An investigation of handwriting legibility and pencil use tasks in healthy older adults

Michelle Dettrick-Janes

Supervisors:

Dr Justin Scanlan, Dr Annie McCluskey, A/Professor Natasha Lannin

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SUPERVISOR'S CERTIFICATE

This is to certify that the thesis entitled "An investigation of handwriting legibility and pencil use tasks in healthy older adults" submitted by Michelle Dettrick-Janes in fulfilment of the requirements for the degree of Master of Applied Science is in a form ready for examination.

Justin Newton Scanlan Signed: _____ Date: 15 June 2018

CANDIDATE'S CERTIFICATE

I, Michelle Dettrick-Janes hereby declare that the work contained within this thesis is my own and has not been submitted to any other university or institution as a part or a whole requirement for any higher degree.

Signed: _____ Date: 15 June 2018

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CONTENTS

ABSTRACT

This project explores handwriting legibility and pencil use tasks in 120 healthy older Australian adults, aged 60 to 99 years. A cross sectional study design was used. The aim of these studies was to explore if handwriting legibility or pencil use performance deteriorated as people aged. This is important to help therapists determine if handwriting difficulties following stroke, or other medical conditions, are more likely a consequence of condition-related impairments or due to 'normal ageing'.

Tasks performed under standardised test conditions included writing copied and self-composed sentences, shopping lists, transcribing a telephone message and completing the 'lines' and 'dots' pencil use Motor Assessment Scale (MAS) subtests. Handwriting legibility was scored using the Modified Four Point Scale-version 2.

The first study explored the distribution of handwriting legibility scores in healthy older adults, relationships between handwriting legibility, age and writing task and reliability of rating procedures. Results indicated that handwriting generally remained legible in older adults, regardless of increasing age. The second study explored the performance of older adults without stroke on the 'lines' and 'dots' tasks, the relationship between age and task performance, and the relationship between writing speed and performance on the 'lines' task. Results indicated that many older adults failed the 'lines' task and many over 90 years of age failed the 'dots' task.

Results suggest that impaired handwriting legibility in older adults who have had a stroke (or other medical condition) is likely due to the effects of the medical condition (or the

complexity of the task) rather than ‘normal ageing’. However, failure to pass the ‘lines’ and ‘dots’ tasks is likely related to a combination of age and individual skill level and not solely due to condition-related impairment. A revised method for rating performance on the ‘lines’ and ‘dots’ tasks is also proposed.

CHAPTER ONE: INTRODUCTION

Background to the Research

Despite the computer revolution, adults continue to handwrite daily to make notes, lists and to complete puzzles (van Drempt, McCluskey, & Lannin, 2011a). For adult handwriting to be functional, it must be legible to oneself (e.g., for re-reading notes or shopping lists) and/or others (e.g., a spouse) and produced in a timeframe deemed appropriate for the task (such as taking messages or completing an exam). During the years I was employed as an occupational therapist for the Sydney South West Area Stroke Outreach Service, I regularly worked with older adults who were three to six months into their stroke rehabilitation journey. Frequently, improved handwriting was identified as a rehabilitation goal for the purposes of making lists, writing letters and cards, completing puzzles or perhaps improving overall hand function. People were particularly interested in improving their ability to pick up, manipulate and skilfully use a pen, improve their handwriting speed and/or legibility.

Whether the problems with handwriting originated from a physical problem such as hemiparesis, or a cognitive problem such as dyspraxia (or both), I regularly used the Handwriting Assessment Battery (HAB) for Adults (Faddy, McCluskey, & Lannin, 2008; McCluskey & Lannin, 2003) to assess stroke survivors' abilities to manipulate writing tools and assess their handwriting legibility and speed. The HAB is one of the few existing handwriting assessment tools available for use with adults and aims to measure pen / pencil motor control, handwriting speed and legibility following stroke or brain injury (Faddy et al., 2008).

In recent years, several studies have described healthy adult handwriting behaviours and concluded that increasing age is associated with deterioration in writing speed (Burger & McCluskey, 2011), as well as downward pen pressure (Engel-Yeger, Hus, & Rosenblum, 2012) and letter size consistency (Yoon, Kim, Kim, Park, & Kim, 2013). However, research investigating handwriting legibility in 'healthy' older adults (who do not have neurological conditions) has not yet been completed. It is therefore unclear whether deterioration in legibility is typical as adults grow older, making it difficult to interpret the handwriting legibility difficulties faced by older adults with stroke or other neurological conditions. Furthermore, if handwriting speed and the ability to apply pressure downward through the barrel of a pen deteriorate with age, would performance on the skilled pencil control tests contained on the HAB also deteriorate with age? Are difficulties with handwriting legibility or completing the pencil control tests contained on the HAB a direct result of stroke, due to ageing, or a combination of both?

The primary aims of this study were to investigate (a) handwriting legibility and (b) pencil control in older adults without neurological conditions, providing rehabilitation therapists with descriptive data to better understand and interpret handwriting problems faced by individuals following stroke or other neurological conditions. A better understanding of legibility and the motor control required to skilfully use a pen / pencil in healthy older adults will assist rehabilitation therapists to establish realistic handwriting retraining goals with individuals who have neurological conditions.

When assessing handwriting legibility, it is important to consider the availability of technologies designed to recognise and convert handwriting into digital data. Handwritten text such as postal addresses on envelopes and demographic information on documents are

increasingly being recognised and digitised by machines (Plamondon & Srihari, 2000). Additionally, many handwriting recognition technology systems can automatically import handwritten text from paper documents or from a digital pen. Use of handwriting recognition technology may seem like an easy and objective method of measuring handwriting legibility, however, recognition of unconstrained handwriting, particularly cursive styles, remains problematic in the field of 'Optical Character Recognition' technology systems (Berchmans & Kumar, 2014; Rusu & Govindaraju, 2006). Compared to machines, humans remain more expert at deciphering handwritten text because humans are more able to correctly interpret diversity in writing styles, inconsistent word and letter spacing, unclear word and line delineation, and unclear letters or words by understanding context (Rusu & Govindaraju, 2006). Reading handwriting also remains the only available method for most occupational therapists to assess legibility when providing handwriting retraining to adults. Therefore, this study will use human assessors, rather than technology systems, to rate handwriting legibility.

In the first study presented in this thesis, legibility of handwriting was assessed using samples obtained from two subtests of the HAB: (a) The Jebsen Speed Test, referred to in this study as the 'copied sentence' subtest, and (b) The self-composed sentence subtest. Two further subtests were developed for the current study: (c) the audio-taped telephone message subtest; and (d) the self-generated shopping list subtest. The HAB is one of the few standardised handwriting assessments available for use with adults, and the only one designed for evaluating the handwriting of older (rather than younger) adults. The two additional subtests were developed for the study so that they could be added to the HAB and reflect common adult handwriting practices described in recent research (Gozzard, McCluskey, Lannin, & van Drempt, 2012; van Drempt, McCluskey, & Lannin, 2011b). Specific details of each subtest are documented in the data collection procedures section of

Chapter 3, and a research article published in *Physical & Occupational Therapy in Geriatrics* (Dettrick-Janes, McCluskey, Lannin, & Scanlan, 2015).

For assessing legibility in adults, previous research has suggested that use of the Modified Four Point Scale (mFPS) is optimal, but that this instrument has limitations (Au, McCluskey, & Lannin, 2012). Measuring legibility of adult handwriting is problematic because legibility is subjective and many factors can influence perceptions of legibility. To date, a reliable tool for measuring the handwriting legibility of adults does not exist (Au et al., 2012). Despite this, measurement of legibility remains important for clinical practice. Therefore a secondary aim of this study was to evaluate the inter rater reliability of a revised version of the mFPS - version 2 (mFPS-v2) and the new Modified Four Point Scale-version 2 – words (mFPS-v2-W), developed for this study.

In the second study presented in this thesis, the motor control required to skilfully use a pen / pencil was assessed using two pencil skill tasks derived from the Motor Assessment Scale (MAS) (Carr, Shepherd, Nordholm, & Lynne, 1985), also contained in the HAB. The MAS is used widely across international clinical settings to measure changes in upper limb function following stroke. Along with other upper limb tests, the MAS includes an 'advanced hand activities' item. Stroke survivors are required to perform tasks requiring intricate hand movements such as brushing hair, pouring water from a jug and two pencil use tasks, referred to in this study as the 'lines' and 'dots' tasks. The 'lines' and 'dots' tasks are both time-limited and require the ability to pick up and use a pencil skilfully to (a) draw 10 horizontal lines across a page (the 'lines' task) and (b) make 10 'clean dots' by rapidly pressing the pencil tip on the page and raising the pencil off the page (the 'dots' task). Both tasks are scored as either 'achieved' (1) or 'not achieved' (0). Several studies have shown that the

'lines' and 'dots' tasks are the most difficult for stroke survivors to achieve compared with other MAS advanced hand activities (K. J. Miller, Slade, Pallant, & Galea, 2010; Pickering, Hubbard, Baker, & Parsons, 2010; Sabari et al., 2005), yet it is unknown if older adults without stroke can achieve the requirements of these two tasks.

A greater understanding of performance on the 'lines' and 'dots' pencil tasks, as well as a description of handwriting legibility in healthy older adults will contribute to a reliable procedure for the assessment and treatment of handwriting difficulties following stroke and other neurological conditions.

Research Problems

Illegible handwriting is a common problem requiring occupational therapy intervention for adults following stroke or other neurological conditions. Yet limited research exists to help occupational therapists determine when handwriting is within or outside the 'normal' legibility range. A valid and reliable handwriting legibility measure is not yet available for use with adults (Au et al., 2012). There is a need for exploration of handwriting legibility in healthy adults, and measurement of legibility. That research will help inform the ongoing development of a valid handwriting legibility measure, help rehabilitation therapists determine handwriting legibility goals and treatment plans, and evaluate clients' progress towards their goals.

Pre-handwriting skills, or the ability to pick up and control a writing implement to draw lines, strokes, curves, circles and dots (required for the formation of written letters) are commonly impaired following stroke, limiting individuals' ability to handwrite. Motor control and manipulation of a pen / pencil is often assessed by therapists using the Motor

Assessment Scale (Carr et al., 1985) 'lines' and 'dots' tasks, also contained in the HAB (McCluskey & Lannin, 2003). While it is known that the 'lines' and 'dots' tasks are difficult for stroke survivors to achieve (Khan, Chien, & Brauer, 2013; Pickering et al., 2010; Sabari et al., 2005), it is unknown if healthy older adults can pass the requirements of these tasks; no descriptive data have yet been published. Descriptive data are needed to develop a valid procedure for assessing pencil/pen usage and help therapists determine realistic handwriting rehabilitation goals and treatment plans.

Purpose of the Research

Handwriting is one of the most frequently performed activities of older persons (Rosenblum & Werner, 2006). Over the last 10 years several researchers have investigated handwriting processes in healthy older adults, including the speed of handwriting (Burger & McCluskey, 2011; Engel-Yeger et al., 2012), downward pen pressure when writing (Engel-Yeger et al., 2012; Rosenblum & Werner, 2006), pen 'in air' and 'on paper' times during writing (Rosenblum & Werner, 2006) and letter size consistency of handwritten samples (Yoon et al., 2013). These studies consistently show that increasing age leads to deterioration in handwriting process capacities. With increasing age adults write more slowly, less fluently (spend more time with the pen in the air and not on the paper) and produce greater letter size inconsistencies in handwriting samples. As a clinician assisting people who had survived a stroke, I found descriptive data produced from handwriting speed studies particularly useful for comparing and discussing clients' performance. For example, I recall a stroke survivor who took over four minutes to write a 26-letter sentence. Published data described the upper range of time taken for healthy adults of a similar age to write the sentence as approximately 26 seconds (Burger & McCluskey, 2011; Jebsen, Taylor, Trieschman, Trotter, & Howard, 1969). I was able to use that data to advise my client of the 'typical' performance of other

adults of a similar age. Motivated by the knowledge provided by research, he was keen to improve his handwriting speed. On his second attempt, the man wrote another 26-letter sentence in approximately two minutes, half the time of his first attempt. However, when working with clients to improve their handwriting legibility, no data were available to describe the range of legibility in healthy older adults (without stroke) for comparison.

As a stroke outreach occupational therapist I also worked with people who, following stroke, were not able to pick up a pen, manipulate the pen or make marks on paper, let alone write legible letters. Using the two MAS pencil use tasks contained in the HAB, I could measure marks made on a page, then discuss possible training strategies to improve a person's pen control. Yet it was unknown if the 'pass' criteria for the 'lines' and 'dots' tasks was 'reasonable' for stroke survivors to achieve. This uncertainty was mainly because no data were available to show whether these tasks were achievable by healthy older adults without stroke or other significant health conditions.

Thus the main purposes of the research presented in this thesis were to (a) describe the range of legibility scores across a variety of handwriting tasks, in healthy adults aged 60 to 99 years and (b) establish if healthy older adults can achieve the requirements of the HAB/MAS 'lines' and 'dots' pencil use tasks.

Specific Research Questions

The primary questions guiding the research presented in this thesis were (a) 'What is the range of legibility scores across a variety of handwriting tasks, in healthy adults aged 60 to 99 years?' and (b) 'Can healthy older adults achieve the requirements of the 'lines' and 'dots' pencil use tasks contained in the HAB and MAS?'

Four additional research questions were added later. These were: (a) 'What is the reliability of the legibility rating procedures used in this study?', (b) 'What is the relationship between legibility and increasing age, the writing task performed and the writing tool (pen or pencil) used?', (c) 'What is the relationship between increasing age and task performance on the 'lines' task of the HAB/MAS, and (d) 'What is the relationship between speed of sentence writing and performance on the 'lines' task of the HAB/MAS?'

This final research question was added following the finding that task performance on the 'lines' tasks deteriorated due to aging or individual skill. The lines task requires individuals to hold a pencil, move their arm across the page and draw 10 horizontal lines within a short time frame. Therefore we questioned whether adults who are able to achieve the requirements of the 'lines' task write faster than people who cannot perform the requirements of the task.

Design of the Research

A cross sectional study design was used. Institutional ethics approval was granted. A convenience sample of 120 older Australian adults was planned, with the aim of obtaining data from 15 men and 15 women from four age groups (60 to 69, 70 to 79, 80 to 89 and 90 to 99 years). A target of 30 participants in each age group allowed sufficient analysis between age sub-groups (Peat, Williams, Xuan, & Mellis, 2001; Portney & Watkins, 2009). The sample was chosen to match the age of many, but not all, stroke survivors. A convenience method was used to recruit participants through personal contacts of the researchers, retirement villages, residential home, community groups and senior citizens' group, in the city of Sydney, in New South Wales and the town of Yeppoon, in Queensland. Recruitment

continued until 30 participants had consented for each age group. In the 90 to 99 year age group, fewer male participants were recruited, so additional female participants were included. Eligible participants were aged 60 to 99 years, able to read and write in English, write without pain and participated voluntarily. Participants were all able to complete the two sentence writing subtests of our study. Participants were excluded if they self-reported having had a stroke, or any other condition that affected their writing such as severe arthritis, macular degeneration, impaired vision, diabetes, major depression, dementia or Parkinson's disease, or they could not complete the subtests due to poor comprehension. A self-report questionnaire was completed first, capturing demographics, health status and hand dominance. The questionnaire was developed by the research team to describe the sample, and has been used in previous studies (Burger & McCluskey, 2011; van Drempt et al., 2011a). All subtests were then administered. Participants completed the handwriting subtests and 'lines' and 'dots' pencil use tasks in sitting, using their dominant, writing hand. Participants signed a consent form and confidentiality was assured (see Appendix 1). A data collection workbook designed for this study, as well as a concurrent study (Burger & McCluskey, 2011) was used to collect handwriting samples produced during the handwriting subtests and the 'lines' and 'dots' tasks (see Appendix 2).

Potential Significance of the Research

A published description of the distribution of handwriting legibility scores in healthy older adults, across a variety of tasks, will be available for comparison with future handwriting research outcomes and clinical assessment of individuals' handwriting legibility following stroke or other neurological conditions. A published description of the performance of healthy older adults on the 'lines' and 'dots' tasks will establish if it is reasonable to test a stroke survivor's ability to pass the tasks in their current form. The results of this research

will contribute to a greater understanding of handwriting legibility and performance on the pencil use MAS / HAB 'lines' and 'dots' tasks in older adults without stroke.

Findings may assist further development of a valid handwriting and pre-handwriting outcome measure. Importantly, findings will assist occupational therapists to (a) measure with greater confidence adult clients' handwriting legibility and pre-writing pencil/pen use, (b) set individually targeted and realistic handwriting goals for their clients and (c) re-measure client progress during the rehabilitation process.

Overview of Thesis Structure

This thesis is formatted, in the main, as two research papers (Chapters 3 and 4) published in peer reviewed occupational therapy journals. Chapter One provides an overview of the basis for the research undertaken, significance of the problem and potential contribution of the research results. Chapter Two provides an overview of literature relevant to the context of studies reported in this thesis.

The first published paper, Chapter Three, describes (a) the range of legibility scores across a variety of tasks, in healthy adults aged 60 to 99 years, (b) the relationship between legibility and increasing age, the writing task and writing tool used, and (c) the reliability of legibility rating procedures.

The second published paper, Chapter Four, describes (a) the performance of healthy older adults on the 'lines' and 'dots' pencil use tasks originally described in the Motor Assessment Scale (MAS) (Carr et al., 1985), (b) the relationship between age and task

performance on the ‘lines’ task and (c) the relationship between writing speed and performance on the ‘lines’ tasks.

Chapter Five concludes this thesis with detailed discussion of the relevance and implications of this research for occupational therapy clinical practice and future research.

CHAPTER TWO: LITERATURE REVIEW

In this chapter, I explore the background literature surrounding legibility and handwriting skills including (a) the concept of handwriting legibility in children and adults, (b) factors influencing handwriting skills and the production of legible text and (c) a review of measures used to evaluate pre-handwriting skill and legibility in adults.

Search Strategy and Terms

To identify relevant literature, a list of topics and search terms was generated including: (a) handwriting; (b) legibility; (c) legibility assessment; (d) reading; (e) handwriting recognition technology, (f) pencil/pen skills and (g) motor assessment scale. Subject and medical subject headings (MeSH) included: writing, text, legibility, assessment, readability, perception, reading, visual perception, word perception and handwriting recognition software. The following databases were searched in July 2010, then again in January 2018: The Cumulative Index to Nursing and Allied Health Literature (CINAHL), Allied and Complementary Medicine (AMED), EMBASE, ERIC, PubMed and Ovid MEDLINE were searched for studies relating to handwriting, handwriting legibility and pen/pencil use skills.

