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Feasibility of a home-based program to improve handwriting after stroke:

A pilot study

Bronwyn Ann Simpson

A thesis submitted in fulfilment of the requirements for the degree of
Master of Applied Science

Faculty of Health Sciences

The University of Sydney

June 2015
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I, BRONWYN ANN SIMPSON, hereby declare that the work contained within this thesis is my own and therefore, to the best of my knowledge and belief, original except as acknowledged within the text. I declare that the material contained within this thesis has not been submitted to any other university or institution as a part or a whole requirement for any higher degree.

I, BRONWYN ANN SIMPSON, declare that I was the principal researcher of all work included in this thesis, including work submitted for publication with multiple authors. In addition, ethical approval from was granted for the study by The University of Sydney Human Research Ethics Committee and Sydney Local Health District Human Research Ethics Committee (CRGH). Participants were required to read a participant information document, and written informed consent was gained, prior to data collection.

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Signed: M. A. McCluskey
Date: 6th June 2015

Supervisor

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Discipline of Occupational Therapy
Faculty of Health Sciences
The University of Sydney
Abstract

Background: Handwriting is an important and valued task, required by adults for many daily occupations. Handwriting can be affected by hemiparesis following stroke. Therefore, handwriting training may be a focus of stroke rehabilitation. Therapists need to be guided by research regarding effective strategies to retrain handwriting following stroke. However, no high quality studies have been published to guide this important area of stroke rehabilitation. While a moderate amount of research has focused on assessment and training of handwriting with children, little research has been conducted with adults with handwriting difficulties. No research of high methodological quality has been published testing the effectiveness of handwriting training for adults with stroke or similar neurological conditions. Research regarding interventions to train other motor tasks post-stroke, as well as paediatric handwriting research, suggests that task-specific motor training is an effective method for retraining handwriting after stroke; however, that hypothesis has not been specifically tested. To guide future research on that hypothesis, the current study aims to investigate the feasibility of a handwriting retraining program for adults with stroke involving task-specific motor training and practice.

Study aims: To test the feasibility of a handwriting retraining program for adults with stroke which will inform the methodology of a future randomised controlled trial (RCT). The study objectives are to:

1. Test the feasibility of recruiting participants with stroke for a four-week handwriting retraining program;
2. Test the feasibility and acceptability of a four-week handwriting retraining program involving task-specific practice; and
3. Explore the utility of the subtest items of the Handwriting Assessment Battery [V2] as outcome measures for use in a future trial.

Methods: A quasi-experimental pre-test post-test design was used. Recruitment was conducted through stroke rehabilitation therapists who disseminated information about the study through a web and email-based stroke listserv and in-person to adult participants with stroke at public hospitals, community stroke rehabilitation services and residential aged care
facilities, health-related websites and in a seniors’ newspaper. Eligibility criteria included having sustained a stroke at least three months previously, having self-reported difficulties with, and goals related to, handwriting, being able to hold a pen, and having sufficient cognitive and communication skills to complete a daily home program.

A four-week, home-based handwriting training program was delivered by an occupational therapist. The intervention applied principles of task-specific motor training, involving intensive practice of meaningful handwriting tasks related to participant goals. Whole handwriting tasks were practised, as well as problematic handwriting task components. An occupational therapist provided supervised practice and coaching, giving feedback on task performance and using shaping to achieve the right level of challenge. Two 1-hour therapy sessions were provided per week. Another three hours per week of independent, unsupervised practice was prescribed to increase practice intensity. Participants were taught cognitive strategies to analyse their handwriting performance and problem-solve ways to improve specific handwriting features.

Handwriting performance was measured at baseline, after the training program (at four weeks) and four weeks later. The primary outcome measure was the modified Evaluation Tool of Children’s Handwriting- Words (mETCH-W), a subtest of the Handwriting Assessment Battery (HAB). Secondary outcome measures included other subtests of the HAB, the modified Four Point Scale, and the modified Disability of the Arm, Shoulder and Hand (DASH) Scale. Legibility was scored by a blinded rater.

Feasibility of recruitment, intervention and outcome measures was evaluated using descriptive statistics, including means, standard deviations and proportions. Utility of the outcome measures was also evaluated by comparing participant score at baseline, post-intervention and follow-up. Mean or median change scores were then calculated between these three time points and reported with a 95% confidence interval or interquartile range.

**Results:** Seven adults with stroke were recruited over 18 months (eligibility fraction 43% of those screened, and enrolment fraction 78% of those eligible). There were no dropouts. Mean time post stroke was 2.6 years (range: 3 months to 7 years). Mean age was 71 years (range: 50 to 87 years). Mean disability measured using the Modified Rankin Scale was 2.3 (range 1 to 4). Although recruitment was slow, the intervention was feasible. Participants completed a mean of 7.9 hours of occupational therapy supervised handwriting practice (range: 7.6 to 8.3 hours) and 10 hours of independent practice (range: 6 to 14 hours). Participants were able to
complete the program and reported satisfaction with the practice tasks and feedback from the occupational therapist. Practice tasks and goals most commonly related to legibility of lists, letters, cards and messages. No statistically or clinically significant changes in legibility were reported in this small sample, but ceiling effects were evident for some measures including the primary outcome measure (mETCH-W). None of the measures evaluated handwriting neatness, an outcome that was important to participants. The study was not powered to determine efficacy.

**Discussion:** The main finding of this study was that recruitment of adequate numbers of people with stroke for a future randomised controlled trial would not be feasible using the same recruitment methods and settings in this study. Second, the intervention program was feasible to deliver and acceptable to adults with stroke, and would be feasible to deliver clinically within the Australian healthcare system. Third, the outcome measures were feasible to administer, and some of the outcome measures detected change across time. The primary outcome measure, the mETCH-W produced changes in handwriting performance for some participants; but a ceiling effect was evident for others. None of the outcome measures captured change in the quality of handwriting that was legible but untidy. A new outcome measure of handwriting quality or neatness is recommended for future studies. Further research is required investigating what constitutes writing quality, and ways to objectively measure this phenomenon.

**Conclusions:** Recruitment of an adequate sample was not feasible, and will require greater investment than the single site used in this pilot for future studies. Delivery of a four-week handwriting intervention, with eight supervised sessions in the community, was feasible and acceptable to adults with stroke. Finally, outcome measures of handwriting performance were feasible to administer, but a ceiling effect was evident for measures of legibility. Several participants in this study had writing that was legible but of poor quality; a feature of handwriting that was not captured by any existing objective handwriting outcome measure, and warrants further research. This study highlights unique factors that are important for clinicians to consider when implementing a similar intervention in practice, as well as lessons for future researchers.
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The completion of this study and thesis was supported by a dedicated team of people. First and foremost, I would like to acknowledge my supervisors, Annie McCluskey, Natasha Lannin and Reinie Cordier. Thank you for your wisdom, advice, encouragement, patient instruction and painstaking reviews and edits of the manuscript and thesis. I have learnt so much from you about research, data analysis and professional writing; skills which I will benefit from in whatever the future takes me. Nadege Van Drempt and Gemma McDonald, skilled occupational therapist researchers, were also key contributors to the study. The support of my husband David kept me going throughout this journey; I am grateful for his patience and encouragement. The study would not have been possible without the stroke survivors who participated. Their hard work and dedication were an inspiration, and working with them was my favourite part of this project. Finally, grateful acknowledgements to the National Stroke Foundation, Australia, who supported the study with a $20,000 Small Projects Grant.
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Published abstracts


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# Glossary

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<th>Description</th>
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<tr>
<td>CO-OP</td>
<td>Cognitive Orientation to daily Occupational Performance</td>
</tr>
<tr>
<td>COPM</td>
<td>Canadian Occupational Performance Measure</td>
</tr>
<tr>
<td>ETCH</td>
<td>Evaluation of Children’s Handwriting</td>
</tr>
<tr>
<td>HAB</td>
<td>Handwriting Assessment Battery</td>
</tr>
<tr>
<td>mDASH</td>
<td>modified Disabilities of the Arm, Shoulder and Hand</td>
</tr>
<tr>
<td>mETCH-L</td>
<td>modified Evaluation of Children’s Handwriting- Letters</td>
</tr>
<tr>
<td>mETCH-W</td>
<td>modified Evaluation of Children’s’ Handwriting- Words</td>
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<td>RCT</td>
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Chapter 1: Review of the Literature

1.1 Synopsis

Handwriting is an important task that is valued by adults, required for many daily occupations including writing lists, notes and messages. (Gozzard, McCluskey, Lannin, & van Dremp, 2012; van Dremp, McCluskey, & Lannin, 2011a). Handwriting involves forming letters, arranging letters and words on a page, error correction, writing legibly and writing at speed (Case-Smith, 2001; Graham, Berninger, Weintraub, & Schafer, 1998). This complex task involves underlying motor, sensory, cognitive and perceptual skills (Maeland, 1992). Loss of any of these component skills can result in poor handwriting performance or output. Stroke is one of several neurological conditions that can lead to impairment of these component skills, thereby reducing handwriting performance. Stroke may cause arm weakness in up to 85% of people (Nakayama, Jorgensen, Raaschou, & Olsen, 1994). Muscle weakness in a person’s hand or arm can affect their handwriting. Only 28% of 140 adults with stroke in a recent study regained dextrous movement one year post-stroke to a level required for handwriting (Kong, Chua, & Lee, 2011), with the majority therefore remaining unable to handwrite. As such, handwriting is an important focus for many adults with stroke and their therapists during rehabilitation. Despite muscle weakness being common, and a large proportion of adults being unable to handwrite after their stroke, no rigorous research has been identified that specifically investigates the feasibility, acceptability and effectiveness of handwriting retraining in adults with reduced motor control post-stroke (Yancosek & Howell, 2011). That research gap will be the focus of the current thesis.

The current study aims to investigate the feasibility of a handwriting retraining program for adults with stroke involving task-specific motor training. Task-specific motor training is an evidence-based intervention used by many therapists working in stroke rehabilitation (Hubbard, Parsons, Neilson, & Carey, 2009). Task-specific training involves repetitive practice that is ‘specific’ to a motor task, such as handwriting, as opposed to ‘non-specific’ tasks such as picking up beads. Practice tasks are goal-directed, meaningful (Bayona, Bitensky, Salter, & Teasell, 2005; Hubbard et al., 2009) and related to a specific task (Dobkin, 2004). Individual components of tasks are often practised, known as ‘part-practice’, in order to concentrate on specific movements or component skills necessary for the task.
Therapists assume a coaching role, setting up the environment to promote movement and discourage compensatory movements, providing feedback on performance (Gilmore & Spaulding, 2001) and encouraging a high number of repetitions.

Evidence is emerging that task-specific motor training improves motor function post stroke (French et al., 2007; Langhorne, Coupar, & Pollock, 2009), and thus, is relevant for use in handwriting rehabilitation. In addition, interventions for improving handwriting performance in children that involve repetitive practice of handwriting tasks are more effective than non-specific training (Hoy, Egan, & Feder, 2011). Therefore interventions that involve task-specific motor training principles are expected to improve handwriting performance in adults following stroke.

1.2 Handwriting definition and importance

Handwriting is a process that involves forming letters, figures and other symbols in order to create written text (Ziviani & Wallen, 2006). The primary purpose of handwriting is communication (Au, McCluskey, & Lannin, 2012; Feder, Majnemer, & Synnes, 2000), reflected in one definition of handwriting as the “…visible trace of a spoken language” (Athènes, Sallagoïty, Zanone, & Albaret, 2004, p. 622). Handwriting is an important task for adults, and improving handwriting performance is often identified as a goal by stroke survivors. Handwriting is used for leisure activities such as word puzzles, and when completing forms or signing documents (Faddy, McCluskey, & Lannin, 2008; van Drempt et al., 2011a). Handwriting is also a means of connecting socially, for example to write cards, letters and notes. Producing a consistent and recognisable signature is another important handwriting task, particularly for legal and financial purposes. A person’s handwriting is considered to be a distinct aspect of their identity and personality, with a recognisable style being formed early in life (Ziviani & Wallen, 2006).

The use of electronic devices such as computers, tablets and smartphones has increased in recent decades. Although typing can replace handwriting in many instances, handwriting remains a convenient means of note-taking and communication for many people, even for frequent users of technology (McMahon, 2008). In summary, handwriting is an important task for adults and improving handwriting performance is often a rehabilitation goal for adults who have handwriting difficulties.
1.3 Reduced handwriting performance in adults

Occupational therapists may work with adults who have reduced handwriting performance as a result of a stroke, and improving handwriting performance may be a goal for rehabilitation. Reduced handwriting performance may impact on an adult’s life in various ways, including a reduced ability to perform leisure and social tasks (van Drempt et al., 2011a). The potential effects of reduced handwriting performance for adults will be described in the next section, followed by a discussion of the conditions that can reduce handwriting performance.

1.3.1 Impact of reduced handwriting performance in adults

Reduced handwriting performance can have a significant impact on an adult’s life. Someone who is unable to form a reliable and recognisable signature may be questioned during financial transactions, or be unable to perform these transactions. A person who is unable to sign forms or cheques may choose to give control of their finances to someone else. A person may not be able to maintain written correspondence with friends, or feel reluctant to do so because their handwriting style has changed. Difficulties with handwriting can reduce social and recreational opportunities for a person who may already be restricted in these areas due to their disability. Handwriting that is of poor appearance or illegible may cause embarrassment to the individual, and a negative or discriminatory perception may be formed by the person reading the handwriting (Sappington & Money, 2003). From a rehabilitation perspective, writing notes is an important memory strategy taught to people with a cognitive impairment, and being slow or unable to take notes or write lists can be detrimental to this strategy. Due to these negative consequences, improving handwriting performance may be an important rehabilitation goal for adults.

The handwriting performance of adults may be reduced for various reasons. Much of the handwriting literature relates to reduced performance in children, who are learning to write letters for the first time. Despite this focus in the literature, reduced handwriting performance is not limited to children; adults may continue to experience difficulties or develop difficulties later in life due to injury or conditions such as stroke. Other causes of handwriting difficulty include illiteracy or difficulties with writing composition, issues that are beyond the scope of the current review and study. The following section explores conditions, including stroke, which may reduce the handwriting performance of adults.
1.3.2 Conditions which may cause reduced handwriting performance in adults

Various conditions can impair an adult’s handwriting performance. Neurological conditions such as traumatic brain injury and stroke can cause impairments that affect handwriting performance, such as hemiparesis, reduced joint range, cognitive, sensory and perceptual impairments. These impairments may also be present in people with progressive neurological conditions such as Parkinson’s disease and multiple sclerosis. Studies involving people with Parkinson’s disease show that handwriting performance problems are common and include difficulty controlling force, slow speed, and reduced stroke size (Gemmert, Teulings, & Stelmach, 2001; Phillips, Stelmach, & Teasdale, 1991). Multiple sclerosis can also negatively affect handwriting performance. One study found that the writing of people with multiple sclerosis was more irregular, narrower, slower, distorted and written with higher tension and tremor than the writing of unimpaired adults (Wellingham-Jones, 1991). Alzheimer’s disease is another progressive neurological condition that can affect handwriting, with problems such as inconsistent stroke length and letter size being common (Slavin, Phillips, Bradshaw, Hall, & Presnell, 1999). Finally, studies have shown that Huntington’s disease can affect handwriting performance (Slavin et al., 1999; Tucha, Mecklinger, Walitza, & Lange, 2006). Therefore a range of neurological conditions, including stroke, may affect handwriting performance in a variety of ways.

Musculoskeletal conditions and injuries may also affect handwriting performance. Hand pain and fatigue can affect legibility, speed and endurance. Pain and fatigue may be present in healthy adults after prolonged periods of writing (Summers & Catarro, 2003). Hand pain and fatigue may also be caused by conditions such as carpal tunnel syndrome (Kuo et al., 2014) or writer’s cramp (Hallett, 2006). Pain and fatigue are secondary consequences of conditions such as stroke (White et al., 2012), and these symptoms may have a cumulative negative impact on handwriting. Finally, upper limb injuries may affect handwriting performance due to weakness, pain or reduced range of motion.

Although several conditions may contribute to handwriting difficulties in adults, the current study will focus on adults with stroke. Stroke is a leading cause of disability in Australian adults (Australian Institute of Health and Welfare, 2013), and predominantly affects older adults. Although adults aged 65 years and older typically create short pieces of writing, handwriting is still valued by this older age group (van Drempt et al., 2011a). Additionally, 30% of adults who have a stroke are of working age (Australian Institute of Health and Welfare, 2013).
Health and Welfare, 2013). Therefore handwriting may be important for work and educational occupations for many stroke survivors. The following section will describe specific impairments caused by stroke that may affect handwriting performance, including reduced motor control, and perceptual and cognitive impairments.

1.4 Impairments caused by stroke which may reduce handwriting performance

One or more of the component skills of handwriting may be affected by stroke, resulting in reduced performance. This section will describe impairments caused by stroke that may result in reduced handwriting performance, including reduced motor control, and perceptual and cognitive impairments.

1.4.1 Reduced motor control

The performance of co-ordinated movements, or motor control, is an important component of handwriting (Cornhill & Case-Smith, 1996; Feder & Majnemer, 2007; Schneck & Amundsen, 2010). Although handwriting may appear to be a simple task, it requires the integration of complex motor tasks (Graham & Weintraub, 1996; Schneck & Amundsen, 2010), all of which may be affected by reduced motor control post-stroke. Handwriting requires adequate joint range, muscle strength and dexterity. Unique among upper limb tasks, handwriting requires movements to be accurate within a few millimetres for legible and neat letter formation. This level of precision requires a high degree of motor control. Reduced motor control is a long-term challenge for many adults with stroke, with between 55% and 75% of adults with stroke still experiencing upper limb weakness three to six months post-stroke (Lai, 2002). Handwriting requires co-ordinated movements of the whole body for maintaining posture, transporting and positioning the arm, and holding and manipulating the writing implement and paper. Therefore, the focus of a handwriting training program usually includes positioning the body, transporting the hand, holding and moving the pen.

**Positioning the body.** Strength and control of the trunk, neck and lower limbs may be important for positioning the body during handwriting (Rosenblum, Goldstand, & Parush, 2006). Handwriting is performed in different positions, depending on the task requirements and preferences of the writer. Reduced motor control of the lower body may limit the positions an adult with stroke is able to maintain for handwriting. For example, a person may
be unable to write a shopping list while standing up. Reduced motor control may also affect a person’s ability to maintain a good writing position when seated, as a stable sitting posture is important to effectively position the arms for writing (Cornhill & Case-Smith, 1996). Poor sitting balance or posture could result in excessive weight being taken through the arms to maintain an upright posture, thereby reducing freedom of movement of the writing arm.

**Transporting the hand for writing.** Strength and control of the arm are important for handwriting. The hand and writing implement are transported forward for writing by movements such as shoulder forward flexion, external rotation and protraction (Schneck & Amundsen, 2010). These movements are used when reaching for the writing implement, positioning the hand at the correct place on the page, moving across and down the page, and creating spaces between letters and words. Forearm and wrist movements are required to position the hand in the optimal position for writing. This position changes as the hand moves around the page, so the wrist and forearm position need to be adjusted when writing. Reduced shoulder and arm function are common following stroke, particularly shoulder external rotation and wrist extension. Such impairments of the arm may affect a person’s ability to transport their hand for writing.

**Holding the pen.** Handwriting usually involves holding a writing implement. Various writing implements such as pens and pencils are used; for brevity this review will refer to the use of pens. Pen grip refers to the hand, finger and thumb position used to hold a pen. Pen grip is closely related to the ability to move a pen (discussed in more detail below). Writers tend to have a preferred pen grip (Schwellnus et al., 2013), which develops at an early age (Rosenbloom & Horton, 1971). The types of pen grips that have been observed and recorded in adults are summarised in Appendix A. Pen grips can be broadly categorised as static or dynamic. Static or ‘immature’ grips involve holding the pen in a fixed position in the hand (e.g., in a ‘fist’ against the palm) with handwriting movements being performed by the rest of the arm. Dynamic or ‘mature’ grips involve holding the pen between the fingers and thumb, allowing the muscles of the hand and fingers to contribute to handwriting movements (Elliott & Connolly, 1984; Schwellnus et al., 2012). Static pen grips are observed in young children in early stages of pen grip development (Elliott & Connolly, 1984). This type of pen grip may also be used by adults with stroke, who are unable to control their hand muscles sufficiently to use a dynamic grip. Static grips are not considered functional for handwriting, as they do not allow for adequate freedom of hand movement for this task (Schwellnus et al., 2013). Therefore, achieving a dynamic pen grip may be a focus of handwriting training for some
adults with stroke, as often occurs during children’s handwriting training sessions (Feder & Majnemer, 2007). However, research suggests that various types of dynamic pen grip are functional and appropriate for writing. The dynamic tripod is not the only dynamic pen grip which allows a person to write neatly (Dennis & Swinth, 2001; Schwellnus et al., 2012; Selin, 2003; Van Drempt, McCluskey, & Lannin, 2011b). Therefore, achieving the ‘ideal’ pen grip is less often an aim of handwriting retraining for adults.

**Moving the pen.** Handwriting requires dexterity to perform precise movements of the pen, form letters and move the pen across and down the page (Cornhill & Case-Smith, 1996). Moving the pen involves movements of the fingers, thumb, wrist, forearm and shoulder (Van Drempt et al., 2011b), and generation of force to produce the desired amount, direction and velocity of movement (Baur et al., 2006; Dooijes, 1983; Slavin, Phillips, & Bradshaw, 1996). A consistent amount of force is needed to produce straight visible lines, with subtle changes in movement requiring force to be modulated and adjusted throughout the handwriting process (Wann & Nimmo-Smith, 1991). Modulating and adjusting force relies on tactile and kinaesthetic feedback from the hand (Cornhill & Case-Smith, 1996). Stroke can impact on a person’s ability to generate and modulate force during handwriting, due to impaired sensation or motor control. Difficulties with regulating grip force are common after stroke, such as using excessive force, difficulties adjusting force and maintaining a stable grip (Blennerhassett, Carey, & Matyas, 2006). Applying too little force can result in faint or uncontrolled lines being produced, affecting legibility. Too much pressure can damage the paper or writing implement (Van Drempt et al., 2011b) and may increase muscle strain during handwriting, leading to fatigue and pain.

In addition to moving the pen for letter formation, the pen also needs to be repositioned within the hand (known as in-hand manipulation) (Exner, 2010), for example, shifting the fingers up the barrel of a pen to reposition the pen grip (Pont, Wallen, & Bundy, 2009). Reduced motor control of the fingers and hand may affect a person’s ability to reposition a pen in their hand during handwriting. People who have difficulty with in-hand manipulation often use compensatory methods. For example, the non-writing hand may also be used to assist with repositioning the pen. Whether or not improved in-hand manipulation is a focus of handwriting retraining may depend on how the impairment affects the handwriting process, and the priorities and goals of the adult with stroke.
1.4.2 Perceptual and cognitive impairments

Perceptual impairments following stroke may also impact on handwriting performance. Perception is an important component of motor control and is fundamental to planning and evaluating movements. Vision is important for early writers as they learn to copy and write letters. Vision is also required for experienced writers, in order to position text on the page, and review writing (Slavin et al., 1996). As writing becomes more familiar, people rely less on vision when forming letters (Cornhill & Case-Smith, 1996) and letter formation is instead guided by tactile and kinaesthetic feedback about the position of the fingers, the force being applied, and the direction and velocity of movement (Ziviani & Wallen, 2006). These visual, tactile and kinaesthetic senses can all be impaired following stroke, affecting handwriting. Unilateral neglect may also reduce a person’s ability to form letters, position letters across a page, and review text. Therefore, perceptual training may be required for adults who have difficulty with handwriting following stroke. However, training with adults who already know how to write may require a different focus than handwriting training with children, which often focuses on recognition and formation of letter shapes.

Cognitive impairment post-stroke may also affect handwriting performance, as handwriting requires cognitive skills (Phillips, Bradshaw, Chiu, & Bradshaw, 1994; Tucha et al., 2006). Cognition is an important aspect of motor control. Cognition may be required to plan unfamiliar movements such as recognising and planning the shape of a letter when a person is first learning to write. Cognition is also required to format text on a page, for example, knowledge of conventions when writing formal correspondence. Cognition may be used to evaluate performance after completing a movement (Cirstea, Ptito, & Levin, 2006). As with perception, cognition may be less important for experienced writers for planning and evaluating movements as planning and evaluating become more automatic (Tucha et al., 2006; Tucha, Tucha, & Lange, 2008). However, adults with stroke who have a handwriting impairment may again need to rely on conscious cognitive processes when writing. Cognitive strategies, such as ‘stop-think-plan-do’ have been used with adults with stroke when training motor tasks such as handwriting (McEwen, Huijbrgets, Ryan, & Polatajko, 2009; McEwen et al., 2014). These cognitive strategies may be helpful to include in a handwriting retraining program.

As well as being involved in the handwriting process, cognition is important for composing the content of writing (Graham, Struck, Santoro, & Berninger, 2006). Memory
enables a person to recall what they want to write or have already written. Attention and concentration are required to stay on task while writing (Feder & Majnemer, 2007). Reading is required for reviewing writing and identifying errors. The cognitive demands of handwriting can be influenced by the purpose of writing. For example, writing a formal piece of text such as an essay may require the ability to plan, format, review and edit text in a structured way (Berninger et al., 1997). Writing a shopping list requires less structure, but planning and memory are still important components for this task. The composition of writing content is not the focus of the current study. However, it is important to note that a person’s overall handwriting performance may be affected by difficulties with writing composition in addition to the handwriting process.

1.4.3 Summary: Impairments caused by stroke which may reduce handwriting performance

Stroke can cause a range of impairments, which can impact on a person’s writing performance in a number of ways. Reduced motor control is common following stroke, and can affect a person’s ability to perform and integrate the precise movements required for handwriting, including positioning the body, transporting the hand, and holding and moving the pen. Perceptual and cognitive impairments may affect a person’s ability to plan and evaluate handwriting movements, attend to the task, plan the content of writing, and to review text. An adult with stroke who has an impairment in one of more of these component skills will experience difficulties with handwriting performance. Handwriting performance involves various sub-tasks including: letter formation, arrangement of letters and words on a page and error correction. These sub-tasks may be the focus of handwriting assessment and training for adults with stroke, and are described in the following section.

1.5 Handwriting sub-tasks which may be affected by stroke

Handwriting is a complex activity, involving completion of several smaller tasks, or sub-tasks. These sub-tasks include letter formation, arrangement of letters and words on a page, and error correction. Adults with stroke who have reduced handwriting performance may have difficulty performing one or more of these sub-tasks. Therefore, handwriting assessment may involve measuring performance of a specific sub-task, such as letter formation, in addition to measuring global handwriting performance. Handwriting sub-tasks may also be the specific focus of handwriting training. While practising meaningful, whole
tasks is important (Dobkin, 2004), adults with stroke may additionally benefit from ‘part-practice’; the goal directed practice of a sub-task may enable a person to concentrate on specific areas of difficulty (Birkenmeier et al., 2010; Turton et al., 2013). For example, a person may practise writing a postcard (a whole handwriting task) followed by practising writing individual words, focusing on keeping spaces between letters and words (part-practice of handwriting sub-task). Therefore, an understanding of the sub-tasks of handwriting is important for researchers and therapists interested in handwriting assessment and training. This section will describe the sub-tasks of handwriting, which may be the focus of handwriting assessments and interventions for adults with stroke.

1.5.1 Letter formation

Letter formation is the process by which letters, numbers and other marks such as punctuation are created on the page. Letter formation involves creating strokes of varying length including ascenders, descenders and horizontal extension (Halder-Sinn & Funsch, 1998). Strokes also vary in terms of their direction (horizontal or vertical, and the amount of slant) and shape (straight or curved). Strokes need to be correctly aligned with other strokes within letters (e.g., the alignment of the three strokes in the letter ‘A’) and strokes may be used to join letters together in cursive writing. Being able to produce these various types of strokes is important for adult handwriting and may be the focus of handwriting retraining.

Although beginner writers are usually taught one convention for forming letters, the way that letters are formed may vary (Graham & Weintraub, 1996). How letters are formed may be influenced by other factors such as the speed at which they were written (Halder-Sinn & Funsch, 1998), the preceding letter (Graham & Weintraub, 1996) and the size of the writing (Marquis, Taroni, Bozza, & Schmittbuhl, 2007). As children become older, a personal handwriting style usually develops which is different to the convention they were taught as beginner writers (Hamstra-Bletz & Blote, 1990; Ziviani & Wallen, 2006). The mode of writing used (cursive, manuscript or mixed) varies between writers (Graham, Berninger, et al., 1998; Summers & Catarro, 2003). Additionally, subtle variations exist in the size, shape, slant of strokes used by different writers (Graham & Weintraub, 1996; Ling, 2002; van der Plaats & van Galen, 1991; van Drempt et al., 2011a). Therefore, producing ‘copybook’ writing may not be a priority for handwriting retraining with adults with stroke, who may instead wish to replicate their pre-stroke handwriting style.
1.5.2 Arrangement of letters and words on a page

Handwriting involves the arrangement of letters and words on a page. Letters within a word need to be adequately spaced to separate them from the adjoining letters. Larger spaces are used to distinguish separate words. Handwriting also involves alignment of words on a page. Commonly, writing needs to start on a particular part of the page, or form such as on a specific line. Words also need to be aligned so they fit on the page with adequate space above and below. The alignment of words may depend on the type and context of writing, such as writing a list with single words or phrases aligned below one another. Other types of writing such as mind mapping may involve grouping words with common themes together on the page. Finally, writing conventions may determine the alignment of words such as indenting the first word of a paragraph. Being able to arrange letters and words on a page involves moving the pen around the page, as well as cognitive and visual perceptual skills. Adults with stroke with an impairment in any of these areas may have difficulty arranging letters and words on a page.

