method for collecting data about handwriting events. Digital pens electronically record handwritten information which can be downloaded onto a computer (PLANiT OrganiZer, 2005). The electronic handwriting samples may then be converted to text. Varying levels of analysis of handwriting parameters may be possible depending upon the pen and software. Different types of digital pens are available; digital pen with digital paper; digital pen with digitising tablet and digital pen and memory unit. Each pen has limitations in terms of capturing the full range of handwriting behaviours and parameters.

The digital pen with digital paper records electronically only what has been written on the special paper. This type of digital pen will not record text which has been written on non-digital paper for example on birthday cards or a bank cheque. The digital pen with digitising tablet is even more limiting as the pen will only record text that has been written on the liquid crystal display tablet. The digital pen with memory unit electronically records all text that has been written with the pen (PLANiT OrganiZer, 2005). As any paper can be used, this pen can most accurately record the frequency of handwriting episodes and the range of activities.
Features and Benefits:
Stores up to 50 A4 pages.
Includes LCD to view and confirm input
Operates both in mobile mode and connected mode (via USB to PC/notebook)
Coverage area: up to A4 size paper
Resolution: 100DPI
Memory: 2MB flash memory
Power: Pen 3 x SR41 batteries
Memory Unit 2 x AAA batteries
Dimensions and Weights:
Memory Unit: (L) 107mm, (W) 65mm, 90 gr.
LCD: 128/64 pixels, (L) 66mm, (W) 32mm.
Pen: (L) 136mm, (D) 13.7mm, 16gr
Cost: Approximately $285

Figure 2.3. Pegasus NoteTaker Digital Pen and Memory Unit.

In the current study, there will be a need to gather information on real-life handwriting practices. Therefore, the digital pen and memory unit will be used for data collection. Figure 2.3 depicts the digital pen and memory unit selected for the proposed study. The digital pen enables data to be collected on handwriting frequency, reasons for handwriting, quantity of written text, and error corrections. As users need to remember to clip the memory unit onto paper before use and not all handwriting samples can be collected by the digital pen alone, other methods also need to be used.

**Direct observation:** Observation refers to participants being directly observed, in their natural environments, and records taken of the behaviours of interest. Observation is an objective technique used to accurately collect data (Bentley, Boot, Gittelsohn, & Stallings, 1994). In the proposed study, observation can provide accurate information on the frequency of handwriting occasions, reasons for, and contexts of writing. Observational data would also enable accurate recording of upper limb movements, postures and pen grips. However, observation can be intrusive and is time-intensive (Bentley, et al., 1994). In addition, the presence of the researcher may influence the
handwriting behaviour, possibly causing participants to write more frequently in an attempt to ‘please’ the researcher (Hawthorne Effect; Sonnenfeld, 1985). Therefore in the proposed study, observation will only be used during the initial meeting while each participant performs a copying task and writes a sentence of their choice. These two handwriting activities will be videotaped to enable accurate categorisation of pen grip.

**Self-monitoring:** Self-monitoring refers to a process whereby a person actively collects and/or records data over time about their own behaviour (Barton, Blanchard, & Veazey, 1999). Self-monitoring is also referred to as self-observation (Foster, Laverty-Finch, Gizzo, & Osantowski, 1999). While direct observation of many participants over several days may not be feasible, self-monitoring offers an alternative method for recording behaviours without relying on retrospective recall (Foster, et al., 1999).

A diary is a common method of recording and monitoring behaviour, for example for collecting information on insomnia, headaches and dietary intake (Barton, et al., 1999). Diaries are inexpensive, portable and easily produced. A recent pilot study found data recorded in diaries to be moderately correlated with pedometer data (Speck & Looney, 2006). Pedometer measures were compared with metabolic equivalent unit scores based upon self-reported daily activity records over two weeks. Data were analysed for 22 participants, showing a correlation of .61 ($p = .003$) between both measures (Speck & Looney, 2006). Diaries and questionnaires were found to have a moderate to high concordance with non-self report measures (such as electronic devices, drug levels and pill counts) in a summary of the 57 studies on the concordance of self-report and other measures of medical adherence (Garber, Nau, Erickson, Aikens, & Lawrence, 2004).
Self-monitoring also has disadvantages. The process of monitoring a behaviour may cause that behaviour to change in form or frequency as a direct result of monitoring (Barton, et al., 1999). In the proposed study, participants may be tempted to write more frequently than usual with a novel digital pen, or to please the researcher. Another important concern with self-monitoring is compliance with the monitoring procedure. It is important to know whether recordings were made as instructed (e.g., when the handwriting occurred) to maximise the reliability and validity of the data. Studies investigating compliance with self-monitoring have shown participants are often noncompliant. High compliance levels were reported (94%) for electronic diaries in a study comparing a pen and paper diary with electronic diaries for fixed-time assessments of pain (Stone, Shiffman, Schwartz, Broderick, & Hufford, 2002). However, when actual compliance for the pen and paper diary was assessed without participants’ knowledge via electronically monitored binder openings compliance dropped to 11%. That study suggests that increased compliance with a self-monitoring technique can be achieved if participants are aware that their compliance is being monitored.

Strategies for increasing compliance and accuracy of self-monitoring procedures have been reported but have limited empirical support (Barton, et al., 1999b; Foster, et al., 1999). Participants need to be trained. Accuracy can be increased through training which includes “explicit instructions, modeled examples of correct self-recording, practice, and feedback” (Foster, et al., 1999, p.431). In addition, advising participants that their recording accuracy may be verified can increase compliance. In the study comparing use of a diary with pedometer results (Speck & Looney, 2006), participants may have been more diligent with recording exercise as they were aware that the pedometer results could be compared with their diary entries. In addition to training, external cues such as beeping
which prompt participants at intervals, may increase self-monitoring compliance (Stone, et al., 2002). Further, selection of the self-monitoring technique should be considered. This technique needs to be convenient and acceptable to the user, but noticeable enough that the technique is not forgotten. In the proposed study, a portable written log form will be used (see Appendix B).

**Surveys and interviews:** Surveys and interviews can obtain a global report of behaviour but rely on recall over an extended period. It is more difficult to test the validity or reliability of such methods. In headache research, only small to moderate correlations have been found between daily and global measures of headache activity ($r = .42$ to $.60$) (Penzien, et al., 1994). Similarly, research involving people with irritable bowel syndrome found that symptom diaries were a better indicator of change than global reports of symptoms (Blanchard & Schwartz, 1988). These results suggest that self-monitoring may produce more valid data than global self-reporting via surveys or interview. There is no validated tool for gathering information on handwriting practices. In addition, no known survey encompassing daily activities comprehensively incorporates handwriting as an item.

**Rationale for selected methods:** The advantages and disadvantages of methods for recording information on handwriting behaviours were considered. The digital pen and memory unit appear to be the most comprehensive method of objectively recording handwriting samples. Self-monitoring and a written log of activities will also enable cross-referencing of handwriting events with the electronic samples and to collect additional information, such as position whilst writing.
To increase the accuracy of self-monitoring, training of participants will raise awareness of as many handwriting situations as possible, and increase the likelihood that participants will record each handwriting occasion (Foster, et al., 1999). Developing a good rapport with participants and explaining the importance of accuracy can help to increase compliance (Foster, et al., 1999). Further, advising participants that the accuracy of their recordings may be verified using the digital pen internal clock may also increase compliance.

In this section, available literature was reviewed to inform the selection of handwriting data collection methods. The digital pen and memory unit will enable objective recording of handwriting samples. Further information will be collected using a written log. Strategies to maximise accuracy of data collection will be used, such as training participants and making ‘reminder’ telephone calls to participants. This chapter has outlined what is known about adult handwriting as well as highlighted some of the gaps in the existing handwriting literature. The current study will address some of these gaps, through the collection of objective handwriting data.

2.10 Statement of the Problem

There is a notable imbalance in the volume of children’s handwriting research compared to research involving adults. This review has summarised what is known about adult handwriting and gaps in current knowledge. These gaps limit the development of valid methods for assessing, measuring and retraining adult handwriting during rehabilitation.
Concerning parameters of handwriting, no gold standard legibility test has yet been developed. Research needs to identify characteristics and the range of ‘normal’ legibility to assist in developing a validated assessment. Variation in pen pressure within words and across a page appears to be normal. However, further investigation is required to determine the range of normal downward pressure, and pressure on the barrel of a pen, for optimal handwriting quality and endurance. A certain percentage of errors made and corrected can be considered normal and appears to increase with age. No normative data exist for error correction in adults aged 65 years against which to compare adults with handwriting deficits.

In regards to the motor aspects of handwriting, grips other than the traditional dynamic tripod are considered ‘normal’ and should be anticipated and accepted as normal in adults as well as schoolchildren. Pen grip is one of the first characteristics of handwriting to be assessed by occupational therapists during rehabilitation, however further research is required to inform clinicians whether the time spent on modifying pen grip is justified. Studies investigating pen control required for handwriting in adults are lacking. Appropriate pen size and features to increase perceived comfort have also received little consideration. Moreover, research is needed into normal movement patterns, and the relationship between distal and proximal muscles (often both affected to varying degrees following a stroke) involved in handwriting.

The context under which text is written may change the processing demands of handwriting. However, currently no information exists on the reasons for and contexts of writing in adults. It is unknown how often, and how much, adults write. Further, although
handwriting appears to be a valued activity, the impact of technology use on handwriting frequency and quality warrants further investigation and monitoring over time.

As the body of information about adult handwriting is relatively limited, it is even more limited for minority groups. The impact of handedness on handwriting is inconclusive, with previous studies reporting conflicting results (Bergmann, 1990; Selin, 2003). While older age is associated with slower handwriting, there is little information about other handwriting features of older adults. Yet, this information is needed as the incidence of stroke increases over the age of 65 years and handwriting retraining is common in this population.

Handwriting assessments and retraining programs need to consider the variability of individuals’ handwriting and the range and contexts of most common handwriting activities. However these factors have not yet been adequately researched. Although the HAB has recently been proposed as a possible clinical assessment of adult handwriting (McCluskey & Lannin, 2003), further development and validation are required. No large-scale studies have investigated the effectiveness of handwriting remediation in adults. As has been repeatedly highlighted in this summary, we still do not know enough about normal handwriting in adults to fully validate an adult handwriting assessment such as the HAB. There is currently little scientific information to guide rehabilitation therapists in developing a handwriting retraining program. The current study will address some of these gaps in the literature.
2.11 Study Aims

In relation to healthy Australian adults, aged 65 years and above, the present cross-sectional observational study aims to describe:

a) Legibility and its components (letter size, spacing and slant);
b) Factors associated with legibility;
c) Frequency and length of writing tasks;
d) Frequency of error corrections;
e) Handwriting styles;
f) Pen grips and posture;
g) Reasons for writing; and
h) Modes of handwriting (copied versus self-generated versus transcribed text from a spoken message).

2.12 Synopsis

In order to address study aims, information on the handwriting practices of participants will be collected using a questionnaire, and objective measurement and self-monitoring will be performed using a digital pen with memory unit, and a handwriting log. This combination of data collection techniques was selected to help increase the rigor of the study and address study aims. Strategies will be used to overcome the limitations of each method. This study will help to inform the development of an ecologically valid assessment and handwriting retraining program for adults over 65 years with handwriting problems as a result of neurological conditions such as stroke or brain injury. This study will also be a stepping stone, leading to further study into adult handwriting practices across different age groups.
Chapter Three: Methods

3.1 Introduction

An exploratory cross-sectional observational study design was used to describe the handwriting practices and performance of unimpaired adults aged 65 years and over. Data collection methods included a self-report questionnaire, handwriting samples obtained while participants addressed an envelope and completed the Mini Mental Status Examination (MMSE; Folstein, Folstein, & McHugh, 1975), digital pen handwriting samples and a log of handwriting occasions. This chapter describes methods used to recruit participants, and to collect and analyse data.

3.2 Sampling and Recruitment

Ethical approval was sought and obtained from the Human Research Ethics Committee (HREC) of The University of Sydney (HREC Approval Number: 06-2007/10208). Thirty adults aged 65 years and over were recruited. Central limit theorem recommends a sample size of 30 to allow use of parametric statistics (Hinkle, Wiersma, & Jurs, 1998). This sample size was selected based on the objectives of the research project, the high likelihood that occasions of handwriting would be observed in all participants, and the proposed analyses. Following a snowball sampling method, the Participant Information Statement (Appendix C) was provided in electronic and paper format to friends, associates and work colleagues of the research team (i.e., the candidate and two supervisors) (Patton, 1990). These third parties were invited to pass information onto, and help recruit, interested friends, family members and colleagues aged 65 years and over. Snowball sampling enabled recruitment of both men and women of varying ages. People
who contacted the researcher had further questions answered by telephone, and a Consent Form (Appendix D) was forwarded by email or post.