Google Scholar was also used at regular intervals to search for new publications, and for 'grey' unpublished literature such as conference abstracts, dissertations and theses. Relevant research was followed up through hand searching of reference lists and citation tracking.

What is Handwriting Legibility?

Legible handwriting refers to handwriting that can be read or deciphered easily (The Macquarie Dictionary, 2004). Handwriting remains an important daily task for older adults, regardless of increasing accessibility to electronic communication devices (van Drempt et al., 2011a). The purpose of handwriting is to record ideas and information by producing graphic signs that represent words, syllables or phonemes of spoken language (Rapcsak, 1997), primarily to communicate (Amundson, 2005). For successful communication, handwriting needs to be read by others, or in some instances, re-read at a later date by one's self. In clinical settings, improving legibility of handwriting is often identified as a goal for older adults recovering from stroke and a range of other health conditions.

Much of what is known about adult handwriting, and the evaluation of handwriting legibility is informed by research involving children. Therefore, this body of paediatric research is important to explore, in addition to studies involving adults.

Handwriting development begins as early as infancy, when children are first able to grasp a writing tool (Berninger, 2012), but handwriting differs from other developing grapho-motor tasks, such as drawing or painting, due to involvement of the linguistic system (Zesiger, Mounoud, & Hauert, 1993). Letters, words or numbers are formed when language is translated into specific motor plans and movements (Rapcsak, 1997). Thus handwriting is a complex task combining sensory-motor, cognitive, psychosocial and speech and language processes with use of a writing tool.

Throughout the world, handwriting is taught in the early years of school (Case-Smith, Holland, Lane, & White, 2012; Weintraub, Drory-Asayag, Dekel, Jokobovits, &

Parush, 2007). In Australia, young primary students first learn how to form well-shaped letters (Government of South Australia, 2007), learning precise grapho-motor sequences to produce the straight and curved strokes of each letter of the alphabet. A variety of methods and media are used in primary school to teach letter formation (Department of Education Queensland, 1984; Government of South Australia, 2007). For example, children may use their index finger to trace letters in sand or on an electronic tablet, or paint letters with a paint brush. Children quickly progress to routine handwriting practice during class time, using pencil and paper to trace and/or repetitively write individual letters of the alphabet. At the same time, children are writing increasingly complex language works, such as whole sentences and short stories. To successfully complete school activities, it remains important for primary school age children to develop legible handwriting for composition of ideas, regardless of increasing classroom use of electronic communication devices (Berninger, 2012; Peverly, 2006). By the 5th or 6th year of school (ages 9 to 11), Australian children are expected to have developed a fluent handwriting style which may be joined (cursive), uses conventional letter shapes, is aesthetically pleasing, and most importantly, is legible (Government of South Australia, 2007).

Handwriting legibility in children

The legibility (or illegibility) of children's handwriting is determined by teachers, and sometimes, by school-based or paediatric occupational therapists (Tseng, 1998). Children's handwriting is commonly described as consisting of five main visual features: letter form, alignment, size, spacing and slant (Alston, 1983; Amundson, 1995; Hadavandkhani, Bahrami, Behnia, Farahbod, & Salehi, 2008). These features are referred to as 'handwriting legibility components' (Amundson, 2005; Feder & Majnemer, 2007; Graham, Boyer-Shick, & Tippets, 1989; Ziviani & Elkins, 1984).

Classroom lessons regularly target correct letter formation, and are a common focus of classroom activities for children aged five to seven years (Case-Smith et al., 2012; Government of South Australia, 2007). Five subcategories of letter formation have been identified in paediatric literature, and 'errors' in letter formation are thought to impact negatively on letter legibility (Alston, 1983; Amundson, 2005). First, children may write letters with distorted shape, write reversed letters, as if seen in a mirror, or greatly rotate letters. Although some reversal of letters is considered age appropriate, particularly left-facing letters (e.g. d and j) (Treiman, Gordon, Boada, Peterson, & Pennington, 2014), until approximately seven or eight years of age, reversed and distorted letters may result in illegible handwriting. Second, children may not use the correct method of leading in and out when writing letters, resulting in poor formation. As one example, for the letter 'a', a child may 'draw' a circle first then lift the pen and place a stalk against the circle. Third, children may not adequately round their letters, so that a letter may be mistaken for a different letter. For example an 'e' without a rounded section above the horizontal stroke may look like a 'c', while capital 'O' may look like a 'D' if not fully rounded. Fourth, incomplete closure of letters or omitted/incomplete parts of letters may impact on legibility. For example, an 'a' that is not fully 'closed' could be mistaken for the letter 'u', and omitting the 'last stroke' from the capital 'R' produces a capital 'P'. Fifth, incorrect length of letter ascenders and descenders affects letter legibility (Amundson, 2005). For example 'h' written without a tall ascender stroke looks like the letter 'n'. In paediatric studies investigating legibility components and their impact on overall legibility, letter formation has consistently been found to contribute more to legibility of writing samples than any other component (Graham et al., 1989; Weintraub et al., 2007).

The four other ‘legibility components’ identified in paediatric literature are spacing, alignment, size and slant. Letter spacing refers to the dispersion of individual letters within a word, and dispersion of words within a sentence (Larsen & Hammill, 1989). Letters generally do not overlap and words should not be joined (Amundson, 2005). Letter alignment refers to the positioning and orientation of written letters on, or along, the writing line, (Amundson, 2005) or the imaginary writing line on a blank (unlined) page. Letter size refers to the size of individual letters relative to the writing lines and to other letters. Letter dimensions should generally be uniform within a word. Additionally, writing an upper case letter in the middle of a word, instead of a lower case letter is considered ‘incorrect’ for primary school aged children (Amundson, 2005). Letter slant refers to the angles or rotation of letters and words. Inclination of letters should be uniform throughout the writing sample (Amundson, 2005).

Many standardised paediatric handwriting assessments score these five ‘legibility components’, and sometimes other components, against predetermined criteria (Amundson, 2005). These assessments are known as analytic measures of handwriting legibility. Analytic measures assume that these legibility components have a direct relationship to overall or global legibility, that is, the ability to read a child’s handwriting (Rosenblum, Weiss, & Parush, 2003). However, paediatric research has not always found alignment, spacing, size and slant to objectively correlate with global (overall) legibility outcomes (Graham et al., 1989; Weintraub et al., 2007).

A substantial amount of research has explored the contribution of specific legibility components to overall legibility in the context of children’s handwriting. The most consistent finding from this research is that letter formation has a substantial impact on the

overall legibility of children's handwriting (Daniel & Froude, 1998; Graham et al., 1989; Hammerschmidt & Sudsawad, 2004; Weintraub et al., 2007). One group of researchers found that letter formation, spacing and 'general neatness'; defined in that study as handwriting without strike-outs, erasures (spots or marks left after erasing) and smudges, with 'appropriate' margin and paragraph indentations and letters that are not too light or dark, were all associated with overall legibility in 9 to 13 year old children with learning disabilities (Graham et al., 1989). Of all legibility components, letter formation had the most substantial impact on overall legibility, explaining 44% of the variance in overall legibility (Graham et al., 1989). Similarly Weintraub et al. (2007) reported that letter formation was the only legibility component to consistently influence overall handwriting legibility in a sample of 134 Israeli students aged 12 to 16 years. Finally, when teachers and therapists were asked for their views on important aspects of legibility, they concluded that letter formation and letter size (Daniel & Froude, 1998), and letter formation and 'proper' spacing (Hammerschmidt & Sudsawad, 2004) were most important for overall handwriting legibility in children.

In summary, correct formation of individual letters has consistently been shown to contribute significantly to global legibility outcomes in paediatric handwriting studies. For primary school aged children, mastering the ability to produce well-formed letters seems imperative for developing legible handwriting and successful completion of many classroom activities. None-the-less, all five legibility components continue to be assessed and remediated by teachers and occupational therapists when handwriting legibility is considered a problem for students. For children developing handwriting skills, improvements in all five legibility components (formation, spacing, sizing, slant and alignment) would presumably improve the overall acceptability of handwriting to teachers

and therapists. However, the bottom line regarding legible handwriting is that children need to produce handwriting that can be read, even in paediatric assessments which examine legibility components in detail (Amundson, 2005). For young children, letter formation seems to be the most important component of legibility contributing to readability.

Handwriting legibility in adults

Published literature regarding adult handwriting is scarce compared to the large body of research investigating development of handwriting in children (Rosenblum & Werner, 2006; van Drempt et al., 2011a; Yancosek & Howell, 2011). Most researchers investigating the legibility of adult handwriting have used a global legibility rating method to describe real-world handwritten text, for example handwritten medical notes (e.g., Berwick & Winickoff, 1996; Murray, Boylan, O'Flynn, O'Tuathalgh, & Doran, 2012; Rodríguez-Vera, Marín, Sánchez, Borrachero, & Pujol, 2002). Only two small Australian studies are known to have explored the relationship between legibility components and overall handwriting legibility in adults (Gozzard et al., 2012; van Drempt et al., 2011a).

The contribution of letter size, slant and spacing to overall legibility was investigated in 30 healthy older adults (van Drempt et al., 2011a). Researchers measured the width and height of letters, letter slant, between-word spacing and baseline orientation. Writing samples were also rated for legibility using a four-point global legibility scale (Au et al., 2012), originally used to rate doctors' handwriting. The vast majority of participants' handwriting (93%) was considered legible (that is, the meaning of text was clear when read) (van Drempt et al., 2011a). Regression analysis revealed that legibility was not associated with letter size, slant, between word spacing, or the amount of text written.

Gozzard et al. (2012) examined handwriting legibility in 16 younger adults aged 20 to 24 years, replicating methods used by van Drempt et al. (2011a). A third of these young adults (31%) wrote at least a few illegible words when generating self-composed text, but the overall meaning of the writing sample could still be understood (Gozzard et al., 2012). Again, legibility was not influenced by letter size, slant or between-word spacing (Gozzard et al., 2012).

In both of the studies presented above, findings suggest that these handwriting legibility components appear to have limited impact on the overall legibility of adult handwriting. However, both studies had small sample sizes, and may have been insufficiently powered to detect an association between letter size, slant and between-word spacing and global legibility. As no associations were detected in the above studies between legibility components and overall legibility, and the vast majority of adult handwriting was rated 'legible', it is questionable whether variances in letter size, slant or word spacing are of any real-world significance to overall legibility.

In summary, legibility of children's handwriting has been described in terms of five key components; letter formation, sizing, spacing, alignment and slant, with letter formation shown to be a key contributor to overall handwriting legibility in primary aged children. However, for adult handwriting, variances in letter sizes, slant and word spacing seem to have little association with overall global legibility. No known studies have explored if individual letter formation is important or not for the overall legibility of adult handwriting compared to children developing handwriting skills.

Published research exploring adult handwriting has mainly used global methods to measure legibility. After forming a judgement concerning the overall readability of the handwriting sample, the reader assigns a categorical rating that best describes handwriting legibility (e.g., Berwick & Winickoff, 1996; Murray et al., 2012; Yancosek & Calderhead, 2012). Global methods for measuring legibility are known to be inherently subjective (Rosenblum et al., 2003; Ziviani & Elkins, 1984) and poor inter rater agreement is a common limitation of global legibility measures (Au et al., 2012). Global legibility is highly subjective mainly because the visual features of text (i.e. the 'handwriting legibility components') are not the main source of information a proficient reader uses to interpret the text. Rather, reading processes and individual word shape recognition greatly influence our ability to read with ease, and our perception of legibility, for both handwritten and computer-generated text (Firth, 1985; Lavidor, 2011).

Reading processes

Context, prior knowledge and word shape recognition influence an individual's perceptions of legibility of handwritten information (Murray et al., 2012). The processes of reading have been the focus of much research in the areas of cognitive psychology and automated handwriting recognition technology. This research can help us to better understand features of handwriting which may increase read-ability - and therefore legibility - and illuminate why objective measurement of handwriting legibility is such a challenge.

Text written in English is read primarily by recognition of word shapes, and by predicting proceeding words using both context and prior knowledge. Regardless of the visual features of handwriting, reading difficulty is largely determined by readers' ability to match key text features, such as word shape, to their own word predictions (Federmeier &

Kutas, 1999). Not every letter needs to be legible to recognise words and not every word needs to be legible to understand the meaning of a sample of handwriting (Federmeier & Kutas, 1999; Kendeou, Muis, & Fulton, 2011; Morton, 1964). The presence of context and prior knowledge reduces the number of visual features, or cues, needed from the individual letters, in order to recognise words correctly (Morton, 1964). Reading research has demonstrated that words are recognised as a whole, using key visual features, especially the first letter, last letter, ascenders and descenders, which make up the 'outer' shape of a word (Lavrenko, Rath, & Manmatha, 2004). Sequential letter processing does not seem to occur when reading (B. Miller, Juhasz, & Rayner, 2006). Rather, the first and last letters of the word, and the outer word shape periphery, are analysed before the inner features of the word (Beech & Mayall, 2005). It is indeed possible to identify a word correctly without locating or recognising all the letters of that word (Powalka, Sherkat, & Whitrow, 1994; Schomaker & Segers, 1999).

For cursive handwriting, recognition of ascender letters (e.g., b, d, h, t) and descenders (e.g., g, p, y) seem to allow readers to distinguish words with greater accuracy (Powalka et al., 1994; Schomaker & Segers, 1999). In one study, reading speed decreased, and mistakes when reading increased, when cursive handwritten words did not contain ascenders or descenders compared to words that did (Brasse, 1991). A further study conducted in 1999 aimed to identify readers' 'zones of interest' when individuals read cursive handwriting (Schomaker & Segers, 1999). Readers were presented with handwritten words on a computer screen with low lighting so that the word could not easily be seen. Readers were asked to click on the screen with the mouse pointer, to light up a small area of the handwritten word, in attempt to identify the zones of interest for word recognition. The study designers hypothesised that the mouse clicking would mimic the unobservable

cognitive process of word feature extraction used when reading cursive handwriting. There was a statistically significant difference between the number of clicks on ascender/descender letters (bdfghjklpqty) compared to other letters (aceimnorsuvwxz) (M=12.8 and 10.6 clicks respectively) (Schomaker & Segers, 1999). These results suggest that ascenders and descenders are given great attention by readers in order to recognise words. The left side of words (first letters) and the right side (last letters) also received high click rates, suggesting that first, last and ascender descender letters are of key importance for word recognition (Schomaker & Segers, 1999).

Another reading process that may influence legibility is experience and knowledge of the vocabulary used by a writer. Only one known study has investigated this question related to perceptions of legibility for information handwritten by adults (Murray et al., 2012). This study assessed the global legibility of Irish hospital doctors' medical notes when rated by other doctors, nurses, medical students, medical support staff and legal professionals. Overall findings suggested that raters with more clinical experience awarded higher legibility ratings. The authors concluded that the legibility of doctors' case notes was influenced by the background and level of clinical experience of the legibility rater (Murray et al., 2012). This suggests that increased knowledge of medical terminology and familiarity with medical report content reduced the need for every letter or word to be legible in order to interpret the meaning of the handwritten medical case notes.

Some researchers have attempted to reduce the impact of reading processes on the overall rating of legibility. An early researcher who attempted to reduce the influence of reading processes on legibility assessment was Turner (1930). Turner's participants were expected to read text upside down and in a mirror. Under these conditions, the research

concluded that manuscript text (printed, separated letters) was ‘more legible’ than cursive text (Turner, 1930). More recently, Yancosek and Calderhead (2012) also attempted to reduce the influence of reading processes on legibility assessment of adult handwriting by presenting words out of their original context. While this may have reduced the impact of word prediction, word recognition processes (first and last letter, ascender, descender identification) are still likely to have had an impact on legibility assessment. While the results of that research are interesting, the intention of handwritten information is to convey a message from the writer to the reader in a real-world context. It could be argued that a reader would never be expected to read text upside down in a mirror or to read words out of context, so why should legibility be assessed under such unnatural conditions?

Overall, it is clear that reading processes have an influence on the overall legibility of adult handwriting. While it would be useful for future research to investigate how much specific reading processes influence the overall legibility of handwriting, trying to remove the influence of reading processes during the assessment of legibility may be of limited value. As perception of legibility and reading processes are interconnected, attempts to eliminate reading processes arguably serve no purpose. No attempt was made in the current study to view words in isolation or out of context when rating handwriting legibility, rather, reading processes are discussed within the context of the study’s results.

Handwriting style

The various forms of letter style, such as upper or lower case, cursive, decorative or other scripts, are known as allographs (Rapcsak, 1997). Proficient writers select an allograph and transcribe that letter style to produce handwritten letters, using pre-learned graphic motor programs that detail specific sequencing, relative sizing and the direction of

each letter stroke or curve (Rapcsak, 1997), as well as where to place the letter on the page (Graham, Struck, Santoro, & Berninger, 2006). Mixed handwriting styles include a variety of letter styles within one writing sample. Allographs or letter styles are commonly mixed together to produce an individual's unique handwriting style (Gozzard et al., 2012; Summers & Catarro, 2003; van Drempt et al., 2011a). One small Australian study investigating handwriting in healthy older adults found that a 'mixed handwriting style' was commonly used by participants (van Drempt et al., 2011a). A 'mixed handwriting style' in that study referred to either a mixed cursive handwriting style, where at least 50% of text was cursive script, with the remaining letters printed, or a mixed print style, where at least 50% of letters were written in lower case print, with the remaining letters written in cursive script. A mixed handwriting style was also associated with better overall legibility, when compared to cursive handwriting alone.

Interestingly, Graham, Weintraub, and Berninger (1998) also concluded that speed and legibility of children in middle school who used mixed script writing styles were equivalent, or superior to, either printed or cursive script alone. That finding is consistent with the results of van Drempt and colleagues (2011a), who suggested that a mixed letter handwriting style may improve overall legibility compared to cursive writing alone.

Neatness

'Neat' handwriting is emphasised and encouraged by teachers of children in the early years of school. However, no uniform definition of what constitutes 'neat' handwriting exists. Previously, neatness has been described as a component of children's handwriting legibility, but more recent research suggests that neatness is not necessarily related to handwriting legibility in older children (Graham et al., 1989). However, previous research

has shown that lower marks are assigned to school students' test answers and assignments by examiners when handwriting is untidy, compared to handwriting which has an attractive aesthetic appearance and yet contains exactly the same content (or content of equal quality) (Morris, 2014; Sweedler-Brown, 1992). Thus, while neatness may not relate to overall legibility, it may be important for children to produce neat handwriting, even though 'neatness' is presumably subjective.