1.5.3 Error correction

Errors made during handwriting, such as an incorrect or misspelled word, an unwanted letter, or problems with the writing surface or pen, may require correction by the writer. Errors may be corrected by retouching parts of a letter, crossing out words or letters, inserting words or letters above the line with a caret symbol (^), or writing the correct letter over the top of an incorrect letter. In a self-report survey of healthy adult writers (aged 20 to 70 years), 79% reported that they made error corrections in their writing (Hennessy, 1997). An observational study of 30 healthy adults aged 65 years and older found that 93% of participants made error corrections in their writing, with an average of 3.2 error corrections per 100 words written (van Drempt et al., 2011a). These studies demonstrate that error corrections are common amongst healthy writers, and they represent an important sub-task of handwriting. Adults with stroke who have a cognitive or perceptual impairment may have difficulty correcting errors in their handwriting. This difficulty may be due to problems with reviewing their work, as a result of a cognitive, language or perceptual impairment. Difficulties with error correction may also be due to problems with motor control, affecting a person’s ability to neatly and legibly cross out words or insert correct words in small spaces. Therefore, error correction may be the focus of handwriting assessment and intervention with adults with stroke.
1.5.4 Summary: Handwriting sub-tasks which may be affected by stroke

Handwriting involves performance of various sub-tasks including letter formation, arrangement of letters and words on a page and error correction. These sub-tasks may be difficult to perform and become the focus of handwriting retraining (described in section 1.8), where handwriting sub-tasks such as moving across a page are assessed then practised. The following section will describe methods of assessing handwriting performance.

1.6 Assessment of handwriting performance following stroke

Handwriting assessment may be used to identify specific impairments and may help to guide and evaluate handwriting training. Handwriting may be assessed to determine whether remediation can improve performance, and/or to determine whether compensatory strategies such as typing may be required. One of the aims of the current study is to test the feasibility and utility of specific outcome measures developed to measure adult handwriting performance.

A number of assessments are available to analyse and measure handwriting. However, most assessments were developed and validated for use with children. Rosenblum and colleagues (2003) and Feder and colleagues (2003) conducted reviews of paediatric handwriting assessments. Several sub-tests included in the paediatric handwriting assessments may be relevant for use with adults, as these sub-tests measure handwriting components or tasks performed by adults. In addition, a number of adult hand function assessments include handwriting sub-tests. These sub-tests have been collated into the Handwriting Assessment Battery (HAB), an assessment of adult handwriting which is still being developed (Au et al., 2012; Faddy et al., 2008). Additionally, a legibility scale used to measure handwriting legibility of doctors has been adapted for use with adults with handwriting impairments (Au et al., 2012).

These adult handwriting assessments will be described in the following section. Due to the lack of well-validated handwriting assessments for adults, this review will also describe several handwriting assessment scales that have been described in the literature, but their psychometric properties have not been published. This section will begin with a discussion of broad approaches to handwriting assessment. Handwriting assessments will then be reviewed
in relation to five important domains of handwriting performance: legibility, speed, fluency, appearance and pen control.

1.6.1 Approaches to handwriting assessment

Handwriting assessment involves two broad approaches: assessment of handwriting output (what is produced), and/or assessment of the handwriting process (how text is written). Both approaches may be of importance to a person after stroke. They may be concerned that their handwriting ‘looks different’, or may find it difficult to write anything at all. Occupational therapists may therefore need to assess both output and process.

Assessment of handwriting output. The output or product of handwriting may be assessed, usually by analysing a sample of written text. Writing may be assessed globally, or by assessing specific components of handwriting such as letter size and spacing (Jongmans, Linthorst-Bakker, Westenber, & Smits-Engelsman, 2012; Rosenblum, Weiss, et al., 2003). Most of the literature involving assessment of handwriting output focuses on legibility. Characteristics of handwriting output that may not specifically relate to legibility, but may still be important to measure, include handwriting neatness or quality (Jongmans et al., 2012; Sappington & Money, 2003; Tucha et al., 2008). Handwriting output may be assessed using rating scales with descriptors (Amundsen, 1995; Au et al., 2012) or by comparing writing samples (Stefansson & Karlsvdottir, 2003). Handwriting rating scales may have a broad focus such as global legibility of a sentence (Faddy et al., 2008) or how easily the writing can be read (Summers & Catarro, 2003). Handwriting rating scales may also have a more specific focus on individual components such as the legibility of individual letters (Amundsen, 1995), letter height or spacing (Jongmans et al., 2012). Limitations of measuring handwriting output include the subjectivity of measuring characteristics such as legibility and appearance. Additionally, measuring handwriting output may not take into consideration process variables that may be important to overall handwriting performance; such as writing speed and the need for rest breaks (Rosenblum, Weiss, et al., 2003). Therefore difficulties with the handwriting process, such as fatigue and slow writing speed, may not be captured by assessments that only measure handwriting output.

Assessment of the handwriting process. The process of writing can be assessed by collecting data while a person writes. Observational methods may be used to assess the handwriting process, such as recording the time taken to write a sample of text or the number
Detailed analysis of the handwriting process is becoming increasingly available using computerised assessments, which measure temporal aspects such as speed, time spent with the pen on the page versus ‘in air’ time (Rosenblum, Parush, & Weiss, 2001), stroke durations (Falk, Tam, Schellnus, & Chau, 2011), and frequency of handwriting (van Drempt et al., 2011a). Computerised assessments have also been used to measure spatial and kinematic aspects of handwriting performance such as force regularity and consistency, movement trajectories (Phillips et al., 1994), position, angle and velocity of movement of the writing implement (Falk et al., 2011), and pressure exerted on the writing implement (Rosenblum, Parush, & Weiss, 2003). Computerised assessments are also able to measure handwriting components such as grip strength and variations in the centre of mass, which are thought to correlate with legibility (Falk et al., 2011).

Advantages of these process assessments are their ability to measure handwriting behaviours, such as the number, length and frequency of breaks taken, which are not captured by assessments that only measure handwriting output (Rosenblum, Parush, et al., 2003). Computerised assessments may provide detailed information about underlying handwriting impairments; for example difficulty modulating force, which may not be captured by assessing handwriting output. However, the cost and availability of these computerised assessments limit their clinical utility (Rosenblum, Weiss, et al., 2003). Their capacity to measure the global quality or legibility of handwriting is also limited.

This section has described broad approaches to measuring handwriting including output and process assessments. Neither approach measures all of the important areas of handwriting performance. Therefore a combination of both approaches is recommended when assessing the handwriting performance of adults with stroke. This study will include handwriting assessments that measure both handwriting output (what is written on the page), and the handwriting process (how text is written). The following section will review specific handwriting assessments that may be used with adults with stroke. Assessments will be reviewed in relation to five important domains of handwriting performance: legibility, speed, fluency, appearance and pen control.

1.6.2 Handwriting assessments: Legibility

Importance of legibility. Legibility is thought to be the most important characteristic of good handwriting (Feder & Majnemer, 2007). Legibility is commonly defined as the
readability of handwriting (Rosenblum, Weiss, & Parush, 2004), or to what extent the content can be understood. Because a major purpose of handwriting is communication, producing handwriting that can be understood is important. Handwriting may need to be legible to others (e.g., the recipient of a letter) and/or to the writer themselves (e.g., a person reading their own shopping list). For some handwriting tasks, all characters need to be legible, for example an email address or a phone number. The consequences of illegible handwriting may be particularly significant for some tasks (e.g., an illegible credit card number may result in a payment not being processed). Therefore, legibility is an important focus of handwriting assessment for adults with stroke. Legibility is a complex domain, influenced by various handwriting components including letter formation, spacing and speed. Comprehension is also affected by reading processes such as writing context and familiarity of the reader with the topic, content and writer of the text (Kendeou, Muis, & Fulton, 2011; Murray, Boylan, O'Flynn, O'Tuathaigh, & Doran, 2012). Factors influencing legibility, and legibility norms are summarised in Appendix B.

Assessments of legibility. The overall (or ‘global’) legibility of a piece of handwriting can be assessed using rating scales, by comparing one handwriting sample with another, and by measuring the ease of reading and comprehension. Legibility can also be assessed by rating individual handwriting components that contribute to the written output, such as closure of letters (Rosenblum, Weiss, et al., 2003). These individual components are usually scored separately according to set criteria or in comparison to a set of handwriting sample with individual component scores used to calculate a composite score. Handwriting assessments measuring legibility will be described in more detail in the following section, and are summarised in Table 1.1.

Modified Evaluation Tool of Children’s Handwriting (mETCH). An assessment of handwriting legibility commonly used with children is the Evaluation Tool of Children’s Handwriting (ETCH) (Amundsen, 1995). This test was modified in 2003 for use with adults and became part of the Handwriting Assessment Battery (HAB), (McCluskey & Lannin, 2003). The HAB includes a collection of subtests from paediatric handwriting assessments and adult upper limb assessments deemed to be relevant to adults (Faddy et al., 2008). A copy of the HAB can be found in Appendix C. The modified ETCH in the HAB contains four subtests, requiring a person to write: i) the alphabet in upper case and ii) lower case, iii) the numerals 1 to 12, and iv) a five word self-composed sentence. Letters and words are compared with samples in the administration manual, and rated as either legible or illegible.
(Faddy, 2008), as shown in Figure 1.1. Rating criteria are based on the original ETCH rating scale (Amundsen, 1995). The number of legible letters or words are divided by the total number of letters or words to give a percentage legibility score. The five word sentence subtest of the HAB is scored using two methods: the proportion of legible words are calculated (mETCH- Words) as well as the proportion of legible letters (mETCH- Letters) in the sentence.

![Legible](image1)

![Illegible](image2)

**Figure 1.1:** Examples of legible and illegible letters from the HAB administration manual used for scoring the mETCH (Faddy, 2008, pp. 28, 30)
### Table 1.1 Summary of measures of adult handwriting performance: Legibility

<table>
<thead>
<tr>
<th>Assessment</th>
<th>Handwriting task assessed</th>
<th>Handwriting domain measured</th>
<th>Global or component legibility measured</th>
<th>Classification/descriptors used</th>
<th>Score produced</th>
<th>Time taken to administer/score the assessment</th>
<th>Psychometric properties of the assessment</th>
<th>Strengths and limitations of the assessment for adults</th>
</tr>
</thead>
<tbody>
<tr>
<td>Writing the alphabet in upper and lower case, and numerals 1-12</td>
<td>Legibility of single characters</td>
<td>Component</td>
<td>Character legible/ illegible – comparison to examples in manual</td>
<td>% legibility (0-100)</td>
<td>20 minutes to administer and up to 15 minutes per sub-test to score (Faddy et al., 2008). Administration time would depend on handwriting speed.</td>
<td>Inter-rater reliability&lt;br&gt;High concordance between 2 raters when administered to 10 adults with TBI (ICC =0.78-0.83) (Faddy, 2008).&lt;br&gt;Validity&lt;br&gt;Not reported.&lt;br&gt;Other&lt;br&gt;Ceiling effect for numeral writing (21% scoring 100 for legibility sub-tests) (Faddy, 2008).</td>
<td>Strengths&lt;br&gt;Assesses legibility of a self-composed sentence, which is a writing task adults commonly perform (Gozzard et al., 2012; van Drempt et al., 2011a). Numeral writing may also be important for writing tasks that adults perform, e.g. writing messages. Good IRR found by some studies, better than other legibility assessments reviewed.</td>
<td>Limitations&lt;br&gt;Lengthy to administer if subject has slow handwriting. Lengthy to score, particularly when rating individual letters of a sentence. Ceiling effect for some sub-tests. Validity not researched. Relevance of alphabet writing is questionable (Au et al., 2012) as this is not a task adults perform often (van Drempt et al., 2011a). Some handwriting tasks relevant to adults are not assessed e.g. writing lists. mETCH rating criteria may not focus on all important features of handwriting output e.g. neatness. No total/composite score- each sub-test needs to be a separate outcome measure.</td>
</tr>
<tr>
<td>HAB – mETCH subtests. (McCluskey &amp; Lannin, 2003)</td>
<td>Writing a self-composed 5 word sentence</td>
<td>Legibility of sentences</td>
<td>Component&lt;br&gt;Letter legible/illegible comparison to examples in manual (mETCH-L)</td>
<td>% sentence legibility (0-100) calculated by proportion of legible letters</td>
<td></td>
<td>Inter-rater reliability&lt;br&gt;Inconsistent results. High concordance between 2 raters when administered to 10 adults with TBI (ICC =0.71) (Faddy, 2008). Good concordance between 3 raters with 30 adults with TBI (ICC= 0.50). Slight exact agreement (κ =0.62) (Au et al., 2012).&lt;br&gt;Validity&lt;br&gt;Not reported.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Component&lt;br&gt;Word legible/illegible according to set criteria with examples in manual</td>
<td>% sentence legibility (0-100) calculated by proportion of legible words</td>
<td></td>
<td>Inter-rater reliability&lt;br&gt;Inconsistent results. High concordance between 2 raters when administered to 10 adults with TBI (ICC =0.79) (Faddy, 2008). Fair concordance between 3 raters with 30 adults with TBI (ICC= 0.39). No exact agreement (κ =0.1.03) (Au et al., 2012).&lt;br&gt;Validity&lt;br&gt;Not reported.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Assessment</td>
<td>Handwriting task assessed</td>
<td>Handwriting domain measured</td>
<td>Global or component legibility measured</td>
<td>Classification/ descriptors used</td>
<td>Score produced</td>
<td>Time taken to administer/ score the assessment</td>
<td>Psychometric properties of the assessment</td>
<td>Strengths and limitations of the assessment for adults</td>
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</tr>
<tr>
<td>Modified Four Point Scale- sentences (Au et al., 2012)</td>
<td>Any handwriting task involving writing sentences</td>
<td>Legibility of sentences</td>
<td>Global</td>
<td>Proportion of words legible, if sentence can be understood on first read</td>
<td>Rating 1-4</td>
<td>2 minutes for a short writing sample (Au et al., 2012). Administration time would depend on handwriting speed.</td>
<td>Inter-rater reliability: Fair concordance between 3 raters with 30 adults with TBI (ICC= 0.37). Slight exact agreement (κ= 0.19) (Au et al., 2012).</td>
<td>Validity: Not reported.</td>
</tr>
<tr>
<td>Modified Four Point Scale- words (Au et al., 2012)</td>
<td>Any handwriting task involving writing sentences</td>
<td>Legibility of words</td>
<td>Component</td>
<td>Proportion of letters legible</td>
<td>Rating 1-4 or % sentence legibility (0-100)- proportion of words scoring 4 (‘perfect legibility’) or 3 or 4 (‘functional legibility’).</td>
<td>Six minutes to score 9 selected letters in sub groups (Au et al., 2012)</td>
<td>Inter-rater reliability: Slight to good concordance between 3 raters with 30 adults with TBI (ICC= 0.16-0.51). No-fair exact agreement (κ= 0.16 to 0.30) (Au et al., 2012). Validity not reported.</td>
<td>Validity: Not reported.</td>
</tr>
</tbody>
</table>

**Strengths**
Quick to administer and score. Could be used to assess handwriting samples of any length, involving sentences.

**Limitations**
Poor IRR compared to mETCH and Modified Four Point Scale- sentences. Validity not researched. Not relevant to some important handwriting tasks that do not involve sentences e.g. writing lists.

**Strengths**
Quick to administer. Could be used to assess a range of handwriting tasks relevant to adults, including writing lists. Better IRR than Modified Four Point Scale- sentences. Considers functional legibility as well as perfect legibility- reflective of normal handwriting performance of older adults (van Drempt et al., 2011a).

**Limitations**
Slower to score than Modified Four Point Scale- sentences. IRR lower than mETCH. Validity not researched. Writing a self-composed sentence is relevant task for adults, but other handwriting tasks relevant to adults are not included in this assessment (van Drempt et al., 2011a).
<table>
<thead>
<tr>
<th>Assessment</th>
<th>Handwriting task assessed</th>
<th>Handwriting domain measured</th>
<th>Global or component legibility measured</th>
<th>Classification/descriptors used</th>
<th>Score produced</th>
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<th>Psychometric properties of the assessment</th>
<th>Strengths and limitations of the assessment for adults</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unnamed (Summers &amp; Catarro, 2003)</td>
<td>Any handwriting task involving writing sentences</td>
<td>Legibility - ease of reading</td>
<td>Global</td>
<td>Ease of reading, number of hesitations</td>
<td>Rating 1-3</td>
<td>Not reported. Likely to be relatively short, but would depend on length of writing task and sample being scored.</td>
<td>Inter-rater reliability Poor, with consensus between 3 raters being achieved in 31% of cases, and between 2 raters in 50% of cases (Summers &amp; Catarro, 2003). Validity Not reported.</td>
<td>Strengths Considers ease of reading (not just whether it can be read). Limitations Poor IRR, possibly due to subjectivity of assessing ease of reading. Validity not researched.</td>
</tr>
</tbody>
</table>

**Notes:** HAB = Handwriting Assessment Battery; mETCH = modified Evaluation Tool of Childrens’ Handwriting; IRR = inter-rater reliability, TBI = Traumatic Brain Injury, ICC = Intraclass correlation.
Two studies have investigated the inter-rater reliability of the HAB legibility subtests (Au et al., 2012; Faddy et al., 2008). In one study, the HAB was administered to 10 adults with brain injury and scored by two raters (Faddy et al., 2008) with high agreement between raters when scoring the five writing legibility subtests (ICC = 0.71-0.83). A ceiling effect was evident for two legibility subtests: numeral writing and sentence composition, with two subjects receiving the maximum score (100%). A subsequent study also investigated the inter-rater reliability of the mETCH, in addition to two other legibility rating systems (a Four Point Scale and a modified Four Point Scale, described later in this section) (Au et al., 2012). For that study, 30 writers produced a self-composed sentence and copied an addressed envelope. These handwriting samples were scored by three raters using the mETCH. The results of that study suggested lower inter-rater reliability for the mETCH compared to the previous study by Faddy and colleagues (2008), with fair to moderate rater concordance (ICC = 0.39–0.50), and no exact agreement (k = -1.03). Limitations of the mETCH subtests include lack of research about test validity, with the relevance of the alphabet writing subtest being questioned (Au et al., 2012), as well as the absence of writing tasks commonly performed by adults such as writing a list (Gozzard et al., 2012; van Drempt et al., 2011a). Time taken to administer and score the HAB (20 minutes and 15 minutes, respectively) has also been raised as a concern (Au et al., 2012), although administration time depends on a person’s writing speed. Slower writing speed will increase administration time.

**Modified Four Point Scale.** The Four Point Scale is an ordinal scale of handwriting legibility that has been researched and modified for use with adults (Au et al., 2012). The Four Point Scale was designed to rate the global legibility of health professionals who write in medical records (Berwick & Winickoff, 1996; Rodriguez-Vera, Marin, Sanchez, Borrachero, & Pujol, 2002). The original version of the Four Point Scale scored legibility as ‘poor’, ‘fair’, ‘good’ or ‘excellent’ (Berwick & Winickoff, 1996). A later study modified the wording of the categories to focus on the level of illegibility of the writing, using categories of ‘illegible’, ‘most words legible’, ‘some words legible’ and ‘legible’ (Rodriguez-Vera et al., 2002). The Four Point Scale was modified for use in adult handwriting retraining by Au and colleagues (2012), and became known as the modified Four Point Scale (see Table 1.2). In addition to the original rating of global sentence legibility, the modified Four Point Scale includes a rating scale of individual word legibility. Therefore the modified Four Point Scale can be used to rate: i) the global legibility of a sentence (1-4, based on the readability of words), and ii) legibility of individual words (1-4, based on the readability of letters).
overall legibility score for each sentence can then be calculated as a percentage (0-100%). Two types of sentence legibility are considered in the modified Four Point Scale: i) ‘functional legibility’ (the meaning can be understood even if not all letters or words are clear), and ii) ‘perfect legibility’ (all letters or words are clear). A functional legibility score is calculated by dividing the number of letters or words scoring 3 or 4 by the total number of letters or words. A perfect legibility score is calculated by dividing the number of letters or words scoring 4 by the total number of letters or words.

Table 1.2: The modified Four Point Scale

<table>
<thead>
<tr>
<th>Category</th>
<th>Global sentence legibility rating descriptors</th>
<th>Word legibility rating descriptors</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>None or few words legible; the meaning of the text is unclear.</td>
<td>None or few letters legible; i.e. 0-10% legibility</td>
</tr>
<tr>
<td>2</td>
<td>Some words legible; the meaning of the text is unclear.</td>
<td>Some letters legible; i.e. 11-50% legibility</td>
</tr>
<tr>
<td>3</td>
<td>Many words legible; the meaning of the text can be understood.</td>
<td>Many words legible; i.e. 51-90% legibility</td>
</tr>
<tr>
<td>4</td>
<td>All words legible; the meaning of the text can be understood.</td>
<td>All words legible; i.e. 91-100% legibility</td>
</tr>
</tbody>
</table>

Modified from Au et al. (2012).

The inter-rater reliability of the FPS and modified Four Point Scale was examined by Au et al. (2012). Writing samples from the 30 participants were rated using the Four Point Scale, the modified Four Point Scale and the mETCH. In that study, the modified Four Point Scale was used to analyse nine selected letters, grouped into three subtests of letters with ascenders (b, h, l), mid-zone letters (a, e, o), and letters with descenders (g, p, y). Rater concordance was fair (ICC = 0.37) for the FPS, and slight to good (ICC = 0.16–0.51) when rating legibility using the modified Four Point Scale subtests, using Krippendorf’s alpha testing. The modified Four Point Scale took six minutes to score, which was quicker than the mETCH. The modified Four Point scale and the mETCH will be included in the current study, to determine their utility for future handwriting research.

Unnamed legibility rating scale. A legibility rating scale was used with young adults to measure their handwriting performance during university examinations (Summers &
Catarro, 2003) and is shown in Table 1.3. The scale developed by Connor (1995) uses a 3 point rating scale, which rates handwriting legibility according to how easily it can be read. Summers and Catarro (2003) added detail to the scale’s category descriptors and increase its specificity. Unlike the mETCH and modified Four Point Scale, the descriptors of this unnamed rating scale refer to ease of reading, which may be an important component of legibility. However, the rating scale had poor inter-rater reliability, with consensus between three raters being achieved in 31% of cases, and between two raters in 50% of cases.

Table 1.3: Unnamed legibility rating scale

<table>
<thead>
<tr>
<th>Legibility ranking</th>
<th>Legibility definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Legibility 1</td>
<td>Can read content smoothly, there may be hesitation on 1-4 words</td>
</tr>
<tr>
<td>Legibility 2</td>
<td>Hesitation occurs with 5 or more words and/or the flow stops on 1-4 occasions because the word is difficult to read or illegible</td>
</tr>
<tr>
<td>Legibility 3</td>
<td>Flow of reading stops on 5 plus occasions because the word is difficult to read or illegible</td>
</tr>
</tbody>
</table>

Modified from Summers and Catarro (2003).

In summary, three handwriting assessments have been used to measure adult handwriting legibility: the mETCH sub-tests, the modified Four Point Scale, and an unnamed legibility rating scale. Some research has been conducted into the inter-rater reliability of these assessments. Although one study found good inter-rater reliability for the mETCH sub-tests, most studies have reported poor inter-rater reliability. Therefore a single rater should be used when administering these assessments in research or clinical practice. No research has investigated the validity of these assessments with adults, provided normative data or explored responsiveness. Additionally, the mETCH sub-tests, the modified Four Point Scale and the unnamed legibility scale vary in the length of time taken for administration and scoring, and the length of the writing sample required. The current study will not use the unnamed legibility scale as it has only been researched for use with long writing tasks such as examinations, which some adults with stroke may be unable to complete. The mETCH and the modified Four Point Scale both measure a short, self-composed sentence but the administration and scoring time varies between these two assessments. Therefore, both the mETCH sub-tests and the modified Four Point Scale will be used in this study, to compare their utility and feasibility with adults with stroke.
1.6.3 Handwriting assessments: Speed

**Importance of handwriting speed.** Many handwriting tasks need to be performed in a reasonable timeframe (Burger & McCluskey, 2011; Rosenblum, Parush, et al., 2003; Ziviani & Watson-Will, 1998) or at speed. Writing quickly is important for note-taking (e.g., phone messages) so that information is not forgotten (Burger & McCluskey, 2011; Peverly, 2010). Writing at speed is also important for time-limited tasks such as examinations (Graham, Weintraub, & Berninger, 1998; O'Mahony, Dempsey, & Killeen, 2008). Although writing at speed is not intrinsically important for some tasks (e.g., writing birthday cards), slow writing speed reduces a person’s efficiency and productivity (Burger & McCluskey, 2011). Writing slowly can also affect automaticity, increasing demands on working memory (Peverly, 2010). Therefore, writing at speed is an important skill or domain that should be assessed in adults with stroke with a handwriting impairment. Handwriting speed may be related to other domains of handwriting performance, including legibility and error correction. Factors affecting handwriting speed and handwriting speed norms are described in more detail in Appendix B.

**Assessments measuring handwriting speed.** Handwriting speed can be measured by recording the time taken to write or copy a block of text, or by calculating the number of words or letters written in a specified time. Two handwriting speed assessments that may be suitable for adults with stroke will now be reviewed: A subtest of the Jebsen-Taylor Hand Function Test (Jebsen, Taylor, Trieschmann, Trotter, & Howard, 1969), and the Handwriting Speed Test (Wallen, Bonnet, & Lennox, 1996). These assessments are summarised in Table 1.4.

**Speed subtest of the Jebsen-Taylor Hand Function Test.** The Jebsen-Taylor Hand Function Test assesses performance of various upper limb tasks for adults and includes a subtest of handwriting speed (Agnew & Maas, 1982; Jebsen et al., 1969). This sub-test requires a person to copy a sentence comprising 24 letters, in cursive writing. Three different sentences of similar difficulty are printed on a card. A stopwatch is used to record the time taken to write one of the three sentences. The time can then be compared to age-related norms (see Appendix B). The Jebsen subtest is included in the HAB, and is known as the Jebsen handwriting speed test (Faddy et al., 2008). The inter-rater reliability of the Jebsen handwriting speed test was investigated in a study by Faddy and colleagues (2008), involving
10 adults with traumatic brain injury. Excellent agreement for the Jebsen handwriting speed test was found between two raters (ICC=1.0, 95% CI 0.99-1.00).

**Handwriting Speed Test (HST).** The HST involves repeatedly copying the sentence “The quick, brown fox jumps over the lazy dog” as quickly and neatly as possible for three minutes (Wallen et al., 1996). The total number of letters written is used to calculate a speed score in letters per minute. Studies have found high (ICC = 0.99) (Wallen & Mackay, 1999) to excellent (ICC = 1.00) (Wallen, 1997) inter-rater reliability for the HST when administered to children. Two studies collected handwriting speed data from adults using the HST. One study collected normative data on handwriting speed of 120 older Australian adults (Burger & McCluskey, 2011). Another study measured the writing speed of 66 university students (Summers & Catarro, 2003). The students completed three different writing tasks: 1) the HST, 2) writing a 2-hour examination paper with prior knowledge of the questions, and 3) writing a 2-hour examination paper without prior knowledge of the questions. Students wrote at less than half the speed during the 2-hour examinations compared to the HST, with a weak or absent relationship \( r = 0.27 \) and \( r = 0.75 \), respectively) between HST scores and the 2-hour examination (with and without prior knowledge of the questions, respectively) (Summers & Catarro, 2003). These results suggest that the short handwriting test may have poor predictive ability of performance during long handwriting tasks. Older adults tend to write only short pieces of text (van Drempt et al., 2011a), therefore short duration handwriting assessments are more suitable for older adults with stroke. For people for whom long handwriting tasks are meaningful (e.g., university students), it may be important to assess performance during a longer handwriting task. No standardised handwriting assessments involving long duration tasks have been found in the literature.