Participants were included if they were aged 65 years or older, had no conditions affecting their ability to handwrite, were able to participate in daily activities and lived in the community within the Greater Sydney metropolitan area. The study only included participants who were able to write in English as no funding was available for use of interpreters. Participants were excluded if they had a health condition which affected the ability to write, such as very poor eyesight or a neurological condition. Mild visual problems or arthritis did not exclude participants due to the high incidence of reduced vision and arthritis in adults aged 65 years and older. Among people aged 65 years and over, the most commonly reported health conditions included visual deficits (including long- and short-sightedness, 96%) and arthritis (49%) in the National Health Survey 2004 to 2005 (Australian Bureau of Statistics, 2006).

3.3 Instrument Development and Pilot Testing

As this study was the first to collect objective data on real-life handwriting occasions, and no validated handwriting surveys were located, several instruments needed to be developed by the research team. First, the handwriting questionnaire was developed (see Appendix E). The aim of the questionnaire was to collect demographic information and self-report information about handwriting behaviours and use of technology. A draft questionnaire was developed in consultation with another research student who had previously surveyed working aged-adults (McMahon, 2008). The questionnaire previously used by McMahon (2008) was shortened to suit the requirements for the participants in the current study. The questionnaire was also modified according to feedback from pilot
testing, which mainly involved rephrasing questions to ensure the question was interpreted in the manner that was intended.

The final questionnaire was three pages long and took approximately 10 minutes to administer. The handwriting questionnaire consisted of 13 open and closed questions which enquired about demographic information, handwriting activities completed in the past three days, the importance of handwriting and the modes of communication used. Three questions were to be asked by the researcher at the end of three days, enquiring about the representativeness of handwriting activities undertaken by the participant over the three day study period, readers of the participant’s handwriting and whether each handwriting episode was accurately recorded.

Second, participants copied an address onto an envelope while their writing arm and hand were videotaped. The videotaping position was piloted on five people aged 33 to 73 years using a digital camera while they copied an address onto an envelope. This pilot sample included one left-handed writer. The optimum angle for observing pen grip, whilst not recording the participant’s face, was determined as being on the side of the table adjacent to their non-writing hand.

Third, digital pen use was trialed by four people (aged 19 to 80 years). Following a two to three day trial, participants answered a questionnaire regarding text they were unable to write using the digital pen and anything which reminded them to use the pen. Lastly, use of the handwriting log was trialed in another pilot. This pilot was designed to gather information and feedback from participants regarding any barriers to compliance with pen use and documentation of handwriting events on the handwriting log. The
handwriting log was trialed by seven people (aged 19 to 46 years) on 10 occasions and was modified according to feedback to make it more portable, easier to use and to obtain the required information. The phrasing of the column headings, column sizes and layout were modified.

3.4 Data Collection Procedures

Data were collected between April and July 2008. An initial interview was conducted by the researcher in participants’ homes to complete a handwriting questionnaire, obtain handwriting samples and conduct the digital pen training. This interview lasted approximately one hour in total. First, the handwriting questionnaire was completed by participants about their personal details, education, previous employment, handwriting activities and modes of communication. Second, participants completed the MMSE (Folstein, et al., 1975) to exclude significant cognitive deficits and to obtain a sample of self-generated text. The MMSE required participants to answer questions pertaining to orientation, registration, attention, recall and language (including writing a self-generated sentence). Third, participants copied an address (the candidate’s name and university postal address) onto a DL size envelope (11cm x 22cm) (see Appendix F). The text consisted of 99 characters including 16 words over 6 lines, written in sentence case onto the envelope. Fourth, the writing arm and hand of participants was videotaped during handwriting tasks to enable categorisation of pen grip. Fifth, participants were shown how to use the Pegasus NoteTaker digital pen to collect handwriting samples over three consecutive days.

Training in the use of the digital pen included demonstration and modeling. Participants then practiced using the pen and were provided with feedback. To address the
possibility of reactivity, that participants would handwrite more or less due to a novel pen and their participation in a research study, participants were instructed to write as usual. Participants were also advised that they were not required to use the pen for any text which was confidential or private such as credit card details.

The digital pen electronically recorded text when used with the memory unit clipped onto the writing surface such as a form, calendar or notepad (see Figure 3.1A). To operate the digital pen and memory unit, the memory unit was turned ‘On’, for each handwriting occasion. The word ‘Capture’ was displayed on the memory unit screen. After pressing ‘OK’, participants used the digital pen to write as normal. The written text appeared on the memory unit screen as shown in Figure 3.1B. When the handwriting occasion was finished, participants replaced the lid on the pen and pressed ‘OK’ on the memory unit. This step stored what was written into the memory unit. Participants then turned the memory unit ‘Off’. The stored text was downloaded onto the researcher’s password-protected computer, under the participants’ identification numbers.

Figure 3.1. Pegasus NoteTaker Memory Unit Clipped Onto Paper (A) and (B) Displaying Recorded Text.
Finally, participants kept a written log of any handwriting completed during the three days. This log was a record of whether or not the digital pen was used, as well as information about their posture. For example whether they were sitting or standing or in some other position while writing. Participants also recorded any concurrent activities such as whether they were watching the television or eating while writing. The log also enabled information to be recorded about handwriting samples which were private and had not been written using the digital pen.

Three primary data collection procedures were used: a handwriting questionnaire, digital pen and handwriting log. Strategies were implemented to increase the accuracy of data collection. Participants were advised that their recordings could be verified using the digital pen internal clock, which enabled the researcher to check and compare digital pen and log entries. Participants were telephoned once or twice during the study period to enable the participants to ask questions and also to remind them to continue to use the digital pen and memory unit. The researcher also asked for clarification about the participants’ handwriting activities at the end of study period to increase the accuracy of data collected. Once all the data were collected, the features of handwriting were measured from the MMSE, envelope and digital handwriting samples.

3.5 Measurement Procedures

Techniques for measuring handwriting parameters were determined by reviewing existing paediatric handwriting assessments, articles and books on forensic examination of documents, and graphology texts. Standardised techniques described by Lowe (2007) were used to categorise pressure, measure between-word spacing, angle of baseline, slant and letter size. No research literature reporting the reliability of these techniques was
located or appears to have been published by Lowe. However, these techniques were
considered more appropriate for measuring adult handwriting than paediatric assessments.
For example, one assessment based its standard for between-word spacing as one quarter
of an inch, or the width of a second grade child’s finger (Reisman, 1999). Handwriting
parameters were measured by the researcher. Where questions arose, consensus was
reached by the research team, such as for the start points of measurements for some letters.

Pen pressure: Pen pressure applied during MMSE handwriting sample was defined
as ‘light’ if the writing could not be manually felt on the other side of the paper (80 gsm),
‘medium’ if the indentation of the paper could just be felt, and ‘heavy’ if the indentation
was very noticeable.

![Image](image.png)

**Figure 3.2. Measurement of Between-Word Spacing, Slant and Baseline Angle.**

Components of legibility: Between-word spacing, angle of baseline and slant were
measured for both MMSE and envelope handwriting samples for each participant.
Between-word spacing was measured in millimeters using a ruler from the end of the exit
stroke of the last letter of the preceding word to the start of the entry stroke of the first
letter of the following word. Where there was no between-word space, or where letters overlapped, the recorded score was ‘0’. Average angle of baseline, drawn in by the researcher as a line of best fit, was measured in degrees from the horizontal baseline (0°). Writing which sloped downwards scored a negative angle. Slant was calculated by measuring the angle of the ascenders from baseline for the letters ‘h’, ‘b’ and ‘l’. For example, letters perpendicular to the baseline had a 90° slant. Figure 3.2 depicts measurement of between-word spacing, angle of baseline and slant.

Figure 3.2. Measurement of Between-Word Spacing, Angle of Baseline and Slant.

Figure 3.3. Measurement of Letter Width and Height. MZW = middle zone width, MZH = middle zone height, LZW = lower zone width, LZH = lower zone height, UZW = upper zone width, UZH = upper zone height.

Letter sizes: Width and height of the middle, upper and lower zones of letters were measured from MMSE and envelope handwriting samples in accordance with techniques described by Lowe (2007). Middle zone width (MZW) and middle zone height (MZH) were calculated by measuring the greatest horizontal and vertical distances respectively between the outside edges of each ‘a’, ‘e’ and ‘o’ in the samples. Only the body of each letter was measured. Entry and exit strokes and connectors were not included in the measurements. The letters ‘l’, ‘b’ and ‘h’ were measured to determine upper zone width.
(UZW) and upper zone height (UZH). The letters ‘y’ and ‘g’ were measured for lower zone width (LZW) and lower zone height (LZH). Upper zone height was measured as the greatest vertical distance from the bottom of the letter’s middle zone to the top of the letter. Lower zone height was measured as the greatest vertical distance from the bottom of the middle zone to the bottom of the letter. Upper zone width and LZW were measured as the greatest width of the loop with the ruler angled perpendicular to the loop angle.

Letter measurements were recorded in millimeters using a ruler. Capital letters were excluded. For each parameter where more than one measurement was obtained per participant (i.e., the sample had more than one of the measured letters), a mean was calculated for each participant. These means were used to calculate a total mean and standard deviation. Figure 3.3 illustrates measurement techniques for letter measurements.

**Legibility:** Legibility of envelope and MMSE samples was rated using a four point scale adapted from Rodriguez-Vera and colleagues (2002). This scale assigns descriptive nominal categories and a number to written text. For example, a score of 4 reflects writing which is described as “All words are clear. The meaning of the text can be understood” (see Table 3.1).

Reliability of this modified four point scale was recently investigated (Au, 2009). In the reliability study three raters underwent training then independently rated 60 writing samples from healthy adults. The modified Four-Point Scale attained fair rater concordance ICC_{3,1} 0.37. Scoring with the modified four-point scale produced a multi-rater kappa (κ) of 0.19 indicating slight agreement (Au, 2009).
Table 3.1
*The Modified Four Point Legibility Scale* *a Adapted From Rodriguez-Vera and Colleagues* *b*

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Most or all of the words are impossible to identify. The meaning of the text is unclear.</td>
</tr>
<tr>
<td>2</td>
<td>Some words are clear. The meaning of the text is unclear.</td>
</tr>
<tr>
<td>3</td>
<td>Not all words are clear, however the meaning of the text can be understood.</td>
</tr>
<tr>
<td>4</td>
<td>All words are clear. The meaning of the text can be understood.</td>
</tr>
</tbody>
</table>

*Note.* *a* (Au, 2009), *b* (Rodriguez-Vera, et al., 2002).

*Handwriting style:* Handwriting style was categorised (for the digital handwriting samples) as either ‘mixed cursive’, ‘mixed print’, ‘cursive script only’, ‘printing only’, ‘capitals only’ and ‘numbers only’ (see Figures 3.4 to 3.6). ‘Mixed cursive’ was defined as text consisting of at least 50% cursive script, with the remaining letters being printed (Graham, et al., 1998b). ‘Mixed print’ was defined as text consisting of at least 50% lower case print, with the remaining letters written in cursive script (Graham, et al., 1998b).

I thought your little dog might
find this picture edifying

*Figure 3.4. Example of ‘Cursive Script Only’.*

Chapter Three: Methods
Figure 3.5. Example of ‘Printing Only’.

Figure 3.6. Example of ‘Mixed Style’.

*Number of words and error corrections:* Words were counted from the digital handwriting sample, if they could be read as a word or as an abbreviation of symbol, such as ‘am’, ‘pm’ or ‘&’. Error corrections were defined as any character that had been overwritten, re-touched or crossed-out. Samples were excluded if the number of words and error corrections could not be easily counted, such as in the case of poor download quality or illegible handwriting.
Pen grip and posture: Pen grip was categorised from videotaped footage of handwriting tasks using Schneck and Henderson’s classifications (1990) of either tripod grip (static and dynamic) or alternative grip. Posture when writing (e.g., sitting or standing) was determined from handwriting log entries.

Frequency of handwriting occasions: The number of handwriting occasions performed per participant was calculated from digital samples and handwriting logs. Frequency was calculated based on the number of occasions over the number of days the digital pen was used, per participant. The duration of the study period was calculated using the digital pen’s in-built date and time clock. The duration of the study period was considered when calculating handwriting frequency and results are presented per day. The time of day when each sample was written was recorded for digital samples and classified according to the ISD Data Dictionary Scotland (ISD Scotland). ‘Day’ was defined as from 08:00 to 17:59, ‘evening’ from 18:00 to 11:59 and ‘night’ from 12:00 to 07:59. These time periods have been used in a previous study (Wunsch, Mapstone, Brady, Hanks, & Rowan, 2004).