Neatness has been described in computerised handwriting analysis research as an 'aesthetic property', relating to the 'beautiful appearance' of a handwritten document (Adak, Chaudhuri, & Blumenstein, 2017). One study (Baxter, 2004) was located that requested younger adult participants (21 to 59 years of age) and older adult participants (60 to 92 years of age) to rate their handwriting legibility and handwriting neatness separately on a scale of zero to 100. Handwriting samples from all participants were also rated in the same way by two independent raters (Baxter, 2004). Results of that study indicated that older adult participants attributed significantly lower ratings for neatness to their handwriting than younger adults. Furthermore, one independent rater also rated the older participant group's handwriting lower than the younger participant group. However, there were no significant differences in ratings of legibility between age groups. While neatness may not have a direct influence on the legibility of adult handwriting, neatness does seem to influence an individual's satisfaction with their overall handwriting legibility (Simpson, McCluskey, Lannin, & Cordier, 2016). Messy handwriting may still be able to be read (i.e. legible) but may be perceived as unsatisfactory to the reader or writer. Therefore, neatness may be an important area for future research in relation to adult handwriting, despite the potential lack of relationship with overall legibility.

Summary

This section presented a review of available research describing concepts of handwriting legibility in children and adults. The construct of handwriting legibility components was reviewed, and the limited research exploring legibility components and their impact on adult handwriting was highlighted. For adult handwriting, the main factors influencing the ability of a reader to decipher and interpret written text include word shape recognition (related to the formation of first, last, ascender and descender letters in a word), context and prior knowledge, as well as handwriting style/script. For adult handwriting, it appears that neatness may not be related to legibility, but does have an impact on satisfaction and may, therefore, be worthy of further research.

Factors Influencing Production of Legible Handwriting

Extrinsic factors relating to the environment or nature of the task can affect an individual's ability to produce legible handwriting. For example, the type of writing task being performed, such as a copying task versus a self-generated sentence can impact on handwriting legibility in children (Feder & Majnemer, 2007). Individual children's abilities or impairments may also impact on handwriting legibility due to problems with orthographic-motor integration (that is the integration of correct language conventions, such as spelling and punctuation, with the fine-motor demands of handwriting) (Wallen, Duff, Goyen, & Froude, 2013). For adults, physical changes due to ageing processes or illness and injury such as stroke, may impair an individual's ability to skilfully use a pencil (or pen) to make purposeful marks on paper and produce legible handwriting. The following section reviews relevant factors that may influence handwriting legibility and pencil control.

The writing task

Legibility of children's handwriting is affected by the handwriting task (Dennis & Swinth, 2001; Graham, Berninger, Weintraub, & Schafer, 1998). In one paediatric study, students in grades 1 to 6 wrote with greater legibly when copying text than when creating a narrative or expository text (Graham, Berninger, et al., 1998). These researchers concluded that for young writers, the cognitive processes required to complete text composition tasks such as planning, generating and organising ideas, required considerable attention, leaving less attentional capacity to produce legible text (Graham, Berninger, et al., 1998). This finding is supported by another study which investigated the handwriting legibility of 46 fourth grade students, during a short and long writing task (Dennis & Swinth, 2001).

Significantly higher legibility scores were recorded for the short writing task compared to the longer writing task (Dennis & Swinth, 2001).

Writing tasks and legibility of adult handwriting were investigated in two cross-sectional observational studies, which used the same study design (Gozzard et al., 2012; van Drempt et al., 2011a). Global legibility was measured using text produced during a copying task (writing a name and address) and a self-generated task (writing a sentence). No difference was found in legibility ratings for self-generated text compared to copied text, for handwriting samples collected from 30 older adults (over 65 years, mean age 75.1 years) (van Drempt et al., 2011a). Regression analysis revealed that legibility also did not depend on how much the participant wrote (van Drempt et al., 2011a). However, for 16 young adults aged 20 to 24 years (mean age 21.6 years), legibility was greater for the self-generated task, compared to the copying task (Gozzard et al., 2012). Findings from both studies should be viewed with caution given the limited size and nature of the study samples. These researchers suggested that descriptive data needed to be collected on handwriting legibility, for adults across a variety of tasks (van Drempt et al., 2011a). That descriptive data will be a focus of research presented in this thesis.

Ageing

Older age has been associated with reduced writing speed (Burger & McCluskey, 2011; Engel-Yeger et al., 2012), inconsistent letter size (Yoon et al., 2013), reduced writing fluency and reduced downward pen pressure (Engel-Yeger et al., 2012; Rosenblum & Werner, 2006). However few studies have investigated increasing age and handwriting legibility in adults. One study, investigating handwriting legibility in medical notes, found that younger people (under age 40) wrote more legibly than people aged 40 years and over

(Berwick & Winickoff, 1996). While no upper age limit was reported in that study (Berwick & Winickoff, 1996), as all participants were working, it is assumed that the majority of the 'older' participant group would be under the age of 65 or 70 years. In another study involving 26 older adults (aged 60 to 92 years), and 32 younger adults (aged 21 to 59 years), legibility was similar for both groups (Baxter, 2004). In that study, handwriting samples were self-rated by participants and two independent raters for both legibility and neatness. The Baxter (2004) study found that while older adults rated significantly lower for neatness than younger adults, there were no statistically significant differences between the two age groups for legibility scores (Baxter, 2004). Of note is that many older participants reported that the quality of their handwriting had deteriorated as they got older (Baxter, 2004). Two other studies investigating adult handwriting also reported an association between older age and deterioration in the appearance of handwriting (Contreras-Vidal, Teulings, & Stelmach, 1998; Yoon et al., 2013). The first study found that older adults had decreased spatial coordination of fine motor finger and wrist movements during handwriting tasks, thereby reducing the straightness of oblique letter strokes, compared to younger adults (Contreras-Vidal et al., 1998). The second study found that increasing age was associated with inconsistencies in letter size (Yoon et al., 2013).

Handwriting speed also decreased with age in a recent study which examined the handwriting speed of 120 healthy older adults across a variety of handwriting tasks (Burger & McCluskey, 2011). Comparisons were made between four age cohorts between ages 60 to 99 years. Statistically significant differences were reported across age groups when participants completed a copied sentence, a self-composed sentence and a shopping list task. These findings are consistent with those from other research (e.g., Engel-Yeger et al., 2012). Another study, involving 53 healthy adults aged 60 to 94 years, found that older age was

associated with reduced writing fluency (longer pen 'on paper' and 'in air' time, greater 'pauses' when writing), reduced writing speed and lower pen pressure implemented downward through the pen onto the writing surface (Rosenblum & Werner, 2006). In that study, legibility of handwriting was not investigated. However, writing fluency (writing continuously without pauses, less pen 'in air' time) was associated with better global and letter legibility in another study investigating the handwriting of 100 third grade children conducted by the same group of researchers (Rosenblum, Goldstand, & Parush, 2006). Although writing fluency has been found to deteriorate due to typical aging processes (Rosenblum & Werner, 2006), it is unknown if a deterioration in writing fluency is associated with reduced handwriting legibility in older age.

In summary, older age in adults is associated with reduced handwriting fluency, changes to writing appearance and reduced writing speed. It is therefore possible that typical ageing processes impact on handwriting legibility. The current study will explore the association of increasing age and handwriting legibility, adding to the limited research available in this area.

Gender

Gender has also been investigated in terms of handwriting legibility in both children and adults. Studies of primary school children's handwriting consistently report that girls produce more legible handwriting than boys (e.g., Blote & Hamstr-Bletz, 1991; Graham, Berninger, et al., 1998; Ziviani & Watson-Will, 1998). Results from the one study that explored gender differences in adult handwriting legibility also found that women produced more legible writing than men when writing a standardised 48-letter sentence in 10 seconds (Berwick & Winickoff, 1996). However, research investigating gender and handwriting

legibility in adults is limited. This research will explore the relationship between gender and handwriting legibility in healthy older adults.

Upper limb movements

Sensory motor impairments resulting from stroke and other medical conditions can impact on a person's ability to generate adequate muscle force and/or perform the precise movements required to pick up a pen, grasp the pen, exert downward pen pressure to make marks and execute the co-ordinated ortho-graphic movements required for handwriting (Carr & Shepherd, 2003). Following stroke, decreased hand strength, loss of sensation in the upper limb, the presence of spasticity, pain or swelling in the upper limb, as well as impaired vision, may affect handwriting (Stroke Foundation, 2017). The ability to pick up a writing implement and perform controlled upper limb movements to move the pen across the page and make purposeful marks on paper is commonly impaired following stroke, thus limiting an individual's ability to produce legible handwriting.

In-hand manipulation, or the ability to adjust an object within the hand after grasp (Exner, 1996) is required for positioning and skilled manipulation of a writing tool. The ability to manipulate the writing implement appears to be important for producing legible handwriting in children (Cornhill & Case-Smith, 1996). However research examining the association between in-hand manipulation and handwriting legibility is limited. In one paediatric study of 48 first grade students, the skilled ability to move pegs quickly between the fingers was associated with better letter formation when children handwrite (Cornhill & Case-Smith, 1996). Authors concluded that, for children, efficient production of letters is related to coordinated muscle action and accurate use of force, when manipulating objects within the hand (Cornhill & Case-Smith, 1996). This conclusion was supported by

subsequent research showing that children aged 6 to 11 years who scored poorly on a hand manipulation assessment were more likely to have handwriting problems, compared to those with higher scores of hand manipulation (Denton, Cope, & Moser, 2006).

Although no known studies have investigated the association between in-hand manipulation and the production of legible handwriting in adults, upper limb movements required to form letters, words and sentences were described in a review of factors that influence adult handwriting performance (van Drempt et al., 2011b). That review reported that proximal joints of the upper limb (i.e. the shoulder and elbow) appear to be primarily responsible for larger between-word movements and larger script size, while distal joints of the hand appear to be responsible for smaller intra-word movements. The researchers suggested that people with reduced distal hand and finger control may therefore write larger text due to increased use of proximal joint movements (van Drempt et al., 2011b).

Anecdotally, impaired sensory-motor abilities after stroke or brain injury can affect an individual's ability to manipulate the writing tool and may therefore affect handwriting legibility. However, upper limb movements required for skilled handwriting may also deteriorate due to normal ageing processes (Contreras-Vidal et al., 1998). One study compared older (M age 69) and younger (M age 25) participants' finger and wrist movements while using a digital pen to make purposeful marks on a digital tablet. Finger and wrist movements were reduced for older participants compared to younger participants (Contreras-Vidal et al., 1998). While lateral pressure exerted around the barrel of the pen appears to be individual and vary greatly amongst healthy adults when handwriting (Ghali, Thalanki Anantha, Chan, & Chau, 2013), no known studies have investigated the association between ageing and lateral pressure application. However, lower pressure,

exerted downward through the pen onto the writing surface, has been associated with older age for a variety of handwriting tasks (Rosenblum & Werner, 2006). As upper limb abilities required for handwriting seem to deteriorate due to normal ageing processes, a focus of the research presented in this thesis is to explore the association between increasing age and the ability to skilfully use a writing tool to produce pre-writing 'lines' and 'dots', as well as increasing age and the production of legible handwriting.

Cognition

Handwriting is a complex cognitive task, requiring systematic instruction to help learners understand the task, and develop a cognitive strategy for selecting and transcribing letters and words by recalling specific motor movements to skilfully use a writing tool (Amundson, 2005; Carr & Shepherd, 2003; Chapparo & Ranka, 2005). For children acquiring handwriting skills, teachers and therapists have long acknowledged that a child must be able to attend to, and focus on, the handwriting task. Memory is also necessary for recalling accurate letter formation, sequencing and organising movements and other aspects of efficient handwriting (Amundson, 2005).

Higher level cognitive processes become more critical as children are required to perform more lengthy and complex written expression tasks (Hooper & Montgomery, 1993). Planning, organising, self-monitoring and revising are examples of higher level cognitive abilities required for children to complete complex handwriting tasks (Hooper & Montgomery, 1993; Levine, 1992). As children progress in handwriting skill acquisition, letter formation becomes automatic, with minimal conscious attention required for letter transcription (Amundson, 2005). Likewise, for healthy adult hand writers, movement execution during handwriting appears to be independent of attention (Tucha, Mecklinger,

Walitza, & Lange, 2006). Tucha et al. (2006) reported that for a sample of 20 adult hand writers, alertness and task vigilance were independent of handwriting movement, as measured by a digital writing board and pen. Although adults seem able to write letters and words with minimal conscious attention, adults, like children, would seemingly require the cognitive abilities to synchronise ideation, planning, text production, spelling, punctuation, grammar, self-monitoring, evaluation and orthographic-moto integration when generating more complex written text (Jones & Christensen, 1999).

Adults who have had a stroke or brain injury often require handwriting skill retraining (Faddy et al., 2008) due to cognitive synchronisation problems (Chapparo & Ranka, 2005). Dysgraphia or agraphia are terms used to describe neurological disorders causing a deficiency in writing ability, regardless of ability to read. Cases of dysgraphia in adults usually occur after neurological trauma where the parietal lobe of the brain has been damaged (National Institute of Neurological Disorders and Stroke, 2011). Writing problems include the inability to remember letter shape which influences legibly (Rapcsak, 1997). Some people with letter production disorders write upper case letters better than lower case letters, while others write lower case letters better than upper case letters. These differences suggest that long term memory storage of upper and lower case letter formation is separate and can be selectively disrupted by brain damage (Rapcsak, 1997).

People with a cognitive impairment have also been observed to produce well formed, but incorrect letters, where words are written with incorrect letter substitutions, while other individuals seem unable to keep handwriting style constant, although attempting to do so (Rapcsak, 1997). Rapcsak (1997) suggested that these examples of impaired letter production are likely a result of cognitive planning problems, rather than cognitive-motor

synchronisation. Cognitive problems impacting mainly on motor performance aspects of handwriting have been referred to as apraxic agraphia. Apraxic agraphia results in the inability to execute skilled movements to transcribe the memorised letter form, and therefore writing strokes are often omitted, repeated or additional strokes inserted, resulting in incorrectly formed letters (Rapcsak, 1997). People with apraxic agraphia can sometimes copy text significantly better than they can write self-generated text (Rapcsak, 1997). Thus it is important to explore the legibility of both copied and self-generated handwriting tasks in healthy older adults, to enable comparison during assessment and treatment of handwriting in adults with cognitive impairment.

Other factors influencing the production of legible text

Handwriting difficulties may result due to other factors, including impaired vision and impaired mood.

Adults with impaired vision often write with alignment problems, drifting up or down the page, or may write letters that are too small or large, joined or overlapped (Watson, Wright, Wyse, & De l'Aune, 2004). These problems may potentially make handwriting illegible. Many eye conditions common in older age result in reduced vision for adults, including age-related macular degeneration and cataracts which may impact on handwriting abilities and legibility. Neurological visual impairment and hemianopia are also common following stroke or brain injury (American Foundation for the Blind, 2010) and may reduce an individual's ability to produce legible handwriting. However, with retraining and use of adaptations such as writing guides and bold line paper, individuals with impaired vision may be able to handwrite with greater ease (American Foundation for the Blind, 2010).

Impaired mood and motivation can occur as a result of injury or illness, such as stroke, brain injury or depression. Emotional, motivational and behavioural changes can be a reaction to a health concern, or a direct consequence of brain damage caused by illness or injury such as stroke (Stroke Foundation, 2017). Adults experiencing apathy experience a deficiency in cognitive, behavioural and emotional components of goal-directed behaviour, which has a wide spread impact on occupational performance (Lane-Brown & Tate, 2009), including an individual's ability to produce functional handwriting.

The study presented in this thesis aimed to recruit healthy older adults and excluded adults who self-reported having depression, a stroke, brain injury or other significant health problems. A description of healthy adult handwriting legibility will assist therapists to understand 'normal ranges of handwriting legibility' to compare with individuals' with handwriting difficulties who may have deficiencies in vision or mood.

Other factors that may affect handwriting appearance yet seem to have no association with legibility

Writing tools

Handwriting legibility in children appears to be similar for text produced by a variety of writing tools, including pencils with various diameters, pencils with and without triangular grips, and felt-tip pens, when investigated in several paediatric studies (Carlson & Cunningham, 1990; Lamme & Ayris, 1983; Oehler et al., 2000; Ziviani & Elkins, 1986). Carlson and Cunningham (1990) investigated the effect of pencil diameter on graphomotor performance of pre-school children, but found no differences in graphomotor performance

when large or regular diameter pencils were used. Some children performed better with large diameter pencils, while others performed better with regular pencils. Therefore the authors recommended providing pre-school children with a variety of different sized tools for writing practice (Carlson & Cunningham, 1990).

No known studies have examined the relationship between adult handwriting legibility and writing tools. McMahon (2008) noted that when adults handwrite, writing tools are often selected based on what is readily available, not necessarily according to the most suitable tool. One recent study examined the relationship between handwriting speed and writing tool (pen versus pencil) with a sample of 120 healthy older adults aged 60 to 99 years (Burger & McCluskey, 2011). Text copied with a pen was written significantly faster than text copied with a pencil (M=107.3 letters/minute vs. 99.5 letters/minute, respectively). The difference was consistent across age sub-groups and gender. However, the self-generated shopping list task was written faster in pencil compared to pen (pencil M=91.1 letters/minute for pencil vs. M=85.8 letters/minute for pen). Reasons for these speed differences are unknown. The authors concluded that while standardisation of tests is important, assessments and retraining should involve the use of preferred writing tools and those which optimise performance (Burger & McCluskey, 2011).

In summary, no known study has compared the relationship between adult handwriting legibility, writing tools or tasks. The research presented in this thesis will investigate the relationship between handwriting legibility, writing tool and writing task.

Grasp

The dynamic tripod grasp has long been considered by teachers and therapists as the optimal pencil grasp for handwriting legibility and speed in children (Bonney, 1992; Tseng & Cermak, 1993). However, a growing body of evidence indicates that fast and legible handwriting can be produced using a range of alternate grasp types (Dennis & Swinth, 2001; Schwellnus et al., 2012). One study videotaped the pencil grasp of 120 typically developing fourth-grade students performing a writing task. That study found that legibility, as well as speed of writing, was similar for six different pencil grasps (Schwellnus et al., 2012). These findings support other earlier studies which found that handwriting legibility and speed were not affected by pencil grasp in children with ages ranging from seven to 16 years (Dennis & Swinth, 2001; Rosenblum et al., 2006; Ziviani & Elkins, 1986).

The effect of pen/pencil grasp on writing legibility and speed in adults was investigated in two known studies (Jaffe, 1987; Shah & Gladson, 2015). In the first study, 40 adult participants copied three paragraphs of text (Jaffe, 1987), while in the recent study 100 college students copied a 382-word excerpt from a book in his/her 'typical handwriting style' (Shah & Gladson, 2015). In both studies, there was no association found between grasp and legibility or grasp and speed (Jaffe, 1987; Shah & Gladson, 2015). Many alternate grasps to the dynamic tripod grasp were observed in both studies, including the lateral tripod and other multiple finger grasps (Jaffe, 1987; Shah & Gladson, 2015). As grasp does not appear to be associated with handwriting legibility in adults, and assessment of grasp is complex, grasp was not assessed in the research presented in this thesis.