As handwriting speed is thought to be important to adults with stroke, the current study will include the Jebsen handwriting speed test. The Jebsen handwriting speed test was chosen over the Handwriting Speed Test as it is a sub-test of the HAB, which is already used in this study to measure legibility.
### Table 1.4: Summary of measures of adult handwriting performance: Speed

<table>
<thead>
<tr>
<th>Assessment</th>
<th>Handwriting task assessed</th>
<th>Classification / descriptors used</th>
<th>Score produced</th>
<th>Time taken to administer/ score</th>
<th>Psychometric properties of the assessment</th>
<th>Strengths and limitations of the assessment for adults</th>
</tr>
</thead>
<tbody>
<tr>
<td>HAB- Jebsen handwriting speed test (Faddy et al., 2008).</td>
<td>Copying 24 letter sentence</td>
<td>Time taken. Can be compared to age-related norms.</td>
<td>Letters per minute</td>
<td>Time taken to write a sentence, plus short calculation time</td>
<td>Inter-rater reliability Excellent concordance between 2 raters when administered to 10 adults with TBI (ICC =1.0) (Faddy et al., 2008).</td>
<td><strong>Strengths</strong> Good IRR. Potentially quick to administer. Normative data available for Australian adults (Burger &amp; McCluskey, 2011). <strong>Limitations</strong> Does not assess self-generated text, which is more commonly written by older adults than copied text (van Drempt et al., 2011a). Administration time may be lengthy for slow writers. Does not assess long handwriting tasks- likely poor predictive ability for long handwriting tasks, similar to Handwriting Speed Test (below).</td>
</tr>
<tr>
<td>Writing speed test of Jebsen-Taylor Hand Function Test (Jebsen et al., 1969).</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Handwriting speed test (Wallen, Bonnet, &amp; Lennox, 1996).</td>
<td>Copying sentence repeatedly for 3 minutes</td>
<td>Number of letters written</td>
<td>Letters per minute</td>
<td>3 minute test plus short calculation time.</td>
<td>Inter-rater reliability High (ICC= 0.99) (Wallen &amp; Mackay, 1999) to excellent (ICC= 1.00) (Wallen, 1997) concordance when administered to children. No reliability data for healthy or impaired adults. <strong>Validity</strong> Poor predictive ability for performance during long (2 hour) handwriting tasks (Summers &amp; Catarro, 2003).</td>
<td><strong>Strengths</strong> Good IRR. Quick to administer, with a consistent administration time for writers of any speed. Normative data available for Australian adults (Burger &amp; McCluskey, 2011). <strong>Limitations</strong> Does not assess self-generated text, which is more commonly written by older adults than copied text (van Drempt et al., 2011a). Additional scoring time required for counting letters. Poor predictive ability for long handwriting tasks (Summers &amp; Catarro, 2003), which may be performed by adults.</td>
</tr>
</tbody>
</table>
1.6.4 Handwriting assessments: Fluency

*Importance of handwriting fluency.* Fluency is another important domain of handwriting performance. Writing fluency has been defined as the ability to write smoothly and efficiently without breaks or pauses (Rosenblum, Goldstand, et al., 2006). Fluency is related to speed (Summers & Catarro, 2003), with increased fluency contributing to faster speed. Decreased fluency may be due to the writer needing to pause due to difficulties with composing the content of the writing (Berninger et al., 1997). Pauses may also be required for error correction (Rosenblum, Chevion, & Weiss, 2006), so a writer who makes more errors will likely have less fluency. Finally, increased pauses may also be required due to difficulties with letter formation. Proficient handwriting is performed with a level of automaticity, where the writer does not need to concentrate on letter formation (Graham et al., 2006; Tucha et al., 2006) and can write with little effort (Graham & Weintraub, 1996). People who are learning to write, or adults with stroke with handwriting impairment, may not have this automaticity, therefore their writing fluency may be decreased.

*Assessments measuring handwriting fluency.* No easily-available assessments of writing fluency have been found in the literature. Writing fluency has been measured by the number of times and amount of time the pen is lifted a certain distance off the paper, measured using a computerised writing tablet (Rosenblum, Goldstand, et al., 2006). Writing fluency has also been measured by computerised examination of abrupt changes in direction of lines, within or between letters (Jongmans et al., 2012). However lack of availability and the technical training required to administer these assessments means they are not likely to be useful as outcome measures when retraining handwriting with adults with stroke. Due to these limitations, no assessments of handwriting fluency will be used in the present study.

1.6.5 Handwriting assessments: Appearance

*Importance of handwriting appearance.* Producing writing that has an acceptable appearance is another domain of handwriting performance that may be important to adults with stroke. Handwriting style is a distinct and recognisable aspect of a person’s identity. Being able to produce handwriting that is similar in appearance to pre-stroke writing may be an important goal during handwriting retraining. Poor handwriting appearance or untidy writing, may also be problematic for adults with stroke. The appearance of handwriting can influence a reader’s perception of the writer. An adult with handwriting of poor appearance
may be concerned about incorrect assumptions being made about them based on their handwriting (Sappington & Money, 2003). Handwriting of poor appearance may be particularly detrimental to the writer in examinations and job applications (Graham, Harris, & Fink, 2000; Rosenblum, Parush, et al., 2003; Sassoon, 1997). Therefore, handwriting appearance is an important domain of handwriting performance for adults with stroke and should be the focus of assessment.

Various features of handwriting appearance have been described in the literature, including beauty (Thorndike, 1910), neatness or tidiness (Armitage & Ratzlaff, 1985; Sappington & Money, 2003) and accuracy according to a standard (Stefansson & Karlsdottir, 2003). Handwriting appearance may also be related to legibility. Indeed some authors seem to use the terms ‘legibility’ and ‘neatness’ interchangeably (e.g., Graham, Berninger, et al., 1998 and Summers & Cataro, 2003)). Handwriting features that contribute to legibility may also contribute to good writing appearance, such as accurate letter formation. In an early study of legibility, writing samples that were rated as extremely legible were consistently rated as having good appearance (Ayres, 1912); although writing with good appearance sometimes had low ratings of legibility, mostly due inadequate spacing between words and lines. Conversely it may be possible for writing to be legible but of poor appearance (Erlebacher & Herrick, 1961; Stefansson & Karlsdottir, 2003). Limited research has been found investigating what factors contribute to good handwriting appearance.

**Assessments measuring handwriting appearance.** Because appearance is difficult to define and highly subjective, it is also difficult to measure reliably. Objective assessments of handwriting appearance for use in research and rehabilitation are rare. Five assessments measuring various aspects of handwriting appearance have been found in the literature, and are summarised in Table 1.5. An early handwriting scale measured ‘general merit’ of handwriting by comparison to a set of handwriting samples of varying quality (Thorndike, 1910). The scale descriptors included legibility and ‘beauty’ of the handwriting, but little detail was given regarding the development of the scale or specific handwriting features thought to contribute to writing of good merit. Additionally, the style of writing used in the scale is now outdated. A more recent unnamed rating scale of handwriting appearance uses a similar method of comparing writing to a sample (Stefansson & Karlsdottir, 2003). That scale considers writing to be of high quality if it conforms to a standard, defining handwriting appearance as ‘accuracy’. Five traits of handwriting are rated using the scale, including shape...
of letters, shape of joins, size, spacing and alignment. The scale descriptors are more detailed than the earlier scale by Thorndike (1910), possibly increasing its objectivity. The scale was evaluated and used with school children, who were being taught to write according to a standard. This type of rating may not be suitable for measuring the handwriting appearance of adults, who use varying writing styles that do not conform to a pre-determined standard (Summers & Catarro, 2003; van Drempt et al., 2011a). Additionally, the scale developed by Stefansson and Karlsdottir (2003) uses Norwegian characters, which vary slightly from English characters. Therefore, this scale would not be suitable to use with Australian adults.

Another scale measuring handwriting appearance was described in a study of handwriting training involving the non-dominant hand (Walker & Henneberg, 2007). This 10-point scale rated handwriting samples in comparison to a sample of writing performed with the dominant hand, with a score of 1 being ‘most unlike’ and 10 being ‘identical to’ the sample written by the dominant hand. Various components of handwriting appearance were compared, including letter slant, size, spacing, shape, smoothness and word spacing. A similar scale could be used for adults with stroke, with post-stroke handwriting being compared to a sample of their pre-stroke handwriting; however, the psychometric properties of this scale have not yet been researched. Additionally, the paper by Walker and Hennenberg (2007) gave limited information on scale descriptors, and some aspects of the assessment administration are unclear (e.g., whether the various aspects of handwriting were scored separately). Therefore, it would be difficult for other researchers or therapists to adopt the scale in their own settings.

Three other rating scales of handwriting appearance were located in the literature. One study used a 5-point Likert scale of neatness, with 1 being “very sloppy”, and 5 being “very tidy” (Sappington & Money, 2003). Another study used a 3-point Likert scale (good, fair and poor) to rate characteristics of the writing of 137 third-grade students, including neatness (Armitage & Ratzlaff, 1985). A third study used a self-rated 100 point visual analogue scale, with end points 0 (“not at all neat” or “easy to read”) and 100 (“extremely neat” or “easy to read”) (Baxter, 2004). The reliability and validity of these scales were not reported, and the scales appear to be highly subjective with little detail in the scale descriptors.

Although handwriting appearance may be a domain that is important to adults with stroke with handwriting difficulties, no well-researched, objective outcome measures were
found for use in the current study. Further research is needed into the features of handwriting that contribute to good appearance and ways to measure this phenomenon.

1.6.6 Handwriting assessments: Pen control

*Importance of pen control.* Pen control is the ability to hold and move a pen to perform handwriting movements. Pen control is an important skill that underlies all handwriting sub-tasks, including holding and moving the pen, repositioning a pen, letter formation, moving around a page and error correction. Therefore an adult with stroke who has poor pen control may have reduced performance on many handwriting sub-tasks, affecting output. Practising basic pen control skills such as picking up and holding a pen, repositioning a pen in the hand and making marks on a page are often the focus of handwriting training for adults with stroke, particularly if a person is not yet able to form letter well.

*Assessment of pen control.* The HAB includes one sub-test that measures pen control. This sub-test is derived from the Motor Assessment Scale (MAS) for stroke (Carr, Shepherd, Nordholm, & Lynne, 1985). The MAS is an assessment of motor function which includes eight sub-tests, three of which focus on upper limb function. One of these sub-tests, Advanced Hand Activities, includes two tests of pen control. These two tests have been included in the HAB and are known as the line and dot drawing tests (McCluskey & Lannin, 2003). The line drawing test requires a person to draw at least 10 lines across a page as fast as possible. To be counted, lines must start and end at two vertical lines marked down either side of the page (Faddy et al, 2008). A stopwatch is used to record the time taken to complete this task, and the test is ‘achieved’ if 10 lines are drawn within 20 seconds. The dot drawing test requires a person to create dots on a page as quickly as possible. To be counted, dots must be a clear dot, not a dash. The test is ‘achieved’ if 10 dots are drawn correctly within five seconds. In the HAB, these tests are scored as achieved or not achieved. The inter-rater reliability of the pen control sub-test of the HAB was investigated in a study by Faddy and colleagues (2008), using data from 10 adults with traumatic brain injury. High to perfect agreement was found between two raters in that study when rating the pen control sub-tests (line drawing subtest, kappa = 1.0; dot drawing subtest, kappa = 0.80).

Pen control is a skill that underlies all handwriting sub-tasks. Although difficulties with pen control affect performance of other handwriting components (e.g. legibility), the pen
control sub-tests of the HAB enable pen control to be assessed individually, and may help when analysing performance. A person who is able to hold a pen may not be able to form letters or words. Therefore these pen control sub-tests may be suitable for adults with stroke who are unable to complete a legibility assessment which requires letter and word formation. The pen control sub-tests of the HAB will be used in the current study. Research into the psychometric properties of the HAB showed good inter-rater reliability, with high to perfect agreement between two raters when administered to 10 adults with brain injury (line drawing subtest, kappa = 1.0; dot subtest, kappa = 0.80) (Faddy et al. (2008). Limitations of the pen control sub-tests include the lack of research into their validity for adult handwriting, although they are well accepted as part of the MAS. Additionally, the dichotomous score produced by the two sub-tests (achieved/not achieved) may not be sensitive to small improvements in pen control. The current study will therefore score the number of lines and dots drawn, in addition to scoring achieved/not achieved, to determine which scoring method is more sensitive to change. No other standardised assessments were found for adults that measure the ability to control a pen using a dynamic grip, or perform in-hand manipulation, two potentially important domains of pen control.

1.6.7 Summary: Assessment of handwriting following stroke

The previous section reviewed methods of handwriting assessment that may be used with adults with stroke. The discussion began with a description of two approaches to assessing handwriting: assessment of handwriting output and assessment of the handwriting process. The assessments reviewed mostly involve measurement of handwriting output. The section also reviewed assessments in relation to important domains of handwriting performance: legibility, speed, fluency, appearance and pen control. Use of these assessment tools may identify specific areas of handwriting impairment to guide and evaluate handwriting training for adults with stroke. Several of these assessments will be used in the current study. Further research is required about the psychometric properties of many handwriting assessments, particularly test validity. Many assessments that measure legibility also have poor inter-rater reliability, possibly due to the subjective nature of this domain of handwriting performance. Although fluency and appearance are important to adults after stroke, no well-validated assessments measure these domains. Finally, the feasibility and utility of handwriting assessments for adults with stroke have not been researched. The current study aims to address these research gaps.
Table 1.5. Summary of measures of adult handwriting performance: Appearance and pen control

<table>
<thead>
<tr>
<th>Assessment</th>
<th>Handwriting task assessed</th>
<th>Handwriting domain assessed</th>
<th>Classification/descriptors used</th>
<th>Score produced</th>
<th>Time to administer/ score</th>
<th>Psychometric properties of the assessment</th>
<th>Strengths and limitations of the assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unnamed (Thorndike, 1910).</td>
<td>Any handwriting task</td>
<td>Appearance (‘merit’)</td>
<td>General ‘merit’ in comparison to samples in scale</td>
<td>Rating 1-18</td>
<td>Not reported. High number of categories (18) likely to increase time taken to score.</td>
<td>Inter-rater reliability Not reported. Validity Not reported.</td>
<td>Strengths Considers overall appearance, which may be of concern to adults with stroke. Limitations No research regarding psychometric properties. Scale uses handwriting samples from 1910, which are not likely to be relevant to adults now. No detail provided on how scale was formed or relevance to ‘merit’. Likely lengthy scoring time due to high number of categories.</td>
</tr>
<tr>
<td>Unnamed (Stefansson &amp; Karlsdottir, 2003).</td>
<td>Any handwriting task</td>
<td>Appearance (‘accuracy’)</td>
<td>Level of conformance to copybook writing, in relation to shape of letters, shape of joins, size, spacing and alignment. Each letter scored as mastered/not mastered.</td>
<td>Proportion of ‘mastered’ letters calculated.</td>
<td>Not reported</td>
<td>Inter-rater reliability High concordance (ICC=0.87) between 2 raters when administered to 23 children. Validity Not reported.</td>
<td>Strengths Good IRR. Can be used to assess various handwriting tasks relevant to adults. Limitations Writing according to a copybook style may not be important to adults (van Drempt et al., 2011a). Uses Norwegian characters, so not relevant to Australian adults.</td>
</tr>
<tr>
<td>Assessment</td>
<td>Handwriting task assessed</td>
<td>Handwriting domain assessed</td>
<td>Classification / descriptors used</td>
<td>Score produced</td>
<td>Time to administer/ score</td>
<td>Psychometric properties of the assessment</td>
<td>Strengths and limitations of the assessment</td>
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<td>--------------------------------------------</td>
</tr>
<tr>
<td>Unnamed (Walker &amp; Henneberg, 2007).</td>
<td>Any handwriting task</td>
<td>Appearance</td>
<td>Similarity to writing performed with the dominant hand.</td>
<td>Rating 1-10</td>
<td>Not reported</td>
<td>Inter-rater reliability Not reported. Validity Not reported.</td>
<td>Strengths Could be adapted to compare pre- and post-stroke handwriting - an aspect of handwriting appearance that may be important to some adults. Limitations Validity and reliability not researched. Limited description of scale and administration limits its utility in other settings.</td>
</tr>
<tr>
<td>Unnamed (Sappington &amp; Money, 2003).</td>
<td>Any handwriting task</td>
<td>Neatness</td>
<td>Sloppiness/ tidiness</td>
<td>Rating 1-5</td>
<td>Not reported</td>
<td>Inter-rater reliability Not reported. Validity Not reported.</td>
<td>Strengths Considers handwriting neatness, which may be of concern to adults with stroke. Limitations No research regarding psychometric properties. Little detail provided regarding scale descriptors.</td>
</tr>
<tr>
<td>Unnamed (Armitage &amp; Ratzlaff, 1985).</td>
<td>Any handwriting task</td>
<td>Neatness</td>
<td>Poor, fair and good</td>
<td>Rating 1-3</td>
<td>Not reported</td>
<td>Inter-rater reliability Not reported. Validity Not reported.</td>
<td>Strengths Considers handwriting neatness, which may be of concern to adults with stroke. Limitations No research regarding psychometric properties. Little detail provided regarding scale descriptors.</td>
</tr>
<tr>
<td>Unnamed (Baxter, 2004).</td>
<td>Any handwriting task</td>
<td>Neatness and legibility</td>
<td>Visual analogue scale (0 - 100) End points: Not at all neat or easy to read, and extremely neat or easy to read</td>
<td>Rating 0-100</td>
<td>Not reported</td>
<td>Inter-rater reliability Not reported. Validity Not reported.</td>
<td>Strengths Considers handwriting neatness, which may be of concern to adults with stroke. Limitations No research regarding psychometric properties. Little detail provided regarding scale descriptors. Combines neatness and legibility, which may have different features.</td>
</tr>
<tr>
<td>Assessment</td>
<td>Handwriting task assessed</td>
<td>Handwriting domain assessed</td>
<td>Classification / descriptors used</td>
<td>Score produced</td>
<td>Time to administer/ score</td>
<td>Psychometric properties of the assessment</td>
<td>Strengths and limitations of the assessment</td>
</tr>
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</tr>
<tr>
<td>HAB– pen control subtests</td>
<td>Drawing lines and dots</td>
<td>Pen control</td>
<td>Whether specified number of lines/ dots drawn in timeframe</td>
<td>Achieved/ not achieved</td>
<td>Not reported</td>
<td>5-20 second test duration for each attempt (x3) plus scoring time.</td>
<td><strong>Inter-rater reliability</strong> High to perfect agreement between 2 raters when administered to 10 adults with TBI (line drawing subtest, kappa = 1.0; dot subtest, kappa = 0.80) (Faddy et al., 2008). <strong>Strengths</strong> Good IRR. Quick to administer. <strong>Limitations</strong> Validity not researched. Assesses a handwriting component, not a functional task performed by adults- no research regarding relationship of this sub-task to overall handwriting performance. Only scores achieved/not achieved- may not capture small improvements in performance.</td>
</tr>
</tbody>
</table>

**Notes:** HAB= Handwriting Assessment Battery; IRR= inter-rater reliability
1.7 Approaches to improving handwriting performance following stroke

The previous section reviewed assessments that may be used to measure handwriting performance during stroke rehabilitation. The next section reviews methods of improving handwriting performance after stroke. Two different approaches are used, compensatory and remedial (Krug & McCormack, 2009). Either of these approaches (or a combination of both) may be used. Compensatory approaches aim to improve writing output by producing text in a different way, such as using adaptive handwriting implements, typing or using speech recognition software, or learning to write with the non-dominant hand. Remedial approaches such as task-specific motor training can be used to improve performance of the writing hand.

1.7.1 Compensatory approaches

Compensatory approaches used for handwriting focus on improving writing output by using alternative methods of creating text, as an alternative or adjunct to handwriting. Three types of compensatory methods are described in the literature: i) the use of modified writing equipment; ii) use of typing or voice recognition software to create electronic text; and iii) relearning to write with the non-dominant hand.

Modified writing equipment. It is common practice for therapists working in stroke rehabilitation to modify implements such as toothbrushes and cutlery to make them easier to hold. Modified writing equipment such as moulded pen grips and pens with larger barrels may also be used. These modifications are usually simple and low-cost, but there is no research regarding their effectiveness. Using compensatory approaches such as modified equipment post-stroke can be detrimental to recovery of the affected hand (Higgins, Mayo, Desrosiers, Salbach, & Ahmed, 2005). Furthermore, practising writing with modified equipment may not enable a person to write well when this equipment is not available. Therefore the intervention in the current study will avoid the use of modified writing equipment.

Typing. Typing is one alternative method of written expression used by adults with a handwriting impairment. Typing is a commonly-prescribed compensatory method for children with significant handwriting difficulties (Freeman, MacKinnon, & Miller, 2004). Typing does not require arm movement across the page, and may be an easier method of producing text for someone with difficulties moving their shoulder. Typing will produce
more legible neat text than handwriting. If a person is able to depress a keyboard key, neat and legible letters will consistently be produced. Typing may also be performed one-handed using the non-affected hand. An adult with stroke who is familiar with typing may find it easier to type one-handed compared to learning to handwrite with their non-dominant hand. However, typing has limitations compared to handwriting, and this method of producing text may not always be a suitable replacement for handwriting. Use of a keyboard and computer may not be practical for all writing situations, although the increased use of touch screen keyboards on portable devices makes accessing typing facilities easier. Typing requires some familiarity with computer use, and may not be possible or practical for some writing situations such as completing a paper form or signing a document. Finally, typing may not be desirable for some writing contexts, particularly for social writing tasks such as writing a card, where handwriting may be seen as being more personal. Therefore, typing may not be a desirable or practical alternative to handwriting for all people or in all situations. Improving handwriting may still be a meaningful rehabilitation goal for many adults with stroke.

**Dictating text using speech recognition software.** Speech recognition software (SRS) provides another method of producing electronic text, using dictation. The software analyses sound patterns and transcribes these into text on a computer or portable electronic device. No research has been found investigating the use of SRS by people with hemiplegia to generate text, during this review or an earlier systematic review (Yancosek & Howell, 2011). SRS requires little or no upper limb movement, and may be a quicker method of producing text than handwriting or typing for people with reduced motor control of the arm. SRS may also help to compensate for difficulties with written communication post-stroke due to aphasia or cognitive impairment. The use of SRS was investigated in a single case study involving one adult with aphasia who had good spoken but poor written communication (Bruce, Edmundsen, & Coleman, 2003). After three months of training using SRS, the participant was able to produce text more quickly and accurately using the software, compared to handwriting similar text at baseline (30 minutes to write one word with 30% accuracy at baseline, compared to 4 minutes to dictate 84 words with 85% accuracy after three months). Limitations of that study include the small sample size ($n = 1$), lack of repeated baseline measures, and no comparison of handwriting output post-treatment. However, in the absence of more robust research, SRS may be worth considering as an alternative method of producing text for people with aphasia that affects written output but not spoken communication.
SRS may not be suitable for all adults with stroke or writing situations. SRS has similar limitations to those described earlier in relation to typing. Additional practical limitations of SRS include the cost, the need for an external microphone, a quiet environment and privacy. Further, the feasibility and effectiveness of SRS for people who have difficulty articulating words has not been well tested. SRS uses context to assist with recognition of words, so presumably a person with expressive aphasia who is unable to say whole phrases clearly and correctly would have reduced success using this software. Dysarthria is another impairment of spoken communication which may impact on the accuracy of SRS for some adults with stroke. Research suggests that SRS can be used accurately by many people with mild dysarthria (Bruce et al., 2003) but whether SRS would accurately transcribe the speech of people with moderate to severe dysarthria is less clear. SRS can be trained to link a particular sound to a word, therefore as long as a person is able to produce consistent sounds, the software could be trained to transcribe even very unclear speech into text. The feasibility of performing this training has not been investigated; presumably significant hours of training would be required for the software to accurately transcribe a wide range of vocabulary for writing. Therefore, the use of SRS may not be a feasible method of producing text for people with moderate to severe dysarthria or expressive aphasia.

**Writing with the non-dominant hand.** Perhaps the most common method of compensation is writing with the non-dominant hand. No studies appear to have trained people with stroke to write with their non-dominant hand. One study involving 21 healthy adults investigated whether participants could be trained to write comfortably and legibly with their non-dominant hand after 28 days (Walker & Henneberg, 2007). Participants wrote a sentence, ‘the quick brown fox jumped over the lazy dog’, twice per day for 28 days using their non-dominant hand. The handwriting samples were rated using a 10-point legibility scale, and compared to a sample of text written with the dominant hand. Walker and Henneberg (2007) reported that 20 of the 21 participants showed a significant change in their legibility over 28 days, but only reported R2 values (ranging from 0.06 – 0.82) and no mean legibility change scores for comparison.

Limitations of that study include the single cohort design, with no control group available for comparison. The authors did not report whether the rater was blinded to which participant and point in time each sample belonged to, which could be a potential source of bias. Only a single sentence was practised and scored, so generalisability to different writing tasks was not tested. Finally, the acceptability of this training program to adults, and their
own satisfaction with handwriting performance were not reported. Despite these limitations, results suggest that even a small amount of handwriting practice may improve handwriting performance with the non-dominant hand. Learning to write with the non-dominant hand may be a useful compensatory method for some adults with stroke who want to improve their written output. Further research is warranted in this area.

No research has been found to guide therapists and people with stroke when choosing which hand to train for motor tasks such as handwriting. At present, this decision is made based on the person’s own preference, and educated guesses regarding the potential of the dominant hand. For the purposes of the current study, a person will be considered as having the potential to improve their handwriting using their dominant hand during a 4-week training program if they are able to hold a pen and make a mark on a page (and will therefore be potentially eligible for inclusion in the study).

**Conclusions.** This section has described compensatory methods that may be used by an adult with stroke and their rehabilitation team/therapist to improve handwriting, including writing implement modifications, typing, using voice recognition software and retraining handwriting using the non-dominant hand. These methods may improve handwriting performance, or may enhance the quality or speed of written output using alternative methods of producing text. Very little research was found that investigated use of these methods with adults after stroke. Using compensatory methods may not be an appropriate or a complete solution for all adults with stroke, and improving handwriting with the dominant hand may be a potential rehabilitation goal. The following section will describe remedial approaches that aim to improve the handwriting performance of adults with stroke using their dominant hand.

### 1.7.2 Remedial approaches

Interventions involving a remedial approach aim to improve impairments of bodily functions (Ma & Trombly, 2002). In stroke rehabilitation, remedial approaches aim to improve performance of a task as much as possible to regain ‘normal’ or pre-stroke performance. Handwriting retraining is a remedial approach for improving performance of a person’s previously-dominant (writing) hand. There is surprisingly little evidence regarding the effectiveness of adult handwriting retraining. At present, therapists working in stroke rehabilitation rely on studies of low methodological quality, research involving children and/or research investigating motor retraining for other tasks post-stroke. These areas of research will be explored in the following section.
Handwriting retraining for adults with stroke or similar neurological conditions.

No studies of high methodological quality have been found that investigate handwriting retraining for adults with stroke. A recent systematic review on handwriting interventions for people with upper limb deficits included four studies that involved adults (Yancosek & Howell, 2011). None of the studies included adults with stroke, or used a RCT design. All four studies involved compensatory approaches rather than handwriting retraining for the dominant hand, including the use of speech recognition software (Bruce, Edmundsen, & Coleman, 2003; Roberts & Stodden, 2005; Yancosek, Daugherty, & Cancio, 2008) and retraining the non-dominant hand (Walker & Henneberg, 2007). The current literature review identified no additional adult studies with adequate statistical power to determine effectiveness of handwriting retraining using the dominant hand. A pilot RCT and three single cohort studies involving handwriting-related goals were published after the systematic review by Yancosek and colleagues (2011) was completed.

Three studies investigated the use of the Cognitive Orientation to daily Occupational Performance (CO-OP) approach for retraining various tasks post-stroke, including handwriting (Henshaw, Polatajko, McEwen, Ryan, & Baum, 2011; McEwen et al., 2014; McEwen, Polatajko, Huijbregts, & Ryan, 2009). The CO-OP approach uses cognitive strategies to acquire or improve a skill including a problem-solving approach known as ‘Goal, Plan, Do, Check’, and task-specific strategies identified by the person and the therapist. Although the CO-OP approach is not exclusively used for motor tasks, application of these cognitive strategies is thought to be an important aspect of improving motor control (McEwen, Huijbregts, et al., 2009). A pilot RCT investigated the use of the CO-OP approach and task-specific training to improve performance on a range of tasks (McEwen et al., 2014). Adults with ischaemic stroke (n=35) were randomly allocated to the experimental or control groups. The intervention involved task-specific practice combined with the CO-OP approach, conducted in an outpatient clinic setting by CO-OP trained occupational therapists. Treatment sessions were generally 45 minutes long, held twice per week and for up to 10 sessions (based on the clinical judgement of the occupational therapist researcher). The control group received usual outpatient care by an occupational therapist, with twice-weekly sessions of 45 to 60 minutes in duration. The total number of usual care sessions was not reported, but may have been up to 36 sessions depending on clinic policy and insurance coverage. The intervention for both groups targeted participant-selected goals. A total of 178 goals were identified by participants, the most common being cooking (n=19), walking (n=16) and
Three of the goals related to handwriting. Specific handwriting goals were not described, but ‘writing legibly’ was an example of one handwriting goal. Not all goal tasks were trained in that study. Performance of untrained tasks was included in the outcome measurement to evaluate transfer of training. The primary outcome measure was the 10-point blinded-assessor-rated Performance Quality Rating Scale (PQRS) (Miller, Polatajko, Mandich, & Macnab, 2001). An effect size (95% CI) of 1.6 (0.5 to 2.7) was reported for trained tasks and 1.1 (-0.1 to 2.3) for untrained tasks measured using the PQRS. These results suggest that task-specific training combined with the CO-OP approach is more effective than usual care for improving performance of goal tasks, including tasks that were not specifically trained. Therefore, elements of the intervention used in the study by McEwen and colleagues (2014) will be integrated into the current study (task-specific practice and cognitive strategies). There are several restrictions when applying the results and principles of the McEwen (2014) study to handwriting retraining. Handwriting was not the specific focus of the McEwen intervention, and improving handwriting performance related to only a small proportion of all participant goals (1.5%). It is unclear if handwriting was a goal of participants in the intervention or control group, or if this was one of the trained or untrained tasks. Further, handwriting performance results were not reported separately, therefore it is unknown whether the CO-OP intervention improved handwriting performance specifically. More targeted research is still required to test the feasibility and effectiveness of handwriting retraining interventions, including CO-OP.