Reasons for handwriting: Reasons for handwriting were categorised based on the handwriting activity and role the participant was fulfilling when writing as defined by the Role Checklist (Oakley, Keilhofner, Barris, & Reichler, 1986), (see Appendix G). Where possible, reasons for handwriting were determined from participants’ recordings in the logs. Where reasons for handwriting were not clear, consensus was reached by the research team based on the log entry and context of the digital handwriting sample.
Modes of handwriting: Modes were classified by the researcher according to whether the text was self-generated, copied or transcribed from a spoken message. Handwriting logs and digital samples were used to make the classification, although this was unclear on some occasions. One such example was addressing an envelope. The address may be known to the participant and therefore be generated text, or the participant may have copied the address from an address book. Where this was the case, the researcher assigned the category of mode (in the above example, the copied text category was assigned).

Questionnaire results: Modes of communication used by participants and readers of the participants’ handwriting were reported in the questionnaire. Importance of handwriting was rated by participants in the questionnaire as an ‘X’ on a 100 mm line. The position of the centre of the ‘X’ on the line was measured on the scale, from 0 to 100, with 0 being not at all important, 50 being somewhat important and 100 being extremely important.

The measurement for all handwriting features was completed, and checked, by the researcher. Where ambiguity existed, such as determining the reasons for handwriting or modes, consensus was reached by the research team based on the log entry and context of the digital handwriting sample. Data were recorded in an Excel spreadsheet on the researcher’s password-protected computer. The following section describes how data were analysed.
3.6 Data Analysis

Descriptive statistics and frequency counts were used to examine categorical and continuous variables respectively. Normality was assumed if the skewness and kurtosis statistics divided by their standard errors were within the range of ±1.96 (Pett, 1997). Standard scores (z-scores) were calculated to allow comparison of letter size, slant, between-word spacing and baseline orientation on the copied and self-generated handwriting samples, with copybook handwriting as taught during schooling (Australian Copy Book, Fifth and Sixth Classes; Melbourne Education Department, 1910).

Z-scores of kinematic parameters for the assessment of legibility were calculated as follows: (Vp–Mc)/SDc; where Vp – parameter value of participant, Mc – mean value of copybook, SDc – standard deviation of copybook (Mechtcheriakov, et al., 2006). Z-scores represent both the relative position of an individual score in distribution as compared to the mean of the copybook writing and the variation of the scores in the distribution. [Note, for those copybook parameters which were found not to vary, i.e. when sigma equaled zero, the analysis reduced to a simple subtraction with no violation [(L. Churilov (personal communication, July 27, 2009))]. In order to evaluate the prevalence of handwriting impairment in healthy people aged over 65 years, we calculated z-scores of kinematic parameters clinically perceived by occupational therapists to be of importance (letter size, slant, between-word spacing and baseline orientation). All participants with a z-score higher than 1.96 (or -1.96 for negative values) were assessed as impaired. For example, if the z-score was greater than 1.96 for between-word spacing, this would indicate that participants in the study had significantly greater between-word spacing than the between-word spacing of the ‘perfect’ copybook text.
Multiple regression analyses were conducted to examine the ability of various handwriting behaviours or characteristics to predict legibility. The assumptions of multiple regression were tested, including outliers, normality, linearity, multicollinearity, singularity, homoscedasticity and independence of residuals. Legibility was regressed on variables of pen grip, variability of handwriting parameters, how much a participant wrote per day, sentence case and handwriting style. Factors thought less likely to be predictors of legibility, such as level of education, pen pressure, error corrections and mode of handwriting, were not included in the equation in line with recommendations by Vittinghoff and McCulloch (2007). Following assumption testing, a log transformation was required for the dependent variable number of words written each day. Pen grip classifications were dichotomized based on Schneck and Henderson’s classifications (1990) as either tripod grip (static and dynamic) or alternative grip, and grip was treated as a dichotomous variable in the equation. All remaining variables were treated as polytomous variables using dummy coding. The Statistical Package for Social Science (SPSS) for Windows (Version 15.0; SPSS, Chicago, IL, USA) was used for data analyses. A two-tailed critical value at an alpha level of 0.05 was used.

3.7 Synopsis

This chapter has described the methods used to address study aims. Thirty participants aged 65 years and over were recruited, provided samples of their handwriting, completed a questionnaire and used a digital pen over a period of three days. Participants also kept a log of handwriting occasions. Features of handwriting were then measured using the MMSE and envelope samples, digital handwriting samples, handwriting logs and videotaped footage. The following chapter presents the results from the data.
Chapter Four: Results

4.1 Introduction

This chapter will outline results in the following order. First, baseline characteristics and modes of communication used by participants will be presented. Second, parameters of adult handwriting will be presented, including pressure, legibility, and handwriting style. Finally data on the written content, reasons for writing and frequency of the handwriting samples collected from 30 older people will be presented.

4.2 Participant Demographics

Thirty-one potential participants were screened, 30 of whom met the study inclusion criteria and participated. One person was excluded as he reported having a condition which affected his eyesight and ability to handwrite.

The sample included mostly well-educated older Australians with a median age of 72.0 years (SD = 6.9, \(IQR = 70\) to 80 years). The most common pre-retirement occupations were professional (30%), teacher (23%), and clerical/sales worker (27%). At the time of the data collection, the majority of participants were retired (57%). Two participants worked in either a part-time or full-time paid capacity (7%) and 11 participants fulfilled volunteer roles (37%).

More women than men participated in the study. Two participants reported being left-handed, however due to encouragement during their schooling, wrote with their right hands. Six participants reported having arthritis and four participants reported having a visual impairment. Due to the common nature of arthritis and visual impairments in older
people, these participants were included. Demographic characteristics of the final sample are presented in Table 4.1.

**Table 4.1**  
*Demographic Characteristics of Participants (N = 30)*

<table>
<thead>
<tr>
<th>Demographics</th>
<th>n</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Gender</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>6</td>
<td>20.0</td>
</tr>
<tr>
<td>Female</td>
<td>24</td>
<td>80.0</td>
</tr>
<tr>
<td><strong>Age in years</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean (SD)</td>
<td>75.1 (6.9)</td>
<td></td>
</tr>
<tr>
<td>Median (IQR)</td>
<td>72.0 (70-80)</td>
<td></td>
</tr>
<tr>
<td><strong>Mini Mental Status Examination score (0 to 30)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean (SD, range)</td>
<td>29.5 (0.9, 27-30)</td>
<td></td>
</tr>
<tr>
<td><strong>Handwriting handedness</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left</td>
<td>0</td>
<td>0.0</td>
</tr>
<tr>
<td>Right</td>
<td>30</td>
<td>100.0</td>
</tr>
<tr>
<td><strong>Reported dominance for non-handwriting tasks</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left</td>
<td>2</td>
<td>6.7</td>
</tr>
<tr>
<td>Right</td>
<td>28</td>
<td>93.3</td>
</tr>
<tr>
<td><strong>Primary written language</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>English</td>
<td>28</td>
<td>93.3</td>
</tr>
<tr>
<td>Other</td>
<td>2</td>
<td>6.7</td>
</tr>
<tr>
<td><strong>Education</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Primary school level or below</td>
<td>0</td>
<td>0.0</td>
</tr>
<tr>
<td>Year 10 level or below</td>
<td>1</td>
<td>3.3</td>
</tr>
<tr>
<td>Completed Year 10 equivalent</td>
<td>3</td>
<td>10.0</td>
</tr>
<tr>
<td>Completed Year 12 equivalent</td>
<td>6</td>
<td>20.0</td>
</tr>
<tr>
<td>Currently studying a higher degree</td>
<td>0</td>
<td>0.0</td>
</tr>
<tr>
<td>Certificate level</td>
<td>6</td>
<td>20.0</td>
</tr>
<tr>
<td>Diploma and advanced diploma</td>
<td>4</td>
<td>13.3</td>
</tr>
<tr>
<td>Bachelor degree</td>
<td>5</td>
<td>16.7</td>
</tr>
<tr>
<td>Graduate diploma and graduate certificate</td>
<td>3</td>
<td>10.0</td>
</tr>
<tr>
<td>Post-graduate degree</td>
<td>2</td>
<td>6.7</td>
</tr>
<tr>
<td><strong>Health conditions self-reported to affect handwriting</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>None</td>
<td>21</td>
<td>70.0</td>
</tr>
<tr>
<td>Arthritis</td>
<td>6</td>
<td>20.0</td>
</tr>
<tr>
<td>Visual impairment</td>
<td>4</td>
<td>13.3</td>
</tr>
</tbody>
</table>

*Note.* *Total percentage exceeds 100% as categories were not exclusive.
4.3 Use and non-use of the digital pen

Real-life handwriting was collected using the Pegasus NoteTaker Digital Pen over a mean of 3.5 consecutive days. Some participants continued using the pen for longer than the required three days. Digital data collected beyond 72 hours were not excluded as it was difficult to determine the cut off for the 72 hour period. As participants were advised the study period was three days, any additional data was collected willingly by participants and therefore included. Results were therefore reported per day, rather than over 72 hours. Participants reported using the digital pen for 321 of 346 possible writing occasions (92.7%). Common reasons cited for not using the pen included not being at home (n = 7, 28.0%), not wishing the content to be recorded (n = 4, 16.0%), difficulty attaching the memory unit onto paper and needing to use another writing implement (n = 3, 12.0%). No reason was given for non-use of the digital pen in nine instances (36.0%), although four writing occasions were journal entries and may have been missing for privacy reasons.

Some inaccuracies between digital samples and log entries were detected. Thirty-one of the total 346 samples (9.0%) were digitally recorded but had not been documented in the handwriting log. A small number of digitally recorded samples (n = 38, 11.0%) did not record accurately. Logged handwriting occasions were not digitally recorded in 14 cases (4.0%). One sample was excluded as it had been written by a grandchild, and not by the participant. All missing and incomplete handwriting samples were excluded from analyses where participants did not provide sufficient information. On one occasion, the memory unit did not download the recorded handwriting samples. These samples were therefore not analysed. Information from the handwriting log regarding these samples was used.
4.4 Parameters of Adult Handwriting

**Pen pressure:** Light pressure was used by approximately half of the sample \((n = 16, 53.3\%)\), while a large proportion \((n = 12, 40.0\%)\) used medium pressure and only two participants \((6.7\%)\) used heavy pen pressure during handwriting.

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**Figure 4.1.** Copybook Handwriting (Melbourne Education Department, 1910).

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**Figure 4.2a.** Excerpt From a Participant’s Handwriting Sample.

---

**Figure 4.2b.** Excerpt From a Participant’s Handwriting Sample.
Components of legibility: One participant wrote exclusively in capitals and another addressed the envelope in capital letters; thus two samples could not be rated for letter width or height. Figure 4.1 shows the copybook standard taught in schools in 1910, when the participants would have been learning to write, and against which participants’ handwriting was compared. Figures 4.2a and b show examples of participants’ actual handwriting. There was significant variability in the parameters of the participants’ handwriting from the copybook standard for between-word spacing (which was larger than copybook writing for copied text). Letters were slanted more to the right for self-generated text. Further, between-word spacing, angle of baseline and slant for self-generated text had standard deviations which were greater than or equal to two, indicating variability across participants (Wilcox, 2001). Average measures of the components of legibility (means and standard deviations) for MMSE and envelope handwriting samples are presented in Table 4.2. This table also presents standardised z-scores comparing the components of legibility from the participants’ writing samples with the 1910 Copybook (Melbourne Education Department, 1910) writing.
Table 4.2
Components of Handwriting Legibility

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Writing Task</th>
<th>1910 Copybook</th>
<th>Z-Scores</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Copied text (Envelope)</td>
<td>Self-generated text (MMSE)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$M$</td>
<td>$SD$</td>
<td>$M$</td>
</tr>
<tr>
<td>Between-word spacing (mm)</td>
<td>5.8</td>
<td>2.3</td>
<td>4.3</td>
</tr>
<tr>
<td>Angle of baseline (degrees)</td>
<td>1.4</td>
<td>2.0</td>
<td>1.7</td>
</tr>
<tr>
<td>Middle zone width (mm)</td>
<td>2.4</td>
<td>0.6</td>
<td>2.3</td>
</tr>
<tr>
<td>Middle zone height (mm)</td>
<td>2.6</td>
<td>0.6</td>
<td>2.4</td>
</tr>
<tr>
<td>Upper zone width (mm)</td>
<td>1.0</td>
<td>0.5</td>
<td>1.1</td>
</tr>
<tr>
<td>Upper zone height (mm)</td>
<td>5.3</td>
<td>1.5</td>
<td>5.3</td>
</tr>
<tr>
<td>Lower zone width (mm)</td>
<td>2.0</td>
<td>1.0</td>
<td>2.3</td>
</tr>
<tr>
<td>Lower zone height (mm)</td>
<td>5.2</td>
<td>1.7</td>
<td>5.2</td>
</tr>
<tr>
<td>Slant (degrees)</td>
<td>60.7</td>
<td>12.1</td>
<td>57.4</td>
</tr>
</tbody>
</table>

Note. MMSE = Mini Mental Status Examination; M = Mean; SD = standard deviation. Parameters described in the method section, pages 82 to 84. *(Melbourne Education Department, 1910). Z-scores are referenced to 1910 copybook writing. * = 1.96 standard deviations above (or below) the mean for copybook measurements (alpha level of significance = .05).
**Legibility:** The majority of participants scored less than a perfect score (4 out of 4) for both the MMSE and envelope handwriting samples, using the four point legibility scale. Results are presented in Table 4.3.