Body posture

Body positioning or posture are also factors thought to influence handwriting legibility in children, with sitting posture often emphasised during handwriting instruction in the early years of school (Graham & Weintraub, 1996). Body posture was one of several factors investigated in a cross-sectional paediatric study comparing the handwriting performance in 50 'proficient hand writers' and 50 'non-proficient hand writers' aged eight to nine years (Rosenblum et al., 2006). In that study, low to moderate correlations were found between poor body posture and lower legibility scores (Rosenblum et al., 2006). However, an 'optimal sitting posture' has not been shown to consistently improve handwriting legibility in children. One randomised controlled trial investigating handwriting in 30 school-aged children with ambulatory cerebral palsy, found that handwriting legibility was not improved when children were seated optimally with specialty school furniture, compared to standard school furniture (Ryan, Rigby, & Campbell, 2010).

For adults, standing, kneeling and lying prone may be alternative functional writing positions to sitting (Amundson, 2005; Gozzard et al., 2012; van Drempt et al., 2011a). Two recent Australian cross-sectional, observational studies described the handwriting practices of healthy adults (Gozzard et al., 2012; van Drempt et al., 2011a). Adults in those studies often wrote when standing (17% of the occasions of handwriting in van Drempt et al. [2011a] and 27% of occasions in Gozzard et al. [2012]), kneeling (2% of occasions [Gozzard et al., 2012]) and lying (3% of occasions [Gozzard et al., 2012]), as well as when sitting (Gozzard et al., 2012; van Drempt et al., 2011a). Participants commonly wrote notes, shopping lists, messages on a calendar and completed their signature when standing (van Drempt, 2010).

While it seems common for adults to write in a variety of positions, no known studies have investigated the relationship between body positioning or posture and legibility for adult hand writers. However, 'improving' body posture when writing does not seem particularly important for improving handwriting legibility in children. Wallen et al. (2013) suggest that assessments of biomechanical aspects of handwriting, such as pen grasp and body position should not guide intervention strategies for children as handwriting intervention is effective only if it includes handwriting instruction and practice (Hoy, Egan, & Feder, 2011). Although little is known about handwriting legibility and its association with differing body postures in adults, the study presented in this thesis collected samples from adults while handwriting in a seated position at a table or desk. Study findings will provide therapists with a description of healthy older adults' 'typical' handwriting legibility across a variety of tasks, while seated, to help guide task-specific handwriting retraining.

Writing Speed

Legibility and handwriting speed do not appear to be strongly correlated in paediatric literature. One study exploring handwriting in 372 Australian children aged between 7 and 14 years reported no significant correlation between handwriting speed and legibility (Ziviani & Watson-Will, 1998). Another study investigating the handwriting of 900 children between grades one and nine, reported that speed was not associated with legibility for a copying task, but did have a small, yet significant association with legibility in narrative and expository handwriting tasks (Graham, Berninger, et al., 1998). No studies are known to investigate the association between writing speed and legibility in adults.

Handedness

Handedness, or hand preference when using a writing tool, seems to have no association with handwriting legibility in adults or children (Graham, Berninger, et al., 1998; Lohman, 1993). One study investigating the cursive handwriting of 138 young adults (M age 21 years) found no association between handedness and legibility (Lohman, 1993). That study attempted to recruit as many left hand dominant writers as possible, thus 22% of participants were left handed, whereas approximately 10% of the general population is left handed (Lohman, 1993). The study presented in this thesis recruited 120 older participants, with only two participants reporting left handedness, therefore no analysis of handedness and its association with legibility was possible.

Summary

This section presented a review of the available research describing the factors that seem to influence the production of legible handwriting in children and adults, including the writing task being performed, age and gender. The research presented in this thesis focuses on investigating handwriting legibility in healthy older adults and its association with (a) differing handwriting tasks (one copied subtest, one transcribed from an audio recording and two self-generated subtests), (b) increasing older age, (c) gender and (d) the writing tool (pencil versus pen), thus increasing the limited body of research available describing factors affecting the production of legible handwriting in older adults. This section of the literature also highlighted that, if impaired, cognition, upper limb movements, vision and mood may influence the production of legible handwriting in adults. Finally, other factors previously investigated and/or thought to influence handwriting legibility in children, such as pen grasp/grip, body position and handedness are reviewed and research relating to knowledge of these factors for adult hand writers was presented.

Measuring Adult Handwriting

Assessment of the skilled use of a writing tool, handwriting legibility and writing speed remains important to researchers in the fields of education, psychology, medicine, bio-science, occupational therapy and physiotherapy. The measurement of handwriting skills is important for occupational therapists working with individuals who want to, or need to improve their handwriting, to: (a) help identify specific handwriting problems, (b) provide direction for intervention and (c) demonstrate intervention efficacy. The following section presents a review of the relevant literature describing available assessments and methods that (a) aim to measure handwriting legibility, (b) standardise the method of collecting handwriting samples for particular tasks and (c) provide a profile of the skilful use of a pen or pencil, which may be important to individuals experiencing difficulties with handwriting following stroke.

Assessments of handwriting legibility

As noted previously, legibility of both adult and children's handwriting is typically measured using one of two approaches; analytic or global measures (Rosenblum et al., 2003). Analytic measures compare legibility components against predetermined criteria and are more typically used in paediatric handwriting assessments than adult assessments. For example, the Minnesota Handwriting Assessment (Reisman, 1993) uses criteria such as 'line straightness' to evaluate legibility. Global measures establish criteria against which users can rate the overall legibility (readability) of a handwriting sample.

Several analytic handwriting evaluation tools have been developed for use with children, to measure legibility. Five standardised paediatric handwriting evaluation tools,

reported to be widely used in research, and their psychometric properties, were summarised in a review by Feder and Majnemer (2003). These reviewed standardised assessments were three analytic measures: (a) The Diagnosis and Remediation of Handwriting Problems (Stott, Moyes, & Henderson, 1985); (b) the Minnesota Handwriting Test (Reisman, 1993), (c) Children's Handwriting Evaluation Scale-Manuscript (CHES-M) (Phelps & Stempel, 1988), as well as two other measures, (d) the Test of Handwriting Legibility (TOHL, previously known as the Test of Written Language - TOWL) (Larsen & Hammill, 1989) and (e) the Evaluation Tool of Children's Handwriting-Manuscript (ETCH-M) (Amundson, 1995). Feder and Majnemer (2003) concluded that for the few valid, reliable handwriting evaluation tools that exist, the complex scoring systems limited their clinical application. Thus, when a paediatric legibility assessment tool is required, available tools should be critically appraised to select the most appropriate for the purpose required and the population in question (Feder & Majnemer, 2003).

The TOHL (Larsen & Hammill, 1989) and the ETCH (Amundson, 1995) have previously been described as 'global readability' assessments (Rosenblum et al., 2006). The TOHL aims to evaluate the overall readability of children's writing on a scale of 1 ('least readable') to 9 ('most readable'), and provides multiple samples of pre-graded handwriting for each score point on the scale. The evaluator is instructed to match the handwritten sample as closely as possible to one of the pre-graded handwritten samples provided (Feder & Majnemer, 2003; Rosenblum et al., 2006). Although an overall judgement is being formed about the writing (rather than judgements of spacing, size, alignment, slant and so on), pre-rated handwriting samples of how the writing 'should look' are used to assign the legibility scores.

Similarly, the ETCH uses a 'global' ratio scale to rate word and letter legibility, and includes pre-scored samples of 'legible' and 'illegible' letters and words which accompany legibility criteria outlined in the ETCH scoring manual. To rate an entire handwritten sample (not a singular word), words contained in that sample are first individually rated as either 'legible' or 'not legible', using the scoring criteria and accompanying pre-scored samples, then a total percentage of legible words is calculated (0-100%). Individual letters in each word are also rated as either 'legible' or 'not legible', with legible letters tallied and divided by the total number of letters in a word to produce a percentage legibility score per word. Although the ETCH produces a score for the percentage of words able to be read in the overall handwritten sample (a word is considered illegible if unable to be quickly, easily, and correctly read as the intended word or is confused for another word [Duff & Goyen, 2010]), individual letters are also scored for legibility by comparing 'the look' of letters with pre-graded letter samples. Information about legibility components of letter formation, size, horizontal alignment, spacing and letter case are entered as 'additional information' on the score sheet. As the TOHL and the ETCH both use pre-graded samples of handwriting to determine legibility scoring (and the ETCH includes additional information relating to legibility components), these two assessments could be considered to perhaps incorporate both global and analytic legibility measurement principles.

Analytic measures of handwriting legibility assume that components of handwriting legibility (alignment, spacing, sizing, slant) are associated with overall legibility (Rosenblum et al., 2003). However, it is possible, that legibility scores produced by analytic paediatric measures, as well as the TOHL and the ETCH (which require raters to match handwriting closely to pre-rated samples), do not reflect whether handwriting can be read easily, or considered legible by teachers and others who need to read a child's handwriting.

Perhaps acknowledging this concern, several studies have investigated the ecological validity of the commonly used ETCH to determine if scores obtained on the ETCH are associated with school teachers' or occupational therapists' perceptions of illegible handwriting (Brossard-Racine, Mazer, Julien, & Majnemer, 2012; Duff & Goyen, 2010; Feder & Majnemer, 2007; Koziatek & Powell, 2002; Sudsawad, Trombly, Henderson, & Tickle-Degnen, 2001).

ETCH-Cursive (ETCH-C, for use with older children) legibility scores were compared with teachers' ratings of legibility in one study that aimed to determine aspects of validity and reliability of the ETCH-C (Duff & Goyen, 2010). In that study, teachers rated students' handwriting legibility on a 5-point scale, with categories collapsed for analysis to just three scale points: (a) very poor-poor; (b) average and (c) good-very good (Duff & Goyen, 2010). Results showed that the children rated for legibility as 'very poor to poor' by their teachers also scored significantly lower on the ETCH than the other two groups. However legibility of handwritten samples rated by teachers as 'average' and 'good-very good' did not differ on ETCH scores (Duff & Goyen, 2010). Modest associations between ETCH scores and teachers' or occupational therapists' ratings of legibility have also been reported in three other studies (Brossard-Racine et al., 2012; Feder & Majnemer, 2007; Koziatek & Powell, 2002).

In contrast, one study of 45 first-grade students found no significant correlations between ETCH scores and teachers' perceptions of legibility when measured on a 7-point scale where -3 indicated legibility 'much below average' and +3 indicated 'much above average' legibility (Sudsawad et al., 2001). In that study, some children rated by their teacher as having legibility that was 'much below average' scored well on the ETCH,

prompting researchers to suggest that handwriting qualities such as neatness and uniformity may contribute to teachers' perceptions of legibility, and these components are not taken into account by the ETCH scoring method (Sudsawad et al., 2001). While this may be a possible explanation for this study's results, it also seems likely that the overall legibility of a handwriting sample does not rely solely on most words and letters being readable when considered separately. Literature presented earlier in this chapter describing reading processes concluded that it is possible for words to be illegible even if only one or two key letters in a word are ill-formed, and sentences may be unable to be understood if only one key word is unable to be easily read. A high percentage score for letter legibility could be obtained using the ETCH, while the overall sample remains difficult to read. For example a child may consistently produce poorly formed letters (such as letters with ascenders or descenders). The consequence may be that certain letters are illegible, yet the majority of letters and words in a sample may be legible, returning a high percentage ETCH score for word and letter legibility. Nonetheless, the entire writing sample may be difficult to read.

Legibility measures that incorporate analytic evaluation of legibility components may be useful for identifying handwriting problems in children. However there is also a need for a global or overall measure of legibility (i.e., handwriting must be considered legible by children's teachers and others). Consequently, numerous global legibility scales have been developed, with descriptor categories (rather than pre-graded handwritten samples) to measure children's handwriting legibility. For example, Ziviani and Watson-Will (1998) developed a 7-point scale to rate the legibility of handwriting samples obtained from 372 typically developing children aged 7 to 14 years in Australia. A score of 1 implied poor legibility and a score of 7 implied good legibility. Weintraub et al. (2007) also scored global legibility of handwriting samples from 134 Israeli students aged 12 to 16 years using

a 7-point scale, where 1 represented very legible handwriting and 7 represented illegible handwriting. More recently, Ferrier, Horne, and Singleton (2013) used a four-point scale to rate the handwriting legibility of 364 year seven students in England. A rating of 1 indicated that writing was unacceptable for an 11-year-old and 4 indicated a good standard of writing (even) for an adult, with overall clear legibility and mature appearance (Ferrier et al., 2013). It is unknown why researchers continue to develop new global legibility measures when investigating children's handwriting, given the existence of many global scales already presented in the literature, and several standardised paediatric handwriting assessments. One possibility is that existing legibility measurement methods, or their data collection processes, are not considered valid for the research being conducted.

In summary, when assessing handwriting legibility in children, there is no established 'gold standard' assessment. For that reason, it is recommended that the available tools are critically appraised when selecting the best assessment for the purpose and population in question (Feder & Majnemer, 2003). The ETCH is one of the most commonly used handwriting standardised assessments reported in the paediatric literature.

Assessing handwriting legibility in adults

Much research in the area of handwriting legibility in adults has been in the context of examining the legibility of medical record entries, mostly written by doctors. These studies have invariably used 'global' legibility scales, typically using a four- or five-point rating scale.

Initially, Berwick and Winickoff (1996) developed a four-point scale to rate the global legibility of handwriting in medical notes from 209 doctors and health care

professionals. Scoring categories were 1=poor, 2=fair, 3-good and 4=excellent legibility (Berwick & Winickoff, 1996). The original Berwick and Winickoff (1996) four-point scale was used in a subsequent study also comparing the handwriting legibility of doctors and other adults (Schneider, Murray, Shadduck, & Meyers, 2006).

Rodríguez-Vera et al. (2002) later refined the four-point scale to also rate the global legibility of doctors' entries in medical files. That scale used more detailed descriptors: 1 = Illegible (most or all words impossible to identify); 2 = Most words illegible; meaning of the whole unclear; 3 = Some words illegible, but the report can be understood by a clinician and 4 = Legible (all words clear) (Rodríguez-Vera et al., 2002, p. 545).

Murray et al. (2012) devised a five-point scale for rating global legibility, which was used to rate handwritten case notes of 25 randomly selected doctors. That scale used similar definitions to those developed by Rodríguez-Vera et al. (2002), but added further detail to criteria, a fifth rating point and included a mix of letter and word legibility criteria. Criteria for each category were: 1 - Totally Legible – Words and meaning clear; 2 - Mostly Legible – Meaning clear, some letters unreadable; 3 - Partially Legible – Some words readable, meaning not fully clear; 4 - Mostly Illegible – Meaning obscured, some letters readable; and 5 - Totally Illegible – Words and meaning obscured (Murray et al., 2012, p. 96).

As with global measures of children's handwriting legibility, the continued development and alteration of these global measures of adult handwriting legibility suggests that researchers are still seeking an optimal measure for their purpose.

In addition to research into handwriting in medical records, other researchers have used existing measures or developed measures to examine the legibility of adult handwriting in other contexts. Some researchers have used paediatric handwriting assessments (or modified versions of these) (e.g., Au et al., 2012; Lohman, 1993; Shah & Gladson, 2015; Simpson et al., 2016), whereas others have further developed the global four-point categorical measures described above (e.g., Au et al., 2012; Gozzard et al., 2012; van Drempt et al., 2011a).

Researchers exploring adult handwriting legibility have adopted (and modified) paediatric assessments including the Evaluation Tool of Children's Handwriting (ETCH) (Amundson, 1995), Test of Handwriting Legibility (TOHL) (Larsen & Hammill, 1989), and the Minnesota Handwriting Assessment (Reisman, 1993). Faddy et al. (2008) used a modified version of the ETCH (referred to as the mETCH) to evaluate the legibility of handwriting from 10 adults who had sustained a brain injury. The mETCH has also been used in subsequent studies investigating handwriting in healthy adults and stroke survivors (Au et al., 2012; Simpson et al., 2016). Like the ETCH, the mETCH uses a ratio scale to rate word and letter legibility.

In the most recent studies, the mETCH method of scoring handwriting legibility in adults was used to rate overall word legibility (referred to as the mETCH-Word [mETCH-W]) and letter legibility (mETCH-Letters [mETCH-L]) (Au et al., 2012; Simpson et al., 2016). In another small-scale study, Lohman (1993) used an early version of the TOHL (known as the Test of Written Language) to evaluate the legibility of undergraduate psychology students' handwriting. More recently, one section of the Minnesota Handwriting Assessment was used in a study investigating handwriting legibility in adults. However,

researchers found it impractical to rate the handwriting legibility components (such as spacing and sizing), given the varied styles of handwriting produced when 100 adults copied text from a book. Therefore, only an overall legibility score was assigned to each writing sample (Shah & Gladson, 2015).

Au et al. (2012) further developed the original four-point global measure of adult handwriting legibility (Berwick & Winickoff, 1996; Rodríguez-Vera et al., 2002) to make the scale more clinically useful. That revision was referred to as the modified Four-Point Scale (mFPS) and changed the focus of descriptors from 'illegibility' to 'legibility'. Furthermore, a new letter legibility rating component was added (Au et al., 2012). The mFPS global legibility categories were as follows: 1= none or few words legible; the meaning of the text is unclear, 2 = some words legible; the meaning of the text is unclear, 3 = many words legible; the meaning of the text can be understood, 4 = most or all words legible; the meaning of the text can be understood. In addition, specific letters were selected for letter legibility rating, rather than rating all letters (to reduce scoring time). Three letters were selected from what are known as the 'upper zone', 'middle zone' and 'lower zone' of letters, and included the letters 'b', 'h', 'l' (ascender letters from the 'upper zone'), 'a', 'e', 'o' (from the 'mid zone') and 'g', 'p', 'y' (descender letters from the 'lower zone'). First, a score of 1-4 was assigned to the 'upper zone', 'middle zone' and 'lower zone' letters: 1=none or few letters legible (i.e. 0-10% legibility), 2=some letters legible; (i.e. 11-50% legibility), 3=Many letters legible (i.e., 51-90% legibility), 4=most of all letters legible (i.e., 91-100% legibility) (Au et al., 2012, p. 349). As opposed to the original four-point scale (Rodríguez-Vera et al., 2002), which returned a single rating of legibility (from 1 for 'illegible' to 4 for 'legible'), the mFPS described by Au et al. (2012), returned four data

points per writing sample, one score for global legibility (1, 2, 3 or 4) and three scores for legibility of letter zones (Au et al., 2012).