Two of the other cohort studies also investigated use of the CO-OP approach with adults after stroke, and reported specific handwriting outcome data (Henshaw et al., 2011; McEwen, Polatajko, et al., 2009). One study used a single case experimental design and included three participants with stroke (McEwen, Polatajko, et al., 2009). Participant 1 in that study received four sessions of handwriting training involving the CO-OP approach to improve handwriting neatness and precision. Performance was again measured using the PQRS (Miller, Polatajko, Mandich, & Macnab, 2001). The authors reported a significant improvement after one month for PQRS scores, using the two standard deviation method (mean PQRS score changed from 3.0 to 5.6, with two successive data points scored at 7.0 and 6.0). A similar study that applied the CO-OP approach used a quasi-experimental design and included two adults with stroke (Henshaw et al., 2011). Participants set three goals, two of which were addressed in each session over 10 sessions. One participant’s goal was to
improve her signature. Her performance on that task, measured each session using the PQRS, improved from 7/10 to 10/10 after 10 CO-OP training sessions.

A third study involving single case experimental design investigated the impact of a two-week handwriting retraining program for four adults with traumatic brain injury (Beaudet, 2004). Participants received a home-based retraining program, using task-specific practice. An occupational therapist delivered three sessions per week, which included goal-setting, supervised practice and feedback on handwriting performance. Participants completed two one-hour sessions per week of unsupervised practice. The program therefore included six supervised and four unsupervised session over two weeks. Practice tasks focused on in-hand manipulation, pen control, writing speed and legibility and included both whole handwriting task practice and practice of specific handwriting components (hereafter known as ‘part-practice’). Clinically important changes in writing legibility were shown, with legibility increasing by 45%, 33%, 24% and 12% for the four participants. Limitations of that unpublished study include the small sample size with large variability in the data. The therapist who delivered the intervention also administered the outcome measures, although a blinded assessor rated the pen control and legibility sub-tests in a random order, helping to reduce measurement bias.

In summary, four studies (Beaudet, 2004; Henshaw et al., 2011; McEwen et al., 2014; McEwen, Polatajko, et al., 2009) involving adults with stroke or traumatic brain injury included handwriting retraining or handwriting-related goals. One pilot RCT included handwriting-related goals, and reported a treatment effect for task-specific training and CO-OP approach over usual care. However, that study was not powered to demonstrate a treatment effect and results cannot be directly applied to handwriting retraining. Small improvements were shown in handwriting performance in three further studies of low methodological quality. All four studies involved some form of task-specific handwriting practice. Cognitive strategies were also used to problem-solve ways to improve performance in three of the studies. Study findings suggest that task-specific handwriting practice is an important component of handwriting retraining for adults with stroke, with more robust research required into the effectiveness of this intervention. The studies also highlight the need for specific, objective measures of handwriting performance.

**Handwriting training for children.** Although evidence for handwriting retraining with adults after stroke is limited, there is a more robust body of literature related to
handwriting interventions for children. This paediatric literature may help to determine factors likely to make training in adults beneficial. The focus on handwriting training for children has likely arisen because handwriting is an important task for school-aged children (Schneck & Amundsen, 2010). Handwriting difficulties are common in that population (Karlsdottir & Stefansson, 2002), and is a common focus for therapists working in paediatric settings (Feder et al., 2000).

Interventions used to train handwriting in children include task-specific practice, practice of fine-motor tasks other than handwriting and sensory based approaches. A recent systematic review investigated child-specific handwriting interventions provided by occupational therapists (Hoy et al., 2011). Nine randomised and two non-randomised controlled trials were involving relaxation, biofeedback, sensory-based training and handwriting practice. A statistically significant effect was found by studies that involved large dosage of direct practice of handwriting tasks (20+ hours). Data from the reviewed studies could not be included in a meta-analysis, but the most relevant study, involving 43 participants, showed a standardised effect size of 1.14 (0.36, 1.93) for legibility in favour of task-oriented practice compared to no intervention (Weintraub et al., 2009). Interventions that did not include handwriting practice were not effective in improving handwriting performance (Hoy et al., 2011).

These paediatric studies support the need for large amounts of handwriting practice, although differences exist between children and adults in handwriting goals and practice tasks. Young children are typically learning to form letters for the first time, while most adults would be familiar with letter formation. Finally, it is not known whether a program involving large amounts of handwriting practice (i.e., 20+ hours) is feasible to deliver or acceptable to adults. Therefore, further research is required investigating handwriting retraining with adults, which will be the focus of the current study.

**Retraining other motor tasks post-stroke.** The evidence reviewed so far suggests that specific, intensive practice of meaningful tasks is effective for improving performance of motor tasks such as handwriting. Intensive task-specific practice is also a key component of interventions that improve other motor tasks post-stroke such as walking, transfers and reaching (Arya, Pandian, Verma, & Garg, 2011; Langhorne et al., 2009). Constraint-induced movement therapy is another intervention that is well-supported in the stroke literature, and
involves intensive practice of motor tasks (French et al., 2007; Nijland, Kwakkel, Bakers, & van Wegen, 2011; Stevenson, Thalman, Christie, & Poluha, 2012; Veerbeek et al., 2014).

Task-specific motor training is an intervention commonly used by therapists to assist adults with stroke to regain motor function (Jette et al., 2005). Other terms are used to describe interventions with a similar approach, including ‘repetitive task training’, ‘repetitive functional task practice’, and ‘task-oriented therapy’ (Arya et al., 2011; Dobkin, 2004), although these terms are not always synonymous in the literature. For the purpose of this review, task-specific motor training refers to intervention that involves intensive, repetitive practice of a series of complex, multi-joint movements required to carry out a meaningful motor task (Dobkin, 2004). Task-specific motor training is a goal-directed intervention (Bayona et al., 2005), involving practice of complex, multi-joint movements related to meaningful motor tasks (French et al., 2007). Task-specific motor training may also involve practice of specific sub-tasks, as long as this ‘part-practice’ relates to the goal task (Dobkin, 2004; Turton et al., 2013). High-intensity practice is a key component of task-specific motor training, with large numbers of repetitions required to improve motor function (Kwakkel, 2006). ‘Shaping’ is another important component of this intervention, involving graded difficulty of practice tasks (Woldag, Stupka, & Hummelsheim, 2010). Task-specific motor training involves practising tasks in a ‘real-life’, meaningful environment (Davis, 2006).

Specific feedback regarding performance is important when re-acquiring skills (Cirstea et al., 2006). As well as receiving feedback from a therapist, adults with stroke may also be able to analyse their own handwriting performance, which may guide problem-solving for strategies to improve their performance (McEwen, Huijbregts, et al., 2009).

There is emerging evidence for the effectiveness of task-specific motor training in stroke rehabilitation. A recent systematic review with meta-analysis of physiotherapy interventions post-stroke found strong evidence for interventions that involve repetitive, high intensity practice of meaningful tasks (Veerbeek et al., 2014). Earlier reviews came to the same conclusion for lower limb performance (French et al., 2007; Hubbard et al., 2009), but there are few RCTs involving high intensity practice (over 20 hours) of upper limb tasks, except those involving constraint-induced movement therapy. Because of the broader evidence, task-specific motor training is recommended in the Australian clinical guidelines for adults with stroke who have upper limb weakness (National Stroke Foundation, 2010). However, further investigation of task-specific motor training for upper limb tasks such as handwriting is warranted. Therefore, task-specific motor training will be used in the current
study. The principles of, and evidence for this intervention are described in more detail in the following section.

Intensive practice of motor tasks is a key component of constraint-induced movement therapy (CIMT), an intervention that is effective for improving performance of upper limb motor tasks post-stroke (Nijland et al., 2011; Stevenson et al., 2012). CIMT involves practice for up to six hours daily using the stroke-affected limb, shaping or behaviour change strategies, a restraint worn for the majority of the waking day on the less affected hand, and transfer tasks to promote carry-over (Taub et al., 2013). The non-affected hand or arm is restrained during practice, to promote ‘forced-use’ of the stroke-affected hand.

Although handwriting is not described in the CIMT literature, it is a common task practised during CIMT. Handwriting practice using the previously dominant, stroke-affected hand may be considered as a type of ‘forced use’ of the stroke affected hand, requiring high levels of practice of a complex motor task without the assistance of the non-affected hand. The general principles of CIMT may also be applied to handwriting practice by discouraging compensatory assistance of the non-affected limb for handwriting sub-tasks, such as for picking up the pen and repositioning the pen in the hand. More restrictive constraint of the non-stroke affected limb may not be appropriate during handwriting practice, as the non-writing arm is typically required for handwriting tasks such as stabilising the paper. The feasibility and effectiveness of using CIMT for handwriting retraining has not been tested and further research is required in this area.

**Summary: Remedial approaches.** For some adults, restoring pre-stroke handwriting function may be a rehabilitation goal. Research in this area is limited with no studies of high methodological quality involving adults with stroke. Handwriting practice was used in several lower-quality studies and a pilot RCT, which showed improvements in the handwriting performance of adults with stroke. Intensive handwriting practice is also a key feature of effective interventions that improve handwriting in children. Intensive practice of meaningful motor tasks is also a major component of task-specific motor training and CIMT, interventions with strong support in the stroke literature, but there is no high-quality research regarding handwriting specifically. The current study aims to address these research gaps by testing the feasibility and acceptability of a handwriting intervention program involving intensive handwriting practice for adults with stroke. Data from this study may assist with
planning a future RCT to test effectiveness. The principles of task-specific motor training are described in more detail in the following section.

1.8 Task-specific motor training to improve handwriting following stroke

Task-specific motor training includes high-intensity practice of meaningful goal-orientated motor tasks, feedback and problem-solving, grading of practice tasks to provide the right level of challenge, and practice in a meaningful environment. These principles and their application to handwriting retraining will be described in the following section.

1.8.1 Goal-based intervention

Purpose and importance of goal-setting. Goal setting is widely recognised as being an important part of the stroke rehabilitation process and is recommended in the Australian clinical guidelines for stroke management (National Stroke Foundation, 2010). Task-specific motor training involves practice of meaningful motor tasks (Bayona et al., 2005; Dobkin, 2004). Goal-setting, sometimes known as goal planning, can be used to identify meaningful practice tasks. To this end, goals should be specific, detailing task and performance requirements that are important to the goal activity (Bovend'Eerdt, Botell, & Wade, 2009). Goals should work towards a level of performance that is challenging but achievable (Playford, Siegert, Levack, & Freeman, 2009). Goal setting is also used in rehabilitation to motivate the learner and measure change (Levack et al., 2006; Playford et al., 2009), requiring goal attainment to be measurable (Turner-Stokes, 2009). Participation by adults with stroke in the goal setting process is important to ensure rehabilitation programs are meaningful and to increase self-autonomy (Leach, Cornwell, Fleming, & Haines, 2010; Rosewilliam, Roskell, & Pandyan, 2011). Progress towards goals (particularly short term goals) needs to be evaluated regularly (Lawler, Dowswell, Hearn, Forster, & Young, 1999) and goals may need to be revised or changed during intervention.

Goal-setting for handwriting retraining. Goal setting for handwriting tasks should involve identification of tasks that are meaningful to the person (e.g. writing a letter), as well as task requirements such as the audience for the writing, or speed requirements. The domain of handwriting performance being targeted should also be considered during goal setting, such as whether the person wants to improve handwriting legibility, neatness and/or speed. Cognitive demands can influence handwriting performance, and may need to be specified in
goals (e.g. writing a phone message while talking). Finally, different writing materials and postures may affect performance, and need to be specified (e.g. writing on a wall calendar in standing). Short term goals may represent steps towards long term goals (Playford et al., 2009); for example, a short term handwriting goal to write 10 lines in five minutes, may be a step towards a long term goal of writing minutes of a meeting at work. Short term goals may be used to set the right level of challenge when a handwriting goal is beyond the immediate scope of an intervention program, and short term-goals may also be used in motor training as practice targets.

Goal-setting alone is not enough to improve performance; goals need to be used as a basis for tailored intervention (Wade, 1999), with practice tasks being tailored towards meaningful goals. For example, practising writing shopping lists or signatures. Practice tasks should also be performed under (or work towards) similar conditions to the goal performance; for example, shopping lists written on a notepad while standing in the kitchen. The following section describes ways that practice tasks can be tailored towards meaningful handwriting goals.

1.8.2 Practice of specific and meaningful tasks

Practice of ‘real-world’ tasks. In rehabilitation, practice involves repetition of a skill to be learned (Shumway-Cook & Woollacott, 1995). Practice of specific and meaningful ‘real-world’ tasks is a key component of task-specific motor training (Dobkin, 2004; Hubbard et al., 2009); in contrast to other strength training interventions involving repeated, non-specific movement of a single joint (French et al., 2007). A study compared the effectiveness of different interventions for improving upper limb function post-stroke: i) standard care (including neuro-developmental training and stretching), ii) non task-specific strength training, and iii) task-specific motor training (Winstein et al., 2004). A sample of 64 stroke inpatients was included in that study, and therapy was delivered one hour per day, five days per week for four weeks (20 hours in total). Both strength training and task-specific motor training resulted in greater improvements in upper limb function than standard care, with task-specific motor training producing more sustained improvements than strength training at the 9-month follow-up. The researcher who administered the outcome measures was not blinded to group allocation, which may have been a potential source of bias in the study by Winstein and colleagues (2004). However, these results suggest that intensive practice of motor tasks improves motor function post-stroke and that task-specific practice produces
longer-term improvements in function. Applying this principle to handwriting training would involve direct practice of meaningful handwriting tasks, as opposed to general finger strengthening or practice of non-meaningful pre-writing tasks such as forming rows of loops across a page.

*Part-practice of task components.* Most functional motor tasks involve complex movements across several joints. For adults with stroke, practising complex movements of a whole task such as handwriting may be challenging. Additionally, problematic sub-tasks such as forming a difficult pair of letters may warrant additional practice. Practising specific components of a goal task, or ‘part-practice’, may enable a person to concentrate on a smaller, more manageable movement, or to increase practice of problematic movements (Dobkin, 2004). This type of intervention is also a feature of motor learning (Carr & Shepherd, 2000), an approach that is closely aligned with task-specific motor training (Hubbard et al., 2009). In contrast to general strength training, which also involves repeated practice of simple movements, part-practice has a functional, goal-directed focus, aimed at incorporating the specific movements into a whole functional task (Hubbard et al., 2009). The additional benefit of part-practice for improving performance of complex motor tasks was demonstrated in a RCT involving 52 adults with stroke (Chan, Chan, & Derrick, 2006). Intervention for the experimental group involved identification of missing performance components in a task, practising these problematic components and transference of these skills into the whole functional tasks. The control intervention involved direct practice of whole functional tasks, without identification or training of specific performance component deficits. Both groups received an intensive program, involving 18, 2-hour sessions over six weeks. Between-group statistically significant improvements were seen in outcome measures of balance, mobility, functional independence and community integration at six weeks. These results suggest that identification and practice of specific problematic task components may be more effective in improving ability to perform functional (mobility) tasks, compared with practice of whole tasks alone. No follow-up results were reported for this study, so the long term additional benefit of part-practice is not known.

Part-practice may be used in handwriting retraining for adults (Beaudet, 2004). The sub-tasks of handwriting described earlier, including letter formation, moving around a page and error correction may be the focus of part-practice during handwriting retraining. Part-practice of letter formation may involve forming individual letters, joining letters, or forming difficult pairs or groups of letters. Part-practice of moving across a page may involve creating
spaces between letters and words, or listing words down a page; while error correction may involve practising crossing out words or inserting small words between lines of writing.

1.8.3 High intensity practice

**How intensity is measured.** Task-specific motor training involves high intensity practice. Intensity is not consistently defined in the rehabilitation literature, referring to number of repetitions (Taub et al., 2013), amount of work or effort (Kwakkel, 2006) or duration of practice (Lohse, Lang, & Boyd, 2014). Amount of work or effort is difficult to measure for tasks such as handwriting that do not involve a defined energy output. Therefore intensity in rehabilitation is usually measured by the number of repetitions (frequency) and the length of time spent practising (duration) (Kwakkel, 2006). Overall session duration may not be an accurate method of measuring intensity, as a one-hour intervention session may not involve one hour of practice. An observational study of 13 adults with stroke found that participants engaged in active practice for only 64% of total session time (Connell, McMahon, Simpson, Watkins, & Eng, 2014).

Measurement of actual handwriting practice time using practice logs may be one way of estimating intensity. The frequency of practice can also be used to estimate intensity, based on the number of repetitions completed. Handwriting involves completion of a range of sub-tasks and no single practice ‘task’ can be counted as a repetition across all handwriting contexts. Handwriting sub-tasks that can be counted as a single repetition include forming an individual letter, letter pair/group or word. Counting repetitions needs to be time-efficient and practical, to maximise therapy time spent in actual task practice. Counting lines of text and estimating the number of letters or words may be a more efficient method of counting repetitions during handwriting practice, compared to counting individual letters or words.

**Effect of increased intensity.** Intensity is important in stroke rehabilitation, with greater doses of therapy yielding greater improvements in function. A meta-analysis was conducted on the effects of increased therapy time on motor recovery post-stroke (Lohse et al., 2014). This meta-analysis of 37 RCTs found that adults with stroke who received more hours of therapy time (mean 33 hours extra) had greater improvements in motor function than those who received less hours of therapy ($g = 0.35; 95\%$ CI: 0.26 to 0.45). Although high intensity interventions yield better motor outcomes in general, little is known about the effect of increased practice intensity on fine motor tasks such as handwriting; although it is presumed that more practice is better. Practical considerations, such as cost and availability
of staff, typically limit the dose of therapy delivered (Kwakkel, 2006). The intensity of practice may be partly determined by what is feasible to deliver and acceptable to the person. The current study will involve 20 hours of handwriting practice and evaluate the feasibility and acceptability of this level of intensity for adults with stroke.

**Methods to increase practice intensity with limited therapist availability.** Therapists may be present during practice to provide feedback and grading (described below), but time and funding constraints may limit availability of a therapist for all of the prescribed practice time. Several methods have been described to increase the intensity of practice within the constraints of therapist availability, including group programs and unsupervised practice.

Group programs enable therapists to supervise more people and provide extra practice, although this mode of therapy provision does not increase the practice intensity of each person unless group practice is additional to standard therapy. Further research is needed investigating what level of handwriting function a person needs to have, and the therapist: client ratios that are required for group interventions to be effective. Programs such as CIMT are also delivered individually as well as in group format to increase practice intensity. Handwriting may be one of the tasks practised during a CIMT program, and constraining the unaffected limb may discourage compensatory assistance of the non-affected hand for sub-tasks such as repositioning the pen.

Completing independent, unsupervised practice is another way of increasing handwriting practice intensity. Tasks need to be carefully set up to enable a person to practise independently. Written or image/video-based instructions may assist a person to practise tasks as intended. When a therapist is not available for feedback during handwriting practice, adults with stroke may need to be taught to provide their own ‘feedback’ through self-analysis and problem-solving. These techniques will be discussed later. A therapy assistant could also be taught similar techniques and supervise some practice sessions. In order to appropriately grade the difficulty of practice tasks, regular review by the treating therapist would be required. Further research is needed regarding the feasibility of having handwriting practice sessions delivered by a therapy assistant and to determine the optimal balance between independent practice, supervised practice with a therapy assistant and supervised practice with a therapist. Even if methods are established to increase practice intensity, whether a person takes advantage of these practice opportunities will depend on other factors such as their motivation. Collaborative goal setting, as described earlier, may assist with
increasing intensity by providing specific and meaningful practice targets (Koh, Barr, & George, 2014). Completion and review of handwriting practice logs may be helpful for identifying problems with meeting practice targets (Rose, 2014) and written practice targets may be included in these logs.

**Summary: High intensity practice.** Greater practice intensity may yield increased improvements in handwriting performance, so adults with stroke should be given as much opportunity to practise handwriting as possible. The current study will deliver 20 hours of handwriting practice using techniques such as independent practice tasks with clear instructions, goal-setting and handwriting practice logs.

1.8.4 Grading practice tasks

**Principles and effectiveness of grading.** A principle of task-specific motor training is practising tasks at the optimum level of challenge (Subramanian, Massie, Malcolm, & Levin, 2010). The ‘just right’ challenge is achieved by gradually increasing task difficulty through grading or shaping (Taub et al., 2013). Grading involves increasing the complexity of a practice task by increasing the speed and quality of movement required, or by introducing a similar but more difficult task (Taub et al., 2013). Grading of practice tasks is an important component of CIMT (Nijland et al., 2011) and is thought to be effective in promoting recovery of motor tasks post-stroke.

**Grading and handwriting retraining.** Although not specifically described in the literature, grading may be used in handwriting retraining by increasing the number of repetitions, the speed (such as aiming to write a certain number of lines in a specified time frame), the complexity of a handwriting task (such as progressing from writing pairs of letters to writing whole words), or the cognitive demands (such as writing while listening to someone speak). Altering the environmental setup may assist with providing the right level of challenge (Davis, 2006), as aspects of the environment may make handwriting easier or more challenging. Environmental components that can be graded include the position of writing materials (such as writing on a wall calendar), the posture used (such as writing a list while standing) and the type of writing materials used (such as a thick wad of sticky notes or felt tip pen).

**Summary: Grading practice tasks.** Grading or shaping involves gradually increasing the difficulty or complexity of practice tasks during a rehabilitation program in order to
provide the optimum level of challenge. Grading methods that may be used during handwriting retraining include altering the intensity, speed, complexity, cognitive demands and environment of a task. Analysis of task performance and feedback are also an important component of grading (Taub et al., 2013; Woldag et al., 2010) and these methods are used in task-specific motor training to problem-solve ways to improve performance. The principles of feedback are discussed in the next section.

1.8.5 Feedback and problem-solving

类型的反馈。反馈是另一个技能获得的重要特征，对改善如书写（Gilmore & Spaulding, 2001; Subramanian et al., 2010）等运动任务的性能非常重要。反馈指的是任务执行期间或之后提供的信息，可能为内在的或外在的（Subramanian et al., 2010）。内在反馈是执行任务时获得的感觉信息。例如，内在反馈可能在书写时从 proprioceptive, tactile and kinaesthetic senses regarding pen grip and pressure. 外在反馈是由环境提供的关于任务表现的信息，如口头或非口头信息由治疗师提供。当一个人正在实践一个新的或困难的技能，或者如果感觉系统提供内在反馈受到损害，如中风后，可能需要额外的外在反馈（Winstein, 1991）。因此，治疗师在中风康复中的一个角色是提供外在反馈来改善书写等运动任务的性能（Dobkin, 2004）。当错误或无益的补偿在练习运动任务时发生时，外在反馈可能作为后续重复中的错误修正的基础（Winstein, 1991）。外在反馈可能有两形式：知识的结果，或知识的表现。知识的结果指的是关于任务结果或结果的反馈。例如，给予关于字母形成（例如，“你写了字母‘o’，是清晰和开放的”）的反馈。知识的表现指的是关于执行一个运动任务时的具体动作使用的反馈（例如，“你能够更好地控制你的拇指时，当您写那个字母时”）（Cirstea et al., 2006）。

有效性反馈改善运动表现后中风。对中风后外在反馈的有效性进行的系统性审查包括了四篇RCT支持使用外部反馈来增强上肢运动任务的性能（Subramanian et al., 2010）的。虽然这些研究中没有一篇专为书写而设计，但其发现可能为正在进行的治疗提供有用的基础。
handwriting therapy interventions. Two studies included in that systematic review compared types of verbal feedback provided by a therapist. One study compared knowledge of results (feedback on task output) with knowledge of performance (feedback on movements performed during the task) (Cirstea & Levin, 2007). The other study compared knowledge of results, knowledge of performance and no extrinsic feedback (Cirstea et al., 2006). The intervention in both studies involved practice of an upper limb motor task, while either type of feedback (or no feedback) was provided by a therapist. Outcome measures included upper limb motor function and kinematic movement analysis recorded at baseline, post-intervention and follow-up. Motor performance improved in both studies following knowledge of results and knowledge of performance feedback compared to baseline (and/or no feedback). The group receiving knowledge of performance feedback improved more post-intervention and at follow-up compared to the group receiving knowledge of results feedback.

The way that feedback is provided may vary (Hubbard et al., 2009). Various methods can be used by a therapist to provide feedback, such as verbal and non-verbal cues. Some research has been conducted investigating alternative feedback mediums including a computer-based display (Jang et al., 2003; Piron et al., 2005) and video recordings (Gilmore & Spaulding, 2007). The timing of feedback may also vary, with feedback being provided during, immediately after or following task performance (Winstein, 1991). The frequency of feedback may be important. Feedback may need to be faded over time to prevent dependency (Davis, 2006; Hubbard et al., 2009). Further research is required investigating which medium, timing and frequency of feedback are most effective for improving motor performance (Subramanian et al., 2010). Despite the limited research investigating how and when feedback should be provided, the evidence suggests that various forms of extrinsic feedback during practice are beneficial for improving motor performance of upper limb tasks post-stroke such as handwriting.

**Feedback on handwriting performance.** Feedback on handwriting performance should include information about the output (knowledge of results) and the process or specific movements used (knowledge of performance). Handwriting is unlike other upper limb tasks in that a visible trace of a movement is produced in the form of lines on a page, and even very slight inaccuracies in a movement will be reflected in this written output. Therefore, knowledge of results can involve analysis of written output. Feedback needs to be specific in order to be useful during subsequent practice. Specific handwriting features that
may be the subject of feedback include letter formation such as letter height, slant, straightness of lines, closure of lines and spacing.

Feedback on the written output may be enhanced by using visual cues, such as circling or underlining letters. Feedback on specific movements, or the process of handwriting (knowledge of performance) may focus on pen grip and pressure, and movements of specific joints such as the wrist, thumb and fingers. This type of feedback involves careful observation and analysis during writing practice. Problem-solving may be used to identify cognitive strategies to improve these handwriting features, such as increasing the height of ascenders, keeping loops open or increasing spacing between letters and words. Part-practice, as described earlier, may enable a person to practise these strategies in a smaller, more manageable task before implementing them in a whole handwriting task.

Using cognitive strategies from the CO-OP program such as self-evaluation may help to improve motor function (McEwen, Huijbregts, et al., 2009); these strategies are supported by preliminary studies which taught the CO-OP approach to adults with stroke (Henshaw et al., 2011; McEwen, Polatajko, et al., 2009). These strategies can be used during supervised and unsupervised practice.

**Summary: Feedback and problem-solving.** Feedback regarding the output and execution of motor tasks is important during rehabilitation. Extrinsic feedback, such as verbal feedback from a therapist, may help to compensate for sensory impairments that affect intrinsic feedback systems and identify specific difficulties in relearning a complex motor task such as handwriting. Feedback provided during handwriting retraining may focus on output, such as features of letter formation and spacing, or on specific movements used during handwriting such as pen pressure (the process). Identifying problematic handwriting features may help adults with stroke to generate their own cognitive strategies. This type of handwriting analysis and problem-solving may also be performed by the writer themselves, including during independent practice sessions. The current study will use these various forms of feedback and problem-solving.

**1.8.6 Meaningful practice environment**

**Importance of a meaningful practice environment.** The environmental setup is an important consideration in task-specific motor training. For practice tasks to be specific and goal-directed, training should involve practising tasks in an environment that is as close as
possible to the goal task (Shumway-Cook & Woollacott, 1995), sometimes referred to as an ‘enriched’ environment (Davis, 2006). The environment may also change the demands of a task. Factors such as the height of surfaces, type of materials used and noise levels can affect the motor, sensory and cognitive demands of a task. Therefore, the practice environment should match the requirements demanded by a real-life environment. Practising a motor task in a meaningful environment also provides context, which can facilitate better performance compared to practising a simulated motor task. A meta-analysis was conducted of studies involving practising meaningful tasks using real-life objects, practising meaningful tasks without objects using imagery and non-task related movements (Lin, Wu, Tickle-Dengen, & Coster, 1997). Results of that analysis supported the practice of meaningful tasks using real-life materials (mean effect size $r = 0.50$). Another RCT compared movements used to chop food using real materials (knife and a vegetable), with performance of the same task using simulated materials (a cardboard knife with no vegetable) (Wu, Trombly, & Tickle-Dengen, 1998). That study included 38 adults: 14 with stroke and 24 healthy adults. Each participant performed the task under both conditions. Kinematic movement analysis found that performing a task using real materials produced more efficient, smooth and pre-planned movement, compared with performing a task using simulated materials. The results of these studies suggest that the environment is an important factor to consider when setting up handwriting practice tasks.

**Handwriting practice environments.** Various environmental factors need to be considered when setting up a meaningful practice environment. The posture and positions used for writing include standing up, for example when signing a form at a counter. Therefore handwriting practice may involve standing to write at a table of a similar height. The writing surface used for the task may also need to be considered, for example a calendar on the wall, or a notepad held in the lap. The materials used may also vary between handwriting tasks, affecting the handwriting task requirements. Therefore the size, thickness and type of writing implement and paper used may need to be considered when setting up practice tasks. The cognitive and sensory demands of the task may also need to be taken into account, such as writing a message while someone is speaking. Finally, a single handwriting task may be completed in a variety of environments. For example, only a pencil may be available when a person needs to write a phone message, or a desk may not be available for writing. Therefore, handwriting retraining may need to be completed in different environments and using materials that enable the person to write anywhere.
1.8.7 Summary: Task-specific motor training to improve handwriting following stroke

Task-specific motor training is an intervention recommended for improving performance of motor tasks. The principles of task-specific motor training include the practice of complex, multi-joint movements related to goal tasks, part-practice of more specific movements related to the goal task. This intervention also involves high intensity practice in a 'real-life', meaningful environment, with analysis, feedback and problem-solving required. Therapists help to set up, review and grade practice tasks and ensure adequate intensity of practice. Methods for increasing intensity include group programs and independent unsupervised practice. The feasibility and acceptability of a handwriting training program involving task-specific motor training principles will be the focus of the current study.