### Table 4.3

*Legibility of MMSE (N = 30) and Envelope (N = 30) Samples as Rated Using the Four Point Legibility Scale*  

<table>
<thead>
<tr>
<th>Four point legibility scale score</th>
<th>MMSE (Self-generated text)</th>
<th>Envelope (Copied text)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( n )</td>
<td>%</td>
</tr>
<tr>
<td>1= Most or all of the words are impossible to identify. The meaning of the text is unclear.</td>
<td>0</td>
<td>0.0</td>
</tr>
<tr>
<td>2 = Some words are clear. The meaning of the text is unclear.</td>
<td>1</td>
<td>3.3</td>
</tr>
<tr>
<td>3 = Not all words are clear, however the meaning of the text can be understood.</td>
<td>23</td>
<td>76.7</td>
</tr>
<tr>
<td>4= All words are clear. The meaning of the text can be understood.</td>
<td>6</td>
<td>20.0</td>
</tr>
</tbody>
</table>

*Note.*  

To estimate the effect of individual handwriting parameters on the legibility scores of handwriting, Table 4.4 regresses the legibility ratings of handwriting samples on the 11 hypothesised features of handwriting and resources commonly assumed to influence the readability of handwriting. The first conclusion to emerge from the results is the lack of importance for how much participants wrote, as well as the consistency of the slant of letters in a word, and the lower zone width and height. Contrary to the literature on outlined in Chapter 2, results indicate that therapeutic intervention in any of the three areas is unlikely to improve the
participant’s handwriting legibility. Variables which were able to predict a proportion of legibility were pen grip, variability (SD) of MZH, variability (SD) of UZW and handwriting script.

Table 4.4
Regression Analysis of Legibility$^a$ of the MMSE Samples ($N=30$)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Regression Coefficient</th>
<th>95% CI</th>
<th>Std. Error</th>
<th>$p$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pen grip</td>
<td>-.211</td>
<td>-1.51 to 1.10</td>
<td>.587</td>
<td>.727</td>
</tr>
<tr>
<td>Variability $^b$ of MZW</td>
<td>.186</td>
<td>-0.39 to 0.76</td>
<td>.257</td>
<td>.485</td>
</tr>
<tr>
<td>Variability $^b$ of MZH</td>
<td>-.509</td>
<td>-1.35 to 0.33</td>
<td>.376</td>
<td>.206</td>
</tr>
<tr>
<td>Variability $^b$ of UZW</td>
<td>-.372</td>
<td>-0.06 to 0.80</td>
<td>.192</td>
<td>.082</td>
</tr>
<tr>
<td>Variability $^b$ of UZH</td>
<td>.151</td>
<td>-0.15 to 0.45</td>
<td>.134</td>
<td>.285</td>
</tr>
<tr>
<td>Variability $^b$ of LZW</td>
<td>.014</td>
<td>-0.20 to 0.23</td>
<td>.097</td>
<td>.889</td>
</tr>
<tr>
<td>Variability $^b$ of LZH</td>
<td>.007</td>
<td>-0.21 to 0.22</td>
<td>.095</td>
<td>.946</td>
</tr>
<tr>
<td>Variability $^b$ of slant</td>
<td>.011</td>
<td>-0.03 to 0.05</td>
<td>.017</td>
<td>.531</td>
</tr>
<tr>
<td>Variability $^b$ of between-word spacing</td>
<td>-.166</td>
<td>-0.46 to 0.13</td>
<td>.131</td>
<td>.231</td>
</tr>
<tr>
<td>Mean words per participant per day</td>
<td>.003</td>
<td>-0.00 to 0.01</td>
<td>.002</td>
<td>.113</td>
</tr>
<tr>
<td>Sentence case $^c$</td>
<td>-.186</td>
<td>-0.69 to 0.31</td>
<td>.224</td>
<td>.425</td>
</tr>
<tr>
<td>Handwriting style</td>
<td>-.325</td>
<td>-0.69 to 0.31</td>
<td>.222</td>
<td>.174</td>
</tr>
<tr>
<td>(Constant)</td>
<td>-.176</td>
<td>-1.25 to 0.90</td>
<td>.482</td>
<td>.723</td>
</tr>
</tbody>
</table>

Notes: $^a$ Dependent Variable: Dichotomous modified four point legibility scale ($1,2,3 = \text{illegible}$, $4 = \text{legible}$) (Au, 2009). $^b$ Variability refers to the standard deviation for each parameter; $^c$ Sentence case refers to whether the text was written in lower case, upper case or sentence case (upper case for the first letter of a sentence and names, lower case for all other letters). CI = Confidence Interval. $R^2 = 0.632$; Adjusted $R^2 = 0.191$; Standard error of the estimate (SEE) = 0.349.

**Handwriting style:** Handwriting style was recorded for 298 of the 321 (92.8%) digital handwriting samples. Samples were excluded if they were illegible or did not download well from the memory unit. Mixed cursive style was the most common handwriting style used for
126 samples (42.3%). Mixed cursive style was used for at least one sample by 27 participants (90.0%). Mixed print style was used for 18 samples (6.0%) and was used for at least one sample by 7 participants (23.3%). A mixed style (cursive/print) was used for 144 samples (48.3%) by 29 participants (97%). ‘Capitals only’ were used for 82 samples (27.5%), particularly for crosswords, with 19 participants (63.3%) writing at least one sample mostly using capitals. ‘Cursive script only’ was used for 51 samples (17.1%). ‘Printing only’ was used for only two samples (0.7%). ‘Numbers only’ were used in 6.4% of occasions, primarily when Sudoku puzzles were being completed. The majority of participants ($n = 24$, 80%) used a combination of styles during the data collection period.

**Number of words:** The number of words per participant per handwriting occasion ranged between 0 for Sudoku number puzzles to 219 in a journal entry ($M = 20.8$, $SD = 14.7$, $Mdn = 18.0$, $IQR = 10.5$ to 26.9 words). Mean number of words written per day per participant was 88.6 words ($SD = 69.0$, $Mdn = 62.1$, $IQR = 36.1$ to 140.3 words). Words could not be counted for 59 of the samples due to illegibility or poor download quality.

**Error corrections:** Detectable error corrections were counted in 106 of 268 samples (39.5%). Only one or two error corrections were made in the majority of samples where error corrections were detected ($n = 77$, 72.6%). The number of samples excluded from analysis was 53. Although not counted as errors in this study, capital letters were substituted for lower case letters on three occasions. Only two participants made no error corrections. Certain activities were associated with higher error correction rates, particularly crosswords, where 15 error corrections (mainly crossing out) were detected in one sample. Consequently, data pertaining to errors are presented in Table 4.5 with and without puzzles.
### Table 4.5

*Mean Error Corrections (SD) in the Writing Samples of Older Adults (N=30) With and Without Puzzles*\(^a\)

<table>
<thead>
<tr>
<th></th>
<th>With puzzles</th>
<th>Without puzzles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean error corrections</td>
<td>4.7 (6.9)</td>
<td>3.2 (2.9)</td>
</tr>
<tr>
<td>Median error corrections</td>
<td>2.6 (0 to 32.6)</td>
<td>2.2 (0 to 10.5)</td>
</tr>
</tbody>
</table>

*Note. \(^a\)‘Puzzles’ included crosswords and Sudoku puzzles. \(^b\) Error corrections per participant per 100 words.*

### 4.5 Motor Control

**Pen grip and posture:** A tripod pen grip was used by the majority of participants (\(n = 29, 97\%\)). Only one participant used an atypical four fingers/quadrapod pen grip. The majority of writing was conducted in a seated position (\(n = 264, 83.3\%\)), with 53 samples (16.7\%) written in a standing position. The most common writing activities conducted in standing were writing notes (\(n = 17.0\%\)), shopping lists and messages on a calendar (\(n = 8, 15.1\%\) each), as well as writing a signature or a message (\(n = 5, 9.4\%\) each). Sixteen participants (53.3\%) wrote at least once in standing. Posture was not recorded for 29 of the samples.

### 4.6 Handwriting Activities and Personal Factors

**Frequency:** Average frequency of handwriting was 3.3 occasions per participant per day (\(SD = 1.5, Mdn = 3, range = 1 to 7\)). Most participants (\(n = 25, 83.3\%\)) wrote at least once each day over the three day study period and all participants wrote at least once over the three day period. The majority of writing samples (\(n = 246, 80.9\%\)) were written during the day, 55 (18.1\%) were written during the evening and only 3 (0.99\%) at night.
**Handwriting activities:** The most common activities were writing notes \((n = 78, 22.6\%)\) such as Bible study notes or information to refer to later and puzzles/games \((n = 76, 22.0\%)\) particularly crosswords and Sudoku puzzles, and lists \((n = 69, 20\%)\) such as shopping and ‘to do’ lists (see Table 4.6). The majority of participants wrote lists \((n = 26, 86.7\%)\) and notes \((n = 20, 66.7\%)\). Half of the participants wrote text for puzzles/games and entries in their calendar/diaries.

**Roles:** When participants completed writing tasks, the most common role being fulfilled was home maintainer, by 28 participants (93.3\%), followed by hobbyist \((n = 21, 70.0\%)\) and friend \((n = 14, 46.7\%)\), (see Table 4.7). The role of health maintainer was added by the research team, as activities pertaining to participants’ health were reported by six participants (20%).
Table 4.6
*Handwriting Activities Completed Over Three Consecutive Days by Participants Aged 65 Years and Over (N = 30)*

<table>
<thead>
<tr>
<th>Activity</th>
<th>Total number of occasions n</th>
<th>(%)</th>
<th>Participants performing activity n</th>
<th>(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Notes</td>
<td>78</td>
<td>(22.6)</td>
<td>20</td>
<td>(66.7)</td>
</tr>
<tr>
<td>Puzzles and games</td>
<td>76</td>
<td>(22.0)</td>
<td>15</td>
<td>(50.0)</td>
</tr>
<tr>
<td>List</td>
<td>69</td>
<td>(20.0)</td>
<td>26</td>
<td>(86.7)</td>
</tr>
<tr>
<td>Journal</td>
<td>22</td>
<td>(6.4)</td>
<td>7</td>
<td>(23.3)</td>
</tr>
<tr>
<td>Calendar or diary</td>
<td>22</td>
<td>(6.4)</td>
<td>15</td>
<td>(50.0)</td>
</tr>
<tr>
<td>Message</td>
<td>16</td>
<td>(4.6)</td>
<td>7</td>
<td>(23.3)</td>
</tr>
<tr>
<td>Letters and cards</td>
<td>16</td>
<td>(4.6)</td>
<td>11</td>
<td>(36.7)</td>
</tr>
<tr>
<td>Envelope</td>
<td>11</td>
<td>(3.2)</td>
<td>7</td>
<td>(23.3)</td>
</tr>
<tr>
<td>Telephone message</td>
<td>10</td>
<td>(2.9)</td>
<td>7</td>
<td>(23.3)</td>
</tr>
<tr>
<td>Recipe</td>
<td>9</td>
<td>(2.6)</td>
<td>8</td>
<td>(26.7)</td>
</tr>
<tr>
<td>Form</td>
<td>8</td>
<td>(2.3)</td>
<td>6</td>
<td>(20.0)</td>
</tr>
<tr>
<td>Signature</td>
<td>6</td>
<td>(1.7)</td>
<td>1</td>
<td>(3.3)</td>
</tr>
<tr>
<td>Cheque</td>
<td>2</td>
<td>(0.6)</td>
<td>2</td>
<td>(6.7)</td>
</tr>
</tbody>
</table>

*Note.* Journal refers to prose reflective writing; calendar/diary refers to appointments scheduled in a diary or on a calendar; message refers to a message to self or someone else.
### Table 4.7
*Roles Fulfilled by Participants Aged 65 Years and Over While Handwriting (N = 30)*

<table>
<thead>
<tr>
<th>Role</th>
<th>Total occasions</th>
<th>Participants performing this role</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>(%)</td>
</tr>
<tr>
<td>Hobbyist</td>
<td>126</td>
<td>(36.6)</td>
</tr>
<tr>
<td>Home maintainer</td>
<td>79</td>
<td>(23.0)</td>
</tr>
<tr>
<td>Friend</td>
<td>32</td>
<td>(9.3)</td>
</tr>
<tr>
<td>Religious participant</td>
<td>31</td>
<td>(9.0)</td>
</tr>
<tr>
<td>Volunteer</td>
<td>29</td>
<td>(8.4)</td>
</tr>
<tr>
<td>Health maintainer</td>
<td>19</td>
<td>(5.5)</td>
</tr>
<tr>
<td>Family member</td>
<td>19</td>
<td>(5.5)</td>
</tr>
<tr>
<td>Participant in organisations</td>
<td>6</td>
<td>(1.7)</td>
</tr>
<tr>
<td>Worker</td>
<td>3</td>
<td>(0.9)</td>
</tr>
</tbody>
</table>

*Note.* Roles are defined as those in “The Role Checklist” (Oakley, et al., 1986).