Au et al. (2012) selected a group of letters for assessment in the mFPS which were hypothesised to contribute to more legible handwriting in a book about handwriting analysis (Lowe, 1999). However, research does not entirely support Lowe's (1999) hypothesis. Literature describing reading processes summarised previously in this chapter, indicates that the first and last letters of a word, as well as all ascender and descender letters contained in a word (the upper zone and lower zone letters in each word), are important for increasing word legibility. Furthermore, selecting only certain letters to represent the three zones of handwriting is potentially limiting, as the targeted letters may be absent in a handwriting sample (Au et al., 2012). When the targeted letters are present, only one or two of the letters may be written in the sample, potentially decreasing the usefulness and validity of the letter legibility rating method. For example, if only one upper zone letter (e.g. 'b') is written in a short handwriting sample, that zone of letters will either score 0% or 100% depending on the legibility of that single letter. Au et al. (2012) also reported that selecting letters in that way within a writing sample is time consuming. For these reasons, this method of rating letters from each zone will not be used in the study presented in this thesis.

The mFPS has been used in two other studies which investigated handwriting legibility in healthy adults (Gozzard et al., 2012; van Drempt et al., 2011a). However, only global legibility for the entire rating sample (and not individual letters from the three letter zones) was scored for the writing samples in those studies (Gozzard et al., 2012; van Drempt et al., 2011a).

Most recently, the mFPS was used to investigate global (not letter) legibility in adults receiving handwriting rehabilitation following stroke (Simpson et al., 2016). In that study, a revised scoring system for the mFPS was adopted (originally developed as part of the first study in this thesis (Dettrick-Janes et al., 2015)). For global legibility measurement, the descriptors for the four mFPS categories were revised to contain the additional words *upon first read*, and the instrument was renamed the modified Four Point Scale – Version 2 (mFPS-v2). To replace the method of rating certain 'upper zone', 'mid zone' and 'lower zone' letters described by Au et al. (2012), a method of measuring word legibility was developed that takes into account the legibility of all the letters contained in a word, referred to as Modified Four Point Scale – version 2 – Words (mFPS-v2-W).

Inter rater reliability of adult handwriting legibility measures

One of the key challenges when using assessments of adult handwriting legibility has been the issue of inter rater reliability (Au et al., 2012). The paediatric TOHL (used in one study with adults [Lohman, 1993]) did not obtain acceptable inter rater reliability when used to evaluate the legibility of handwriting in children with learning difficulties (Graham et al., 1989). A recent study involving the mETCH found that inter rater reliability was below acceptable standards for clinical use (Au et al., 2012). In that study, three independent raters used the mETCH, (and two other legibility rating methods) to rate 60 handwriting samples obtained from 30 healthy adults. Each participant completed two handwriting tasks, copying an address and writing a self-generated sentence (Au et al., 2012). Results of this study showed 'no agreement' of mETCH scores when examining exact agreement determined by multi-rater kappa (k) with the letter subtest attaining a kappa of -0.62, and the words subtests attaining a kappa of –1.03 (Au et al., 2012). These researchers concluded that poor inter rater reliability together with a lengthy scoring time limited the clinical utility of

the mETCH (Au et al., 2012). However, in earlier research, two occupational therapists achieved high inter rater reliability (ICC = 0.71 to 0.83) when using the mETCH to independently rate 10 handwriting samples collected from 10 adults with brain injury who completed the Handwriting Assessment Battery for adults (HAB) (Faddy et al., 2008). However, results of the Faddy study are limited by the small sample (n=10) which is under the recommended sample size of 30 for the evaluation of inter rater reliability (Peat et al., 2001; Portney & Watkins, 2009) . Furthermore, the authors also recommended that further reliability testing of the HAB be carried out with larger sample sizes (Faddy et al., 2008).

Although inter rater reliability of the original 1996 four-point scale (Berwick & Winickoff, 1996) was reported by authors to be 'high' when four non-clinician volunteers independently rated the legibility of the 209 writing samples (Berwick & Winickoff, 1996), pairwise correlation coefficients reported in that study (ranging from 0.60 to 0.76), would generally be considered only 'moderate'. In the 2002 study (Rodríguez-Vera et al., 2002), 117 clinical case notes were rated using a four-point scale by two medical residents who went through a training process. In this study, the authors reported that raters 'went through a training process in order to reach a kappa concordance coefficient of 0.85' (Rodríguez-Vera et al., 2002, p. 545), but it is unclear whether this concordance was based on handwriting samples included in the training process or whether it was calculated based on ratings of the 117 clinical case notes included in the study. Therefore, it is unclear whether this concordance coefficient is a true evaluation of the inter rater reliability of this version of the four-point scale.

Inter rater reliability of Rodríguez-Vera et al.'s (2002) version of the original four-point scale (Berwick & Winickoff, 1996) as well as the Modified Four Point Scale (mFPS)

was more recently investigated in the study by Au et al. (2012) (which also investigated inter rater reliability of the mETCH). In that study, three raters each scored 60 writing samples obtained from healthy adults (Au, et al., 2012). The original four-point scale produced a multi-rater kappa (κ) of 0.19 indicating 'slight' rater agreement (Au et al., 2012). The mFPS attained a multi-rater kappa (κ) of 0.30 for the upper-zone measure of letters ('fair agreement'), 0.06 for the mid-zone measure ('no agreement'), and 0.14 for the lower-zone measure ('slight agreement') (Au et al., 2012). No results were reported for inter rater reliability on the global rating of legibility produced by the mFPS. Results from this study showed that inter rater reliability was below the generally acceptable level (Au et al., 2012). These findings highlight one of the main difficulties researchers face when attempting to develop instruments to assess global handwriting legibility. Inter rater reliability between multiple raters is difficult to achieve due to the inherently subjective and individual nature of perceptions of legibility (Rosenblum et al., 2003).

In summary, the development of a useful, valid measurement tool to quantify handwriting legibility is challenging. Challenges include the complex nature and interaction of many factors required for the production of legible handwriting, in an established time frame. Consequently, researchers have used many different tools to measure the handwriting legibility of children and adults. A reliable legibility rating instrument for adults remains elusive, especially with regard to inter rater reliability. Yet, as handwriting legibility assessment is still required in clinical practice, individual clinicians use the available handwriting legibility rating methods to diagnose problems, rate clients' handwriting and qualitatively monitor progress (Au et al., 2012).

Standardised data collection procedures for adult handwriting assessments

In addition to the need for a valid and reliable approach to evaluating handwriting legibility, it is also important to standardise the handwriting samples that are assessed. Multiple assessments developed to measure children's handwriting have aimed to standardise both the collection of handwriting samples and the evaluation process to produce quantitative scores of handwriting quality (Chu, 1997; Reisman, 1993; Rosenblum et al., 2003). Standardising the collection of handwriting samples is also important for the assessment of adult handwriting, as legibility may be influenced by the writing task (Gozzard et al., 2012).

Two adult handwriting assessments were located that include standardised processes for collecting handwriting samples. The Handwriting Assessment Battery (HAB) (Faddy et al., 2008; McCluskey & Lannin, 2003) is one of the few standardised handwriting assessments available for adults. One component of the HAB is the mETCH which includes four writing tasks adopted from the original ETCH. These are: (a) writing the alphabet in lowercase (a-z), (b) writing the alphabet in upper case (A to Z), (c) writing numerals one to 12 and (d) writing a self-composed sentence. The HAB also includes the Jebsen Speed Test (Jebsen et al., 1969) which requires participants to copy one of three sentences 'as quickly and as neatly as possible'. The Detailed Assessment of Speed of Handwriting for 17 to 25-year-olds (DASH-17+) (Barnett, Henderson, Scheib, & Schulz, 2010) is an assessment of handwriting speed and includes five pencil use tasks, four of which are handwriting tasks. These handwriting tasks are copying the sentence 'The quick brown fox jumps over the lazy dog' for two minutes, under two conditions (best handwriting and as quickly as possible but making sure that every word is readable), writing self-generated text for ten minutes on the

topic “My Life” (the free writing task) and writing the letters of the alphabet in lower case (Barnett, Henderson, Scheib, & Schulz, 2011).

The validity of alphabet writing tasks such as those included in the HAB and the DASH-17+ has recently been questioned (Au et al., 2012). Few adults need to write the alphabet. Adults commonly handwrite to make notes, messages and lists, and to complete puzzles (Gozzard et al., 2012; van Drempt et al., 2011a). These types of self-generated writing tasks could be included in the handwriting assessment process, to better reflect real-world adult handwriting practices.

In summary, a reliable handwriting legibility assessment needs to have a repeatable process for generating handwriting samples, and a valid, reliable way of measuring the legibility of those samples. Self-generated handwriting tasks that reflect the handwriting practices of most adults, as well as copying tasks (important for individuals who may have difficulty generating writing for a variety of reasons) rather than alphabet writing, could be used to standardise the collection of handwriting samples for adults.

Assessing motor control when skilfully using a pencil / pen in adults

In addition to the assessment of handwriting legibility following stroke, occupational therapists may need to assess an individual’s ability to pick up a pencil/pen and skilfully manipulate the writing tool to make purposeful marks on paper. In clinical practice, this is a necessary starting point for individuals who have some hand movements following stroke, but are unable to produce handwritten letters or words. The ability to skilfully use a pencil/pen also provides a measure of advanced hand function following stroke (Lannin, 2004; K. J. Miller et al., 2010; Pickering et al., 2010) and may be a useful way of measuring

hand function improvements (that relate to handwriting) over time rather than picking up peas or beans.

The HAB (Faddy et al., 2008; McCluskey & Lannin, 2003) and DASH-17+ (Barnett et al., 2010) are the only two known adult handwriting assessments that include pencil/pen control subtests that require the skilful use of a pen or pencil to make particular, specified marks on paper but do not require the production of letters or words. The HAB includes two pencil use tasks from the upper limb component of the Motor Assessment Scale (Carr et al., 1985), a well-known measure of motor performance following stroke. The two tasks involve making 'lines' or 'dots' on a page with a pencil according to pre-specified criteria within a specific time frame. The DASH-17+ includes a subtest that requires participants to make 'X' shapes within pre-printed circles on a page within a specified timeframe and to pre-established quality criteria. The pencil/pen control and manipulation tasks within the HAB and the DASH-17+ appear to attempt to assess similar pencil/pen motor control skills (or as described in the DASH-17+ manual, perceptual motor control). The DASH-17+ is designed for university/college students between the ages of 17 to 25 years, while the 'lines' and 'dots' tasks from the HAB are derived from the MAS, an assessment designed for adults who have experienced a stroke.

The MAS is well known to therapists internationally, used widely in clinical settings, and is often used as an outcome measure in randomised controlled trials to measure changes in function during stroke rehabilitation (Alston, 1983; Hayward et al., 2013; Olaleye, Hamzat, & Owolabi, 2014). The MAS contains three items that measure upper limb motor performance including upper arm function (item six), hand movements (item seven) and advanced hand activities (item eight). These three items, assessing 18 motor behaviours (or

tasks), are collectively known in the literature as the upper limb MAS (UL-MAS) (Hsueh & Hsieh, 2002; Lannin, 2004; K. J. Miller et al., 2010; Pickering et al., 2010).

Multiple studies describing the UL-MAS report a hierarchal scoring method for each item, stating that the six tasks within each item are ordered, from easier to more difficult (Dean & Mackey, 1992; K. J. Miller et al., 2010; Sabari et al., 2005; Williams, Galea, & Winter, 2001). However, for item eight, the 'advanced hand activities' item, Rasch analysis has consistently shown that the tasks are not ordered hierarchically, with the two most difficult tasks for stroke survivors to achieve being the 'lines' and 'dots' pencil use tasks (Aamodt, Kjendahl, & Jahnsen, 2006; K. J. Miller et al., 2010; Pickering et al., 2010; Sabari et al., 2005). As speed and downward pen pressure are known to deteriorate due to aging (Burger & McCluskey, 2011; Engel-Yeger et al., 2012), is it possible that performance on the 'lines' and 'dots' tasks declines as healthy adults' age? The study presented in this thesis attempts to answer this question.

In summary, one subtest contained on the DASH17+ and two subtests contained on HAB, (derived from the MAS) are the only known tests available for use with adults that attempt to measure motor control when using a pencil/pen, yet do not require the production of letters or words. Motor control when using a pencil may be important to measure, especially if, following stroke, an individual cannot, as yet, produce handwritten letters or words. The skilful use of a pencil/pen is often measured following stroke using the 'lines' and 'dots' MAS pencil tasks (also contained on the HAB), yet it is unknown if healthy older adults can pass the requirements of these tasks.

Summary

This section presented a review of the available research examining the measurement of adult handwriting, specifically, in relation to handwriting legibility and pen/pencil control.

Conclusion

Overall, the existing literature suggests that perceived legibility of adult handwriting is greatly influenced by reading processes, including word recognition which relies on the correct formation of first, last, ascender and descender letters. It seems common for adults to write with a 'mixed style' of letters within the one handwritten sample (cursive and printing styles) and this seems to help, rather than hinder a reader to decipher adults' and older children's handwriting.

The production of legible handwriting in adults may be influenced by the writing task being performed, ageing and gender. Legible handwriting may also be influenced by various types of impairments following illness or injury, such as cognitive or sensory-motor impairments. Currently no data exists describing handwriting legibility in healthy older adults across a variety of handwriting tasks, so as to compare the handwriting legibility of people who have had a stroke. The first research paper presented in this thesis attempts to fill this research gap. While there is no established valid and reliable instrument to measure adult handwriting legibility, measurement of handwriting is important during rehabilitation. The research paper presented in this thesis will therefore investigate some measurement properties of the mFPS-v2, which was further developed for this study to measure adult handwriting legibility, in attempt to provide therapists with a more useful method of measuring legibility in practice.

Standardised data collection procedures for adult handwriting assessments are also important for clinical and research purposes. Self-generated handwriting tasks that reflect the real-world handwriting practices of most adults, as well as copying tasks (important for individuals who may have difficulty generating writing for a variety of reasons), may be more useful for obtaining handwriting samples for the assessment of speed and legibility, than alphabet letter writing, which is included on the known adult handwriting assessments available. The two additional sub-tests developed to collect data for the research presented in this thesis were developed in an attempt to replicate relevant and real-world situations where older adults use handwriting. This expanded the number of handwriting samples available for legibility assessment.

Finally, although the skilful use of a pen/pencil is often measured following stroke using the two MAS pencil use tasks, also contained on the HAB, it is known that these tasks are difficult for stroke survivors to pass. As it is unknown if healthy older adults can pass the requirements of these tasks, the second research paper presented in this thesis attempts to establish if healthy older adults can meet the requirements of the 'lines' and 'dots' tasks. This information is important to assist in the interpretation of the potential causes of challenges related to these tasks for stroke survivors. Are these challenges likely to be related to stroke-related impairments, a consequence of 'normal ageing' or a combination of both?

CHAPTER THREE: JOURNAL ARTICLE 1

Handwriting Legibility in Healthy Older Adults

In the article presented in this chapter, I investigate handwriting legibility in healthy older adults across a variety of handwriting tasks under test conditions. The relationships between handwriting legibility and increasing age are explored. Additionally, a preliminary exploration of the reliability of rating procedures used to score handwriting legibility is described.

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Handwriting Legibility in Healthy Older Adults

Michelle Dettrick-Janes[1], Annie McCluskey[1], Natasha A. Lannin[2,3], & Justin Newton Scanlan[1]

[1]Discipline of Occupational Therapy, Faculty of Health Sciences, The University of Sydney, Australia, [2]Alfred Health, Melbourne, Australia, [3]Faculty of Health Sciences, La Trobe University, Melbourne, Australia

Note: The relationship across gender and handwriting legibility was explored in this study, however was removed from the publication of the research for simplicity. Results of this exploration showed that women had a higher percentage of legible words for the self-composed sentence subtest when written in pencil (p=.042), however, not when written in pen. There were no significant differences between men and women in terms of global legibility scores in all subtests.

The formatting and referencing of this chapter has been altered to be consistent with the overall formatting of this thesis. All references are presented at the end of this thesis in the combined *References* chapter. Tables and figures have been placed within the text for easy reference.

Statement of Contribution of Authors

As co-authors of the following article:

Dettrick-Janes, M., McCluskey, A., Lannin, N. A., & Scanlan, J. N. (2015). Handwriting legibility in healthy older adults. *Physical and Occupational Therapy in Geriatrics, 33*, 189-203. doi:10.3109/02703181.2015.1037978

we confirm that Michelle Dettrick-Janes has made the following contribution:

- *Conceptualisation and design of research;*
- *Collection of data;*
- *Analysis and interpretation of results; and*
- *Writing paper and critical appraisal of content.*

Annie McCluskey Signed: _____ Date: 13/06/2018

Natasha A. Lannin Signed: _____ Date: 13/06/2018

Justin Newton Scanlan Signed: _____ Date: 13/06/2018

Handwriting Legibility in Healthy Older Adults

Abstract

Aims: Handwriting processes deteriorate with age and following neurological conditions. Improving handwriting is often a focus of rehabilitation. Yet knowledge of handwriting legibility in the elderly is limited. This study describes the distribution of handwriting legibility scores in healthy older adults, relationships between handwriting legibility, age and writing task, and reliability of rating procedures.

Methods: A cross sectional study design was used involving 120 healthy older Australians. Tasks included writing sentences, shopping lists and transcribing a telephone message. Legibility was scored using the Modified Four Point Scale-version 2.

Results: Legibility differed between tasks but was not related to increasing age.

Conclusions: Impaired handwriting legibility in the elderly is less likely due to the effects of aging than the required task or medical conditions. Findings from this study may help therapists set intervention goals and measure legibility changes during handwriting retraining.

KEYWORDS: readability, writing style, rehabilitation, elderly

Introduction

Despite increasing use of electronic devices, handwriting continues to be an important activity in day-to-day life (Feder & Majnemer, 2007; Yancosek & Howell, 2011). Older adults handwrite daily for activities such as list making, recording messages and completing crossword or Sudoku puzzles (van Drempt et al., 2011a). Legible handwriting is essential for communicating with others (Amundson, 2005) and for re-reading one's own handwriting, for example text written in a personal diary or shopping list. In clinical settings, improving legibility of handwriting is often identified as a goal for older adults recovering from stroke and a range of other health conditions.