1.9. Statement of the problem

Handwriting is a valued task for adults and handwriting performance may be reduced following stroke. Most of the handwriting literature relates to training children, who may have difficulty learning how to hold a pencil or form letters. Little evidence exists to guide therapists addressing handwriting retraining for adults with handwriting difficulties, such as people with stroke. This chapter has summarised what is known about handwriting assessment and retraining for adults, and identified research gaps in these areas.

Objective assessment of handwriting performance is necessary before setting goals, and to help inform handwriting retraining. However, the assessment of adult handwriting is still under-researched. Several standardised assessments exist for assessing handwriting in children. Some components of these assessments are relevant to adults, such as the legibility of a sentence and writing speed. Additionally, several assessments of adult arm function include handwriting tasks. These relevant sub-tests have been collated into the HAB for adults. The HAB sub-tests measure pen control, speed and legibility. The inter-rater reliability of the HAB was the focus of two recent studies; however, the validity of this assessment battery has not been researched. Additionally, the feasibility and utility of the HAB have not been tested for use in therapy and research for people with stroke.

Legibility is a common focus of handwriting assessment and intervention. Several sub-tests of handwriting assessments used with adults focus on legibility. The HAB includes
five sub-tests measuring legibility: upper and lower case alphabet, numerals, and sentence legibility measured by rating word and letter legibility. Another legibility scale, the modified Four Point Scale, has been adapted from a scale used to rate the handwriting legibility of doctors. This scale is quicker to administer and score than the sentence legibility sub-test of the HAB. Research is required to determine the feasibility and utility of these legibility sub-tests.

Handwriting assessments primarily focus on legibility and speed. Other domains of handwriting performance that may be important to adults, such as appearance and fluency, are not included in any standardised handwriting assessments. Several subjective scales have been described in the literature that focus on appearance and fluency, but no well-researched objective assessments have been found to measure these more subjective domains of handwriting performance. No studies have described the handwriting goals of adults with stroke to determine what domains of handwriting performance are important to this population. Research with adults with handwriting difficulties may help to guide further development of handwriting assessments for this population, based on their difficulties and priorities.

Handwriting training is another area in which there is a notable imbalance in the volume of research for adults compared to children. Handwriting training is a common reason for referral to therapists in school-aged children and various interventions are used. There is a robust body of evidence suggesting that handwriting training for children should involve direct practice of handwriting. Additionally, several single cohort or single case studies have included handwriting training for adults with stroke and brain injury. The interventions used in these studies included handwriting practice and cognitive strategies to improve performance. Small improvements in handwriting performance were shown in these studies.

Repetitive practice of meaningful tasks is a key component of CIMT and task-specific motor training, two interventions with good support in the stroke literature. This broader evidence suggests that handwriting training for people with stroke should involve intensive handwriting practice. Other well-supported intervention principles that may be applied to handwriting training include: i) practice of specific task components as well as whole tasks; ii) performance analysis and feedback; iii) cognitive strategies such as problem-solving to improve performance; and iv) graded difficulty of practice tasks.
More rigorous research involving RCTs is required to determine the effectiveness of a handwriting intervention program involving these principles for adults with stroke. However, several research gaps need to be addressed prior to planning a larger RCT on this topic. Firstly, it is not known whether it is feasible to recruit adequate numbers of adults with stroke to a RCT with adequate power to demonstrate a treatment effect. Secondly, the utility of outcome measures of handwriting performance need to be determined. Finally, the feasibility of a handwriting intervention program, and its acceptability for adults with stroke need to be researched. The current feasibility study attempts to address these research gaps to inform future research, and these gaps inform the aims and research questions of the study.

1.10 Study aims and research questions

The current study aims to test the feasibility of a four-week handwriting retraining program involving task-specific practice for adults with stroke, to inform future research. Specific aims of this study are to:

1. Test the feasibility of recruiting participants with stroke for a four-week handwriting training program;
2. Test the feasibility and acceptability of a four-week handwriting retraining involving task-specific practice; and
3. Explore the utility of the subtest items of the Handwriting Assessment Battery [V2] as an outcome measure for use in a future trial.

In order to achieve these study aims, the following research questions need to be answered:

1. What is the recruitment rate during an 18 month period (including enrolment and eligibility fractions)?
2. What are the common handwriting goals and self-reported handwriting difficulties of adults with stroke?
3. Is a four-week program involving intensive and repetitive practice of handwriting feasible for an occupational therapist to deliver?
4. Are adults with stroke able and willing to engage in such a program?
5. What outcome measures of handwriting performance are feasible to deliver and useful for research purposes?
Chapter 2: Methods and Results

Paper accepted for publication:

Feasibility of a home-based program to improve handwriting after stroke: A pilot study

2.1 Introduction

The methods and results of this study are presented in the form of a manuscript submitted to Disability and Rehabilitation (in press). The manuscript also includes an abridged background and discussion, which are presented in more detail in this thesis in Chapters one and three. The formatting, numbering and referencing style (Council of Science Editors) of the submitted manuscript have been edited for this chapter to be consistent with the APA (6th edition) style and the thesis. Minor edits have also been made for this thesis, such as references to thesis appendices.
2.2 Faculty of Health Sciences Author Contribution Statement

Candidate Name: Bronwyn Ann Simpson

Degree Title: Master of Applied Science

Paper Title: Feasibility of a home based program to improve handwriting after stroke: A pilot study

As the primary research supervisor, I confirm that the above candidate has made the following contributions:

- Conception and design of the research
- Analysis and interpretation of the findings
- Writing and editing the paper

Signed

[Signature]

Name  Dr Annie McCluskey  Date  6th June 2015
2.3 Background

Handwriting is an important and valued task for adults (van Drempt et al., 2011a) and is integral to many vocational, educational and recreational activities. Handwriting involves letter formation, speed, legibility, and moving across a page (Case-Smith, 2001). As a complex upper limb task, handwriting requires underlying motor, sensory, cognitive and perceptual skills (Maeland, 1992). Impairment of any of these underlying skills can result in poor handwriting performance or output. Stroke is one of several neurological conditions that can impair handwriting performance in adults. Stroke causes upper limb hemiparesis in up to 85% of people (Nakayama et al., 1994) and few (27%) regain dexterous movement at one year post-stroke to a level required for handwriting (Kong et al., 2011). Therefore handwriting is an important focus for stroke survivors and therapists during rehabilitation.

Little research of high methodological quality has been published testing the efficacy of handwriting retraining for adults after stroke. A systematic review of handwriting interventions for adults with upper limb deficits included four studies (Yancosek & Howell, 2011). The interventions used in these studies involved compensatory methods (e.g., using voice recognition software) rather than motor retraining for the writing hand, and none of the studies included stroke survivors or used a RCT design. There are, however, handwriting retraining studies published after the Yancosek and Howell (2011) systematic review. Three studies used a single case experimental or quasi-experimental design, and a fourth study used a pilot randomised design with a small sample. The studies included adults with stroke (Henshaw et al., 2011; McEwen et al., 2014; McEwen, Polatajko, et al., 2009) and traumatic brain injury (Beaudet, 2004). Each study provided a different number of sessions targeting handwriting (ranging from 4 to 10; unspecified by McEwan and colleagues 2014) and different program content but all included elements of task-specific practice. Three studies (Henshaw et al., 2011; McEwen et al., 2014; McEwen, Polatajko, et al., 2009) focused on a single self-selected handwriting goal (e.g., writing a signature or writing neatly and precisely), in addition to addressing other non-handwriting goals, while the other study (Beaudet, 2004) focused only on handwriting, covering a broader range of handwriting elements (e.g., pen control, speed and legibility). Approaches also differed between the studies, with three (Henshaw et al., 2011; McEwen et al., 2014; McEwen, Polatajko, et al., 2009) applying the Cognitive Orientation to daily Occupational Performance (CO-OP) approach with handwriting practice, and the other study (Beaudet, 2004) applying task-specific practice of whole handwriting tasks and part-practice of relevant handwriting components. While limited in their methodologies and inconsistent in their...
theoretical approach, all studies reported improvements in handwriting performance. The pilot randomised controlled trial by McEwen and colleagues (2014) involved 35 adults with stroke, and reported an effect size of 1.6 (95% CI 0.5 to 2.7) in favour of the intervention when performance was measured on the assessor-rated Performance Quality Rating Scale. This result was for all tasks trained and handwriting outcome data were not reported separately. Studies which evaluate the effect of task-specific upper limb retraining (Langhorne et al., 2009) or constraint-induced movement therapy (Nijland et al., 2011) sometimes involve handwriting as a training task; however, the specific effect of handwriting practice and measurements are not reported separately in such studies.

While evidence that handwriting retraining improves handwriting performance in adult stroke survivors remains limited, there is a more robust body of literature related to handwriting interventions for children. A systematic review of RCTs concluded that interventions that improved handwriting performance in school-aged children involved extensive (20+hours) direct handwriting practice (Hoy et al., 2011). The inclusion of handwriting practice, rather than non-specific finger exercises, is consistent with task-specific practice, an intervention that improves motor abilities when training motor tasks with adults with stroke (French et al., 2007; Hubbard et al., 2009). The principles of task-specific practice could be applied to handwriting retraining with adults post-stroke but there is limited research to date to determine if this intervention would be effective in improving adults’ handwriting. Handwriting goals and practice tasks are likely to be different between adults and children, as they perform different handwriting tasks and thus, have different occupational goals. Children are learning to form letters for the first time, while most adults are already familiar with letter formation. While no research has been identified about the amount or intensity of handwriting practice needed to improve handwriting performance in adults, evidence does exist regarding practice hours needed to improve motor performance. Veerbeek and colleagues (2014) recently reported that 17 hours of additional therapy time and practice over 10 weeks are necessary to improve motor performance in adults with stroke. That amount of practice is consistent with the 20+ hours advocated to improve children’s handwriting (Hoy et al., 2011). It is not known whether a program involving large amounts of handwriting practice (i.e., 17 to 20 hours) is feasible to deliver or acceptable to adults with stroke. Therefore further research is needed to specifically investigate handwriting retraining for adults with stroke using a RCT design and replicable protocol.

Goals related to improving handwriting performance may arise later in the rehabilitation process as handwriting becomes an important task, or if upper limb function improves to the point of
being able to hold a pen. Therefore handwriting retraining may be more common in home- or community-based rehabilitation programs, compared to inpatient rehabilitation programs. A systematic review of studies involving home-based therapy programs for adults with various conditions (including stroke) found that home-based programs were equally as effective as inpatient therapy for achieving a range of outcomes (Novak, 2011). Home programs that had more favourable outcomes were targeted to meaningful participant goals and involved feedback on performance, important features of task-specific training which will be applied in the current study. The studies included in the review did not involve handwriting training, and it is not known whether delivering such a handwriting retraining program in a home-based setting is feasible and acceptable to adults with stroke.

The current study set out to address these knowledge gaps by testing the feasibility of a four-week home-based handwriting retraining program involving task-specific practice for adults with stroke. Specific aims were to investigate: i) the feasibility of recruiting people with stroke to the study, ii) the feasibility of delivering the handwriting retraining program, and its acceptability for adults with stroke, and iii) the usefulness of outcome measures of handwriting performance for use in a future trial. The study will be the first to investigate the utility of various outcome measures of handwriting performance when used with adults with stroke, and contribute pilot data on the handwriting performance of this population. Moreover, the study will contribute useful information on the feasibility and acceptability of a handwriting retraining program for adults, a topic which has not been investigated to date.

2.4 Methods

2.4.1 Study design and recruitment

A quasi-experimental, pre-test post-test design was used. All participants received the handwriting retraining program. Outcome measures were collected from each participant before and after the intervention to investigate their utility for a future study. Ethical approval was obtained from a University Ethics Committee (approval number: 08-2011/ 13945) and two health services (approval number CH2/6/2012- 056).

Participants were eligible for recruitment to the study if they: i) had sustained a stroke at least three months previously; ii) had self-reported difficulties with handwriting; iii) had one or more goals related to handwriting performance; iv) were able to hold a pen and make a mark on a page; v) had sufficient cognitive and communication skills to follow instructions and complete a daily home
program; and vi) did not have apraxia or language impairment that significantly impacted on handwriting performance. The Mini Mental State Examination (Folstein et. al., 1975) and Apraxia Screen of Tulia (Vanbellingen et. al., 2010) were used if clinical observations suggested a cognitive impairment or apraxia. No formal standardised language screening instrument was used. Recruitment was conducted through third-parties including occupational therapy and physiotherapy colleagues and stroke associations, who were either sent a media release or the Participant Information Statement and study flyer. These third-parties disseminated information about the study through a web and email-based stroke listserv and in-person to patients at public hospitals, community stroke rehabilitation services and residential aged care facilities. Written advertisements were also forwarded and published on health-related websites and in a seniors’ newspaper (Appendix H). Interested participants or their therapist contacted the chief investigator by telephone or email.

### 2.4.2 Intervention

A four-week handwriting retraining program was conducted in participants’ homes including a nursing home, and other community-based locations including a workplace. The program included two, one-hour sessions per week (target of 8 hours overall) of supervised practice, with feedback by a research occupational therapist. Participants were additionally asked to complete three hours of independent (unsupervised) practice per week (target of 12 hours overall). The target of 20 hours of practice, supervised and unsupervised, was planned based on previous research on practice intensity (Hoy et al., 2011; Veerbeek et al., 2014), while still being feasible for therapists and stroke participants to complete (Kwakkel, 2006). The program used task-specific practice, with goals, feedback and high levels of repetitive practice, as described below and in table 2.1.

**Goals:** Goals were set in the first session, in collaboration with the occupational therapist and participant. These goals were based around handwriting tasks that were meaningful to participants, such as completing puzzles in the newspaper. Factors such as the type of writing, the audience, and desired outcomes were discussed. An example of one goal was: “To write a two-sentence telephone message that a family member can easily understand”. Participants could set multiple goals. The intervention, including the type of practice tasks used, was tailored to these goals. (Bayona et al., 2005; Dobkin, 2004). Goals were informally reviewed during the retraining program and new goals set if necessary. Short-term goals represented a step towards achieving long-term handwriting goals, and were also used as targets in practice sessions (e.g., writing 12 lines in 10 minutes).
Table 2.1: Example of a handwriting retraining program for Participant 3

<table>
<thead>
<tr>
<th>Handwriting goals</th>
<th>Handwriting tasks practised</th>
<th>Handwriting components practised</th>
<th>Outline of a session</th>
<th>Grading methods</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. To write a phone message, with two sentences and a phone number, that can be understood by my wife.</td>
<td>• Writing messages on note pad • Writing lists</td>
<td>• Writing individual letters, focusing on size and keeping loops open • Writing words, focusing on spacing between letters • Writing lists, focusing on moving down the page</td>
<td>• Review independent practise and achievement of targets (5 min) • Practise writing phone messages (10 min) • Feedback and problem-solving: Identify features to focus on and strategies to improve these (3 min) • Part-practice, focusing on features and strategies identified above (10 min) • Practise writing phone messages, incorporating strategies practised above (5 min) • Write lists (10 min) • Feedback and problem-solving: Identify features to focus on and strategies to improve these (3 min) • Part-practice, focusing on features and strategies identified above (10 min) • Practise writing lists, incorporating strategies practised above (5 min)</td>
<td>Writing position</td>
</tr>
<tr>
<td>2. To write a shopping list that I can read</td>
<td></td>
<td></td>
<td></td>
<td>Cognitive and speed demands</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Writing materials</td>
</tr>
</tbody>
</table>

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**Practice exercises:** The intervention program for each participant was tailored to address specific handwriting tasks related to individual goals. While the tasks and practice varied between participants, they all completed up to 20 hours of task-specific handwriting practice using principles described in the following sections. Whole handwriting tasks such as writing a postcard were practised. Part-practice was also used where participants practiced specific components of handwriting tasks, such as forming difficult letters or groups of letters. This part-practice allowed participants to concentrate on specific movements or component skills that were difficult (Birkenmeier et al., 2010; Turton et al., 2013); However, the ultimate aim of part-practice was to integrate these component skills into the whole task (Birkenmeier et al., 2010). Example practice instructions for whole- and part-practice tasks are presented in Appendix E and F. Tasks were practised in contextually relevant environments (e.g., writing while standing at a kitchen bench). Real-life resources were used such as writing in the person’s own calendar, rather than using simulated resources (Davis, 2006). Practice tasks were reviewed weekly by the occupational therapist, and graded throughout the program to provide the optimum level of challenge to participants (Birkenmeier et al., 2010; McEwen et al., 2014). Grading methods included increasing the number of repetitions, speed and/or cognitive demands (e.g., writing while listening to someone speak, and changing writing position or materials).

**Practice intensity:** Improving motor function requires high-intensity practice of tasks (Kwakkel, 2006). A high number of repetitions of practice tasks was encouraged. How a repetition was defined varied for each participant, based on their level of function, the type of practice tasks, and what outcomes were practical and efficient to count. A repetition could be defined as the number of letters, words or pages of text written. Repetitions per practice session were not recorded by participants and are not reported. Handwriting log sheets (Appendix G) recorded session duration and time spent on each practice task.

**Feedback and problem-solving:** Feedback is another characteristic of skill acquisition that is important for improving motor performance (Gilmore & Spaulding, 2001; Subramanian et al., 2010). An important role of the occupational therapist was to provide extrinsic feedback on participants’ handwriting performance. The feedback was specific and provided either during handwriting performance or immediately thereafter. Feedback included knowledge of results (e.g., the quality of letter formation) and knowledge of performance (e.g., thumb movements when forming letters) (Cirstea et al., 2006). Visual cues were used for feedback, such as circling or underlining problem areas and noting strategies to focus on during practice. Where possible, objective methods were used.
to provide measurable feedback, such as the number of lines of text written in a nominated time. Problem-solving was used to identify strategies to improve the features needing improvement (e.g., increasing height of ascenders, keeping loops open, and increasing spacing between letters and words). Participants were also taught to analyse their own handwriting and use problem-solving to generate strategies to improve handwriting performance (McEwen et al., 2014).

### 2.3.3 Outcome measurement

Two types of outcome measures were collected, in addition to participant demographic data: *Feasibility measures* and *participant outcome measures*. Feasibility measures included the recruitment rate, number of hours of supervised and unsupervised practice, and the type and frequency of handwriting goals and practice tasks completed during the study. Acceptability was measured using a written, self-report questionnaire administered after the follow-up period (eight weeks). Participant outcome measures included observed and self-rated measures of handwriting performance. These measures were collected at baseline, immediately following completion of the four-week program, and four weeks after completion of the program (eight weeks). Baseline measures were administered by the first author (BS), who also conducted the intervention program. Post-intervention and follow-up measures were administered by a research assistant not otherwise involved in the study. To achieve assessor blinding, legibility and pen control samples were de-identified, placed in random order then scored by the second author (AM). In this feasibility study, outcome measures were administered to investigate their utility for use in a future study, rather than to demonstrate a treatment effect.

The *Handwriting Assessment Battery (HAB)* (Faddy et al., 2008) was first used to measure handwriting speed, legibility and pen control. The HAB (Appendix C) is a collection of sub-tests from paediatric handwriting and general upper limb assessments that are relevant to adult handwriting. The written output of some sub-tests was scored using more than one rating scale. The sentence legibility subtest from the HAB, a five-word self-composed sentence, was also scored using a second rating method, the *modified Four Point Scale (mFPS)* (Au et al., 2012). The mFPS includes two Likert scales which rate the legibility of sentences (mFPS-Sentences) and words (mFPS-Words). Finally, handwriting performance and disability were self-rated by participants using the *modified Disabilities of the Arm, Shoulder and Hand Scale (modified DASH)*. The modified DASH is a self-report measure of handwriting disability, with questions and scales from the Disabilities of the Arm, Shoulder and Hand scale (DASH) (Hudak, Amadio, & Bombardier, 1996) modified to focus on handwriting. The outcome measures produced by this process are summarised below.
Sentence legibility was the primary outcome of interest. Legibility of a five word, self-composed sentence was scored using five rating scales, to compare their utility and feasibility: (a) the modified ETCH-Word (mETCH-W) rating system from the HAB (Faddy et al., 2008), which was considered the primary outcome measure for this study. Each word was rated as either legible (score of 1) or illegible (score of 0), legible words were counted, and a percentage legibility score was calculated for the sentence (0-100%); (b) the modified ETCH-Letter (mETCH-L) rating system from the HAB was also used. Each letter was rated as legible (score of 1) or illegible (score of 0), legible letters counted, and a percentage legibility score was calculated for the sentence (0-100%); (c) functional legibility was calculated using the mFPS-Words (1-4), where the number of words in a sentence with ‘functional legibility’ were counted (i.e., not all letters are clear but the meaning can be understood: a score of 3 or 4), and a functional legibility score was calculated for the sentence (0-100%); (d) perfect legibility was calculated using the mFPS-Words, where the number of words in a sentence with ‘perfect legibility’ were counted (i.e., all letters are clear and the meaning can be understood: a score of 4 on the m4PS), and a perfect legibility score was calculated for the sentence (0-100%); and (e) sentence legibility was calculated using the mFPS for sentences (categories 1-4).

Legibility of single characters was measured using sub-tests of the HAB: (a) legibility of upper case alphabet letters (range 0-26 letters) with a proportion calculated for example 22/26, producing a percentage legibility score, (0-100%); (b) legibility of lower case alphabet letters (range 0-26 letters) with a proportion calculated producing a percentage legibility score, (0-100%); and (c) legibility of numerals (range 1-12). Pen control was measured using the line and dot drawing sub-tests of the HAB, where participants attempted to draw 10 lines across an A4 page in 20 seconds, and 10 dots on the page in five seconds. These tests were scored as: (a) achieved/not achieved; and (b) the number of lines/dots drawn (n). Writing speed was measured using the writing speed sub-test of the HAB, recording the time taken to copy a 24-letter sentence (seconds). Self-perception of handwriting performance was measured using the modified DASH: (a) ability to perform handwriting tasks (range 1-5, with 5 representing unable); (b) level of impact of handwriting impairment on social activities (range 1-5, with 5 representing extreme); and (c) ability to perform work and other activities of daily living as a result of the handwriting impairment (range 1-5, with 5 representing unable).

2.3.4 Data analysis

Feasibility of recruitment, the outcome measures and intervention were analysed using descriptive statistics, including means, standard deviations and proportions. Written self-reported comments obtained at the end of eight weeks about participant preferences were analysed.
Qualitatively, and grouped into simple topic categories. No in-depth qualitative data analysis was conducted. Utility of the outcome measures was also measured by examining participant results. Descriptive statistics including means and standard deviations, and/or medians and interquartile ranges were calculated for baseline, post-intervention and follow-up measures. Mean or median differences were calculated between these three time points, reported with a 95% confidence interval (CI) for continuous variables (percentage legibility and speed), and interquartile range for dichotomous (achieved/not achieved) and ordinal (modified Four Point Scale and modified DASH) variables. Statistical significance of differences in proportions were analysed using McNemar’s test (dichotomous measures). Changes between time points on ordinal and continuous variables were analysed using Wilcoxon Signed Ranks test (data from two time points: pre-to-post; and post-to-follow-up; and pre-to-follow-up). Data were analysed using SPSS (IBM Corp, 2011); p-values ≤0.05 were considered statistically significant.

2.5 Results

2.5.1 Description of the participants

Seven participants (four male, three female) met the inclusion criteria and were recruited. Participant characteristics are presented in Table 2.2. The mean age of participants was 69 years (SD=15). One participant was left-handed with a left-sided paresis, and five participants were right-handed with a right-sided paresis. One participant was right-handed, had a right-sided lesion and mild ataxia, but no visible paresis. Two participants were in paid employment at the time of their stroke, and one of these participants remained in paid employment at the time of the study. Level of disability at the time of the study was measured using the modified Rankin Scale (mRS) (UK TIA Study Group, 1991) The majority of participants (72%) were classified as having no significant disability or a slight disability.

2.5.2 Feasibility of recruitment

Twenty-one people expressed interest and contacted the researchers by phone or email during the recruitment period. A summary of recruitment methods used and outcomes is shown in Appendix I. Twelve people (57%) did not meet the inclusion criteria and were excluded from the study. Reasons for exclusion were that the person: had not had a stroke (n=3), had a hemiparesis in the non-writing arm (n=5), had a severe communication and cognitive impairment affecting their ability to follow instructions and generate text (n=1), or lived too far away for weekly visits (n=3). Nine people met
the inclusion criteria and were invited to participate (eligibility fraction 43%). Of the nine eligible people, seven were recruited (enrolment fraction 78%). Two people declined to participate, stating that they were too busy to complete the program. The seven participants were recruited in an 18-month period, with a recruitment rate of 0.3 participants per month. There were no dropouts.

Table 2.2: Participant characteristics (N=7)

<table>
<thead>
<tr>
<th>Participant data</th>
<th>N (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age - mean (SD)</td>
<td>69 (15)</td>
</tr>
<tr>
<td>Years since stroke- mean (SD)</td>
<td>3 (3)</td>
</tr>
<tr>
<td>Gender</td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>3 (43%)</td>
</tr>
<tr>
<td>Female</td>
<td>4 (57%)</td>
</tr>
<tr>
<td>Side of paresis</td>
<td></td>
</tr>
<tr>
<td>Left</td>
<td>1 (14%)</td>
</tr>
<tr>
<td>Right</td>
<td>5 (71%)</td>
</tr>
<tr>
<td>Ataxia- no visible paresis</td>
<td>1 (14%)</td>
</tr>
<tr>
<td>Pre-stroke hand dominance</td>
<td></td>
</tr>
<tr>
<td>Left</td>
<td>1 (14%)</td>
</tr>
<tr>
<td>Right</td>
<td>6 (86%)</td>
</tr>
<tr>
<td>In paid employment at time of stroke</td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>2 (29%)</td>
</tr>
<tr>
<td>No</td>
<td>5 (71%)</td>
</tr>
<tr>
<td>mRS: Level of disability at time of study</td>
<td></td>
</tr>
<tr>
<td>0- No symptoms at all</td>
<td>0 (0%)</td>
</tr>
<tr>
<td>1- No significant disability</td>
<td>2 (29%)</td>
</tr>
<tr>
<td>2- Slight disability</td>
<td>3 (43%)</td>
</tr>
<tr>
<td>3- Moderate disability</td>
<td>1 (14%)</td>
</tr>
<tr>
<td>4- Moderately severe disability</td>
<td>1 (14%)</td>
</tr>
<tr>
<td>5- Severe disability</td>
<td>0 (0%)</td>
</tr>
</tbody>
</table>

Note. mRS= modified Rankin Scale
2.5.3 Feasibility and acceptability of the intervention

Participants completed a mean of 10.5 hours (SD=3) supervised practice with an occupational therapist across eight sessions. Most participants (n=6) felt that the frequency of sessions and duration of the program was appropriate. One participant commented that the program was “about the right length. I felt like I couldn’t get any better by the end”, with one participant commenting that a longer duration may have been preferable “It was a good length – needed to get the muscles working. I may have benefited from longer because I was better when the OT was present”. Participants completed a further 7.9 hours (SD=2.7) of independent (unsupervised) practice over four weeks, which was less than recommended (3 hrs/week, 12 hours in total). Participants felt the target of three sessions of independent practice per week was appropriate and important, however some found this target difficult to achieve: “I was juggling family so it could be difficult sometimes. It’s good to aim for 3 hours a week but you need to be organised”. All participants felt that the home or residential care setting was appropriate, as it was “very convenient” and “easier, you don’t have to worry about transport”.

Categories and the frequency of handwriting goals are summarised in Table 2.3, and practice tasks are summarised in Table 2.4. Participants varied in the type of practice tasks they most enjoyed writing. One task that produced mixed responses was writing self-generated text (e.g., writing a story or postcard), compared to copying text. Several participants enjoyed writing self-generated text because it encouraged self-expression and creativity, while others enjoyed copying because they could concentrate on writing without thinking about what to write. Although some tasks were less enjoyable, participants realised the importance of repetitive practice; for example, “The envelopes were boring but gave me a lot of practice. Writing out [difficult] words repeatedly was disappointing but had to be done. You have to do things over and over again, especially if you are having difficulty”.

All participants commented on the usefulness of the feedback and self-analysis: “Feedback, encouragement, analysing features then concentrating on them in practice [was useful]. [The supervised practice] made me focused”, and “The practice was good but it wasn’t the be-all-and-end-all. The writing homework wasn’t the main focus; it was learning strategies ... The practice helped to apply the strategies”. Another participant valued specific, constructive feedback: “They were encouraging but quick to point out anything going wrong that needed to be corrected. ... Handwriting is an area with particular skills that need to be relearned, redeveloped and pointed out.”
“Great” and “You’re doing well” are warm fuzzies that don’t really help. Specific feedback is important.”