**Modes of handwriting:** Self-generated text was written most often ($n = 295, 85.3\%$), such as letters and lists, followed by copied text ($n = 35, 10.1\%$), such as a copied recipe or envelope address. All participants wrote self-generated text, but only around half of the sample ($n = 16, 53.3\%$) copied text during the data collection period. Transcribed text was written rarely ($n = 16$ occasions, $4.6\%$) and was primarily used when recording telephone messages.

**Concurrent activities:** Recording of concurrent activities was omitted on the handwriting log for 32 (9.2\%) handwriting occasions. Concurrent activities performed simultaneously with a handwriting activity were reported for 96 (30.6\%) occasions and included
listening to the radio/music ($n = 57$, 59.4%), reading and drinking ($n = 10$, 10.4% each). Talking, eating and watching the television were also performed concurrently to writing. Concurrent activities during at least one handwriting occasion were reported by 23 participants (76.7%).

4.7 Questionnaire Results

Readers of handwriting: Participants’ handwriting was read in the month prior to, and during the data collection period, by family members ($n = 20$, 66.7%), bank clerks, postal workers and members of other community organisations ($n = 18$, 60.0%) and friends ($n = 16$, 53.3%). Less frequent readers of participants’ written text included partners ($n = 13$, 43.3%), health professionals and employers. Only one participant reported that their handwriting had not been read by someone other than themselves in the previous month.

Importance of handwriting: Participants rated the importance of handwriting highly (mean score = 72.6, $SD = 16.8$).

Modes of communication: Most frequently reported modes of communication used in the previous three days were face-to-face contact ($n = 30$, 100.0%), landline telephone and handwriting ($n = 22$, 73.3%). E-mail and mobile telephones were also reportedly used to communicate with others. One fifth of participants reported using ‘SMS’\(^1\) texting in the previous three days. Communication modes that were rarely used included internet-based telephoning (such as Skype), video-conferencing and hand-held devices including PDAs or ‘palm pilots’.

Figure 4.3 depicts use of technology in the previous three days.

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\(^1\) SMS refers to Short Message Service used to send short written text messages from one mobile telephone to another.
4.8 Synopsis

Key findings of this study address some of the gaps in handwriting research. The majority of participants (73.3%) scored less than a perfect score for both the MMSE and envelope handwriting samples, using a modified four-point rating scale (Au, 2009). There was significant variability in the parameters of the participants’ handwriting from the copybook standard for between-word spacing (copied text), upper zone height (copied text), and slant (self-generated text). Further, between-word spacing, angle of baseline and slant were variable across participants (SD ≥ 2). Participants did not write often ($Mdn = 3$ occasions per day) and sample lengths were short ($Mdn = 18$ words per occasion). Handwriting was at times performed in standing (16.7%) and whilst attending to another activity (30.6%) such as listening to the radio. The most common reasons for handwriting were writing notes (22.6%), doing puzzles (22.0%) and writing lists (20%). The majority of handwriting involved self generated text (85.3%).

Figure 4.3. Communication Modes and Technology Used by Participants ($N = 30$) in the Previous Three Days. Responses as reported in the Handwriting Questionnaires. MSN = Microsoft Network. MSN refers to MSN Messenger, the instant messaging service from MSN.
followed by copied text (10.1%) and transcribed text (4.6%). These data provide the basis of a normative data set. These results provide insight into the handwriting behaviours of unimpaired adults aged 65 years and over to inform rehabilitation clinicians working with people who have had a stroke or other neurological condition. Results and their implications will be discussed in the following chapter.
Chapter Five: Discussion

5.1 Introduction

This cross-sectional observational study aimed to describe the handwriting practices of 30 unimpaired adults aged 65 years and over to inform adult handwriting rehabilitation after stroke. A digital pen was used to collect handwriting samples of real-life handwriting situations. In addition, participants kept a record of their handwriting in a log. Self-generated and copied text samples were also collected.

There were seven key findings from this study that will be discussed in depth in this chapter. First, there was variability in the parameters of the participants’ handwriting from the copybook standard and between participants. Second, this study raised issues regarding measuring the legibility of adult handwriting. Third, use of a mixed script and error corrections did not negatively affect legibility. Fourth, participants did not write often and sample lengths were short. Fifth, a substantial proportion of handwriting was performed in standing and while attending to a concurrent activity. Sixth, common reasons for handwriting were writing notes, doing puzzles and writing lists, mostly consisting of self-generated text. Finally, self-generated text was more common than copied text. This chapter will discuss these findings and their contribution to knowledge about handwriting. Implications for practice and recommendations for further research will also be outlined.

5.2 The Sample

The sample included 30 older Australians with a median age of 72.0 years. Snowball sampling enabled convenient and efficient recruitment of eligible people. However, some
sampling biases also resulted, limiting the generalisability of the findings to other populations. Approximately 80% of participants were women, compared with 55% of the total population of Australian adults aged 65 to 94 years (Australian Bureau of Statistics, 2008c). Unlike previous studies, there were no left-handed writers in this sample, for example in the study by Peters and colleagues (2006) where 13% of respondents said they wrote with their left hand. Half of the sample had previously been employed in professional work roles, compared with 41% of the Australian population of working age in May 2008 (Australian Bureau of Statistics, 2009). Participants also all lived in a greater metropolitan area of a major city.

Part-time or full-time employment was held by 7% of participants compared with 3% of the older Australians in this age group (Australian Bureau of Statistics, 2008a). Volunteer roles were fulfilled by 37% of participants, which is higher than the 20% of Australians aged 55 years and over who volunteer (Australian Bureau of Statistics, 2008b). Further, 13 participants were recruited from the same Bible study group, and two other participants also reported undertaking Bible study or church-related activities. The proportion of participants involved in religious activities (50%) was almost double that of the general population, with around a quarter of people aged 65 years and over participating in church or religious activities (Australian Bureau of Statistics, 2004). These differences are likely to have been as a result of the recruitment methodology - snowball sampling - whereby participants referred friends and family members to also take part.

In summary, the current sample included more women, more right-handed adults and a better educated sample than the total population. Participants also all lived in a greater metropolitan area of a major city. Findings may not be generalisable to people living in rural and
regional areas, however there is no reason to expect major differences in handwriting behaviour or parameters between adults living in urban and rural areas. Participants were more likely to be working in paid or unpaid roles and attending to religious activities. The types of roles fulfilled by participants impacted upon the handwriting activities they performed during the three day study period. Readers should interpret findings with some caution because of these sample differences.

5.3 Variability of Adult Handwriting

Overall, results indicate that participants wrote middle, upper and lower zone letters in a similar size compared to the 1910 copybook letters. However, between-word spacing was significantly larger than copybook writing for copied text. Letters were significantly more slanted towards the right in the self-generated text than copybook writing. Further, between-word spacing, angle of baseline, middle zone width and slant all had a standard deviation of two or above for both copied and self-generated writing samples, indicating large variability in handwriting across participants (Wilcox, 2001). These findings are consistent with previous work undertaken with 45 right-handed adult Ontario residents (Simner, 1998). In that study, participants’ letters matched the upper and lower case Ontario copybook letters in only 14 out of the 52 total letters ($p < .001$). Therefore variations from copybook letters occurred more often than matches for 38 (73.1%) out of 52 letters. No other studies comparing older adult handwriting with copybook handwriting were located.

Legibility scores also revealed variability of participants’ handwriting from near perfect copybook writing with few participants being categorised as having legible writing (4 out of 4). Legibility was rated more highly for adults aged up to 40 years than adults aged over 40 years in
the study by Berwick and Winickoff (1996). Greater variability of handwriting parameters such as spacing, letter size and slant was found in unimpaired older adults (aged 66 to 91 years) compared with younger adults (aged 39 to 65 years) in a longitudinal study (Walton, 1996). Similarly, variability of handwriting between 10 participants was found in another study, particularly for the height of the middle zone letters and letter slant (Ling, 2002).

Handwriting variations as children develop into early adulthood include deterioration of letter formation and spacing, and increased use of mixed style (Hamstra-Bletz & Blote, 1990; Weintraub, et al., 2007). In the current study, variations in the features of handwriting (such as letter size, spacing and slant) between participants’ handwriting and copybook writing did not all reach statistical significance. Nevertheless, large standard deviations suggest that handwriting variability between writers is common. Thus, legibility may not depend exclusively on the handwriting script that a beginning writer is taught. Instead, a number of factors impact upon legibility, particularly as a child gets older. Variability of participants’ handwriting suggests that paediatric assessments comparing parameters such as between-word spacing and letter slant against a copybook standard (e.g., Amundson, 1995) may not be suitable to assess adults’ handwriting.

5.4 Measuring Legibility

Predictors of legibility included variability of middle zone height and variability of upper zone width. Variability of letter size has been associated with reduced legibility in previous studies (Graham, et al., 2006; Ziviani & Elkins, 1984). Further, in the current study, using a mixed handwriting style was associated with better legibility, consistent with a previous study (Graham, et al., 1998b). However, slant and between-word spacing were not predictors of
legibility in this study, which is in contrast with paediatric studies (Graham, et al., 2006; Graham, et al., 2001; Ziviani & Elkins, 1984). Not all parameters studied in paediatric studies (such as letter formation) were investigated in the current study. The overall goodness of fit of the model is high, however caution in interpreting the results is warranted. The sample size was small which may explain some of the non-significant p values. A potential further limitation of the small sample size was the low response count for participants scoring a 4 in the legibility scale. This result may not be representative of the general population. A larger sample size would be required to develop a more statistically robust model.

The most suitable method for measuring adult handwriting legibility, either using global or analytical scales or digital technology, remains uncertain. The measurement of handwriting parameters is time consuming. It can be difficult for rehabilitation clinicians to justify time spent measuring and scoring handwriting performance, before they even begin a retraining program. Global legibility scales are faster to score than analytic scales however may lack sensitivity. One study which compared a global scale, an analytical scale and digital technology, found that a global scale discriminated best of all between proficient and poor paediatric handwriters (Rosenblum, et al., 2004). In clinical settings, time, cost and ability to measure change are the most important factors for clinicians to consider when assessing handwriting legibility of patients in rehabilitation. Analytical and global scales both have strengths and limitations which have been discussed. Digital methods provide another approach to measuring legibility and letter recognition. However digital techniques, such as a digital pen or software can be expensive and also time consuming.
In the current study, the method used for measuring legibility involved measuring some components of legibility (analytic method) for selected letters, as well as using a global legibility scale (Au, 2009). The results of this study suggest that parameters of older adult handwriting vary from the copybook writing taught at school. These results therefore question theoretical assumptions for the way we assess adult handwriting (currently adapted from paediatrics assessments) and the parameters of handwriting that we address. This study contributes the first known data on the use of a combined global and analytic method for assessing adult handwriting legibility. Use of a combined analytic and global method for assessing legibility may be a more appropriate alternative to methods used in paediatric assessments for measuring adult handwriting. Methods for assessing adult handwriting legibility need further research to ensure sound psychometric properties and clinical utility.

5.5 Mixed Script and Error Corrections Did Not Negatively Affect Legibility

A mixed handwriting style was used by the majority of participants for approximately half of the samples. Further, use of a mixed style was associated with greater legibility. This finding is consistent with that of Graham and Weintraub (1998), where almost 40% of 600 students used a mixed style. In that study, students who used a mixed style wrote faster than those who used either cursive only or printing only. The legibility of mixed script was either equivalent or superior to both printing and cursive script alone (Graham, et al., 1998b). Accepted handwriting styles for children include cursive or printed text, with a combination of styles being penalised in handwriting assessments (e.g., Amundson, 1995). Findings from the current study and that of Graham and Weintraub (1998) suggest that a mixed style is both a common and efficient deviation from school font. This study provides information on the handwriting styles
used by unimpaired adults, which can inform the development of an ecologically valid assessment tool, and assist rehabilitation clinicians when retraining handwriting.