Legible handwriting refers to writing that can be read or deciphered easily (Amundson, 2005). Overall legibility relies on several factors. Firstly, 'legibility components' are the visual features of handwriting (size, spacing, alignment, slant and formation) that make text readable (Amundson, 2005; Feder & Majnemer, 2007; Ziviani & Elkins, 1984). Secondly, perceived legibility is also related to reading processes (Murray et al., 2012) such as context, prior knowledge of word combinations and word prediction based on first, last and ascender and descender letters (Beech & Mayall, 2005; Kendeou et al., 2011; Morton, 1964). Handwriting style has also been associated with legibility, with print or 'mixed' (print and cursive) handwriting styles rated more legible than cursive handwriting alone (Graham, Weintraub, et al., 1998; van Drempt et al., 2011a). Finally, writing tasks may also influence legibility. Children produced more legible writing during copied tasks compared to self-generated writing tasks (Graham, Berninger, et al., 1998). However, no association was reported in older adults, between the writing task and legibility (van Drempt et al., 2011a). Given the complexity of factors that influence legibility, previous authors have indicated the need for robust methods of measurement (Au et al.,

2012; Daniel & Froude, 1998), as well as descriptive and normative data about handwriting in healthy adults, across a variety of tasks (van Drempt et al., 2011a).

Legibility is typically measured using one of two approaches; analytic or global (Rosenblum et al., 2003). Analytic measures compare legibility components against predetermined criteria and are typically used in paediatric handwriting assessments, for example the Minnesota Handwriting Assessment (Reisman, 1999) uses criteria such as 'line straightness' to measure legibility. Analytic measures assume that legibility is directly related to legibility components (Rosenblum et al., 2003). This assumption is problematic. As outlined above, multiple factors influence legibility therefore scores produced by analytic legibility measures may not reflect whether handwriting can be understood when read. A further limitation of analytic measures is reduced sensitivity to personal handwriting styles (Rosenblum et al., 2003).

Global legibility measures have several advantages over analytic measures. They accommodate the many factors that influence legibility, and are typically used in adult handwriting research (e.g., Baxter, 2004; Berwick & Winickoff, 1996; Yancosek & Calderhead, 2012). One limitation of global legibility measures is low inter rater reliability. Although some studies have reported acceptable inter rater reliability (Berwick & Winickoff, 1996; Faddy et al., 2008), achieving agreement between raters is difficult because of differences in reading processes including word prediction. Au et al. (2012) recently examined the inter rater reliability of three methods for rating adult handwriting legibility. Inter rater reliability was fair to low for all methods although individual raters were internally consistent in their rating procedures and severity. Despite this potential limitation, a practical method of measuring legibility is still required to guide adult

handwriting retraining in clinical settings. Au et al. (2012) recommended the use of a modified Four-Point Scale (mFPS) or modified Evaluation Tool of Children's Handwriting (mETCH), where the same person rates legibility over time, as the optimal method for evaluating improvements in the legibility of adults' handwriting.

Research investigating the handwriting legibility of older adults is scarce, but important to help inform an ecologically valid handwriting assessment (van Drempt et al., 2011a). Aging leads to negative changes in handwriting, such as decreased speed (Burger & McCluskey, 2011; Engel-Yeger et al., 2012), reduced downward pressure (Engel-Yeger et al., 2012; Rosenblum & Werner, 2006) and inconsistent letter size (Yoon et al., 2013). However, the impact of normal aging processes on handwriting legibility has been investigated very little. The handwriting legibility of 30 healthy older adults aged 65 years and over was measured using a four-point categorical global scale, the mFPS, in one Australian study (van Drempt et al., 2011a). In that study, 29 of 30 handwriting samples (97%) were scored as legible (category 3 or 4: the global meaning of the text could be understood), although the influence of increasing age on legibility was not reported. In another study, Baxter (2004) examined legibility in younger (21 to 59 years) and older (60 to 92 years) adults. Although older participants were rated lower on measures of 'neatness,' there were no significant differences in overall legibility of handwriting between the two groups. Thus handwriting may become more untidy with age, but remain legible and functional in older adults (Baxter, 2004).

Despite handwriting being one of the most frequently performed activities of older persons (Rosenblum & Werner, 2006), the range of legibility in healthy older adults has not been described, across a variety of tasks, under test conditions. Therefore, the aims of this

study were to describe (a) the range of legibility scores across a variety of tasks, in healthy adults aged 60 to 99 years, (b) the relationship between legibility and increasing age, the writing task and writing tool used, and (c) the reliability of legibility rating procedures.

Methods

Institutional ethics approval was granted. Participants signed a consent form prior to data collection and confidentiality was assured. A cross sectional study design was used. Older adults completed four handwriting subtests in pencil and pen under test conditions, and a self-report questionnaire to obtain demographic data and their views about handwriting.

Recruitment

A convenience sample of 120 older adults was planned, with the aim of obtaining data from 15 men and 15 women from four age groups (60 to 69, 70 to 79, 80 to 89 and 90 to 99 years). A target of 30 participants in each age group, allowed sufficient numbers for sub-group analyses (Portney & Watkins, 2009). Eligible participants were aged 60 to 99 years, able to read and write in English and able to write without pain. Participants were excluded if they had a self-reported condition that affected their writing such as severe arthritis, macular degeneration, dementia or Parkinson's disease. All writing tasks were completed in English, therefore non-English speakers were excluded.

Participants were recruited through personal contacts of the researchers, retirement villages, residential homes, nursing homes, community groups and senior citizens' groups, in metropolitan and regional areas of Australia. Recruitment continued until 30 participants

had consented for each age group. In the 90 to 99 year age group, fewer male participants were recruited, so additional female participants were included.

Data Collection Procedures

Testing was completed in sitting. Participants wrote with their dominant hand only. A self-report questionnaire, with six open and eight closed questions, was completed first, capturing demographics, health status and hand dominance. The questionnaire was developed by the research team, has been used in previous studies (Gozzard et al., 2012; van Drempt et al., 2011a) and enabled the sample to be described. Four handwriting subtests (described below) were then administered in the following order: (a) The Jebsen Speed Test (a copied sentence), (b) a self-composed sentence, (c) a message transcribed from a telephone recording and (d) a self-generated shopping list. Subtests examined legibility and speed under different conditions, such as copied versus self-generated text, writing in pencil versus pen. Global and word legibility were calculated for each handwriting subtest.

The Jebsen Speed Test: Copied sentence subtest. Participants copied a standardised sentence containing 24 letters using 'cursive writing' and writing speed was timed as per the Jebsen method (Jebsen et al., 1969). The Jebsen speed test has established inter rater reliability ($ICC_{3,2}$ = 1.00) (Hackel, Wolfe, Bang, & Canfield, 1992) and was selected for data collection as it is well known to many occupational therapists and forms part of the Handwriting Assessment Battery for adults (the HAB) (Faddy et al., 2008). Participants in our study picked one of three cards presented upside down, turned the card over and copied a pre-typed sentence 'as quickly and neatly as possible'. The three possible sentences were: 'John saw the red truck coming', 'Fish take air out of the water' and 'The old man seemed to be tired'. One sentence was written first in pencil, then a second,

different sentence was written in pen. The speed data collected from this sample of older Australians were recently published (Burger & McCluskey, 2011). For the current study, the copied sentences produced from the Jebsen test were scored for legibility only, not speed. This subtest will be referred to hereafter as the 'copied sentence' subtest.

Self-composed sentence subtest. Participants thought of a five-word sentence, then wrote it down as 'quickly and neatly as possible' using their 'usual style of handwriting'. The self-composed sentence subtest has been used in previous adult handwriting studies (Burger & McCluskey, 2011; Faddy et al., 2008). Handwriting performance was timed. If participants had difficulty composing a sentence, suggestions were offered, such as 'What you did this morning?' Participants wrote one sentence in pencil, then another different sentence in pen.

Audio-taped telephone message subtest. Key words were written by participants while they listened to a pre-recorded telephone message and held a phone handset in one hand. The message was approximately 40 seconds in length. The subtest was completed once only in pencil, in their 'usual handwriting style'. Once participants confirmed that the message was audible, the message was played once only. This subtest was developed for the current study and was not timed.

Self-generated shopping list subtest. Participants thought of five single word items they might write on a shopping list and wrote them down using their 'usual handwriting style'. This subtest was developed for the current study and handwriting performance was timed. One list was written in pencil, then another different list was written in pen. If participants could not think of items, prompts were given such as 'food items'. If

participants continued having difficulty thinking of items, they were offered a grocery catalogue.

Legibility Rating Instruments and Procedures

First, global legibility of text was rated for the copied sentence, self-composed sentence and the audio-taped telephone message subtests (the shopping list could not be rated for global legibility as it contained single words). Second, single words from all four subtests were rated individually for legibility. Finally, legible word percentages were calculated. Text with spelling or sentence construction errors was excluded if the error created ambiguity in text legibility. Crossed-out text, printed text written for the copied sentence (which participants were required to write in cursive), text written using the incorrect writing tool and handwritten numbers were also excluded.

Writing style. Writing style was coded as (a) cursive and/or mixed cursive (category combined), (b) capital letter printing or (c) lower case letter printing, for subtests where participants were required to use their 'usual handwriting style'

Global legibility. Global legibility was measured using a revised version of the Modified Four Point Scale (mFPS) (Au et al., 2012). The mFPS is a ranked ordinal scale with four categories of legibility, from illegible (1) to legible (4). Descriptors for the four mFPS categories were revised for the current study to contain the additional words, '*upon first read*', and the instrument re-named the Modified Four Point Scale – Version 2 (mFPS-v2) (Figure 1). This revision was made to simplify scoring decisions and help improve inter rater agreement, which was fair to poor in earlier research (Au et al., 2012). The mFPS-v2 is a ranked ordinal scale (categories 1 to 4, from illegible to legible). A score between 1 and 4

was awarded for written text, returning one data point or score per writing sample (see Figure 1). The mFPS-v2 was used to rate global legibility of the copied sentence (pencil and pen), the self-composed sentence (pencil and pen) and the audio-taped telephone message (pencil only) subtests, returning five scores of global legibility per participant. Text from each subtest was read in its entirety, then a global legibility rating assigned.

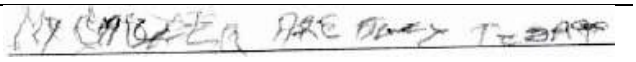
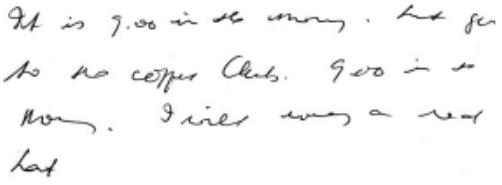
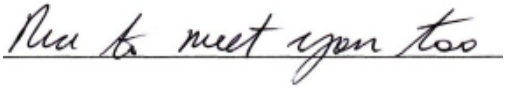
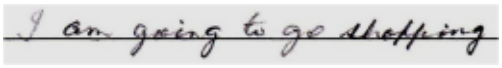
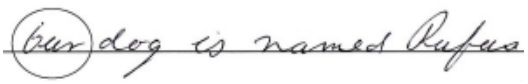
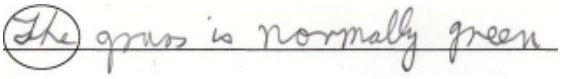
Category	Global legibility rating descriptors	Handwriting examples
1	None or few words legible; the meaning of the text is unclear upon first read	
2	Some words legible; the meaning of the text is unclear upon first read	
3	Many words legible; the meaning of the text can be understood upon first read	
4	Most or all words legible; the meaning of the text can be understood upon first read	

Figure 1. Modified Four Point Scale – version 2 (mFPS-v2) global legibility categories and rating descriptors

Word legibility. Word legibility was rated using the Modified Four Point Scale version 2 for Words (mFPS-v2-W, see Figure 2) developed for use in this study. The mFPS-v2-W uses descriptive categories to allocate a numerical score to a word (1 to 4), returning one data point per word. A pre-determined number of words were individually rated for each subtest. No attempt was made to conceal adjacent words. Words were viewed within the context of the entire handwritten sample.

Category	Word legibility rating descriptors	Handwriting examples
1	None or few letters legible; the meaning of the word is unclear upon first read	
2	Some letters legible; the meaning of the word is unclear upon first read	
3	Many letters legible; the meaning of the word can be understood upon first read	
4	All letters legible; the meaning of the word can be understood upon first read	

Note. Circled words were selected consistently in all samples for rating

Figure 2. Modified Four Point Scale – version 2 – Words (mFPS-v2-W) legibility categories and rating descriptors

Participants made errors during subtests, writing fewer or more words than instructed. For consistency, a pre-determined number of words were selected from each

subtest when rating word level legibility. For the copied sentence, up to seven of the first words written by participants were selected for legibility rating, as the pre-written sentences contained either six or seven words. For the self-composed sentence and shopping list subtests, up to five of the first words written were rated for word level legibility, as both of these subtests required participants to write five words. Additional words appearing in these three subtests were excluded when rating word legibility. For the audio-taped message subtest, participants wrote a varying number of words; to ensure consistency, five words were selected for rating as follows: (a) a minimum of one word containing three letters or less, (b) a minimum of three words containing four letters or more, (c) the word 'coffee' was selected for rating, if it appeared in the text; if not, the word containing the most letters was rated.

Percentage of legible words. The percentage of legible words produced during each subtest was then calculated. Percentages were calculated by dividing the number of words awarded a rating of 3 or 4 ('legible') by the total number of words rated. Percentages were calculated separately for words written in pen and pencil. Seven percentage scores were produced per participant, as the audio-taped telephone message was written in pencil only.

Reliability of the Legibility Rating Procedures

Inter rater and intra rater reliability of scoring procedures with the mFPS-v2 and mFPS-v2-W were examined with 33 randomly selected writing samples produced from the self-composed sentence and audio-message subtests; a random sample of over 30 was deemed necessary for testing reliability (Peat et al., 2001). The data produced from these two subtests were chosen as these subtests are meaningful to rehabilitation clinicians who often assess legibility. For example, the self-composed subtest is quick to administer,

requires little cognitive load for the writer, and typically produces legible text. Conversely, the audio message subtest is more complex, cognitively demanding, and as a result, often produces illegible text. Writing samples were independently scored by the first and second authors, both of whom are occupational therapists with experience rating writing samples and retraining adult handwriting. Written instructions were provided, with face-to-face and phone call follow-up discussions being used to clarify legibility rating methods.

For intra rater reliability of scoring procedures, writing samples were re-rated by the first author on two occasions, with approximately 22 months between initial and subsequent scoring.

Data Analysis

Descriptive statistics including means and frequencies were used to summarise demographic data such as age (groupings 60 to 69, 70 to 79, 80 to 89 and 90 to 99 years) and handwriting styles (upper case printing, lower case printing or cursive / mixed cursive). Frequencies were used to summarise the mFPS-v2 data (scores 1-4) and descriptive statistics including mean, standard deviation, median and inter-quartile range, used to summarise the percentage of legible words.

Inter rater and intra rater agreement were examined using the kappa (κ) coefficient, for the nominal measure of global legibility, and by calculating percent exact and percent close agreement (responses within one score of each other). Kappa agreement was interpreted using criteria proposed by Viera and Garrett (2005) (i.e. $\kappa < 0$ = less than chance agreement, κ 0.01-0.20 = slight agreement, κ 0.21-0.40 = fair agreement, κ 0.41-0.60 = moderate agreement, κ 0.61-0.80 = substantial agreement, κ 081-0.99 = almost perfect

agreement). For the continuous measure of legible word percentages, inter and intra rater reliability of ratings were assessed using a two-way mixed, absolute agreement, single measures intra-class correlation coefficient ($ICC_{2,1}$). We also calculated the limits of agreement (the range in which 95% of the differences in ratings lie), measurement error and error range (the range in which the participants true rating is expected to lie) (Bland & Altman, 1996). ICC was considered 'good' if the value was 0.75 or above, and 'moderate to poor' if below 0.75 (Fleiss, 1986; Portney & Watkins, 2009). To determine if there were systematic errors in measurement, Kendall's correlation coefficient between the means and the differences was calculated.

As variables were not normally distributed, non-parametric tests were used to test group comparisons for both ordinal and continuous data. Comparisons of more than two independent groups were performed using the Kruskal-Wallis test (i.e. for comparisons of legibility scores among age groups per subtest). Age groups were collapsed to form one category for all further comparisons. Comparisons of more than two related groups were performed using Friedman's non-parametric analysis of variance (i.e. for comparisons of legibility scores among subtests, as multiple subtests were completed by the same participants). For univariate analyses involving dependant scores, the Wilcoxon signed rank test was used (i.e. for writing tool comparisons of legibility scores as the same participants completed subtests in pencil first, then pen). For all analyses, p-values of less than 0.05 were considered statistically significant. Analyses were conducted using IBM SPSS version 20.0 (IBM Corp.).

Results

Participant Demographics

A total of 128 participants were recruited. Eight participants were unable to complete the assessment due to a health condition such as macular degeneration, dementia, Parkinson's disease or severe arthritis (n=7), or poor comprehension (n=1) and were excluded. The final sample included 120 participants (mean age 78.9 years, SD 11.2). As planned prior to recruitment, there were equal numbers of men and women in each age group except for the 90 to 99 years cohort, which contained more women (n = 20) than men (n = 10) as older men were more difficult to recruit. Ten participants (8.3%) with self-reported arthritis and two (1.7%) with vision impairments were included due to the prevalence of these conditions in older adults. A further three participants (2.5%) reported other minor ailments ('muscle weakness in [their] arm', being 'shaky sometimes', having 'undiagnosed arm pain'), but were able to complete all subtests, so their data were included. Demographic characteristics are presented in Table 1.

Table 1

Participant demographic information (n = 120)

Characteristic	**n**	**(%)**
Gender		
Male	55	45.8
Female	65	54.2
Age		
60-69	30	25.0
70-79	30	25.0
80-89	30	25.0
90-99	30	25.0
Handedness		
Right	118	98.3
Left	2	1.7
Language		
English	120	100.0
Health conditions[§]		
Yes	15	12.5
No	105	87.5

§Conditions included arthritis and vision impairment; these participants were included if they could complete the questionnaire and handwriting tests.

Printed Versus Cursive / Mixed Cursive Text

The proportion of participants that used printed text when instructed to use their 'usual handwriting style' varied between subtests. Furthermore, participants used different writing styles across subtests when given a choice. While printing was used exclusively for one subtest, a mixed cursive or cursive style may have been used for another. For all subtests, more than 10% of samples were written in printed text (either capital or lower case printing). For example, the self-composed sentence was written (in pen) exclusively using upper case printing (capitals) by 11 participants (9.4%), while four participants (3.4%) used lower case printing, but the majority of participants (n=102, 87.2%) used cursive/mixed cursive styles. For the self-composed sentence written in pencil, 10 participants (8.4%) wrote using upper case printing (capitals) and six (5%) wrote using lower case printing, but the majority (n=103, 86.6%) used cursive/mixed cursive styles.