Table 2.3: Category and frequency of handwriting goals (N=7)

<table>
<thead>
<tr>
<th>Broad handwriting goals</th>
<th>Number of participants</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Legibility-related goals</strong></td>
<td></td>
</tr>
<tr>
<td>Signature that is consistent and recognisable</td>
<td>4 (57%)</td>
</tr>
<tr>
<td>Shopping lists that are legible to self</td>
<td>3 (43%)</td>
</tr>
<tr>
<td>Letters and cards that are neat and legible to others</td>
<td>3 (43%)</td>
</tr>
<tr>
<td>Calendar entries that are legible to self</td>
<td>2 (29%)</td>
</tr>
<tr>
<td>Address book entries and revisions that are legible to self</td>
<td>2 (29%)</td>
</tr>
<tr>
<td>Puzzles and word games in newspapers</td>
<td>1 (14%)</td>
</tr>
<tr>
<td>Improved handwriting performance in general</td>
<td>1 (14%)</td>
</tr>
<tr>
<td>Financial and other forms that are legible to self</td>
<td>1 (14%)</td>
</tr>
<tr>
<td>Cheques that are legible to self and others</td>
<td>1 (14%)</td>
</tr>
<tr>
<td><strong>Legibility- and speed-related goals</strong></td>
<td></td>
</tr>
<tr>
<td>Phone messages that are legible to self and others</td>
<td>3 (43%)</td>
</tr>
<tr>
<td>Notes recorded during interviews and meetings that are legible to self</td>
<td>1 (14%)</td>
</tr>
<tr>
<td>Notes and forms completed during work interviews and assessments that are legible to self</td>
<td>1 (14%)</td>
</tr>
</tbody>
</table>

*Note.* Proportions do not add up to 100% because participants had more than one goal.
Table 2.4: Frequency of practice tasks completed by participants (N=7)

<table>
<thead>
<tr>
<th>Categories of practice tasks</th>
<th>n (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Story or a passage on a particular topic</td>
<td>6 (86%)</td>
</tr>
<tr>
<td>Lists</td>
<td>5 (71%)</td>
</tr>
<tr>
<td>Phone messages in a small notebook or adhesive notes (seated and standing)</td>
<td>5 (71%)</td>
</tr>
<tr>
<td>Signature (seated and standing)</td>
<td>4 (57%)</td>
</tr>
<tr>
<td>Events and phone numbers in calendar (seated and standing)</td>
<td>4 (57%)</td>
</tr>
<tr>
<td>Messages and addresses on postcards and cards</td>
<td>3 (43%)</td>
</tr>
<tr>
<td>Copying out passages from a book or magazine</td>
<td>3 (43%)</td>
</tr>
<tr>
<td>Word-finding puzzle</td>
<td>3 (43%)</td>
</tr>
<tr>
<td>Addressing envelopes</td>
<td>3 (43%)</td>
</tr>
<tr>
<td>Taking notes during TV show, radio program, conversation or meeting</td>
<td>3 (43%)</td>
</tr>
<tr>
<td>Writing names, phone numbers and addresses in address book</td>
<td>2 (29%)</td>
</tr>
<tr>
<td>Completing forms</td>
<td>2 (29%)</td>
</tr>
<tr>
<td>Writing name</td>
<td>1 (14%)</td>
</tr>
<tr>
<td>Writing cheques</td>
<td>1 (14%)</td>
</tr>
</tbody>
</table>

Note. Proportions do not add up to 100% because participants practised more than one task.
2.5.4 Feasibility and utility of the outcome measures

Within-group differences for the primary and secondary outcome measures are presented in Table 2.5. Individual participant characteristics (e.g., hours of independent practice completed) and primary outcome measure scores are presented in Table 2.6. None of the outcome measures showed a clinically or statistically significant change in mean scores. The primary measure was the mETCH-W, which recorded the proportion of legible words in a sentence (0-100%). Non-significant changes in legibility were recorded over time, with a mean increase of 13% (95% CI -24 to 50) from baseline to follow-up (6% pre to post, 7% post to follow-up, on the 0-100% mETCH-W scale). Five different rating systems of sentence legibility were included in the study, to compare their relative feasibility and utility. Baseline, post-intervention and follow-up scores for individual participants for these sentence legibility measures are shown in figure 1. Three participants showed a clinically significant improvement on the mETCH-W from baseline to follow-up (P1 = 0% to 60%; P3 = 40% to 100%; P6 = 80% to 100% legibility, respectively). However, a ceiling effect was evident for this measure, as the maximum score of 100% was achieved on eight occasions across the study (n=3 at baseline, n=2 post-intervention and n=3 at follow-up; 38% of all mETCH-W scores). The presence of ceiling effects are indicative that the measure has limited interpretability for this sample (Terwee et al., 2012).

Although some of the secondary outcome measures changed over time (see Table 2.5), these changes were not clinically or statistically significant, with large standard deviations and wide confidence intervals due to the small sample. Scoring sentence legibility by rating individual letters (mETCH-L) was slower than the mETCH-W and was no more sensitive to change. The modified Four Point Scale-Sentences was quick to administer, but did not show any significant change. Five participants scored 3 or 4 on this measure at baseline, which is thought to be the norm for healthy older adults (van Drempt et al., 2011a). A ceiling effect was evident for the modified Four Point Scale-Functional Legibility, with the maximum score of 100% being achieved on nine occasions across the study (n=3 at baseline, n=3 post-intervention and n=3 at follow-up; 43% of all modified Four Point Scale-Functional Legibility scores across the study). This ceiling effect was not evident for the modified Four Point Scale-Perfect Legibility; however, this outcome measure showed less mean change than the primary outcome measure (mETCH-W).
Table 2.5: Handwriting outcomes showing within-group scores at each time point and change scores

<table>
<thead>
<tr>
<th>Measure</th>
<th>Baseline (T1)</th>
<th>Post-intervention (T2)</th>
<th>Change: T1-T2 (95% CI)</th>
<th>p-value T1-T2</th>
<th>Follow-up (T3)</th>
<th>Change: T2-T3 Mean (95% CI)</th>
<th>p-value T2-T3</th>
<th>Change: T1-T3 Mean (95% CI)</th>
<th>p-value T1-T3</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Sentence legibility (0-100%)</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>mETCH-W rating</td>
<td>64 (36)</td>
<td>70 (34)</td>
<td>6(-34 to 46)</td>
<td>0.34</td>
<td>77 (29)</td>
<td>7(-29 to 43)</td>
<td>0.46</td>
<td>13(-24 to 50)</td>
<td>0.37</td>
</tr>
<tr>
<td>mETCH-L rating</td>
<td>56 (30)</td>
<td>61 (27)</td>
<td>5(-27 to 37)</td>
<td>0.50</td>
<td>62 (24)</td>
<td>1(-28 to 30)</td>
<td>0.92</td>
<td>6(-25 to 37)</td>
<td>0.96</td>
</tr>
<tr>
<td>Functional legibility - mFPS-Words</td>
<td>77 (37)</td>
<td>74 (38)</td>
<td>-3(-45 to 39)</td>
<td>0.79</td>
<td>80 (31)</td>
<td>6(-33 to 45)</td>
<td>0.59</td>
<td>3(-35 to 41)</td>
<td>0.81</td>
</tr>
<tr>
<td>Perfect legibility - mFPS-Words</td>
<td>40 (28)</td>
<td>37(31)</td>
<td>-3(-36 to 30)</td>
<td>0.90</td>
<td>46(34)</td>
<td>9(-28 to 46)</td>
<td>0.26</td>
<td>6(-29 to 41)</td>
<td>0.80</td>
</tr>
<tr>
<td>Sentence legibility - mFPS-Sentences (1-4) mdn(IQR)</td>
<td>3(2 to 3)</td>
<td>3(2 to 4)</td>
<td>0</td>
<td>0.56</td>
<td>3(2 to 4)</td>
<td>0</td>
<td>0.32</td>
<td>0</td>
<td>0.08</td>
</tr>
<tr>
<td><em>Single character legibility (0-100%)</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lower case alphabet writing legibility</td>
<td>65(32)</td>
<td>72(30)</td>
<td>7(-28 to 42)</td>
<td>0.35</td>
<td>66(29)</td>
<td>-6(-39 to 27)</td>
<td>0.44</td>
<td>-1(-36 to 34)</td>
<td>0.62</td>
</tr>
<tr>
<td>Upper case alphabet writing legibility</td>
<td>63(37)</td>
<td>75(24)</td>
<td>12(-22 to 47)</td>
<td>0.20</td>
<td>74(26)</td>
<td>-1(-29 to 27)</td>
<td>0.87</td>
<td>11(-25 to 47)</td>
<td>0.37</td>
</tr>
<tr>
<td>Numeral writing legibility</td>
<td>72(38)</td>
<td>69(36)</td>
<td>-3(-45 to 39)</td>
<td>0.79</td>
<td>77(20)</td>
<td>8(-23 to 40)</td>
<td>0.40</td>
<td>5(-23 to 35)</td>
<td>0.74</td>
</tr>
<tr>
<td><strong>Pen control</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Line drawing - participants who achieved task (n)</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1.00</td>
<td>2</td>
<td>0</td>
<td>1.00</td>
<td>1</td>
<td>1.00</td>
</tr>
<tr>
<td>Line drawing - number of lines drawn</td>
<td>8(3)</td>
<td>8(3)</td>
<td>0(-3 to 3)</td>
<td>0.91</td>
<td>7(3)</td>
<td>-1(-4 to 2)</td>
<td>0.85</td>
<td>-1(-4 to 2)</td>
<td>1.00</td>
</tr>
<tr>
<td>Dot drawing - participants who achieved task (n)</td>
<td>4</td>
<td>4</td>
<td>0</td>
<td>1.00</td>
<td>6</td>
<td>2</td>
<td>0.50</td>
<td>2</td>
<td>0.63</td>
</tr>
<tr>
<td>Dot drawing - number of dots drawn</td>
<td>13(8)</td>
<td>10(5)</td>
<td>-3(-10 to 4)</td>
<td>0.31</td>
<td>16(7)</td>
<td>6(1 to 13)</td>
<td>0.03</td>
<td>3(-5 to 11)</td>
<td>0.10</td>
</tr>
<tr>
<td><strong>Writing speed</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Writing speed (sec)</td>
<td>39(31)a</td>
<td>64(63)</td>
<td>25(-30 to 81)</td>
<td>0.46</td>
<td>73(81)</td>
<td>9(-72 to 90)</td>
<td>0.61</td>
<td>34(-32 to 100)</td>
<td>0.51</td>
</tr>
<tr>
<td><em>Impact of handwriting disability (1-5) (mdn; IQR)</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Handwriting ability</td>
<td>4(3 to 4)</td>
<td>3(2 to 4)</td>
<td>-1</td>
<td>0.10</td>
<td>4(2-4)</td>
<td>1</td>
<td>1.00</td>
<td>0</td>
<td>0.10</td>
</tr>
<tr>
<td>Interference with social activities</td>
<td>3(1 to 4)</td>
<td>2(1 to 3)</td>
<td>-1</td>
<td>0.26</td>
<td>2(1-3)</td>
<td>0</td>
<td>0.68</td>
<td>-1</td>
<td>0.34</td>
</tr>
<tr>
<td>Interference with work and other ADLs</td>
<td>3(3 to 4)</td>
<td>2(2 to 4)</td>
<td>-1</td>
<td>0.21</td>
<td>2(1-4)</td>
<td>0</td>
<td>0.50</td>
<td>-1</td>
<td>0.04</td>
</tr>
</tbody>
</table>

Note. T1 = baseline; T2 = 4 week post-intervention; T3 = 8 week follow-up (4 weeks after program completion). mETCH-W = modified Evaluation of Children’s Handwriting-Words. mETCH-L = modified Evaluation of Children’s Handwriting-Letters. mFPS = modified Four Point Scale. Descriptive statistics are mean(SD) unless otherwise indicated. Change scores were calculated by the difference between the two time points indicated in column heading, and are recorded as mean (95% confidence interval (CI)) unless otherwise indicated. *n=6 one participant could not complete the test; *McNemar’s test. All other p-values reported used Wilcoxon Signed Ranks Test.

## Table 2.6 Individual participant characteristics and primary outcome measure scores

<table>
<thead>
<tr>
<th>Participant</th>
<th>Age (years)</th>
<th>Time since stroke (years)</th>
<th>MRS score</th>
<th>Amount of practice (hours)</th>
<th>mETCH-W (T1) (%)</th>
<th>mETCH-W (T2) (%)</th>
<th>Change: T1-T2</th>
<th>mETCH-W (T3) (%)</th>
<th>Change T2-T3</th>
<th>Change T1-T3</th>
</tr>
</thead>
<tbody>
<tr>
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*Note: MRS= Modified Rankin Scale (0-6, 6= higher level of disability), T1 = baseline; T2 = 4 week post-intervention; T3 = 8 week follow-up (4 weeks after program completion). mETCH-W = modified Evaluation of Children’s Handwriting-Words (0-100%)*
Figure 2.1: Individual participant scores at three time points for the five legibility measures

*Note.* mETCH-W = modified Evaluation of Children’s Handwriting-Words. mETCH-L = modified Evaluation of Children’s Handwriting-Letters. mFPS = modified Four Point Scale.
Interestingly, writing speed showed a small decrease over the three time points (i.e. slower speed) for four of the seven participants. The line drawing test did not show significant changes when scoring either the number of lines drawn or successful test completion. The dot drawing test also produced insignificant changes, however counting the number of dots drawn was more sensitive than scoring successful test completion. The completion rate for the outcome measures was 100%, with the exception of the writing speed test. One participant (P1), who wrote very slowly due to poor pen control, was unable to complete the writing speed test at baseline due to fatigue. This participant completed the line and dot drawing, alphabet writing and sentence composition tests, taking approximately 70 minutes, before asking to cease the assessment.

2.6 Discussion

There were three key findings from this study of handwriting retraining with adults with stroke. First, recruiting adequate numbers of people with stroke for a randomised trial may not be feasible using the methods employed in the present study. Second, the intervention program was feasible to deliver and acceptable to adults with stroke, with participants able to complete the program and reporting satisfaction with the practice tasks and feedback from the occupational therapist. Third, the primary outcome (mETCH) produced changes in handwriting performance for some participants. However, there was a ceiling effect evident for this measure, and it did not show change for participants with readable but untidy handwriting.

Recruitment was slow and unexpectedly difficult. The low recruitment rate of this study (0.3 per month) suggests that recruiting an adequate number of people with stroke for a RCT, for this intervention, in a single metropolitan city in Australia may not be feasible. A multi-site study may yield greater recruitment numbers. Another method of recruitment may be by contacting potential participants through registers such as the Australian Clinical Stroke Registry (AUSCR) (Cadilhac et al., 2010). Recruiting participants from inpatient facilities before discharge may also increase numbers; however, participating in a handwriting program may not be attractive or appropriate for people in inpatient facilities, where handwriting may be a lower priority amongst other goals related to upper limb function or discharge from hospital. Widening the eligibility criteria to people with other neurological
conditions such as traumatic brain injury may help to increase the sample size, although that would limit the generalizability of results to people with stroke. The intervention program was suitable for one participant with mild ataxia, and it is recommended that people with mild-to-moderate ataxia be considered for inclusion in future studies of handwriting retraining post-stroke.

The handwriting program would be feasible to deliver in a future study, and was acceptable to participants. Selection bias may have affected this result, as only people who were motivated to complete handwriting practice agreed to enrol. Two adults with stroke declined to participate due to the hours of practice time required. The program would also be feasible to deliver in clinical practice, as it is likely that a publically-funded therapist would be able to deliver eight sessions of therapy through an out-patient or day therapy service. If an adult with stroke has rehabilitation goals additional to handwriting and/or resources do not permit an occupational therapist delivering this number of sessions, having a trained therapy assistant deliver some of the sessions may be considered. Delivering the intervention by distance may also be feasible. Distance training would require a real-time video link with a high quality close-up image in order to deliver specific feedback on the handwriting process and output. The intervention could also be delivered in an inpatient setting, provided that writing materials and the environment are set up to simulate a realistic environment for the goal task e.g. writing shopping lists on a surface at the height of a kitchen bench.

The primary outcome measure (mETCH-W) appeared to capture change in handwriting performance for some participants, showing what could be considered clinically significant change across the three time points for some individuals. A ceiling effect was evident for this measure, and it may not be a suitable measure for all adults with a handwriting impairment. Several participants in this study had writing that was readable (the main criteria for the mETCH-W rating system), but they still expressed a concern that their handwriting was untidy or of poor quality. This concern about handwriting quality was reflected in goals such as “writing a neat Christmas card”. Features of handwriting that may contribute to writing quality, such as straightness of lines, consistency of spacing and evenness of letters, are not addressed by the mETCH-W. An additional outcome measure that can evaluate handwriting neatness or quality is recommended for future studies. Further research is required investigating features that contribute to writing quality and ways to evaluate this phenomenon.
Additionally, scoring only five words using the mETCH-W may have reduced the ability of this outcome measure to accurately reflect a person’s handwriting performance. Occasional illegible letters or words are common even amongst healthy writers [(van Drempt et al., 2011a)], but each illegible word resulted in a large (20%) decrease in score on the mETCH-W when only five words were scored. Additionally, when only a five word handwriting sample was rated it was possible to achieve a high score on the mETCH even when other important impairments affecting handwriting were present. One participant (P4) who scored 100 at baseline held his pen using a static, immature grasp, and performed writing movements using his shoulder and arm, which was reportedly painful, fatiguing and not functional for writing more than one or two sentences. Rating a larger writing sample with more words may have provided a more accurate representation of this participant’s writing performance. Therefore it is recommended that more than five words are rated using the mETCH-W.

Sentence legibility was measured using four rating systems for comparison with the mETCH-W. The mFPS-Sentences (scoring the global legibility of a sentence using a four-point scale) was quick to administer and may be suitable for clinical practice, but this outcome measure does not appear to be sensitive enough for research purposes. The other three rating systems scored five words in the sentence based on whether the individual letters were legible. This method is more time-consuming than scoring words. Two of these outcome measures (mETCH-L and mFPS-Words: Perfect Legibility) required every letter in the sentence to be legible. These outcome measures did not have the ceiling effect that was evident for the mETCH-W and the mFPS-Words: Functional Legibility, however the mETCH-W showed more mean change than these outcome measures. Additionally, scoring individual letters may not be as meaningful as scoring the overall readability of words or sentences. Therefore, the mETCH-W is recommended for measuring sentence legibility in future studies. Outcome measures of single character legibility, including alphabet and numeral writing, were time-consuming to score. As writing the alphabet is not a task most adults perform (Gozzard et al., 2012; van Drempt et al., 2011a), these outcome measures may be less meaningful than measuring sentence legibility.

Writing speed showed a small mean decrease for some participants. Measuring writing speed may not have been meaningful for this sample, as only one participant wished to increase their writing speed. Additionally, reduced speed was a strategy that most
participants used to increase legibility. However, if improving writing speed is a goal of intervention, the time taken to write a sentence would be a quick and objective way of measuring this in clinical practice.

2.7 Limitations

Limitations of this study include the small sample size \((N=7)\) and absence of a control group. The aims of this study related to feasibility, rather than demonstrating a treatment effect. Therefore outcome data which are reported should be interpreted with caution due to the likely biases inherent in a non-randomised, underpowered study. Further, outcomes including feasibility may have been influenced by selection bias, where only people who were motivated to complete handwriting practice contacted the researchers and enrolled in the study. Additionally, the seven participants had different levels of motor function, and ranged in ages between 56 and 87 years. While these differences may be viewed as a limitation, the variability allowed us to test the feasibility of outcome measures and the program. Nonetheless, older adults do write more slowly than younger adults, and age rather than stroke may partly explain the variability in handwriting performance at baseline and follow-up. A further limitation of this study was the use of the modified DASH to measure participant perceptions of their own handwriting. This self-rating scale may have been a potential source of bias, and patient perception and self-rating scales have not been correlated with actual writing capability. Finally, practice intensity was recorded based on time spent performing practice activities, rather than number of repetitions, which may be a less accurate estimate of intensity.

2.8 Conclusions

A quasi-experimental single cohort feasibility study has been completed with seven participants. Recruitment was the main threat to feasibility in this study. Recommendations have been made which may increase recruitment to a future study, although findings suggest that recruiting adequate numbers for a RCT would not be feasible in a single metropolitan city in Australia. The four-week intervention using task specific practice and feedback from an occupational therapist was feasible to deliver, and was acceptable to adults with stroke. A similar program would be feasible to deliver in a future study and in clinical practice. The mETCH-W may record change in handwriting legibility in future studies with a larger sample, but more words than five should be rated. Given that the mETCH-W had a ceiling
effect, a measure of handwriting quality may need to be developed to capture change in handwriting performance of people with stroke whose writing is already legible. Further research investigating ways to measure this phenomenon is required.
Chapter 3: Discussion

3.1 Introduction

The broad aim of this study was to investigate the feasibility of a four-week task-specific handwriting retraining program for adults with stroke. Specific aims of the study were to investigate the feasibility of recruitment of adults with stroke to a study involving a four-week home-based handwriting retraining program, feasibility and utility of handwriting outcome measures, and feasibility and acceptability of the handwriting training program. Outcome measures were collected before and after the intervention. Key points in this discussion relate to the three specific aims of the study.

First, recruiting adequate numbers of people with stroke for a randomised controlled trial may not be feasible using the methods employed in the present study. Second, the outcome measures were feasible to administer, and some of the outcome measures demonstrated change across the time points for this small sample. The primary outcome (mETCH) produced changes in handwriting performance for some participants, but a ceiling effect was evident for this measure. Additionally, the outcome measures did not show change for participants with readable but untidy handwriting, as such additional ecologically valid outcome measures may be required in a future study. Third, the intervention program was feasible to deliver and acceptable to adults with stroke. Participants were able to complete the program and reported satisfaction with the practice tasks and feedback from the occupational therapist.

3.2 Recruitment to a randomised controlled trial may not be feasible

Recruitment for the study was slow and unexpectedly difficult. Seven participants were recruited in an 18-month period, which was less than the target number (n = 20). The low recruitment rate of this study (0.3 per month) suggests that recruiting an adequate number of people with stroke for a randomised controlled trial, for this intervention, in a single metropolitan city in Australia may not be feasible. Recruitment of stroke participants to a future study should address the factors as listed below.
3.2.1 Reaching out to people with stroke

In Australia, many stroke survivors are not in regular contact with the health system or researchers after the first year post-stroke. This situation limits the opportunities to promote studies of this kind amongst people with chronic disabilities post-stroke. A multi-site study with investigators at each site may yield greater recruitment numbers. Levels of contact with stroke survivors may be increased by contacting participants via the Australian Clinical Stroke Registry (AUSCR) (Cadilhac et al., 2010). Recruiting participants from acute inpatient facilities before discharge may also increase numbers; although participation in a handwriting may be a low priority in an inpatient setting when compared with other goals related to upper limb function or discharge from hospital.

3.2.2 Recruitment methods and duration

Various methods of recruitment were used, including distribution of study information by therapists working in rehabilitation, stroke recovery clubs, an on-line stroke forum and residential aged care facilities, and a media release resulting in media articles about the study (Appendix H). The most successful method of recruitment in terms of number of responses was public media. The largest number of responses \((n = 10)\) and people recruited \((n = 4)\) were from readers of a newspaper, \textit{The Senior}, which was distributed amongst seniors in NSW through mail subscriptions and aged-care facilities. Future studies should be promoted more widely in public media including seniors’ newsletters and websites. The duration of this study was limited by funding and time constraints, therefore recruitment needed to cease after 18 months before adequate numbers were recruited. Although recruitment is still likely to be slow, a longer recruitment period should result in more participants.

3.2.3 Eligibility criteria

The intervention program may also be suitable for people with handwriting impairment caused by other neurological conditions such as traumatic brain injury, although widening the eligibility criteria would limit the generalisability of the results to stroke. This study included one participant with handwriting disability due to ataxia, rather than hemiparesis. The intervention program was suitable for that participant, and it is recommended that people with mild to moderate ataxia be included in a future randomised
controlled trial. Suitability of the intervention program for people with severe ataxia was not investigated.

3.3 The intervention was feasible and acceptable to adults with stroke

An aim of the study was to investigate the feasibility and acceptability of a four-week handwriting retraining program, involving task-specific practice. Research questions included the common goals and difficulties of adults with stroke, whether the program was feasible to deliver, and the perception of adults with stroke of the program. The discussion in the following section relates to these research questions.

3.3.1 Supervised practice with an occupational therapist

Participation in the intervention program was feasible, with participants able to complete the targeted amount of occupational therapy coaching sessions. Participants were mostly able to participate in occupational therapy coaching sessions as scheduled. Sessions with the occupational therapist were usually arranged one week in advance. When appointments needed to be changed, they were rescheduled within the same week where possible. For three participants, cancelled sessions could not be rescheduled within the same week, resulting in their intervention program running longer than the four weeks. For two of these participants, this was due to an interstate trip scheduled at the last minute. For these two participants, the eight occupational therapy sessions were completed within five weeks, instead of the usual four weeks. They performed independent practice sessions while they were away from home. The other participant was seen at a place of work, and unexpected urgent events often arose resulting in sessions being cancelled at short notice. This participant’s program ran over eight weeks, which included a two-week break over the Christmas period where the program was ‘on hold’ and no practice was completed.

The handwriting program would be feasible to deliver in a future study, and was acceptable to participants. The program would also be feasible to deliver in clinical practice, as it is likely that a publically-funded therapist would be able to deliver eight sessions of therapy through an out-patient or day therapy service. If an adult with stroke has rehabilitation goals additional to handwriting, and/or if resources do not permit an occupational therapist delivering this number of sessions, having a trained therapy assistant deliver some of the sessions may be considered. Delivering the intervention by distance may
also be feasible, requiring a real-time video link with a high quality close-up image in order to deliver specific feedback on the handwriting process and output. The intervention could be delivered in an inpatient setting, or an outpatient, day therapy or clinic setting, provided that writing materials and the environment are set up to simulate a ‘real life’ environment (e.g., writing shopping lists on a surface at the height of a kitchen bench). The feasibility and cost of these different models of service delivery warrant further investigation.

3.3.2 Independent practice.

Participants were asked to complete three hours per week of independent, unsupervised practice, a total of 12 hours over the four-week program. The mean amount of practice time for the group was less than this target (7.9 hours). There was variability in the group, with some participants completing much less than the target amount of practice, while others completed more. Reasons for not completing practice were mostly related to lack of time, for example participant 5 reported she found it difficult to complete the practice in addition to her household and motherhood duties. Some participants appeared to require a second person to be present in order to complete the practice, possibly for motivation or to provide feedback. A relative of Participant 1 reported that she did not complete the practice exercises unless he was present. It is unclear whether the target amount of practice was too high for this participant, or scheduling practice sessions in that person’s diary may have been helpful in increasing practice time.

3.3.3 Handwriting goals

The handwriting goals of most participants related to legibility. Legibility-related goals varied in terms of the reading audience (i.e., who needed to read it) and specific aspects needing improvement. Participants with poorer handwriting performance wanted to produce writing that was readable to themselves (e.g., understanding a shopping list they had written) or others (e.g., writing a phone message that was clear to the recipient). Participants with better handwriting performance and whose writing was already readable, wanted to produce better quality writing. These participants used terms such as ‘childish’ or ‘not neat’ to describe their handwriting, and identified components of letter formation such as the straightness of the lines or consistency of letter size as needing improvement. These participants’ goals often related to the perception of others when viewing their writing (e.g., writing notes that the person was confident to send to their child’s school). These factors may
need to be considered as part of the goal-setting process, in both clinical practice and future handwriting research.

Participants had goals related to handwriting features that were not included in the outcome measures, such as a participant feeling confident to send a handwritten letter to their child’s school. Evaluation of goal attainment, which was not conducted in this study, is recommended for future handwriting research as a way of measuring performance of specific handwriting features or tasks. Goal attainment scaling is a well-researched method of evaluating goal attainment, and this method could be used in future studies (Kiresuk & Sherman, 1968).

3.3.4 Compensatory strategies vs. remediation

One discussion raised earlier in this study was whether compensation or remediation should be used to improve written output. Much of the adult handwriting retraining literature teaches compensatory strategies, such as typing and writing with the non-dominant hand (Yancosek & Howell, 2011). All participants in our study wanted to improve handwriting using their dominant hand (as opposed to using compensatory strategies), although this result may reflect a selection bias as participants volunteered to be in the study and initiated contact with the researchers. There is little research available to guide therapists and adults with stroke when considering whether remediation or compensation may be more appropriate for a writing task. The results of the current study suggest that even people with very poor dexterity may be able to complete an intensive handwriting retraining program.

Collaborative goal setting may guide the clinical reasoning process when considering compensation versus remediation for adults with stroke. Even small changes in handwriting performance may be meaningful. Participant 1 who had very poor dexterity, was able to achieve her goal of writing short single words and complete a word puzzle in the newspaper independently by the end of the program. Conversely, the goal setting process may reveal that compensatory strategies are more appropriate for a particular writing task. Participant 7 resorted to using a compensatory method (typing) for some work tasks that she would previously have written, because the outcome of the task (high quality, legible text produced quickly) was more important than the method used to create text. Compensation was not used by this participant for all handwriting tasks, and retraining addressed other handwriting goals such as writing legible shopping lists. Finally, it is possible that adults with stroke may commence handwriting retraining and later decide to use compensatory methods to write.
Participant 2 reported at follow-up that he had started writing with his non-dominant hand, as he found writing with his dominant hand too difficult. Ongoing review of handwriting performance and goals may guide clinical reasoning regarding compensation versus remediation.