*Error corrections* may be penalised in handwriting assessments or during retraining (e.g., Amundson, 1995). However, most participants in the current study corrected errors in their real-life handwriting samples. Error corrections were noted in around 40% of samples, with one or two error corrections made on most occasions. Error corrections occurred more often as people aged in a longitudinal study (Walton, 1996). Results of the current study support those of Walton (1996) that a small number of error corrections (approximately 2 to 3 per 100 words) can be considered normal in unimpaired older adults. These results provide the basis for normative values for handwriting errors corrected by unimpaired older adults.

5.6 **Handwriting Was Infrequent and Sample Lengths Were Short**

*Frequency* of handwriting averaged around three occasions per day. The majority of participants wrote at least daily and all participants wrote at least once over the three day period. While involvement in the study may have caused participants to write more frequently than usual (Barton, et al., 1999), results concur with a previous self-report study of adults aged 60 years and over in Israel. In that study, 94.3% of participants reported writing ‘daily’ or ‘almost daily’ (Rosenblum & Werner, 2006). Similarly, most working-age adults also reported they had written in the past three days (McMahon, 2008). Therefore, handwriting appears to be performed infrequently but almost daily by adults and older adults. The current study provides the first known objective data about the frequency of handwriting performed by adults. Data suggest that an adult handwriting assessment and retraining program should contain a few select activities, as adults do not typically write very often per day.
The number of words written per handwriting occasion was low. However, the number of words written varied greatly depending upon the activity. Participants often wrote more words when writing in their journals or writing a letter, than when writing a list or telephone message. The number of words written per participant per day was not a predictor of legibility in this study. That is, older adults who wrote a large amount of text did not write more or less legibly than those who wrote few words. This is the first known study to investigate the relationship between number of words written and handwriting legibility. Longer handwriting tasks have been associated with reduced letter legibility, irrespective of pen grip, in students aged nine to 10 years (Dennis & Swinth, 2001). No other studies measuring the number of words written by adults in real-life handwriting situations have been located.

5.7 Handwriting and Other Demands

Standing whilst writing and attending to an activity whilst writing both place extra demands on individuals. Whilst sitting was the most common position assumed by participants, a sizeable proportion of handwriting occasions were performed while standing. Body posture is generally considered to be associated with handwriting quality in children (Graham & Weintraub, 1996). However, one study suggests only a moderate correlation ($r = .60$) exists between sitting posture and the handwriting performance of nine year old students (Rosenblum, Goldstand, et al., 2006). The relationship between sitting versus standing and legibility of adult handwriting has not yet been investigated. In the absence of such data, reinforcing good postural habits during handwriting retraining may be worthwhile from a biomechanical perspective to reduce strain on the spine (O’Sullivan, et al., 2009).
Concurrent activities whilst handwriting were reported by participants for almost one-third of handwriting occasions. The most commonly reported concurrent activity was listening to the radio. These data have not been previously reported and can be used to inform handwriting assessment, such as the inclusion of items performed while standing if appropriate, and dual tasking, for example handwriting whilst the radio is playing.

5.8 Reasons for Handwriting

Common handwriting activities completed by participants were writing notes, puzzles and lists. A number of participants attended a common Bible study group which may have led to an over-representation in the sample, and a larger proportion than in the general population writing Bible study notes. The most common reasons for handwriting in working-age Australian adults were to sign their name, to take down notes and ideas, and write reminders (McMahon, 2008). In that study, rarely performed tasks were associated with the leisure role, including journal writing, puzzles and crosswords. This finding may be explained by the significant proportion of time that working-age adults spend at work, therefore limiting time engaged in leisure roles. Gender, level of education and occupation were related to the types of handwriting activities performed (McMahon, 2008). For example, females were more likely to write to-do lists than male respondents \((p = .001)\) and blue collar workers reported using diaries more often than white collar workers. In addition, respondents who had a higher degree reported signing their signatures more frequently than those that did not.

The handwriting activities performed by people with stroke have not yet been studied. However, some of the handwriting tasks performed by participants in the current study are likely to be similar to those completed by people who have had a stroke who can write, because the age
groups are similar. For example, memory deficits are common following stroke, and memory aids such as notes, lists, diaries/calendars and reminders are often recommended as compensatory strategies (Nair & Lincoln, 2007) and require regular handwriting. An ecologically valid test needs to contain information that is relevant to a person’s daily function (Moseley, et al., 2004). Therefore, in order to measure handwriting, an ecologically valid assessment needs to contain test items including handwriting activities that are relevant to, and performed by, the intended population. The current study describes the reasons behind why older adults choose to perform handwriting. Findings from this study about common handwriting activities performed by older adults should influence the content of an ecologically valid handwriting assessment.

5.9 Self-Generated Text Was More Common Than Copied Text

Self-generated text was used for the majority of handwriting samples. This finding suggests that older adults may copy or transcribe text from spoken messages less frequently than they self-generate text. Anecdotally, handwriting activities appear to involve self-generated text much more frequently for adults than for young children who spend the majority of their handwriting time completing copying tasks for education purposes. No data were located on the percentage of writing that is self-generated text versus copied text in adults of any age group. Copied text was rated as being more legible than self-generated text in a study involving grade 1 to 6 students (Graham et al., 1998). For older students, handwriting may often involve taking down notes from spoken lectures. Each of these modes of handwriting involves different cognitive loads. In the current study, legibility was not found to differ between copied and self-generated text samples, although findings should be confirmed with a larger sample. Programs aimed at measuring and retraining handwriting need to consider each of these modes, however
study findings suggest that a greater emphasis should be placed on self-generated text which is more commonly used.

5.10 Other Findings

Light to medium pen pressure was used by the majority of participants. People with neurological conditions anecdotally use very light or very heavy pressure due to their motor deficits. Heavy pressure is thought to produce fatigue or strain with continued application (e.g., Baur, et al., 2006). The impact of downwards pen pressure on legibility or fatigue was not measured in this study. However, the average length of handwriting episodes was short. Pen pressure may not have had a significant impact on the handwriting performance of older adults where writing episodes contain a median of only 18 words.

The categorisation of pressure as light, medium or heavy based on the indent of the writing on the paper in this study is not comparable with more objective measures of pressure (i.e., Newtons) used in other studies (e.g., Dooijes, 1983; Wann & Nimmo-Smith, 1991). Nonetheless, categorisation of pressure through the indentation of the paper has wider clinical applications as the technology required to measure the forces exerted by the pen are not readily available in most rehabilitation centres. Categorisation by indentation of the paper is often used by clinicians to check whether clients are applying too much or too little downward force. Handwriting samples performed by patients in real-life contexts or as their rehabilitation homework may also be assessed. Clients themselves can observe the paper indentation to self-monitor their downwards pen pressure. Other clinical observations such as hyper-extended joints or white knuckles (Selin, 2003) can be used to indicate whether excessive pen grip pressure is being exerted. The impact of downward pen pressure and pen grip pressure on writing
endurance and legibility is inconclusive in children (Selin, 2003) and unknown in adults. Moreover, the relationship between grip and downwards pressure has not been widely studied.

The pen grip used by almost all participants was the tripod grip. A higher incidence of atypical grips (particularly the lateral tripod grip, 9.3%) has been found in a previous study involving adults (Bergmann, 1990). In the current study, having an atypical (four fingers) grip was associated with poorer legibility. However, as the current study sample was small, no inferences can be made regarding the impact of pen grips on aspects of handwriting performance and output. Anecdotally, remediation of the pen grip is a focus of occupational therapy in both children and adult handwriting retraining. Yet, existing research suggests that a range of pen grip types are used and do not have a negative effect on writing speed, legibility or endurance (Dennis & Swinth, 2001; Rosenblum, Goldstand, et al., 2006; Ziviani & Elkins, 1986). Therapists’ instructions to clients during rehabilitation to change their pen grip may therefore be unnecessary. Further studies involving larger samples of adults are required.

5.11 Study Limitations

As with all studies, this exploratory observational study had limitations. First, snowballing recruitment enabled convenient recruitment of participants. However, some sampling biases resulted with higher proportions of women, people with professional backgrounds and people involved in paid and volunteer work and religious activities than in the general older Australian population. A much larger sample containing more men, people with unskilled backgrounds and more retired individuals may enable findings to be generalised to a larger population. Further, people from rural and regional areas could be actively recruited in future studies. Although the study had a relatively small sample size and analysis did not reach
statistical significance, clinical importance of the estimates of effect size were used to interpret the regression coefficients.

Second, the challenge of measuring handwriting is to measure the parameters that highlight underlying problems. While the methods used to measure handwriting parameters in the current study represent a practical strategy, matching participant’s handwriting parameters against perfect copy-book handwriting parameters, there are limitations to the method. The method used to mathematically compare the handwriting sample to the copybook handwriting is only accurate if the participant has attempted to write letters of the same size (letter height and width) as the copybook handwriting. The analysis method is unable to accommodate uniform increases (or decreases) in letter widths and heights. For example, a ‘perfect copybook’ letter which has been enlarged uniformly (for instance, on a photocopier) would still be found to differ unacceptably from copybook handwriting in the parameters of letter height and width and would therefore be rated as illegible.

Finally, some measures of handwritten text were obtained using a ruler and protractor. This technique can introduce measurement error, but is practical and more likely to be used by clinicians in Australia than digital methods. Due to time constraints, parameters of handwriting were only measured for the MMSE samples and addressed envelopes. Measurement of the MMSE and envelope samples only resulted in small numbers for some of the handwriting parameters such as for lower zone letters (g and y). Results form the basis for normative values and indicate trends in older adult handwriting, but need to be interpreted with caution.
5.12 **Implications for Practice**

The findings of this study have implications for clinical practice, education and research. Practice implications for rehabilitation therapists include considerations regarding the assessment of legibility, and data on the real-life handwriting situations of older adults, to inform handwriting assessment and retraining:

a) Variations from copybook values were found for upper zone letter height, slant and between-word spacing. Variations across participants were also found. Paediatric assessments such as the ETCH expect little variability in letter height, slant and spacing and often form the basis of non-standardised adult handwriting assessments. This method of comparing handwriting against a copybook standard may not be suitable for use with adults, whose writing varies substantially from copybook writing. A valid adult handwriting assessment needs to allow for large variations in handwriting styles as well as measuring change.

b) The majority of participants were rated as having handwriting that was not ‘legible’ (i.e., they scored less than 4 out of 4). However, for most of the samples, the majority of words could be read and the context of the text could be understood. These results suggest that the aim of handwriting retraining after a stroke should be achieving functional handwriting legibility (where the meaning of the writing can be understood), rather than achieving a legibility score of 4, when it is likely that the client would not have achieved a perfect score prior to their stroke.

c) Test items of an ecologically valid adult handwriting assessment for older adults should include note-writing (for example a news item), crossword puzzles and writing a
shopping list. Activities that an individual is required to perform should be considered when designing the retraining program. It is recommended that most time be spent on practicing self-generated text and samples with few words.

d) A mixed style and correcting a certain amount of errors per 100 words may be common. It is recommended that an adult handwriting assessment should permit, and not penalise, mixed styles. Further, normative data need to be established for error corrections per 100 words for unimpaired adults.

e) Handwriting while standing should be assessed, where physical capacities allow. Handwriting activities commonly performed whilst standing, such as writing on a calendar, could then be addressed in the ensuing retraining program. Concurrent activities should be considered in the assessment of handwriting in stroke survivors and may include items that involve handwriting whilst the radio is playing.

To date, there has been little empirical information about real-life adult handwriting. The findings of this study provide some direction to guide the assessment and retraining of adult handwriting. This study also has implications in the area of education, both for health professionals working with people whose handwriting has been interrupted as a result of a neurological condition and for teachers working with children learning to handwrite.

5.13 Implications for Education

Education for entry-level and graduate students and rehabilitation therapists is needed to disseminate the findings of the current study. Possible formats of this education include
conferences, workshops, inservices and training packages. There is a paucity of clinically relevant research in the area of adult handwriting to inform practice. Rehabilitation therapists need to base their interventions on available evidence to increase the effectiveness of their interventions and to establish and maintain their credibility as health professionals.

For teachers working with school children, the findings of this study provide information on how handwriting develops as adults get older. Firstly, parameters of handwriting varied from the copybook writing that was taught at school. This finding supports previous findings that students’ handwriting changes as they get older (Hamstra-Bletz & Blote, 1990). Deviation of children’s handwriting from what was taught to them may not be problematic as long as the components of legibility that contribute to global readability are maintained. For example, larger than normal handwriting may not be a concern as long as the size is consistent and the letters and words are adequately spaced. Secondly, older adults commonly used a mixed style of handwriting in this study. These results are similar to a previous study that found children commonly use a mixed style with no detriment to legibility or speed (Graham, et al., 1998b). It appears that this adaptation to the handwriting taught in school is practical in older adulthood.