Inter rater and Intra rater Agreement of Legibility Rating Procedures

Table 2 presents the inter rater and intra rater reliability of two of the handwriting subtests, the self-composed sentence and audio taped message. Two independent raters did not achieve acceptable inter rater agreement, therefore we examined intra rater reliability and used one, consistent rater for the study. For the self-composed sentence subtest written in pen, lack of variation in the data prevented calculations for (a) the $ICC_{2,1}$ value for inter rater agreement of legible word percentages (b) the kappa coefficient for intra rater agreement of global legibility ratings and (c) the $ICC_{2,1}$ value for intra rater agreement of legible word percentages. For both subtests, a systematic bias in the measurement error was identified affecting inter rater reliability, with one rater consistently rating more severely than the other.

Table 2

Inter and intra rater reliability of legibility scoring procedures.

	Inter rater reliability	Intra rater reliability
Self-composed sentence subtest (pen)		
Global legibility ratings		
Kappa co-efficient (p-value)	0.09 (.19)	Unable to calculate
% exact agreement	60.6	94
% close agreement	94	100
Legible word percentages		
ICC, 95%CI (p-value)	Unable to calculate	Unable to calculate
Limits of agreement (%)	-40 to 19	-8 to 10
Measurement error (%), Error range (%)	10.7, 21.1	3, 7
Kendall's tau (p-value)	0.91 (.001)*	-1 (.12)
Perfectly legible word percentages		
ICC, 95%CI (p-value)	0.53, 0.23, 0.74 (.001)	0.79, 0.62, 0.89 (.001)
Limits of agreement (%)	-81 to 33	-33 to 43
Measurement error (%), Error range (%)	20.5, 40.2	14, 27
Kendall's tau (p-value)	0.09 (.51)	0.09 (.29)
Audio taped message subtest (pencil)		
Global legibility ratings		
Kappa co-efficient, p-value	-0.01 (.82)	0.48 (.002)
% exact agreement	18.7	76
% close agreement	87.5	100
Legible word percentages		
ICC, 95%CI (p-value)	0.34, -0.001, 0.61 (.025)	0.75, 0.56, 0.87 (.001)
Limits of agreement (%)	-100 to 60	-23 to 21
Measurement error (%), Error range (%)	14.9, 29.1	7.7, 15.2
Kendall's tau (p-value)	0.5 (.001)*	0.05 (.74)
Perfectly legible word percentages		
ICC, 95%CI, p-value	0.67, 0.43, 0.83 (.001)	0.82, 0.68, 0.91 (.001)
Limits of agreement (%)	-29 to 49	-25 to 27
Measurement error (%), Error range (%)	14.4, 28	9, 18.3
Kendall's tau (p-value)	0.08 (.60)	0.26 (.048)*

* significant p-value indicates a systematic bias between measurement error. Statistics presented are for the self-composed sentence subtest written in pen and the audio taped message subtest written in pencil

Legibility and Age

Legibility was similar across age groups for all four writing subtests. No statistically significant differences were found for comparisons of global legibility among age groups using the Kruskal-Wallis test for the copied sentence written in pencil (p=0.16) and pen (p=0.10), the self-composed sentence written in pencil (p =0.21) and pen (p =0.58) or the audio taped message subtest (p=0.30). No statistically significant differences were found for comparisons of legible word percentages among age groups using the Kruskal-Wallis test for the copied sentence written in pencil (p=0.16) and pen (p=0.11), the self-composed sentence written in pencil (p=0.22) and pen (p = 0.59), the audio message subtest (p=0.28) or the shopping list subtest written in pencil (p= 0.24) and pen (p= 0.37).

Legibility and Handwriting Subtest (Task)

Global legibility scores were high for all subtests, with 91.3% of handwritten samples awarded a rating of '4' (most or all words legible, the meaning of the text could be understood upon first read), 7.3% rated '3' (many words legible, the meaning of the text could be understood upon first read) and 1.4% rated '2' (some words legible, the meaning of the text is unclear upon first read).

Significant differences in legibility were found across subtests for both global legibility (Chi-square=21.17, df=2, p=.001) and legible word percentages (Chi-square=26.63, df=3, p=0.001), for subtests completed in pencil. Writing produced from the audio-taped message subtest resulted in the lowest legibility ratings. Table 3 presents the legibility differences across subtests.

Table 3

Handwriting legibility: Descriptive statistics for each subtest

	Copied sentence		**Self-composed sentence**		**Audio-taped message**		**Shopping list**		**Test statistics for legibility between subtest**	
	Pencil	**Pen**	**Pencil**	**Pen**	**Pencil**	**Pen**	**Pencil**	**Pen**	**Pencil**	**Pen**
Global legibility rating	*n* = 118	*n* = 119	*n* = 119	*n* = 117	*n* = 100	N/A	N/A	N/A	*chi-square*	*Z* = -1.29,
1: None or few words legible	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	N/A	N/A	N/A	= 21.17, *df*	*p* = .20
2: Some words legible	1 (0.8%)	1 (0.8%)	4 (3.3%)	0 (0.0%)	2 (2.0%)	N/A	N/A	N/A	= 2, *p* =	
3: Many words legible	7 (5.9%)	7 (5.9%)	5 (4.2%)	4 (3.4%)	19 (19.0%)	N/A	N/A	N/A	0.001	
4: Most or all words legible	110 (93.2%)	111 (93.3%)	110 (92.4%)	113 (96.6%)	79 (79.0%)	N/A	N/A	N/A		
Test statistics for legibility between pencil and pen	*Z* = 0.00, *p* = 1.00		*Z* = -1.57, *p* = .12		N/A		N/A			
Percentage of legible words	*n* = 118	*n* = 119	*n* = 119	*n* = 117	*n* = 100	N/A	*n* = 120	*n* = 120	*chi-square*	Unable to
Mean (SD)	99% (4%)	99% (3%)	98% (5%)	100% (3%)	93% (14%)	N/A	98% (5%)	99% (5%)	= 26.63, *df*	calculate
Median (IQR)	100% (100%-100%)	100% (100%-100%)	100% (100%-100%)	100% (100%-100%)	100% (100%-100%)	N/A	100% (100%-100%)	100% (100%-100%)	= 3, *p* = 0.001	due to lack of variation in data
Test statistics for legibility between pencil and pen	*Z* = -1.57, *p* =.12		*Z* = -1.94, *p* = .052		N/A		*Z* = -0.03, *p* = .98			

Notes: df = degrees of freedom; SD = standard deviation; IQR = inter-quartile range.

Legibility and Writing Instrument

No statistically significant differences were found between pen and pencil writing for any subtest. Table 3 presents the Wilcoxon signed rank test statistics for pen and pencil comparisons.

Discussion

The aims of this study were to describe (a) the range of legibility scores across a variety of tasks, in healthy adults aged 60 to 99 years, (b) the relationship between legibility and increasing age, the writing task and writing tool used, and (c) the reliability of legibility rating procedures. The key findings from this study were that global legibility was high across all subtests, and legibility was not related to increasing age.

Printing was used as a preferred writing style by more than 10% of participants per subtest, for subtests other than the copied sentence which was instructed to be written in cursive. Printing should not be discouraged when assessing and retraining handwriting in older populations. Previous studies have found that mixed print handwriting styles are more legible than cursive writing alone (Gozzard et al., 2012; van Drempt et al., 2011a) and therapists retraining handwriting legibility may encourage the use of printed letters as a strategy to ensure that first, last and ascender/descender letters in words are formed well to improve word readability.

Inter and Intra rater Reliability of Legibility Rating Procedures

Differences in inter rater agreement when rating legibility were not unexpected because evaluation of handwriting legibility is inherently subjective (Rosenblum et al., 2003) and may be influenced by background knowledge (Murray et al., 2012). For both subtests,

although inter rater reliability of global legibility ratings was poor, percent close agreement was high. Our results demonstrated that intra rater reliability was acceptable (close agreement for rating global legibility = 100%). Although a reliable instrument for measuring handwriting legibility for research and clinical practice remains elusive, the mFPS-v2 method of rating global legibility is clinically useful if repeated assessments are completed by the same rater.

When rating percentage legible words, a difference in agreement of one word between raters created a large difference in ratings. For example, when participants wrote a sentence containing five words, if one word was considered illegible by one rater, but all words considered legible by the second rater, that rating difference yielded a 20% difference in legible word percentages. This issue has previously been identified as a barrier to achieving good inter rater reliability in handwriting assessments (Duff & Goyen, 2010). In our study, intra rater error range results were less than 20%, meaning in clinical terms, only one word would need to improve from 'illegible' to 'legible' to be confident an actual improvement in word legibility had occurred (because an improved rating of a single word using the mFPS-v2-W method yields a 20% increase of legible word percentages). These findings suggest that this method to rate word legibility may prove useful in clinical settings when the same rater repeats scoring procedures.

Legibility and Age

Results of our study showed that handwriting legibility was not related to increasing age. This finding is consistent with that of Baxter (2004), where older and younger participants had similar levels of overall legibility. When produced under test conditions,

illegible writing in the elderly is likely due to medical conditions affecting handwriting or the required handwriting task, rather than the consequence of 'normal ageing'.

Legibility and Handwriting Task

The complex task of transcribing an audio-taped telephone message resulted in the lowest legibility, for both global and word level legibility outcomes. However, despite increased word illegibility compared to other subtests, the overall meaning of the text could be understood upon first read for 98% of transcribed messages. Transcribing auditory information is cognitively demanding, requiring quick, fluent handwriting and good language comprehension (Peverly et al., 2013), challenging the working memory of older adults (Hoskyn & Lee Swanson, 2003). Listening to the message, deciding what key information to write and writing text quickly under test conditions appeared to compromise legibility.

Writing a short self-generated sentence in participants' 'usual handwriting style' produced similar legibility ratings to copied text written in cursive. Writing a self-generated note in a personal handwriting style is likely to be an engaging, real-world task for older adults (Gozzard et al., 2012; van Drempt et al., 2011a). While standardised tests such as the Jebsen speed test are important, clinicians should ensure adult handwriting performance is also assessed using self-generated tasks performed in an individual's preferred handwriting style. However copying may remain an important rehabilitative activity as adults with cognitive problems may not remember, plan or produce letter forms correctly when initially self-generating text (Rapcsak, 1997).

Legibility and Writing Instrument

Pen and pencil writing produced similar legibility ratings in this study. Although handwriting speed is generally faster when a pen is used compared to a pencil, adult handwriting assessment and retraining should involve use of preferred writing tools, and those which optimise an individual's performance (Burger & McCluskey, 2011).

Limitations

While a cross sectional (observational) study design is commonly used in health research to determine prevalence, we acknowledge that the design does not permit distinction between cause and effect (Mann, 2003). Therefore, it is possible that our results are reflective only of individual handwriting variations and not the effects of ageing. A well-funded longitudinal study is warranted to confirm our study's findings. In our study, participants were recruited through convenience sampling which may have led to a less representative sample of ageing Australians than a randomly selected sample may have produced. The inclusion criteria of our study did not involve a cognitive screening tool. Therefore it is possible that individuals who did not self-report dementia, or other health conditions affecting cognitive function, may have been un-intended participants of this study. A final limitation of our study inclusion criteria means that findings cannot be applied to non-English-speaking populations.

Future Research

Future research is warranted investigating the legibility of people who have been affected by stroke and other neurological conditions, who identify as having 'poor legibility'. Finally, aesthetics and 'neatness' as concepts were not examined in this study. Research investigating handwriting quality or 'neatness' and its relationship to legibility would be

useful for therapists retraining handwriting, and those clients who perceive this aspect of handwriting to have altered.

Conclusions

Healthy older adults in this study wrote with high global legibility almost all the time, but the complex task of transcribing an audio-taped message resulted in reduced word legibility. Importantly, age was not related to legibility outcomes. Illegible handwriting produced under test conditions is likely due to the required task or specific health conditions rather than the effects of aging. Findings from this study may help rehabilitation therapists determine when legibility is 'impaired', set intervention goals and measure legibility changes during handwriting retraining.

CHAPTER FOUR: JOURNAL ARTICLE 2

Older adults experience difficulty completing the lines and dots tasks of the Motor Assessment Scale

In the article presented in this chapter, I investigate the performance of older adults without stroke on the 'lines' and 'dots' tasks contained on the Motor Assessment Scale. Relationships between age and task performance, and between writing speed and performance on the 'lines' task are also explored.

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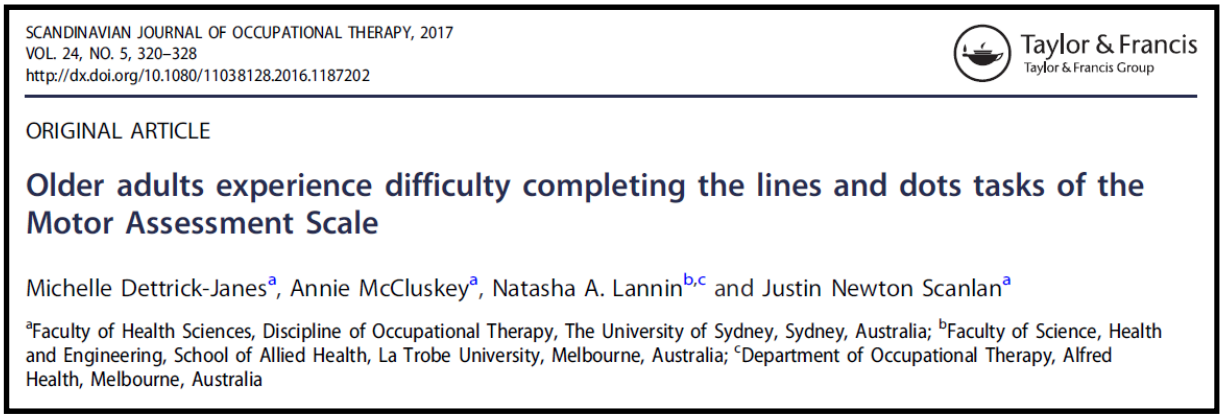

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ORIGINAL ARTICLE

Older adults experience difficulty completing the lines and dots tasks of the Motor Assessment Scale

Michelle Dettrick-Janes[a], Annie McCluskey[a], Natasha A. Lannin[b,c] and Justin Newton Scanlan[a]

[a]Faculty of Health Sciences, Discipline of Occupational Therapy, The University of Sydney, Sydney, Australia; [b]Faculty of Science, Health and Engineering, School of Allied Health, La Trobe University, Melbourne, Australia; [c]Department of Occupational Therapy, Alfred Health, Melbourne, Australia

The formatting and referencing of this chapter has been altered to be consistent with the overall formatting of this thesis. All references are presented at the end of this thesis in the combined *References* chapter. Tables and figures have been placed within the text for easy reference.

Statement of Contribution of Authors

As co-authors of the following article:

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we confirm that Michelle Dettrick-Janes has made the following contribution:

- *Conceptualisation and design of research;*
- *Collection of data;*
- *Analysis and interpretation of results; and*
- *Writing paper and critical appraisal of content.*

Annie McCluskey Signed: _____ Date: 13/06/2018

Natasha A. Lannin Signed: _____ Date: 13/06/2018

Justin Newton Scanlan Signed: _____ Date: 13/06/2018

Older Adults Experience Difficulty Completing the Lines And Dots Tasks Of The Motor Assessment Scale

Abstract

Background: The advanced hand activities item of the Motor Assessment Scale (Upper Limb items, UL-MAS) includes the 'lines' and 'dots' tasks, which require skilful pencil use. Prior Rasch analysis studies identify these two tasks as the most difficult for stroke survivors to achieve compared to other advanced hand activities. Yet it is unknown if healthy, older adults can perform these two tasks.

Objectives: To describe the performance of older adults' without stroke on the 'lines' and 'dots' tasks, relationship between age and task performance, and relationship between writing speed and performance on the 'lines' task.

Methods: Cross sectional study design. A sample of healthy older Australians (n=120) aged between 60 and 99 years completed the UL-MAS 'lines' and 'dots' tasks and wrote two sentences using pencil.

Results: Fifty-four participants (45%) failed the UL-MAS 'lines' task. Differences in line drawing performance across age groups were statistically significant (chi-square=9.02, df=3, p=.03). Eleven participants (9%) failed the 'dots' task, mostly from the 90 to 99 year age group. Participants who passed the 'lines' task wrote sentences faster than participants who failed (p<.001*)*.

Conclusion: Older adults may not pass the UL-MAS 'lines' and 'dots' tasks due to age and individual skill level.

KEYWORDS: Elderly, Rehabilitation, Handwriting

Introduction

The Motor Assessment Scale (MAS) was designed to measure motor performance following stroke, using everyday activities such as standing up from a chair, drawing lines and making dots on a page in pencil (Carr et al., 1985). The MAS is well known to therapists internationally, used widely in clinical settings, and is often used as an outcome measure in randomised controlled trials to measure changes in mobility and upper limb function (Askim et al., 2010; Hayward et al., 2013; Olaleye et al., 2014). With over two thirds (86%) of stroke survivors experiencing upper limb weakness one year post-stroke (Kong, Chua, & Lee, 2011) and needing ongoing rehabilitation, the MAS can measure changes over time in fine motor skills such as holding and using a pencil (Kwakkel & Kollen, 2007).

The MAS includes eight items each with six motor behaviours (Carr et al., 1985). Three items measure upper limb motor performance including 'upper arm function' (item six), 'hand movements' (item seven) and 'advanced hand activities' (item eight). These three items, assessing 18 motor behaviours, are collectively known as the upper limb MAS (UL-MAS) (Hsueh & Hsieh, 2002; Lannin, 2004; K. J. Miller et al., 2010; Pickering et al., 2010). The UL-MAS is a uni-dimensional scale that measures a single construct, upper limb motor performance (Khan et al., 2013; Lannin, 2004; K. J. Miller et al., 2010; Sabari et al., 2005). Each item is scored on a seven-point ordinal scale ranging from 0 (unable to perform any of the motor behaviours) to 6 (able to perform all six motor behaviours) (Carr et al., 1985). Multiple studies describing the UL-MAS report a hierarchal scoring method for each item, stating that the six motor behaviours within each item are ordered, from easier to more difficult (Dean & Mackey, 1992; K. J. Miller et al., 2010; Sabari et al., 2005; Williams et al., 2001). These studies all cite the original publication of the MAS, which states that 'all items except general tonus are constructed so that point 6 indicates the optimal motor behaviour'

(Carr et al., 1985, p. 175). Therefore, for each item, completion of a higher level motor behaviour assumes successful performance on all lower level motor behaviours (Khan et al., 2013; Sabari et al., 2005).

Factor analysis suggested that a single, composite UL-MAS score (ranging from 0 to 18), obtained by summing the scores from the three UL-MAS items, is a valid measure of upper limb performance (Lannin, 2004). However, problems have been reported with the hierarchical order of motor behaviours in the advanced hand activities item (item eight). Consequently, it has been recommended that all six motor behaviours on that item be scored and reported separately (Dean & Mackey, 1992; Poole & Whitney, 1988). Subsequent Rasch analysis confirmed that for item eight, the motor behaviours are not ordered hierarchically (Aamodt et al., 2006; K. J. Miller et al., 2010; Pickering et al., 2010; Sabari et al., 2005). Consistently, the two most difficult behaviours for stroke survivors to achieve on the advanced hand activities item are motor behaviours three and four. These two motor behaviours involve drawing 10 horizontal lines and making 10 dots in a set timeframe respectively and will hereafter be referred to as the 'lines task' and 'dots task'.