3.4 Outcome measures were feasible but did not capture all important features of handwriting performance

Outcome measures were administered to participants before and after the intervention. The purpose of administering outcome measures in this study was not to demonstrate a treatment effect, but rather to test the feasibility of using these outcome measures in future research. Several measures of legibility are available for use with adults with stroke, and one of the research questions of the study related to which legibility measures were the most feasible to deliver and suitable for research purposes. The following section of this discussion chapter relates to that question.

3.4.1 Sentence legibility

Sentence legibility was measured using various legibility outcome measures to compare the feasibility and utility of each measure. The primary outcome measure was the mETCH-W. This measure appeared to capture change in handwriting performance for most participants, showing what could be considered a clinically significant change across the three time points for some individuals. A ceiling effect was evident for this measure for this sample of participants, with the maximum score of 100% being achieved on eight occasions (38% of all scores across all participants and time points), including a maximum score achieved by three participants at baseline. Therefore, the mETCH-W may not be a suitable outcome measure for all adults with a handwriting impairment, particularly those with a mild impairment who are already able to write five legible words. Additionally, scoring only five words using the mETCH-W may have reduced the ability of this outcome measure to accurately reflect a person’s handwriting performance. Each illegible word resulted in a 20% decrease in score on the mETCH-W when only five words were scored, which seems a disproportionate decrease when occasional illegible letters or words are common even amongst healthy writers (van Drempt et al., 2011a). Clinicians and researchers should take this calculation into account when determining what a clinically significant change should be, if scoring a five word sentence using the mETCH-W.
The mETCH-W may not be sensitive to other important impairments affecting handwriting performance such as untidiness, or problems with legibility in longer writing samples. For some participants it was possible to achieve a high score for legibility on the mETCH, even when other impairments were present. One participant achieved 100% for writing legibility at baseline despite using a static, immature pen grip, and moving his hand across the page using his shoulder and upper arm. Writing was reportedly painful, tiring and limited to no more than one sentence per occasion. A larger writing sample with more words would have provided a more accurate representation of that participant’s writing performance. Further research is needed to determine whether scoring a larger handwriting sample or increasing the number of participants reduces the ceiling effect found in this study on the mETCH-W.

Sentence legibility was measured using four additional rating methods for comparison with the mETCH-W. Scoring the global legibility of a sentence using the modified Four Point Scale-Sentences was quick and may be suitable for clinical practice, but this method is not sensitive enough for research purposes. The other three outcome measures scored words in a sentence based on whether letters were legible. Rating individual letters in a sentence is more time-consuming than rating words. These outcome measures did not show as much change as the mETCH-W, but no ceiling effect was evident. Additionally, rating the legibility of individual letters may not be as meaningful as rating the overall readability of words or sentences. Therefore, the mETCH-W is recommended for measuring sentence legibility in future studies.

3.4.2 Legibility of single characters

Legibility of single characters was measured using three sub-tests of the HAB: Alphabet writing (lower case), alphabet writing (upper case) and numeral writing. The added benefit of measuring alphabet legibility in addition to sentence legibility is questionable, as these outcome measures were no more sensitive to change than the sentence legibility measures. Writing the alphabet is not a task commonly completed by adults (van Drempt et al., 2011a), therefore this measure may not be as meaningful or functional as writing a sentence. Finally, rating and scoring legibility is time-consuming for researchers and completing these outcome measures may be onerous for participants. One participant was not able to complete the alphabet writing tasks at baseline due to slow writing speed and fatigue.
Therefore reducing the number of outcome measures is recommended in future studies. Sentence legibility should be prioritised over alphabet legibility.

Although it is desirable to limit the number of outcome measures, it is recommended that numeral legibility be included in future studies, in addition to sentence legibility. Numeral writing is a meaningful task for adults, performed during activities such as writing a phone message or completing forms. Additionally, numeral legibility has different requirements than sentence legibility, because when reading numbers there is often no context to assist with deciphering a poorly written numeral. Finally, the impact of illegible numerals may be greater than the impact of illegible words or letters in a sentence. A single illegible number may mean the writing task is unsuccessful (e.g., an illegible numeral in a credit card number may result in a transaction not being processed), whereas an illegible letter or word would not usually have the same consequences. Therefore, writing numerals should be considered an important handwriting task in addition to writing sentences, requiring measurement in future research.

### 3.4.3 Pen control and writing speed

The four pen control outcome measures (line and dot drawing tests) showed a small improvement across the three time points, with the exception of the number of lines drawn, which showed a slight decrease. Recording the number of participants who completed the line drawing task successfully (drawing 10 lines in 20 seconds), showed more mean change for the group compared with scoring the actual number of lines drawn. Most participants were unable to complete the line drawing test. A cross-sectional study of 120 healthy older adults was conducted after the current study was completed, investigating the line and dot drawing tests (Dettrick-Janes, McCluskey, Lannin, & Scanlan, 2015); 54% of adults in that study were unable to complete the line drawing test, and 9% were unable to complete the dot drawing test. In the current study, greater mean change was shown for the dot drawing test when the number of dots drawn was counted (compared to number of participants with successful test completion). Therefore the HAB dot drawing subtest, when the number of dots drawn is counted, appeared to be the most useful outcome measure of pen control.

Writing speed showed a small mean decrease over the three time points (i.e., slower speed). This result may be explained by the fact that writing more slowly was a strategy that most participants used to increase legibility. Increased writing speed was not as meaningful as improved legibility for the participants in this study, with only one participant expressing a
goal of increasing writing speed. However, measuring writing speed in addition to legibility may be a useful way of capturing overall handwriting performance, particularly for people who are only able to write legibly if they write slowly. An outcome measure that involves a calculation of both legibility and speed would be useful in future research, but the assessments currently available measure these domains separately.

3.4.4 Handwriting quality

Writing quality was important to several participants in this study. Although most goals set by participants related to legibility (or readability), aspects of writing quality such as consistency, recognisability, general performance and neatness were included in eight participant goals (34% of all goals). Therefore, writing quality is an important feature of adult handwriting that needs to be measured in future research. The outcome measures used in this study do not appear to be sensitive to change in handwriting quality. The modified Four Point Scale rates legibility based on readability of the words or letters, whether they can be understood or not. This scale was not sensitive to changes in writing samples that were legible but of poor quality. The mETCH may be more sensitive than the modified Four Point Scale to changes in handwriting quality, as features are included that may contribute handwriting quality such as letter closure. However, other handwriting components that may affect writing quality, such as straightness of lines and evenness of letters, are missing from the mETCH rating criteria. The sensitivity of rating writing quality versus readability is illustrated in Figures 3.1 and 3.2, which show writing samples and scores from the sentence composition tests for two different participants.

Both participants received similarly high scores on the three outcome measures. These scores appear to be an accurate reflection of the readability of the sentences (as they can both be understood); however, the similar scores are not a good reflection of the difference in subjective writing quality, which appears much better for Participant 3 compared with Participant 4. The difference in writing quality is perceived ‘at first glance’ as well as when specific features of the writing are examined, such as consistency of letter size, letter and word spacing, and the downward height of letters. The mETCH-Words was the only outcome measure that showed some difference between the quality of the two samples, although a 20% difference in score on this outcome measure may not be clinically significant (i.e., only reflecting illegibility in one word out of five), whereas subjectively the difference in writing quality between these two participants appears large. In addition, the sensitivity of these
outcome measures to demonstrate change over time for these participants would be very limited, due to a ceiling effect. Although Participant 3’s writing appears to be of better quality than Participant 4, improving ‘neatness’ was a goal for both participants. Any improvements in neatness would not be captured by these outcome measures, as both participants were both at, or near, the maximum score at baseline. These examples illustrate the lack of sensitivity of the outcome measures used in this study to writing quality.

An additional outcome measure of handwriting quality is recommended for future studies, as increased writing quality was important to participants but was not captured by the outcome measures used in this study. Handwriting quality is not well understood. Most research about handwriting assessment relates to the readability or speed of writing (Rosenblum et al., 2004). Further research is needed investigating the features that contribute to writing quality and ways to evaluate this phenomenon. This research may include
qualitative studies investigating features seen as contributing to good and poor quality handwriting, involving people who have a handwriting impairment, as well as the general population (as several participants were concerned about how their writing was viewed by others).

3.5 Limitations

Limitations of this study include the small sample size \((N = 7)\). Second, the aims of this study related to feasibility, rather than demonstrating a treatment effect. Therefore outcome data which are reported should be interpreted with caution due to the likely biases inherent in a non-randomised, underpowered study. A further limitation of this study was the use of the mDASH to measure participant perceptions of their own handwriting. This self-rating scale may have been a potential source of bias and patient perception and self-rating scales have not been correlated with actual writing capability.

3.6 Implications for research and clinical practice

There is a lack of research related to task-specific handwriting retraining involving adults with stroke. A feasibility study has been conducted to inform a future randomised controlled trial. Implications for further research relate to recruitment, intervention and outcome measurement. Although outcome data should be interpreted with caution, findings from this study, including qualitative feedback from participants, may be useful for clinical practice.

3.6.1 Recruitment

Recruiting adequate numbers for a randomised controlled trial would not be feasible in a large metropolitan city in Australia using the methods and context of this study, and additional methods or recruitment sites would be needed. Levels of contact by researchers to people with stroke may be increased by recruiting participants via the Australian Clinical Stroke Registry (AUSCR) and/or inpatient facilities. A longer recruitment duration and including people with handwriting impairment related to other neurological conditions may also increase the number of participants required. Advertising via public media was the most successful promotional method and is recommended for future studies.
3.6.2 Mode and frequency of program delivery

A four-week home-based intervention involving twice-weekly supervised practice and coaching with an occupational therapist and three independent practice sessions per week was feasible in this study, and seemed to be the right pattern of delivery for most participants. In a future study, consideration should be given to whether the intervention program relates to a certain duration (e.g., four weeks) or the number of occupational therapy sessions (e.g., eight), as this will determine how cancelled sessions should be dealt with. This pattern of delivery would be feasible in many clinical practice situations. If not feasible, this chapter has included a discussion of alternative modes of delivery, such as on-line delivery and supervision by a therapy assistant, provided important principles of task-specific training (e.g., the provision of detailed feedback) can be implemented.

3.6.3 Handwriting goals

Goal setting is an important component of task-specific motor training, and handwriting goals should be set and reviewed as part of an intervention program. Use of Goal Attainment Scaling (Turner-Stokes, 2009) is recommended to objectively measure goal achievement. Specifically, handwriting goals often need to include the type of handwriting task, the audience of the writing and specific features requiring improvement. Consideration should particularly be given to whether a goal relates to readability or quality of writing. Goal setting and regular review of goal attainment may help to guide adults with stroke and their therapists when deciding whether remediation or compensation is more appropriate for improving performance of a handwriting task.

3.6.4 Practice tasks

Practice tasks should relate to whole and part handwriting tasks, and the type of practice tasks used should be tailored to individual goals and interests. Participants in this study varied in the types of practice tasks they enjoyed (e.g., copying out text vs. self-generated writing). These types of preferences need to be taken into account when setting up and reviewing practice tasks, in order to maintain interest and motivation to practice. Provision of feedback by the occupational therapist was valued by participants during the supervised practice sessions. Participants should also be encouraged to examine their own handwriting and problem-solve regarding improving specific features. Attempts should be made to introduce more objective evaluation methods, such as rating handwriting on a Likert
scale. These scales can be adapted for specific goals, and may form the basis of short-term goals or targets during an intervention program.

### 3.6.5 Outcome measurement

The primary outcome measure, the mETCH-W, was feasible to administer and score. This outcome measure may be suitable as an outcome measure in a future study if a larger sample of words is rated, and a measure of handwriting quality or ‘neatness’ is added. The modified Four Point Scale is an alternative legibility outcome measure which may be more suited to a clinical setting for use by therapists or stroke survivors, to evaluate handwriting legibility.

Outcome measures of single character legibility, including alphabet and numeral writing, were feasible to administer but time consuming (to administer and score). As writing the alphabet is not a task most adults perform, sentence legibility is a more meaningful measure for use in future. Writing speed is an objective outcome measure that is quick to administer, but may not relate to handwriting goals and speed may actually decrease as legibility improves. Further research is needed into ways to evaluate writing quality or ‘neatness’.

### 3.7 Overall Conclusions

A quasi-experimental single cohort feasibility study has been completed with seven participants. Findings from this study have addressed the original research aims and questions, by testing the feasibility and utility of a four-week intervention program and handwriting outcome measures, and making recommendations for future research. Recruitment was the main threat to feasibility in this study and is likely to be the most significant challenge in future randomised controlled trials. Recommendations have been made which may increase recruitment in a future study, although findings from this study indicate that recruiting adequate numbers for a randomised controlled trial would not be feasible in a large metropolitan city in Australia. The four-week intervention using task-specific practice and feedback from an occupational therapist was feasible to deliver, and was acceptable to adults with stroke. A similar program would be feasible to deliver in a future study and in clinical practice. The mETCH-W may show change in handwriting legibility in a larger sample if a larger sample of words are rated. Including an additional outcome measure
of handwriting quality is recommended to capture change in participants whose writing is already readable and for whom the mETCH-W had a ceiling effect. Further research investigating ways to measure this phenomenon is required.
References


Beaudet, M. (2004). Effectiveness of an adult handwriting training program [Honours dissertation]. (Honours), University of Western Sydney, Campbelltown, NSW.


Appendix A: Pen grips

Handwriting usually involves holding a writing implement, such as a pencil or pen. While early writers may write only with a certain type of implement such as a pencil, adults may use various writing implements depending on the writing task and what is easily available. For brevity, this review will refer to the use of pens. Pen grip refers to the hand, finger and thumb position used to hold and move a pen. Pen grips vary between writers, with various configurations of finger and thumb positions being used (Schwellnus et al., 2013). The type of pen grip used is distinct from, but closely related to, the ability to move the pen (Elliott & Connolly, 1984; Rosenbloom & Horton, 1971). Writers tend to have a preferred pen grip, which develops at an early age (Rosenbloom & Horton, 1971).

One method of broadly categorising pen grips is static vs. dynamic grips. These grips are sometimes referred to as ‘immature’ and ‘mature’ grips respectively (Elliott & Connolly, 1984; Schwellnus et al., 2012). Static grips involve holding the object against the palm of the hand rather than in the fingers. Static grips provide power and stability, but less freedom of movement in the intrinsic muscles of the hand, and rely on the arm for movement of the pen (Elliott & Connolly, 1984; Rosenbloom & Horton, 1971). Therefore, static grips may not allow sufficient pen movement for handwriting, and are usually only used by young children in the early stages of pen grip development (Elliott & Connolly, 1984). Static pen grips may also be used by people with poor motor control following stroke. This type of grip may not allow the stroke survivor adequate freedom of movement for handwriting.

Dynamic grips involve holding an implement between the fingers and thumb. The object is manipulated within the hand itself, with movements occurring in both the intrinsic and extrinsic muscles of the hand. Dynamic grips provide less stability and power than static grips. However dynamic grips enable greater freedom of movement within the hand, decreasing the reliance on arm movements, and making movement more efficient (Elliott & Connolly, 1984). Therefore dynamic grips are seen to be better than static grips for handwriting (Schwellnus et al., 2012).

Various types of dynamic pen grips, involving different configurations of finger and thumb positions are used by people who write. The most common grip is the dynamic tripod grip, where the pen is positioned between the second and third fingers, and the thumb. The
thumb and fingers form a ‘tripod’ shape around the pen (Schwellnus et al., 2012). The thumb is positioned in opposition, with the inter-phalangeal joint slightly flexed. The fourth and fifth fingers rest against the writing surface (Schwellnus et al., 2012), and may also move together with the third finger. The development of the dynamic tripod grip was charted in an observational study of 128 children aged between 1 ½ and 7 years (Rosenbloom & Horton, 1971). In the early stages of development of this grip, the child’s fingers and thumb assumed the tripod position, but movements of the intrinsic muscles were not observed. The tripod grip was held in a stationary position, with arm movements being used to move the pen. This hand position was referred to as the ‘tripod posture’. As the dynamic tripod grip developed, intrinsic movements of the hand were introduced to move the pen. This stage, referred to as the ‘dynamic tripod’ typically occurred in children between four and six years old. Other pen grips that have been described in the literature include the dynamic quadropod grip and the lateral (thumb) tripod grip (Dennis & Swinth, 2001; Schwellnus et al., 2012). The dynamic quadropod grip is similar to the dynamic tripod, but with the pad of the fourth finger positioned on the pen. The lateral (thumb) tripod grip has the thumb adducted so that it rests on the second finger or over the top of the pen. With this grip, movement of the pen is controlled by the fingers only, with the thumb providing stability.

The dynamic tripod grip has traditionally been considered to be the optimal pen grip, and is commonly taught to children by therapists and teachers (Bonney, 1992). However a descriptive study of 447 adults found that 14% of writers used grips other than the dynamic tripod (Bergmann, 1990). Research suggests that the type of dynamic pen grip used may not correlate with handwriting performance (Selin, 2003). Studies that analysed the handwriting of children with various types of dynamic pen grips found no correlation between the type of pen grip used and writing speed, legibility (Dennis & Swinth, 2001; Ziviani & Elkins, 1986) or self-rated writing effort (Schwellnus et al., 2012). Similar results were found in studies with adults (Nadege van Drempt, McCluskey, & Lannin, 2011b). The research suggests that various types of dynamic pen grips are functional for writing.
Appendix B: Factors relating to handwriting performance and handwriting performance norms

Handwriting legibility

Factors affecting legibility

The handwriting sub-tasks described earlier are all thought to contribute to legibility. Letter formation is an important aspect of legibility (Parush, Lifshitz, Yochman, & Weintraub, 2010). Incorrectly placed strokes or added strokes can reduce legibility (Graham, Struck, Santoro, & Berninger, 2006). If lines are not properly shaped, joined or closed, the letter may not be legible or may be confused for a different letter. (e.g. a letter d that is not properly joined may be mistaken for cl, or e may be confused for c). The way letters and words are positioned on a page also affects legibility, with too much or too little space (Graham & Weintraub, 1996; Lui & Arditi, 2001), and not writing in a straight line (Schneck & Amundsen, 2010) affecting readability. Finally, error correction also relates to legibility. Correcting errors is an important task to ensure writing communicates the intended message. However, poorly corrected errors can also reduce handwriting legibility. Because a stroke survivor may have difficulty performing these handwriting sub-tasks, they may have poor handwriting legibility.

Context can affect the legibility of handwriting. For example, a letter or word may not be legible if viewed on its own, however in the context of the other letters or words it can be understood (Kendeou, Muis, & Fulton, 2011; Murray, Boylan, O’Flynn, O’Tuathaigh, & Doran, 2012). Long pieces of text are thought to be understandable when greater than 50% of the words are legible (Karlsdottir & Stefansson, 2002). The writing task may provide context that assists with legibility, for example the word ‘butter’ may be legible in the context of a shopping list. Familiarity of words may affect their legibility, for example a familiar name may be more easily understood than an unfamiliar name if not all letters are written legibly. Familiarity of the reader to the writer may also influence whether handwriting can be understood, for example an address on an envelope may be more easily understood by the writer’s wife than a postal worker. Handwriting legibility may also be affected by the amount of time taken when reading the writing, as handwriting that is difficult to read initially may be understood after careful study. However many contexts require handwriting to be read
quickly, e.g. when reading correspondence at work or marking an exam. Therefore, being able to produce writing that is able to be understood quickly and easily may be an important goal of handwriting training. Several handwriting assessments take into account how quickly the writing can be understood (Ayres, 1912; Summers & Catarro, 2003).

**Handwriting legibility norms**

One study collected normative data of the handwriting of healthy older adults (van Drempt et al., 2011a). Writing samples were collected using a digital pen over 3 days from 30 healthy adults aged 65 years and older. Legibility of the writing samples was rated using a modified 4 point scale (Au, McCluskey at al., 2012), which rates whether the meaning of a sentence can be understood based on the legibility of its words. Most handwriting samples (76.7% for self-generated text and 73.3% for copied text) were rated as 3 on the scale, where the meaning of the sentence can be understood even though not all words were clear. Only 20% of samples were rated as 4, where all words are clear. Very few handwriting samples were rated as being globally illegible, with 3.3% of handwriting samples scoring 2 (some words are clear but the meaning of the text cannot be understood), and no samples scoring 1 (most or all the words are impossible to identify). The results of this study suggest that while most healthy older adults produce handwriting that is legible overall, occasional illegible words are common.

One study investigating the handwriting speed of 66 university students under different writing conditions also reported legibility data (Summers & Catarro, 2003). That study rated legibility using a 3 point scale modified from Connor (1995), which rates legibility based on the smoothness at which writing can be read. Page 6 of a 2-hour examination paper was rated. 68% of pages were rated as 1 on the scale (can be read smoothly, with hesitation on 1-4 words). 26% of pages were rated as 2 (hesitation occurs with 5 or more words and/or the flow stops on 1–4 occasions because the word is difficult to read or illegible) and 6% were rated as 3 (flow of reading stops on 5 plus occasions because the word is difficult to read or illegible). These results suggest that adults of university age produce mostly legible handwriting in a single page of writing. The authors reported that the legibility of some students deteriorated towards the end of the paper (14-16 pages) however these legibility results were not reported.

No normative data have been found for handwriting legibility of adults with stroke. One unpublished study reported handwriting legibility scores for adults with brain injury.
(Beaudet, 2004). That study investigated the effectiveness of a handwriting retraining program for four adults with handwriting impairment following brain injury. Legibility of a five-word self-composed sentence was rated using a modified Evaluation of Children’s Handwriting (ETCH) (Au et al., 2012), which rates the percentage legibility of a sentence based on the proportion of legible letters and words. Legibility scores ranged from 31% to 82% for the four participants with brain injury. The study used a different rating scale than the study by van Drempt et al. (2011a.), so results cannot be directly compared. Additionally, collecting normative data on handwriting legibility was not an aim of the study. However, the results of the study do suggest that adults with handwriting impairment following brain injury have poorer handwriting legibility than healthy older adults.

**Handwriting speed**

**Factors affecting handwriting speed**

Handwriting speed may be influenced by the speed of various handwriting component skills, including motor control, cognition and perception. Handwriting speed may also be affected by handwriting subtasks, such as the need for error correction and speed of moving around the page. Finally, handwriting speed may relate to other domains of handwriting performance, such as legibility. The relationship between handwriting speed and legibility is not clear (van Drempt et al., 2011b). One study analysed handwriting samples of 17 healthy adults written at varying speeds (Halder-Sinn & Funsch, 1998). This study found that higher writing speed was associated with increased letter deformation, while very slow writing speed resulted in increased tremor; features that could negatively affect legibility. However, the small sample size of this study limits the generalisability of the results. In contrast, a study involving 66 university students found low correlation between writing speed and legibility (Summers & Catarro, 2003). However, this study used a subjective scale of writing legibility, which had poor inter-rater reliability. The low correlation between handwriting speed and legibility is consistent with studies of children’s handwriting (Graham, Weintraub, et al., 1998; Ziviani & Watson-Will, 1998). No studies have been found that investigate the relationship between handwriting speed and legibility for adults with handwriting impairment, although decreasing writing speed was a strategy used by an adult with brain injury to improve handwriting legibility in one study (Beaudet, 2004).

Handwriting speed of healthy adults. Handwriting speed data exists for healthy adults for the Jebsen-Taylor Hand Function test and Handwriting Speed Test. Normative data were
published with the original study, for American adults (Jebsen, Taylor, Trieschmann, Trotter, & Howard, 1969). Normative data for healthy Australian adults was collected by Agnew and colleagues (1982). Writing speed data were collected more recently in a descriptive cohort study with 120 healthy Australian older adults (aged 60+) (Burger & McCluskey, 2011).

Handwriting speed was measured using four different writing speed tests: 1) The Jebsen-Taylor Hand Function Test, 2) the Handwriting Speed Test, a 3 minute copying task, 3) a self-generated five-word sentence and 4) a self-generated five-item shopping list. This study found no difference between the writing speed of men and women. Writing speed decreased with age for this older adult population, which is a similar finding to earlier studies (Agnew & Maas, 1982; Dixon, Kurzman, & Friesen, 1993; Hackel, Wolfe, Bang, & Canfield, 1992). This study also found a significant difference in writing speed between different writing tasks, with copied text being written faster than self-generated text. The authors of this study hypothesised that the increased cognitive demands of composing a piece of text made handwriting slower for self-generated text compared to copied text. Unexpectedly, significant speed differences were found between different writing tools. Writing with a pencil was faster than writing with a pen for copied text, while a pen was faster than a pencil for a self-generated shopping list.

Handwriting speed data for young adults were collected in another study which measured the writing speed of 66 university students (Summers & Catarro, 2003). The students completed three different writing tasks: 1. the Handwriting Speed Test, 2. writing a 2-hour examination paper with prior knowledge of the questions, and 3. writing a 2-hour examination paper without prior knowledge of the questions. Participants wrote a mean of 37.83 words/minute (SD=4.71) for the 3-minute Handwriting Speed Test. Similar to the findings of Burger & McCluskey (2011), the study by Summers and Catarro (2003) found that tasks with increased cognitive demands resulted in slower handwriting. Writing speed was 17.75 (SD= 2.78) words per minute when participants had prior knowledge of examination questions, compared to 15.37 (SD=3.12) words per minute when they had no prior knowledge of the questions. An important funding of this study was that the length of writing task had a significant impact on writing speed, with longer writing tasks resulting in slower writing speed. Writing speed for the 2 hour examination was less than half the speed of the 3 minute Handwriting Speed Test (17.75 words per minute (SD=2.78) and 37.83 words per minute (SD=4.71) respectively). The authors concluded that short writing tests are not predictive of a person’s writing speed in long writing tasks such as examinations.
limitation of the study by Summers and Catarro (2003) was that the type of writing was not consistent when comparing tasks of different length, with self-generated text used for the examination, and copied text used for the Handwriting Speed test. Because writing self-generated text is slower than copied text, this phenomenon may have influenced the results when comparing tasks of different length.

Handwriting speed of adults with handwriting impairment. No normative data have been found for the handwriting speed of adults with stroke. However, writing speed data exits for adults with brain injury. Two studies reported handwriting speed data of adults with brain injury using the Jebsen-Taylor Hand Function Test. One study that analysed ten writing samples of ten adults with brain injury reported times taken to complete the 24 letter test ranged from 27 to 174 seconds (8.3 to 53 letters per minute) (Faddy, McCluskey, & Lannin, 2008). Another study investigating the effectiveness of a handwriting retraining program for four adults with handwriting impairment following brain injury reported times taken to complete the test ranging from 24.8 seconds to 142.8 seconds (10 to 58 letters per minute) (Beaudet, 2004). These studies suggest that writing speeds are slower for adults with brain injury than for healthy adults, and that there is a wide range of writing speeds for adults with brain injury. However, these studies had small samples, and collecting normative data on handwriting speed was not a stated aim of these studies.
Handwriting Assessment Battery for Adults

Test Booklet

Prepared by

Dr Annie McCluskey & Dr Natasha Lannin

[Version 5]


Acknowledgement: Assistance gratefully received from Kathrine Faddy to revise the layout and formatting of this document
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
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>Male</th>
<th>Standard Deviation</th>
<th>Female</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 – 59</td>
<td>12.2 seconds +/- 3.5 seconds</td>
<td>11.7 seconds +/- 2.1 seconds</td>
<td></td>
<td></td>
</tr>
<tr>
<td>60 - 94</td>
<td>19.5 seconds +/- 7.5 seconds</td>
<td>16.7 seconds +/- 4.7 seconds</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Writing Legibility

**ALPHABET WRITING**

**Lower Case Letters**
Number of Illegible Letters = __________

Letter Legibility = __________ %

**Upper Case Letters**
Number of Illegible Letters = __________

Letter Legibility = __________ %

**NUMERAL WRITING**

Number of Illegible Numbers = __________

Number Legibility = __________ %

**SENTENCE COMPOSITION**

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

Word Legibility = __________ %

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

Sentence Letter Legibility = __________ %
Writing Speed Cards

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 D- Example of an exercise sheet for a whole handwriting practice task

Writing: Journaling

**Purpose:** To correctly form the shape of letters and words within sentences

**Goal:**

**Short-Term:**

**Medium term:**

### Instructions

- To start, write ___ lines of journal writing.
- Next, study your writing carefully. Circle any letters or words that are not properly formed.
- For each line, give yourself a rating out of 4. If there are multiple lines that are similar, you can score them as a group.

<table>
<thead>
<tr>
<th>Score</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>

- Next, look at the words or letters that a circled. Find a common theme or issue (if there is one) e.g. letters at the end of the word aren’t as clear.

- Practice writing these (or similar) words. Things to focus on:

  
  *(List of strategies generated here)*
Appendix E - Example of an exercise sheet for a part-practice task

Writing: Keeping spaces between letters

Purpose: To write legible words with well-spaced letters

Short-Term: To write words without the letters touching by the end of 1 week

Medium term: To write words without the letters touching by the end of 2 weeks

Instructions

✓ Think of a four letter word. If you can't think of a word, choose one that is on this page.
✓ Write the word in the grids below- one letter per box. Imagine you are completing a crossword puzzle.
✓ Aim to complete at least letters that do not touch other letters or cross outside the boxes.