In summary, this study has addressed some of the gaps in adult handwriting literature, particularly regarding the parameters of handwriting. However due to the small sample size and the vastness of the topic, replication studies and research involving larger sample sizes are required. A number of gaps were not addressed in this study and many questions remain in the field of adult handwriting.
5.14 Implications for Future Research

Possible areas for future research include studies of adult handwriting legibility, to determine handwriting parameters that contribute to legibility and reach a consensus on the gold standard approach to measuring legibility. A practical and reliable method for measuring pen pressure has yet to be identified. Research is required to determine the reliability of the pressure categorisation implemented in this study, to establish normative data for downwards pen pressure and to determine the impact of downward pen pressure on endurance and legibility in adults.

Studies involving larger samples of older (and younger) adults are also recommended to investigate the impact of the number of words written on handwriting legibility, speed and endurance; establish normative values for handwriting errors corrected; and examine the relationships between handwriting style, legibility and speed. Further research is also recommended to examine the difference in the quality of adult handwriting for copied and transcribed text compared with text which has been self-generated.

With regard to motor control, relationships between pen grip, handwriting speed, legibility and endurance have not been studied in adults. As rehabilitation therapists often spend substantial time retraining pen grip during adult handwriting rehabilitation, further research on pen grips is recommended with a larger sample. The relationship between standing and handwriting performance has also not yet been investigated. Further research into the relationships between posture and handwriting movements and performance is recommended.
Personal factors such as gender, professional/educational background, writing hand preference, writing implement choices and their relationship with handwriting performance requires much further investigation. Moreover, technology use will continue to replace some handwriting tasks and it is recommended that the impact of technology use on handwriting continue as the focus of future studies.

The development of an ecologically valid adult handwriting assessment, with robust normative data, is greatly needed. The reliability and validity of such an assessment will require rigourous study to ensure sound psychometric properties. The HAB aims to be a valid and reliable instrument. It requires further development to include handwriting activities that are relevant for adults. The legibility component of the HAB, currently based on the ETCH, also needs review to ensure it is appropriate for the variability of handwriting parameters found in adults. The speed component of the HAB currently involves copying text as quickly as possible, and may include self-generated text which is a more commonly used handwriting mode by adults. The results of the current study will help to inform the development of the HAB to be more ecologically valid.

The handwriting practices of stroke survivors and people with other neurological conditions need further research in order to most effectively remediate handwriting deficits. Only one study was located on the remediation of handwriting in adults. That study investigated the effectiveness of a two-week handwriting retraining program (6 sessions at home) for four adults with brain injury (Beaudet, 2004). Handwriting legibility improved following task-specific handwriting training and practice, however due to the small sample size, results cannot be generalised. A handwriting retraining program, informed by studies into the handwriting of
unimpaired adults as well as that of people with stroke and other neurological conditions, will require investigation in the form of randomised controlled trials to determine its effectiveness.

Further studies of adult handwriting should involve larger samples, including people from varying age groups, and from metropolitan, rural and regional areas to increase the generalisability of findings. These studies may involve a similar method to the current study, or include other methods such as direct observation and videotaped footage.

5.15 Conclusion

This study used a cross-sectional design to describe the handwriting features of 30 adults aged 65 to 90 years. Of particular significance, variation existed across participants’ handwriting as well as some variation from copybook writing. These results suggest that adapted paediatric assessments, which are commonly used for adults, may not be suitable for the adult population. Findings provide a basis for normative data on the components of legibility and error correction. Handwriting is commonly performed while standing or at the same time as another activity. A mixed handwriting style and self-generated text are frequently used. The content of the text is often short, and is dependent upon the reason for the handwriting.

The results of this study are highly relevant to neurological rehabilitation therapists. Results highlighted that handwriting is an activity which continues to be valued by older adults, despite increased use of communication technologies in our society. Health professionals working with older people who have had a stroke or other neurological condition need to be aware of the importance of handwriting, and address handwriting retraining as part of a comprehensive rehabilitation program. This study provides the first insight into the real-life
handwriting of older adults, providing baseline information against which the handwriting of people with neurological conditions such as stroke can be compared. This study is also a stepping stone for further research into this important subject. Findings concerning why, what, how much and in what context older adults handwrite should influence the content of a comprehensive, ecologically valid handwriting assessment and retraining program.
References


Appendices

Appendix A  HAB Data Collection Form
Appendix B  Handwriting Log
Appendix C  Participation Information Statement
Appendix D  Consent Form
Appendix E  Handwriting Questionnaire
Appendix F  Envelope Address Copying Task
Appendix G  The Role Checklist
Handwriting Assessment Battery for Adults

Test Booklet

Prepared by

Dr Annie McCluskey & Dr Natasha Lannin

[Version 5]


Acknowledgement: Assistance gratefully received from Katherine Faddy to revise the layout and formatting of this document
Section 1: Pen Control and Manipulation (Horizontal Lines)

Aim: To draw at least 10 lines, with five of these touching and stopping at the vertical line in 20 seconds.

You are timed from the moment you put the pencil on the paper to start the examination. You will be stopped once the 20 second time period has elapsed.

ATTEMPT 1
Section 1: Pen Control and Manipulation (Horizontal Lines)

Aim: To draw at least 10 lines, with five of these touching and stopping at the vertical line in 20 seconds.

You are timed from the moment you put the pencil on the paper to start the examination. You will be stopped once the 20 second time period has elapsed.

ATTEMPT 2
Section 1: Pen Control and Manipulation (Horizontal Lines)

Aim: To draw at least 10 lines, with five of these touching and stopping at the vertical line in 20 seconds.

You are timed from the moment you put the pencil on the paper to start the examination. You will be stopped once the 20 second time period has elapsed.

ATTEMPT 3
Section 1: Pen Control and Manipulation (Dots)

Aim: To make at least 10 dots in 5 seconds. You must make a dot not a stroke.

You are timed from the moment you put the pencil on the paper to start the examination. You will be stopped once the 5 second time period has elapsed.

ATTEMPT 1
Section 1: Pen Control and Manipulation (Dots)

Aim: To make at least 10 dots in 5 seconds. You must make a dot not a stroke.

You are timed from the moment you put the pencil on the paper to start the examination. You will be stopped once the 5 second time period has elapsed.

ATTEMPT 2
Section 1: Pen Control and Manipulation (Dots)

Aim: To make at least 10 dots in 5 seconds. You must make a dot not a stroke.

You are timed from the moment you put the pencil on the paper to start the examination. You will be stopped once the 5 second time period has elapsed.

ATTEMPT 3
**Section 2: Writing Speed**

- Take a pencil in your writing hand and arrange everything so that it is comfortable for you to write.
- There is a sentence on the other side of the card the therapist will give you.
- When the therapist says ‘go’ copy the sentence in writing not PRINTING.
- You will be timed from the word ‘Go’ until you have completed the sentence.
- If a word is misspelt or printed you will need to rewrite the sentence using a different card.

Please write the sentence below:

________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________

Time Taken: __________

Attempt 2 (Only to be completed if a word is misspelt or printed):

________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________

Time Taken: __________
Section 3: Writing Legibility

I. Alphabet Writing - Lower Case Letters

II. Alphabet Writing - Upper Case Letters

III. Numeral Writing

IV. Sentence Composition  Time:______________
The Handwriting Assessment Battery Score Sheet

Pen Control & Manipulation

Horizontal Lines:  □ Achieved  □ Not Achieved
Dots:  □ Achieved  □ Not Achieved

Writing Speed

Time Taken To Complete Sentence: ……………  Standard Deviation: ……………

<table>
<thead>
<tr>
<th>Age</th>
<th>Average Time</th>
<th>Standard Deviation</th>
<th>Average Time</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 - 59</td>
<td>12.2 seconds</td>
<td>+/- 3.5 seconds</td>
<td>11.7 seconds</td>
<td>+/- 2.1 seconds</td>
</tr>
<tr>
<td>60 - 94</td>
<td>19.5 seconds</td>
<td>+/- 7.5 seconds</td>
<td>16.7 seconds</td>
<td>+/- 4.7 seconds</td>
</tr>
</tbody>
</table>

Writing Legibility

ALPHABET WRITING

Lower Case Letters
Number of Illegible Letters = __________

Upper Case Letters
Number of Illegible Letters = __________

\[
\text{Legibility \%} = \frac{26 - \# \text{ of illegible letters}}{26} \times 100
\]

Letter Legibility = ________ \%  
Letter Legibility = ________ \%

NUMERAL WRITING

Number of Illegible Numbers = ________

\[
\text{Legibility \%} = \frac{12 - \# \text{ of illegible numbers}}{12} \times 100
\]

Number Legibility = ________ \%

SENTENCE COMPOSITION

Word Legibility
Total Number of Words = __________
Number of Legible Words = __________

\[
\text{Legibility \%} = \frac{\# \text{ of legible words}}{\text{Total \# of words}} \times 100
\]

Word Legibility = ________ \%

Letter Legibility
Total Number of Letters = __________
Number of Legible Letters = __________

\[
\text{Legibility \%} = \frac{\# \text{ of legible letters}}{\text{Total \# of Letters}} \times 100
\]

Sentence Letter Legibility = ________ \%
These cards can be photocopied and cut out for assessment use.

FISH TAKE AIR OUT OF THE WATER

JOHN SAW THE RED TRUCK COMING

THE OLD MAN SEEMED TO BE TIRED
Appendix B  Handwriting Log

Pen Use and Instructions

- Please use the **digital pen and memory unit** for your usual handwriting activities **as much as you can** over the 3 days.
  
  For example:
  Letters, messages, telephone messages, notes, to do lists, shopping lists, recipes, poems and ideas.

- Whatever you write using the digital pen and memory unit will be recorded and downloaded electronically.

- Do not use the memory unit for anything you do not wish to be recorded.

- Please remember to replace the pen lid when not in use

Remember to **clip the memory unit onto the paper** each time you write.
The pen cannot record what you write without it.

**Please complete this table each time you have written, even if you weren’t able to use the digital pen and memory unit.**

<table>
<thead>
<tr>
<th>Date:</th>
<th>What did you write?</th>
<th>Did you use the digital pen? Y/N</th>
<th>In what position were you? For example, standing/ sitting/ stooping</th>
<th>Where were you?</th>
<th>What were you doing whilst writing? For example, eating, listening to music</th>
<th>Other comments?</th>
</tr>
</thead>
<tbody>
<tr>
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</table>


# Handwriting Log

<table>
<thead>
<tr>
<th>Date:</th>
<th>What did you write?</th>
<th>Did you use the digital pen? Y/N</th>
<th>In what position were you? E.G. standing/ sitting/ stooping</th>
<th>Where were you?</th>
<th>What were you doing whilst writing? E.G. eating, listening to music</th>
<th>Other comments?</th>
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</tr>
</tbody>
</table>
PARTICIPANT INFORMATION STATEMENT
Research Project Title: Handwriting in healthy people aged 65 years and over

(1) What is the study about?
The purpose of the study is to obtain information about handwriting practices and performance of people aged 65 years and over. This greater understanding of adult handwriting will be used by therapists who teach people to write during rehabilitation after a stroke or brain injury.

(2) Who is carrying out the study?
The study is being conducted by Nadege Demoiseau (Occupational Therapist) and will form the basis for the degree of Masters in Occupational Therapy by Research at The University of Sydney under the supervision of Dr Annie McCluskey (Senior Lecturer, The University of Sydney) and Dr Natasha Lannin (Lecturer, Rehabilitation Studies Unit, The University of Sydney).

(3) Why have you been approached to participate in the study?
You are eligible to participate in this study because you:
- Do not have any problems which affect your ability to handwrite
- You live in the community and
- You have indicated interest in participating in this study.

(4) What does the study involve?
If you decide to participate, you will have an initial meeting with the researcher where:
- The research project will be explained.
- You will be asked to answer a short survey about your personal details, education, previous employment and handwriting activities.
- You will be asked to complete the Mini-Mental State Examination which will ask questions about your memory and thinking.
- You will be asked to address an envelope.
- Your arm and hand will be videotaped while you are handwriting. Your face will not be captured on video.
- You will be asked to use a digital pen for up to 3 days. The pen and paper will be provided, and use will be thoroughly explained. The training session will last approximately 1 hour.
- You will be asked to keep a short record of any text you wrote during these 3 days. The researcher will also ask for clarification about these activities at the end of 3 days.
- You may be contacted by telephone up to twice by the researcher during the 3 days to ensure the study is running smoothly.
Digital Pen
- You will be given a digital pen which will electronically record everything you write when you clip a memory unit on the paper. The researcher will be able to print a copy of what you have written. You will be asked to go about your usual activities for these 3 days. When you need to handwrite, you will need to use the digital pen and clip the memory unit on the paper. You may elect to not use the memory unit in cases where you do not want the researchers to see what you have written.

- Information you have written with the pen and memory unit will be downloaded and analysed by the researchers using specific software
- The researcher will arrange to collect the pen after 3 days.

(5) How much time will the study take?
- The meeting with the researcher, involving an explanation about the research, how to use the digital pen and the questionnaire are expected to take one hour.

- After that, you will receive training on how to use the pen and memory unit. The researcher will provide examples of possible handwriting situations relevant to you. The researcher will demonstrate use of the digital pen. You will be able to practice using the pen and will be given feedback. This is expected to last approximately one hour.

- You will then be asked to use the digital pen for any handwriting you would usually do over 3 days. You will also be asked to record on a recording sheet each time you wrote. After 3 days, the researcher will ask you some questions to get your feedback and clarify any information. Use of the pen, recording other activities and follow-up questions will involve approximately another hour in total of your time and some minor inconvenience.

(6) What are the risks and benefits of participating in the study?
There are no known risks associated with this study. Your participation in this study may not directly benefit you. It will however provide valuable information which will guide therapists with the measurement or retraining of adult handwriting performance.

(7) Can I withdraw from the study?
Participation in this study is entirely voluntary. You are not obliged to participate. If you do decide to participate you may withdraw at any time without prejudice or penalty and any data collected will be destroyed. Whatever your decision it will not affect your relationship with The University of Sydney or the researchers.
PARTICIPANT INFORMATION STATEMENT (CONT’D)
Handwriting in healthy people aged 65 years and over

(8) Will anyone else know the results?
All data collected during this study, including the results, will remain strictly confidential. Only
the research team will have access to information on participants. Any information with
identifying details (for example, name and address) will be stored in a locked filing cabinet by
the Chief Investigator.

Video footage and writing samples may be presented at future conferences or included in
published reports of the study. In these cases, individual participants will not be identified.

After study completion, records will be stored at the University, accessible only by the
researchers. They will be kept for 7 years. At this time computer records will be deleted and
hard copies will be shredded.

(9) Can I tell other people about the study?
You are welcome to tell other people about the study, and to pass on the researcher contact
details to other people you feel may be eligible and interested in participating.

(10) What if I require further information?
When you have read this information, Nadege Demoiseau will discuss it with you further and
answer any questions you may have. If you would like to know more, please contact any of the
researchers:

Nadege Demoiseau
Occupational Therapist
0403 655 705

Dr Annie McCluskey
Senior Lecturer
Occupational Therapy,
Faculty of Health Sciences
The University of Sydney
(02) 9351 9834

Dr Natasha Lannin
Lecturer and Conjoint,
Rehabilitation Studies Unit
The University of Sydney
(02) 9808 9236

(11) What if I have a complaint or concerns?

Any person with concerns or complaints about the conduct of a research study can
contact the Senior Ethics Officer, Ethics Administration, University of Sydney on (02) 9351
4811 (Telephone); (02) 9351 6706 (Facsimile) or gbriody@usyd.edu.au (Email).

This information is for you to keep.
Appendix D  Consent Form

CONSENT FORM

I, ................................................................., give consent to my participation in the research project:

Name (please print)

Handwriting in healthy people aged 65 years and over

In giving my consent I acknowledge that:

1. The procedures required for the project and the time involved have been explained to me, and any questions I have about the project have been answered to my satisfaction.

2. I have read the Participant Information Statement and have been given the opportunity to discuss the information and my involvement in the project with the researcher/s.

3. I understand that I can withdraw from the study at any time, without affecting my relationship with the researchers, now or in the future.

4. I understand that my involvement is strictly confidential and no information about me will be used in any way that reveals my identity.

Signed:

Name:

Date:
Appendix E  Handwriting Questionnaire

Handwriting Questionnaire

Please complete this questionnaire, which will take approximately 10 minutes of your time. The survey requests personal details and information on your handwriting. With your consent, your arm and hand will be videotaped while you complete the questionnaire.

Thank you for your time - Nadege Demoiseau, Dr Annie McCluskey, and Dr Natasha Lannin

1. What is your gender?
   □ Male
   □ Female

2. What is your age?______________

3. In what language do you most commonly write?
   □ English
   □ Other
   If you have ticked ‘Other’, please give details: ____________________________________________

4. What is your highest level of education?
   Please choose one option only
   □ Primary School or below
   □ Year 10 or below
   □ Year 10 Equivalent
   □ Year 12 Equivalent
   □ Year 12 Equivalent but currently studying a degree
   □ Certificate (i.e. TAFE certificate)
   □ Post-graduate degree
   □ Advanced diploma/Diploma
   □ Bachelor Degree
   □ Graduate Diploma/ Certificate
   □ Other Education (please specify):

5. If you are retired, what was your primary occupation(s) before retirement?
   ____________________________________________
   ____________________________________________

6. What is your primary occupation now? (include any unpaid or voluntary work)
   ____________________________________________
   ____________________________________________

7. Which is your writing hand?
   □ Right
   □ Left

8. Do you have any health condition which affects your arms or ability to write (e.g., neurological condition, arthritis, low vision)?
   □ No
   □ Yes
   If you have ticked ‘Yes’, please give details: ____________________________________________
9. When do you last recall completing the following handwriting activities? Please tick all options that apply:

<table>
<thead>
<tr>
<th>Writing tasks</th>
<th>Frequency of activity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>I do not perform this task</td>
</tr>
<tr>
<td></td>
<td>Today</td>
</tr>
<tr>
<td></td>
<td>Within the past 3 days</td>
</tr>
<tr>
<td></td>
<td>Within the past week</td>
</tr>
<tr>
<td></td>
<td>Within the past 2 weeks</td>
</tr>
<tr>
<td></td>
<td>Within the past month</td>
</tr>
<tr>
<td>To do list</td>
<td></td>
</tr>
<tr>
<td>Writing in diary</td>
<td></td>
</tr>
<tr>
<td>Taking telephone messages</td>
<td></td>
</tr>
<tr>
<td>Shopping list</td>
<td></td>
</tr>
<tr>
<td>Notes / ideas / personal reminders</td>
<td></td>
</tr>
<tr>
<td>Cheques / finances (e.g., bank deposit)</td>
<td></td>
</tr>
<tr>
<td>Puzzles (e.g., Sudoku, crosswords)</td>
<td></td>
</tr>
<tr>
<td>Letters / cards</td>
<td></td>
</tr>
<tr>
<td>Forms (e.g., applications, claims)</td>
<td></td>
</tr>
<tr>
<td>Signature</td>
<td></td>
</tr>
<tr>
<td>Writing in/on a calendar</td>
<td></td>
</tr>
<tr>
<td>Writing a number/message on your hand</td>
<td></td>
</tr>
<tr>
<td>Writing personal reminders on paper</td>
<td></td>
</tr>
<tr>
<td>Writing on whiteboard (e.g., on fridge)</td>
<td></td>
</tr>
<tr>
<td>Editing documents (e.g., assignments, homework tasks)</td>
<td></td>
</tr>
<tr>
<td>Other notes (e.g., ideas)</td>
<td></td>
</tr>
<tr>
<td>Journal writing</td>
<td></td>
</tr>
<tr>
<td>Other writing task (please specify):</td>
<td></td>
</tr>
<tr>
<td>Other writing task (please specify):</td>
<td></td>
</tr>
<tr>
<td>Other writing task (please specify):</td>
<td></td>
</tr>
</tbody>
</table>

10. Please rate on the following scale how important handwriting is to you using a cross [x]:

I ___________________________ I ___________________________ I

0 5 10

Not at all                Somewhat                Extremely
Important                Important                Important

Please give reasons for your answer:
11. How recently have you used any of the following modes of communication? Please tick all options that apply:

<table>
<thead>
<tr>
<th>Mode of communication</th>
<th>Frequency of mode of communication</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>I have not used this recently</td>
</tr>
<tr>
<td></td>
<td>Today</td>
</tr>
<tr>
<td></td>
<td>Within past 3 days</td>
</tr>
<tr>
<td></td>
<td>Within past week</td>
</tr>
<tr>
<td></td>
<td>Within past 2 weeks</td>
</tr>
<tr>
<td></td>
<td>Within past month</td>
</tr>
<tr>
<td>Telephone</td>
<td>Made a call</td>
</tr>
<tr>
<td></td>
<td>Received a call</td>
</tr>
<tr>
<td>Mobile phone</td>
<td>Made a call</td>
</tr>
<tr>
<td></td>
<td>Received a call</td>
</tr>
<tr>
<td>SMS text message via mobile phone</td>
<td>Sent a message</td>
</tr>
<tr>
<td></td>
<td>Received a message</td>
</tr>
<tr>
<td>Email</td>
<td>Sent a message</td>
</tr>
<tr>
<td></td>
<td>Received a message</td>
</tr>
<tr>
<td>Used a PDA/palm pilot or similar device</td>
<td></td>
</tr>
<tr>
<td>Face-to-face communication</td>
<td></td>
</tr>
<tr>
<td>Handwritten communication</td>
<td></td>
</tr>
<tr>
<td>Video conferencing (e.g., web cam)</td>
<td></td>
</tr>
<tr>
<td>Internet (e.g., to pay bills, book tickets, look up factual information)</td>
<td></td>
</tr>
<tr>
<td>Internet telephoning (e.g., Skype)</td>
<td></td>
</tr>
<tr>
<td>Used other messenger services (e.g., msn, yahoo messenger, face book)</td>
<td></td>
</tr>
<tr>
<td>Other mode of communication: (please specify)</td>
<td>Sent a message</td>
</tr>
<tr>
<td></td>
<td>Received a message</td>
</tr>
</tbody>
</table>

12. Do you have any further comments regarding handwriting?

__________________________________________________________________________________
__________________________________________________________________________________
__________________________________________________________________________________
__________________________________________________________________________________

Thank you for taking the time to complete this questionnaire.
At the completion of the 3 data collection days, participants will be asked the following questions:

13. Have the last 3 days have been representative of your usual handwriting activities?
   □ Yes
   □ No
   If you have ticked ‘No’, please give details:____________________________________________

14. In the past month, from ___________ to ___________ who has had to read your handwriting (other than yourself)?
   □ My partner
   □ A friend
   □ A family member
   □ Company / an organisation
   □ My employer / employees / work colleagues
   □ A health professional
   □ Bank clerk
   □ A shop keeper
   □ Post office / Post Worker
   □ Other persons (please specify)_______________________________________

15. Did you accurately record each handwriting episode?
   □ Yes
   □ No
   Please explain your response:_________________________________________________

16. Do you have any comments or feedback regarding the study?

The researcher will request to view the handwriting record sheet and will request clarification of any information if further details are required.

Thank you very much for your time and participation. Nadege Demoiseau
Appendix F  

Envelope Address Copying Task

Participants were asked to address a supplied, blank envelope to the University of Sydney address as shown below.

Participants were asked to write their name and address on the back of the envelope. They were instructed to write at their usual pace, without stopping.

This task was videotaped.
**Appendix G  The Role Checklist**

<table>
<thead>
<tr>
<th>Role</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Student</td>
<td>Attending school on a part-time or full-time basis</td>
</tr>
<tr>
<td>Worker</td>
<td>Part-time or full-time paid employment</td>
</tr>
<tr>
<td>Volunteer</td>
<td>Donating services to a hospital, school, community, neighbourhood, political campaign or similar benefit</td>
</tr>
<tr>
<td>Caregiver</td>
<td>Responsibility for the care of someone such as a child, spouse, relative, or friend</td>
</tr>
<tr>
<td>Home maintainer</td>
<td>Responsibility for the upkeep of a home such as cleaning or yard work</td>
</tr>
<tr>
<td>Friend</td>
<td>Visiting or doing something with a friend</td>
</tr>
<tr>
<td>Family member</td>
<td>Spending time or doing something with a family member such as one’s partner, child or parent</td>
</tr>
<tr>
<td>Religious participant</td>
<td>Participant in activities sponsored by a religious organization</td>
</tr>
<tr>
<td>Hobbyist/amateur</td>
<td>Involvement in a hobby or amateur activity such as sewing, playing a musical instrument, woodworking, sports, theater, or participation in a club or team</td>
</tr>
<tr>
<td>Participant in an organization</td>
<td>Involvement in an organization such as the American Legion, National Organisation for Women, Parents Without Partners, or Weight Watchers</td>
</tr>
<tr>
<td>Other: Health maintainer</td>
<td>Any activity pertaining to personal health matters such as setting medical appointments, keeping fluid intake list, chemist list</td>
</tr>
</tbody>
</table>

*Note.* (Oakley, et al., 1986).