Tips /Things to Remember

✓ Rest forearm on a table.
✓ Let the pen/pencil rest against your webspace and third (middle) finger.
✓ After you finish a letter, roll your forearm so that the pen lifts off the page. Then slide your arm across slightly before lowering the pen again to write the next letter.

Number of letters not touching (total):
Aim: letters not touching
Appendix F - Flowchart detailing outcome measures

<table>
<thead>
<tr>
<th>Writing task</th>
<th>Outcome measure</th>
<th>Calculations</th>
<th>Score</th>
<th>Type of data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Composing and writing a five word sentence</td>
<td>mETCH-W legibility of each word (legible/illigible)</td>
<td>Legible words/total words x 100%</td>
<td>% sentence legibility (0-100%)</td>
<td>Continuous</td>
</tr>
<tr>
<td></td>
<td>mETCH-L legibility of each letter (legible/illigible)</td>
<td>Legible letters/total letters x 100%</td>
<td>% sentence legibility (0-100%)</td>
<td>Continuous</td>
</tr>
<tr>
<td></td>
<td>mFPS global legibility of sentence (1-4)</td>
<td>Nil</td>
<td>% sentence legibility (0-100%)</td>
<td>Continuous</td>
</tr>
<tr>
<td></td>
<td>mFPS legibility of each word (1-4)</td>
<td>Number of words scoring 3 or 4/total words x 100%</td>
<td>% sentence legibility (0-100%)</td>
<td>Continuous</td>
</tr>
<tr>
<td>Writing the alphabet - lower case</td>
<td>mETCH-L: legibility of each letter</td>
<td>Number of legible letters/total letters x 100%</td>
<td>% legibility (0-100%)</td>
<td>Continuous</td>
</tr>
<tr>
<td>Writing the alphabet - upper case</td>
<td>mETCH-L: legibility of each letter</td>
<td>Number of legible letters/total letters x 100%</td>
<td>% legibility (0-100%)</td>
<td>Continuous</td>
</tr>
<tr>
<td>Writing numerals 1-12</td>
<td>mETCH-L: legibility of each numeral</td>
<td>Number of legible numerals/total numerals x 100%</td>
<td>% legibility (0-100%)</td>
<td>Continuous</td>
</tr>
<tr>
<td>Drawing lines across a page</td>
<td></td>
<td>10 lines drawn in 20 seconds?</td>
<td>Achieved/ not achieved</td>
<td>Categorical</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Number of lines drawn</td>
<td>Number drawn</td>
<td>Continuous</td>
</tr>
<tr>
<td>Drawing dots</td>
<td></td>
<td>MAS: 10 dots drawn in 5 seconds?</td>
<td>Achieved/ not achieved</td>
<td>Categorical</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Number of dots drawn</td>
<td>Number drawn</td>
<td>Continuous</td>
</tr>
<tr>
<td>Copying a sentence</td>
<td></td>
<td>Time taken</td>
<td>Time (seconds)</td>
<td>Continuous</td>
</tr>
<tr>
<td>Self-rating of handwriting impairment</td>
<td>Score on mDASH (1-5)</td>
<td>Nil</td>
<td>Category 1-5</td>
<td>Ordinal</td>
</tr>
<tr>
<td>Self-rating of impact on social activities</td>
<td>Score on mDASH (1-5)</td>
<td>Nil</td>
<td>Category 1-5</td>
<td>Ordinal</td>
</tr>
<tr>
<td>Self-rating of impact on work and other ADLS</td>
<td>Score on mDASH (1-5)</td>
<td>Nil</td>
<td>Category 1-5</td>
<td>Ordinal</td>
</tr>
</tbody>
</table>
# Appendix G – Handwriting log sheet

<table>
<thead>
<tr>
<th>Day and Date</th>
<th>Amount of practice for each task (e.g. 10 min)</th>
<th>Practice task/s (e.g. pen shifting, writing speed)</th>
<th>Results in relation to target/goal (e.g. moved fingers 5 times in 20 seconds, wrote 6 words in 2.5min)</th>
</tr>
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<tbody>
<tr>
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</tbody>
</table>

Participant ID:
Appendix H – Study advertisement in Seniors Newspaper

Research a stroke of genius?

HANDWRITING is an important part of our identity, and losing the ability to write can have devastating effects on daily life for stroke survivors.

A team of researchers at the University of Sydney hope to help solve the problem through a program to help survivors regain handwriting skills.

Research student Bronwyn Simpson said arm and hand weakness after a stroke often affected writing ability.

“Stroke survivors may have difficulty controlling a pen and forming legible letters,” she said.

“They may not be able to write quickly or move their arm freely across a page.

“Handwriting is used to make notes and lists and is important for paid work.

“Being able to create a recognisable signature is also legally important, and a person’s handwriting style is an integral part of their personality.”

Ms Simpson said despite the frequency of handwriting loss and the frustration it caused, there had been little research into the most effective way to retrain handwriting skills after a stroke.

“Most materials available for handwriting difficulties are directed at children rather than adults.”

WRITE ON – Bronwyn Simpson will help stroke survivors regain handwriting skills.

She said, “This study will test the feasibility of a four-week long program conducted in participants’ homes, which will involve home practice tasks and coaching from an occupational therapist.”

To be eligible, people need to have suffered a stroke at least three months previously and be aged over 18, living in Sydney metropolitan area, be able to speak, read and write in English, and be able to follow instructions and complete a home program independently or with support from a family member.

Participants will be asked to complete one hour of handwriting practice five times a week for four weeks.

Phone Bronwyn Simpson on 0430-125-223, email bsim8892@uni.sydney.edu.au
### Appendix I - Methods of recruitment used and outcomes

<table>
<thead>
<tr>
<th>Method of recruitment and target audience</th>
<th>Number of responses</th>
<th>Number of participants recruited</th>
</tr>
</thead>
<tbody>
<tr>
<td>Media release resulting in articles published about the study in Seniors Newsletter and health-related website</td>
<td>10</td>
<td>4</td>
</tr>
<tr>
<td>Electronic copies of Participant Information Statement and flyer mailed or posted to:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Private sector or hospital occupational therapists, physiotherapists and rehabilitation specialists working in the community in stroke rehabilitation</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Occupational therapists and physiotherapists working in inpatient rehabilitation services</td>
<td>9</td>
<td>2</td>
</tr>
<tr>
<td>NSW stroke recovery club leaders</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Stroke-specific on-line forum</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Other community forums with participants who may have stroke</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Aged care residential facilities</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>24</strong></td>
<td><strong>7</strong></td>
</tr>
</tbody>
</table>
Feasibility of a home-based program to improve handwriting legibility after stroke: A pilot study

PARTICIPANT INFORMATION STATEMENT

(1) What is the study about?

The study explores methods for improving handwriting after stroke. The study will investigate if a retraining program is feasible, and if the program improves handwriting speed, control and legibility. There is very little research in this area, so information and feedback will also be collected to help plan a future larger study.

(2) Who is carrying out the study?

The study is being carried out by Bronwyn Simpson, an occupational therapist and postgraduate student as part of the degree of Masters of Applied Science at the University of Sydney. The research is being supervised by Drs Annie McCluskey, Natasha Lannin and Reinie Cordier from The University of Sydney.

(3) What does the study involve?

You will receive a four-week handwriting retraining program targeted at your stroke-affected hand. Your handwriting speed and legibility will be measured in the first week, after the 4 week program, and again after another 4 weeks. All participants will be asked not to participate in any other therapy targeting handwriting during the time of the study.

(4) How much time will the study take?

Your involvement in the study will run over four months. Measurement sessions will take a total of 2-3 hours. You will then participate in approximately 20 hours of handwriting training and practice. All sessions will be conducted in your home. They will involve:

a) An assessment session. You will complete a handwriting assessment to measure the speed and legibility of your handwriting with your stroke-affected hand. You will also complete some questions about the impact of your handwriting disability. We will also ask your age, date of birth and date of stroke. This session will take approximately 45 minutes.

b) A four-week handwriting retraining program:

- An initial session with the occupational therapist to establish handwriting goals and a practice program- 60-90 minutes
• Two sessions / week at home with the occupational therapist for training and coaching throughout the four weeks—seven sessions approximately 60 minutes each.

• Participating in a home practice program an additional three days/ week throughout the four weeks. You will also keep a log of the type and time of practice you did, and comments on the program—twelve sessions approximately 60 minutes each.

c) Two reassessment sessions after the four weeks and then again after 4 weeks. You will complete the handwriting assessment again. The therapist will also ask you about your expectation of and experiences with the process. These sessions will take approximately 45 minutes.

(5) Who can participate?

You may participate if you:
• Are aged 18 years or older
• Live in the Sydney metropolitan area
• Have had a stroke at least 3 months previously
• Have difficulties with handwriting
• Are able to provide informed consent, follow instructions and complete a home program independently or with support of a family member
• Are able to speak, write and read in English
• Cease other therapy related to handwriting or similar tasks during the study and follow-up period (2 months in total)

(6) Can I withdraw from the study?

Being in this study is completely voluntary - you are not under any obligation to consent. If you do consent you can withdraw at any time without affecting your relationship with the researchers or the University of Sydney.

(7) Will anyone else know the results?

All aspects of the study, including results, will be strictly confidential and only the researchers will have access to information on participants. A report of the study will be submitted for publication and presented at a conference, but individual participants will not be identifiable.

(8) Will the study benefit me?

Although no guarantees can be made about benefits for participants, it is hoped that participants who complete the handwriting program will show improvements in their handwriting performance.

(9) Can I tell other people about the study?

Yes. You are welcome to tell other people about the study.

(10) What if I require further information about the study or my involvement in it?

Bronwyn Simpson will discuss this information with you before you decide whether you would like to participate. If you would like to know more at any stage, please contact either Bronwyn Simpson (occupational therapist and researcher) on 0430 125 223 or bsim8092@uni.sydney.edu.au.

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

This study has been approved by the Sydney Local Health District Human Research Ethics Committee—CRGH. If you have any concerns or complaints about the conduct of the research study, you may contact the Executive Officer of the Ethics Committee, on (02) 9767 5622.

The conduct of this study at <<name of hospital>> has been authorized by <<name of organization>>. Any person with concerns or complaints about the conduct of this study may contact the Research Governance Officer on <<phone>> and quote protocol number <<SSA/xx/xxx/2012>>.

This information sheet is for you to keep
PARTICIPANT CONSENT FORM

I ............................................................................................(please print your name) give my consent to participate in the research project “Feasibility of a home-based program to improve handwriting legibility after stroke: A pilot study.”

In giving my consent I acknowledge that:

1. The procedures required for the project and the time involved have been explained to me.

2. Any questions I have about the project have been answered to my satisfaction.

3. 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.

4. I understand that I can withdraw at any time, without affecting my relationship with the researchers or the University of Sydney, now or in the future.

5. I understand my involvement will be confidential. The researchers will make every effort to avoid my identity being known during presentations and in publications were writing samples are used.

6. I understand that being in this study is completely voluntary- I am not under any obligation to consent.

Signed:

Name:

Date
One aim of this study is to provide information to help plan a larger trial in the future. Your feedback on your expectations and experiences will be very valuable in this process.

Please feel free to make comments on this questionnaire throughout the study. It will be discussed with you and collected at the assessment session.

Recruitment and information

1) Where did you hear about the study?

2) Was the information provided prior to the study (the advertisement and participant information statement) accurate and adequate?

   If not, what information was misleading or missing?

Assessment sessions

3) Please comment on:

   a. The type of tasks you completed during the assessment sessions

   b. The length of the assessment sessions
4) Did you feel the assessments provided an accurate impression of your handwriting performance?

**Handwriting retraining program**

5) Please comment on:

   a. The length of the retraining program (4 weeks):

   b. The amount and type of home practice

   c. The amount of coaching with the occupational therapist

   d. The setting of the program (home-based)

6) What did you find useful in the coaching sessions with the occupational therapist?

7) What could be improved about the coaching sessions?

8) Which activities did you find most useful, interesting or enjoyable?

9) Which activities did you find least useful, interesting or enjoyable?

10) Do you have any other suggestions or comments?
Appendix M- Feedback questionnaire responses

<table>
<thead>
<tr>
<th>Participant number 1</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Where did you hear about the study?</strong></td>
</tr>
<tr>
<td>Word of mouth.</td>
</tr>
</tbody>
</table>

| **Was the information provided prior to the study (the advertisement and participant information statement) accurate and adequate? If not, what information was misleading or missing?** |
| Yes it was fine. |

| **Please comment on the type of tasks you completed during the assessment sessions** |
| They were easy to understand. But harder to do them. |

| **Please comment on the length of the assessment sessions** |
| Quite lengthy but OK. |

| **Did you feel the assessments provided an accurate impression of your handwriting performance?** |
| Yes. |

| **Please comment on the length of the retraining program (4 weeks)** |
| It was too short to really make any progress. |

| **Please comment on the amount and type of home practice** |
| Fairly intense, but manageable. The lack of outside assistance made this more of an issue. |

| **Please comment on the amount of coaching with the occupational therapist** |
| It was about right. |

| **Please comment on the setting of the program (home-based)** |
| Essential as [name] is home-bound in the nursing home. |

| **What did you find useful in the coaching sessions with the occupational therapist?** |
| In general they were good. |

| **What could be improved about the coaching sessions?** |
| Nothing specifically. |

| **Which activities did you find most useful, interesting or enjoyable?** |
| Nothing specifically. |

| **Which activities did you find least useful, interesting or enjoyable?** |
| Drawing dots and lines was least enjoyable but may have been important regardless |

| **Do you have any other suggestions or comments?** |
| No |

<table>
<thead>
<tr>
<th>Participant number 2</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Where did you hear about the study?</strong></td>
</tr>
<tr>
<td>Seniors Newspaper. Phoned [chief investigator].</td>
</tr>
</tbody>
</table>

| **Was the information provided prior to the study (the advertisement and participant information statement) accurate and adequate? If not, what information was misleading or missing?** |
| The advertisement got me interested. Yes it was adequate. |

| **Please comment on the type of tasks you completed during the assessment sessions** |
| It was difficult. My hand won’t do what I want. |

| **Please comment on the length of the assessment sessions** |
| OK |

<p>| <strong>Did you feel the assessments provided an accurate impression of your handwriting performance?</strong> |</p>
<table>
<thead>
<tr>
<th>Question</th>
<th>Response</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Please comment on the length of the retraining program (4 weeks)</strong></td>
<td>About the right length. I felt like I couldn’t get any better by the end.</td>
</tr>
<tr>
<td><strong>Please comment on the amount and type of home practice</strong></td>
<td>3x week was Ok for me. It could be too much for others though. I am quiet so I have time.</td>
</tr>
<tr>
<td><strong>Please comment on the amount of coaching with the occupational therapist</strong></td>
<td>Balance of OT to homework was good. It was good to have OT sessions to encourage me to write.</td>
</tr>
<tr>
<td><strong>Please comment on the setting of the program (home-based)</strong></td>
<td>If it was in hospital, it may be more structured and disciplined. Transport would be difficult [for an outpatient clinic]. I had no problem with people coming into the home.</td>
</tr>
<tr>
<td><strong>What did you find useful in the coaching sessions with the occupational therapist?</strong></td>
<td>Just having someone there meant that I would do it.</td>
</tr>
<tr>
<td><strong>What could be improved about the coaching sessions?</strong></td>
<td>Can’t think of anything.</td>
</tr>
<tr>
<td><strong>Which activities did you find most useful, interesting or enjoyable?</strong></td>
<td>It wasn’t particularly exciting, but I knew it was important. Writing small words.</td>
</tr>
<tr>
<td><strong>Which activities did you find least useful, interesting or enjoyable?</strong></td>
<td>Nothing particularly</td>
</tr>
<tr>
<td><strong>Do you have any other suggestions or comments?</strong></td>
<td>People could trace letters, like in children’s’ books.</td>
</tr>
</tbody>
</table>

**Participant number 3**

<table>
<thead>
<tr>
<th>Question</th>
<th>Response</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Where did you hear about the study?</strong></td>
<td>[Inpatient rehabilitation facility]</td>
</tr>
<tr>
<td><strong>Was the information provided prior to the study (the advertisement and participant information statement) accurate and adequate? If not, what information was misleading or missing?</strong></td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Please comment on the type of tasks you completed during the assessment sessions</strong></td>
<td>They were very useful and helped me to improve my handwriting.</td>
</tr>
<tr>
<td><strong>Please comment on the length of the assessment sessions</strong></td>
<td>The length of the sessions were adequate.</td>
</tr>
<tr>
<td><strong>Did you feel the assessments provided an accurate impression of your handwriting performance?</strong></td>
<td>Yes.</td>
</tr>
<tr>
<td><strong>Please comment on the length of the retraining program (4 weeks)</strong></td>
<td>The length of the retraining program could be a little longer, say 6 weeks.</td>
</tr>
<tr>
<td><strong>Please comment on the amount and type of home practice</strong></td>
<td>Adequate</td>
</tr>
<tr>
<td><strong>Please comment on the amount of coaching with the occupational therapist</strong></td>
<td>Adequate</td>
</tr>
<tr>
<td><strong>Please comment on the setting of the program (home-based)</strong></td>
<td>Very convenient.</td>
</tr>
<tr>
<td><strong>What did you find useful in the coaching sessions with the occupational therapist?</strong></td>
<td>Being able to control the fingers better.</td>
</tr>
<tr>
<td><strong>What could be improved about the coaching sessions?</strong></td>
<td>Increase the length of the training program.</td>
</tr>
<tr>
<td><strong>Which activities did you find most useful, interesting or enjoyable?</strong></td>
<td></td>
</tr>
<tr>
<td>Writing passages and shopping lists.</td>
<td></td>
</tr>
<tr>
<td>---------------------------------------</td>
<td></td>
</tr>
<tr>
<td><strong>Which activities did you find least useful, interesting or enjoyable?</strong></td>
<td></td>
</tr>
<tr>
<td>None</td>
<td></td>
</tr>
<tr>
<td><strong>Do you have any other suggestions or comments?</strong></td>
<td></td>
</tr>
<tr>
<td>I very much enjoyed the sessions. I am very grateful that I was able to take part in these sessions. I am very grateful to [chief investigator and OT researcher] for their friendly and professional way they conducted the program.</td>
<td></td>
</tr>
<tr>
<td><strong>Participant number 4</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Where did you hear about the study?</strong></td>
<td></td>
</tr>
<tr>
<td>[Inpatient rehabilitation facility]</td>
<td></td>
</tr>
<tr>
<td><strong>Was the information provided prior to the study (the advertisement and participant information statement) accurate and adequate? If not, what information was misleading or missing?</strong></td>
<td></td>
</tr>
<tr>
<td>Yes. The phone call to [chief investigator] for enquiry was warm and encouraging – it really helped. It’s good to not be too officious.</td>
<td></td>
</tr>
<tr>
<td><strong>Please comment on the type of tasks you completed during the assessment sessions</strong></td>
<td></td>
</tr>
<tr>
<td>Assessment was perfectly appropriate. I did the dots and lines in another study.</td>
<td></td>
</tr>
<tr>
<td><strong>Please comment on the length of the assessment sessions</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Did you feel the assessments provided an accurate impression of your handwriting performance?</strong></td>
<td></td>
</tr>
<tr>
<td>Sentences were a good reflection. Writing fluctuated -I was having an off day for the second assessment. I did feel some pressure to perform, but more during the intervention sessions because I knew you and wanted to please you [the therapists].</td>
<td></td>
</tr>
<tr>
<td><strong>Please comment on the length of the retraining program (4 weeks)</strong></td>
<td></td>
</tr>
<tr>
<td>It finished at an appropriate time. The frequency was OK. Once a week for longer would have been better.</td>
<td></td>
</tr>
<tr>
<td><strong>Please comment on the amount and type of home practice</strong></td>
<td></td>
</tr>
<tr>
<td>Good</td>
<td></td>
</tr>
<tr>
<td><strong>Please comment on the amount of coaching with the occupational therapist</strong></td>
<td></td>
</tr>
<tr>
<td>Frequency was OK.</td>
<td></td>
</tr>
<tr>
<td><strong>Please comment on the setting of the program (home-based)</strong></td>
<td></td>
</tr>
<tr>
<td>Good</td>
<td></td>
</tr>
<tr>
<td><strong>What did you find useful in the coaching sessions with the occupational therapist?</strong></td>
<td></td>
</tr>
<tr>
<td>[Chief investigator and OT researcher] were very good. I am commenting as a teacher- the level of OT expertise was fantastic. They pointed out issues and ways to correct these e.g. pen grip. They had a high level of interest in handwriting- this attitude had a positive impact. They were encouraging but quick to point out anything going wrong that needed to be corrected. Feedback e.g. where to start letters, slope, features to improve. Don’t just say ‘yeah great’ – this makes it just another practice activity to be completed. Handwriting is an area with particular skills that need to be relearned, redeveloped and pointed out. “Great” and “you’re doing well” are warm fuzzies that don’t really help- specific feedback is important.</td>
<td></td>
</tr>
<tr>
<td><strong>What could be improved about the coaching sessions?</strong></td>
<td></td>
</tr>
<tr>
<td>I felt pressure to perform in the intervention sessions. My pre-stroke attitude- I was a high achiever and I perform worse when watched. This improved as I got to know [the therapists]. There was nothing the OTs could have done to change this.</td>
<td></td>
</tr>
<tr>
<td><strong>Which activities did you find most useful, interesting or enjoyable?</strong></td>
<td></td>
</tr>
</tbody>
</table>
Writing a store- this was interesting and engaging. I want to keep working on it and kept writing after the study about 8 lines per day until I started another research project.

**Which activities did you find least useful, interesting or enjoyable?**
Nothing

**Do you have any other suggestions or comments?**
Participants should write something continuous e.g. a life story, about family. It’s a great feeling for someone always involved in handwriting as a teacher and principal to have OTs with a particular interest in that area to help. For me it was very encouraging and very very helpful.

**Participant number 5**

**Where did you hear about the study?**
My parents saw the article in the Seniors Newspaper

**Was the information provided prior to the study (the advertisement and participant information statement) accurate and adequate? If not, what information was misleading or missing?**
Yes. I thought it was worth giving it a go. I was told what I had to do.

**Please comment on the type of tasks you completed during the assessment sessions**
They looked at pen grip, hand control and fatigue.

**Please comment on the length of the assessment sessions**
Good length.

**Did you feel the assessments provided an accurate impression of your handwriting performance?**
The tests were enough. The third one I wasn’t as good because it was a little while after.

**Please comment on the length of the retraining program (4 weeks)**
It was a good length – needed to get the muscles working. I may have benefited from longer because I was better when the OT was present.

**Please comment on the amount and type of home practice**
I was juggling family so it could be difficult sometimes. Its good to aim for 3 hours a week but you need to be organised.

**Please comment on the amount of coaching with the occupational therapist**
Three OT sessions a week would be better. They were a good length. I enjoyed them and they enhanced improvement.

**Please comment on the setting of the program (home-based)**
Easier- you don’t have to worry about transport.

**What did you find useful in the coaching sessions with the occupational therapist?**
Feedback, encouragement, analysing features then concentrating on them in practice. They made me focused. There was a good variety and related to everyday life and my goals.

**What could be improved about the coaching sessions?**
Nothing

**Which activities did you find most useful, interesting or enjoyable?**
There was a good variety. Copying out was easier [than thinking of what to write on postcards] – I could concentrate on formation rather than what to say.

**Which activities did you find least useful, interesting or enjoyable?**
Standing up for signatures – it was harder to do so frustrating, and harder to concentrate.

**Do you have any other suggestions or comments?**
I really appreciated all the encouragement. Now I’m writing better and feel more confident. Its clearer and legible.
<table>
<thead>
<tr>
<th><strong>Participant number 6</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Where did you hear about the study?</strong></td>
</tr>
<tr>
<td>Read about it in the Seniors Newspaper and called [chief investigator].</td>
</tr>
<tr>
<td><strong>Was the information provided prior to the study (the advertisement and participant information statement) accurate and adequate? If not, what information was misleading or missing?</strong></td>
</tr>
<tr>
<td>Yes. I knew I would need to work hard on my writing to improved</td>
</tr>
<tr>
<td><strong>Please comment on the type of tasks you completed during the assessment sessions</strong></td>
</tr>
<tr>
<td>I have done similar assessments for other programs. It covered the necessary areas.</td>
</tr>
<tr>
<td><strong>Please comment on the length of the assessment sessions</strong></td>
</tr>
<tr>
<td>Satisfactory</td>
</tr>
<tr>
<td><strong>Did you feel the assessments provided an accurate impression of your handwriting performance?</strong></td>
</tr>
<tr>
<td>It was a reasonable assessment. [questioned about vision and shakiness affecting results] - still an accurate assessment. The shakiness affected the lines but I still managed reasonably well.</td>
</tr>
<tr>
<td><strong>Please comment on the length of the retraining program (4 weeks)</strong></td>
</tr>
<tr>
<td>Quite a reasonable length provided you work. Best as a short, intensive program (compared to longer with less OT sessions) because the OT sessions encourage you to practice.</td>
</tr>
<tr>
<td><strong>Please comment on the amount and type of home practice</strong></td>
</tr>
<tr>
<td>Good. It is important to do it. This will depend on how busy the person is. I had the time free. Activities were fairly broad based and covered most things you would normally do. They improved my writing generally.</td>
</tr>
<tr>
<td><strong>Please comment on the amount of coaching with the occupational therapist</strong></td>
</tr>
<tr>
<td>Good. Two times a week is fine. You might feel pressured if it was more often.</td>
</tr>
<tr>
<td><strong>Please comment on the setting of the program (home-based)</strong></td>
</tr>
<tr>
<td>Good in the home.</td>
</tr>
<tr>
<td><strong>What did you find useful in the coaching sessions with the occupational therapist?</strong></td>
</tr>
<tr>
<td>All good. They added accountability for doing homework. Advice e.g. holding pen was helpful.</td>
</tr>
<tr>
<td><strong>What could be improved about the coaching sessions?</strong></td>
</tr>
<tr>
<td>I don’t know, I’m not a handwriting expert. Advice was all good and helpful.</td>
</tr>
<tr>
<td><strong>Which activities did you find most useful, interesting or enjoyable?</strong></td>
</tr>
<tr>
<td>Copying out, so I didn’t have to think what to write. Lists were good, and I could keep the margins straight so that was encouraging.</td>
</tr>
<tr>
<td><strong>Which activities did you find least useful, interesting or enjoyable?</strong></td>
</tr>
<tr>
<td>The only problem with the lists was thinking of what to list. I’m not a natural author.</td>
</tr>
<tr>
<td><strong>Do you have any other suggestions or comments?</strong></td>
</tr>
<tr>
<td>It’s marvelous that this sort of thing is available. It is encouragement for people who have had a stroke to get back to doing things. I had a friend who had a stroke and didn’t do anything once he got home. He got depressed. Improvement in handwriting could inspire people to work on other areas.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Participant number 7</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Where did you hear about the study?</strong></td>
</tr>
<tr>
<td>I saw it in the Seniors Newspaper and work, and emailed you.</td>
</tr>
<tr>
<td><strong>Was the information provided prior to the study (the advertisement and participant information statement) accurate and adequate? If not, what information was misleading or missing?</strong></td>
</tr>
</tbody>
</table>
More than adequate. I thought maybe I didn’t fit the profile but then you came back to say I could be included.

**Please comment on the type of tasks you completed during the assessment sessions**
Simple - I would say everyone could do them. More suitable for people with weakness.

**Please comment on the length of the assessment sessions**
OK

**Did you feel the assessments provided an accurate impression of your handwriting performance?**
Yes, it captured it. I found it easy.

**Please comment on the length of the retraining program (4 weeks)**
If I had been able to stick to the 4 weeks I probably would have had the same results.

**Please comment on the amount and type of home practice**
It wasn’t so much the practice, it was the words of wisdom. Actually tracking what I’m doing and finding a way around that. Practice was good but it wasn’t the be all and end all. The writing homework wasn’t the main focus, it was learning strategies e.g. size, double letters, start and end of words. The practice helped to apply the strategies.

**Please comment on the amount of coaching with the occupational therapist**
The less intensive and longer program worked OK for me, I just felt bad for cancelling.

**Please comment on the setting of the program (home-based)**
OK.

**What did you find useful in the coaching sessions with the occupational therapist?**
I needed the guidance. I should have known but the OT picked up things that were obvious that I wasn’t thinking of. Someone else looking at my handwriting and figuring out what was wrong. Being made to examine my own writing and figure out a solution was helpful.

**What could be improved about the coaching sessions?**
Nothing.

**Which activities did you find most useful, interesting or enjoyable?**
Writing stories of things that happened to me. I could get a point across rather than just copying something out.

**Which activities did you find least useful, interesting or enjoyable?**
The story and imagination was far better than writing out rows of the same thing. The envelopes were boring but gave me a lot of practice. Writing out [difficult] words repeatedly was disappointing but had to be done. You have to do things over and over again, especially if you are having difficulty. Taking notes made me angry because I let myself down - I couldn’t keep up and this was confronting. But it made me work out a solution. I’m very happy now because I can do my role [take minutes in meetings].

**Do you have any other suggestions or comments?**
Overall the research was very good. You have to want to do it, or you wouldn’t bother with the work. You need a lot of enthusiasm because it’s so repetitious - if you didn’t want to do it you’d give up. It’s given me more confidence.