The performance of stroke survivors on all UL-MAS motor behaviours is scored as 'achieved' (score 1) or 'not achieved' (score 0). This dichotomous scoring procedure, and stated aim of the MAS, to measure motor performance following stroke using everyday activities (Carr et al., 1985), implies that healthy adults can perform the lines and dots tasks successfully. However, handwriting processes such as speed and the application of downward pen pressure are known to deteriorate with increasing age (Burger & McCluskey, 2011; Engel-Yeger et al., 2012; Rosenblum & Werner, 2006). Therefore, reduced speed and/or

downward pen pressure due to aging may reduce performance on the lines and dots tasks of the UL-MAS in healthy older adults as well as stroke survivors.

Descriptive data are needed to determine the performance of healthy adults on the lines and dots tasks of the UL-MAS. Furthermore, although these tasks require the skilful use of pencil and are timed, the relationship between task performance and handwriting speed has not been investigated. For handwriting to be functional, individuals need to write a sufficient quantity of text in a specified timeframe (Ferrier et al., 2013; Wallen et al., 2013) or in a timeframe considered appropriate for the task. The lines task requires individuals to hold a pencil, move their arm across the page and draw 10 horizontal lines within a short time frame. We questioned whether adults who are able to achieve the requirements of the lines task write faster than people who cannot perform the requirements of the task. Therefore, the purpose of this study was to investigate the performance of healthy older adults' on the lines and dots tasks, describe the relationship between age and task performance, and the relationship between writing speed and performance on the 'lines' task.

Methods

A cross sectional study design was used.

Sample

A convenience sample of 120 older adults was planned, with the aim of obtaining data from 15 men and 15 women across four age groups (60 to 69, 70 to 79, 80 to 89 and 90 to 99 years). A target of 30 participants in each age group, allowed sufficient numbers for sub-group analyses (Portney & Watkins, 2009). The sample was chosen to match the age of many, but not all, stroke survivors, and with the intention of later collecting similar data for a

younger cohort aged 18 years up to 60 years. Participants were initially located through personal contacts of the researchers and by approaching older adults at retirement villages, residential homes, community groups and senior citizens' groups in two states of Australia. Recruitment occurred May to September 2010, at which time the required number of participants in each sub-group was achieved. In the 90 to 99 years age group older men were difficult to recruit therefore additional female participants were included.

Eligible participants lived in metropolitan and regional areas, were aged 60 to 99 years, able to read and write in English, write without pain and participated voluntarily (without any form of reimbursement). Included participants were able to complete two sentence writing subtests of our study (described below). Participants were excluded if they self-reported having had a stroke, or any another condition that affected their writing such as severe arthritis, macular degeneration, impaired vision, diabetes, major depression, dementia or Parkinson's disease, or they could not complete the subtests due to poor comprehension.

Data collection

Researchers met with eligible participants in a convenient location, including private dwellings, retirement villages, residential homes, and a church hall. Data collection took approximately 30 minutes. Testing was completed in sitting. Participants completed tasks and subtests in pencil, with their dominant, writing hand only. A self-report questionnaire was completed first, capturing demographics, health status and hand dominance. The questionnaire was developed by the research team, has been used in previous studies (Gozzard et al., 2012; van Drempt et al., 2011a) and enabled the sample to be described. The horizontal lines and dots tasks of the UL-MAS were then administered followed by a copied sentence and self-composed sentence subtest.

Test Administration and Scoring Procedures

Lines task. Procedures for administering the UL-MAS lines task were originally described as follows: 'Draw horizontal lines to stop at a vertical line 10 times in 20 seconds (at least five lines must touch and stop at the vertical line)' (Carr et al., 1985, p. 179). Participants in our study were provided with an A4 page (210mm x 297mm) with two black pre-printed vertical lines, one 14mm from the right side of the page and the other 22mm from the left side, leaving a 175 mm wide space for participants to draw horizontal lines. Instructions for the subtest were printed at the top of the page. Participants in our study were invited to practice drawing one or two lines (untimed). Participants then attempted the lines task in pencil up to three times, as per original MAS administration guidelines (Carr et al., 1985). Lines drawn during practice attempts were not rated.

The total number of lines drawn were counted and recorded, per attempt. Next, a ruler was used to determine if each line 'touched and stopped' at the right vertical line. To ensure consistency when scoring, lines that finished within 2mm either side of the right vertical line were considered 'accurate' and were counted as a line that 'touched and stopped at the vertical line'. Participants were not explicity asked to start drawing horizontal lines from the left vertical line, therefore accuracy regarding the starting position of lines on the left side of the page was not taken into account during scoring. The number of 'accurate' lines drawn were counted and recorded per attempt. If the requirements of the lines task were achieved in the specified time frame, a score of '1' (achieved) was recorded. A score of '0' (not achieved) was recorded if the requirements were not achieved after three attempts. Participants had three opportunities to achieve a score of 1, as per original MAS guidelines (Carr et al., 1985).

Dots task. Procedures for administering the UL-MAS dots task were originally described as follows: 'Holding a pencil, make rapid consecutive dots on a sheet of paper (patient must do at least 2 dots a second for 5 seconds. Patient picks pencil up and positions it without assistance. Patient must hold pen as for writing. Patient must make a dot not a stroke)' (Carr et al., 1985, p. 179). Participants in our study were asked to 'make at least 10 dots in 5 seconds' and instructed to 'make a dot, not a stroke'. Participants used pencil and were provided with an A4 piece of paper with a large blank space for making dots. Instructions were printed at the top of the page. Participants were invited to make one or two dots on the page (untimed). Practice attempts were not rated. Participants were provided with a verbal definition of a 'dot' versus a 'stroke' (a dot with a 'tail' would be considered a 'stroke'). The scoring of a practice 'dot' was demonstrated for participants who had difficulty understanding the instructions. Participants then attempted the dots task up to three times, as per original MAS administration guidelines (Carr et al., 1985).

The number of dots produced were counted and recorded (up to a maximum of 10 dots) per attempt. If the requirements of the dots task were achieved, a score of '1' was recorded. A score of '0' was recorded if the requirements were not achieved after three attempts (ie participants had three opportunities to achieve a score of 1). In our study, to distinguish between a 'dot' and a 'stroke', a transparent ruler was used to measure the diameter of each 'dot' at its widest point. If the dot diameter was 1mm or less, the dot was counted. If the dot diameter was greater than 1mm it was considered a 'stroke' and was not counted. Counting the total number of dots during the reliability study proved too difficult as dots were often produced in clusters. However, it was possible to determine if 10 or fewer dots had been achieved or not.

The lines and dots tasks has established inter rater reliability for scoring procedures (lines task $\kappa = 1.0$; dots task $\kappa = 0.80$) (Faddy et al., 2008).

The Jebsen Speed Test / Copied sentence subtest. Participants held a pencil in their (dominant) writing hand ready to copy a standardised sentence containing 24 letters, using 'cursive writing'. Participants selected and turned over one of three cards (with their non-writing hand). The cards were presented with the printed side face down. The three possible sentences were: 'John saw the red truck coming', 'Fish take air out of the water' and 'The old man seemed to be tired'. Participants turned the card over then copied the printed sentence 'as quickly and neatly as possible'.

Writing speed was timed from when the researcher said 'go' until the participant lifted the pencil from the page after completing the sentence, as described for the Jebsen hand function subtest (Jebsen et al., 1969). The Jebsen speed test has established inter rater reliability (ICC3,2 = 1.00) (Hackel et al., 1992) and was selected for data collection as it is well known to many rehabilitation therapists. Time taken to copy the sentence was recorded in seconds, and the number of letters written per minute calculated. Speed results have been published previously, with handwriting speed found to decrease with increasing age (Burger & McCluskey, 2011). This test will be referred to hereafter as the 'copied sentence' subtest. Legibility results have also been published, with 99% of copied sentences considered legible (Dettrick-Janes et al., 2015).

Self-composed sentence subtest. Participants used their 'usual style of handwriting' to write a self-composed five-word sentence as 'quickly and neatly as possible' using pencil.

If participants had difficulty composing a sentence, suggested topics were offered, such as 'What did you do this morning?' The self-composed sentence subtest has been used in previous adult handwriting studies (Burger & McCluskey, 2011; Faddy et al., 2008). Time taken to write the sentence was recorded in seconds and the number of letters produced per minute calculated. Speed results have been published previously, with handwriting speed found to decrease with increasing age (Burger & McCluskey, 2011). Legibility results have also been published, with 97% of self-composed sentences considered legible while the remaining 3% contained some legible words (Dettrick-Janes et al., 2015).

Reliability of Scoring Procedures

Inter rater agreement between two independent raters was calculated using data from 31 randomly selected participants for the lines and dots tasks. A random sample of over 30 was deemed necessary for testing reliability (Peat et al., 2001). Data were independently scored for both tasks as 'achieved' (score 1) or 'not achieved' (score 0) by the first and second authors, both of whom are occupational therapists with experience using the UL-MAS. For participants' first attempt at the lines task, the total number of lines recorded, and the 'accurate' number of lines recorded by both raters was also tested for inter rater agreement. Standard written instructions were provided, with discussion used to clarify scoring procedures.

Data Analysis

Descriptive statistics including frequencies were used to summarise demographic data such as age (groupings 60 to 69, 70 to 79, 80 to 89 and 90 to 99 years) and gender. To test inter rater reliability for scoring the horizontal lines and dots tasks (achieved=1 / not achieved=0), the kappa coefficient and percent exact agreement were calculated. Kappa

agreement was interpreted using the following criteria: κ <0 = less than chance agreement, κ 0.01-0.20 = slight agreement, κ 0.21-0.40 = fair agreement, κ 0.41-0.60 = moderate agreement, κ 0.61-0.80 = substantial agreement, κ 081-0.99 = almost perfect agreement (Viera & Garrett, 2005).

For the lines task, the total number of lines recorded, and the 'accurate' number of lines recorded by both raters was assessed for inter rater reliability using a two-way mixed, absolute agreement, single measures intra-class correlation coefficient ($ICC_{2,1}$). We also calculated the limits of agreement (the range in which 95% of the differences in measurements between raters lie). Scoring procedures were considered 'clinically acceptable' if the ICC was 0.90 or above (Fleiss, 1986; Portney & Watkins, 2009).

Scores for the lines and dots tasks (0-1) between age groups (1-4) were compared using Pearson's chi square test. A linear by linear statistic was used to investigate whether there was a linear relationship between ability to achieve the task requirements and increasing age. The relationship between achieving (or not achieving) the requirements of the lines task and writing speed when participants copied and composed a sentence was investigated using independent samples t-tests. For all analyses, *P* values of less than 0.05 were considered statistically significant. Analyses were conducted using IBM SPSS version 22.0 (IBM Corp.).

Institutional ethics approval was granted. Participants signed a consent form prior to data collection and confidentiality was assured.

Results

Participant Demographics

A total of 128 participants were screened. Eight participants were excluded due to a self-reported health condition (macular degeneration, dementia, Parkinson's disease or severe arthritis [n=7], or due to poor comprehension when attempting to complete tasks [n=1]). The final sample included 120 participants (mean age 78.9 years, SD 11.2) (Figure 1). As planned prior to recruitment, there were equal numbers of men and women in each age group except for the 90 to 99 years cohort, which contained more women (n = 20) than men (n = 10) as it proved difficult to recruit older men. Ten participants (8.3%) with self-reported (mild) arthritis and two (1.7%) with vision impairments were included due to the prevalence of these conditions in older adults, and because they were able to complete all writing subtests. A further three participants (2.5%) reported other minor ailments ('muscle weakness in [their] arm', being 'shaky sometimes', having 'undiagnosed arm pain') but were able to complete the study requirements. Their data were included. Demographic characteristics are presented in Table 1.

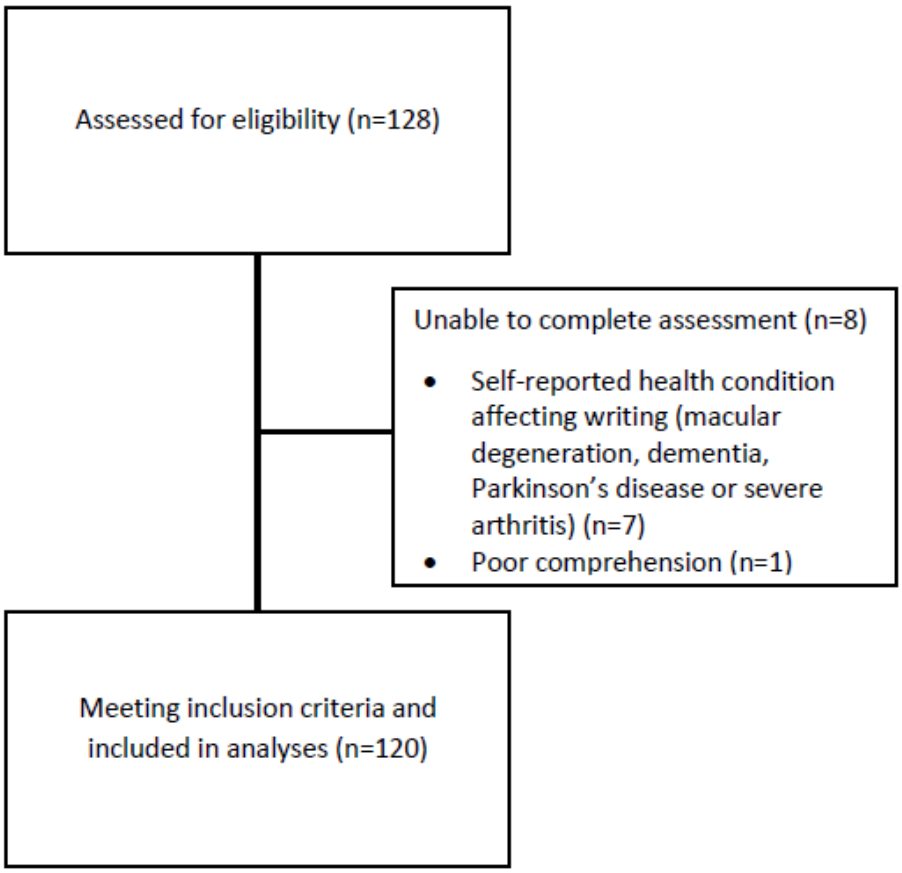


Figure 1. Flowchart of inclusion of participants in data analysis

Table 1

Participant demographic information (n = 120)

Characteristic	**n**	**(%)**
Gender		
Male	55	45.8
Female	65	54.2
Age		
60-69	30	25.0
70-79	30	25.0
80-89	30	25.0
90-99	30	25.0
Handedness		
Right	118	98.3
Left	2	1.7
Language		
English	120	100.0
Health conditions*		
Yes	15	12.5
No	105	87.5

*Conditions included arthritis and vision impairment; these participants were included if they could complete the questionnaire and handwriting tests.

Inter rater Reliability

Lines task. There was 'perfect agreement' for scoring (0=not achieved, 1=achieved) between two independent raters (κ=1.00, p<.001; exact agreement=100%). For the total number of lines recorded, inter rater reliability was acceptable for clinical use ($ICC_{2,1}$=0.99, p=.001); limits of agreement were -0.49 to 0.69 (mean of differences=0.097). For the number of 'accurate lines' recorded, inter rater reliability was acceptable for clinical use ($ICC_{2,1}$= 0.92 p=.001); limits of agreement were -2.52 to 2.00 (mean of differences=-0.26).

Dots task. There was 'almost perfect' agreement between two independent raters for scoring (0=not achieved, 1=achieved) (κ=0.87, p=.001, exact agreement=97%).

Age and Performance

Lines task. Nearly half of the healthy older adults who participated in the study did not achieve the requirements of the UL-MAS lines task (n=54, 45%). Statistically significant differences in scores were found between age groups (chi-square=9.02, df=3, p=.03). The linear by linear statistic showed a significant trend for not achieving the requirements of the task to increase with age (chi-square=7.72, df=1, p=.01). Table 2 details the number of participants who achieved and did not achieve the requirements of the lines task, according to age cohorts.

Dots task. The majority of participants who did not achieve the requirements of the dots task were aged 90 to 99 years (n=9 from a total of n=11 failures, 82%). Differences in scores amongst age groups were statistically significant (chi-square=21.12, df=3, p<.001). Table 2 details the number of participants that achieved and did not achieve the requirements of the dots task, according to age cohorts.

Table 2

Number and proportion of healthy older adults that achieved and failed the horizontal lines and dots subtests (n=120)

		Age groups				
	Total Sample	**60-69**	**70-79**	**80-89**	**90-99**	
	n=120	**n=30**	**n=30**	**n=30**	**n=30**	**Test statistics for subtest score**
Subtest	**n (%)**	**n (%)**	**n (%)**	**n (%)**	**n (%)**	**among age groups**
Horizontal Lines						
Did not achieve (score 0)	54 (45)	10 (33.3)	10 (33.3)	14 (46.7)	20 (66.7)	Chi-square=9.02, df=3, p=.03
Achieved (score 1)	66 (55)	20 (66.7)	20 (66.7)	16 (53.3)	10 (33.3)	
Dots						
Did not achieve (score 0)	11 (9.2)	0 (0)	1 (3.3)	1 (3.3)	9 (30.0)	Chi-square=21.12, df=3, p<.001
Achieved (score 1)	109 (90.8)	30 (100)	29 (96.7)	29 (96.7)	21 (70)	

Drawing 10 Lines in 20 seconds Proved Too Difficult for Many Healthy Older Adults

Fifty-one of the 54 participants who did not achieve the requirements of the lines task were unable to draw a total of 10 lines in the 20-second timeframe, regardless of line accuracy. When participants failed to draw 10 lines in total, the range of lines drawn was two to nine (see Table 3). Only three of the 54 participants who failed the lines task drew at least 10 lines in total, yet were unable to draw the specified number of 'accurate lines' (five). These three participants were all aged 90 to 99 years.

Table 3

Horizontal lines subtest: Descriptive statistics for total number of lines drawn (best attempt; regardless of accuracy) by those who failed to meet the scoring requirements of the 'lines' task.

		Age groups			
	Total Sample	60-69	70-79	80-89	90-99
	n=51	n=10	n=10	n=14	n=17
Median (IQR)	8 (7-9)	9 (8-9)	8 (6-9)	8 (7-8.25)	7 (5.5-8)
Min - Max	2 – 9	6 - 9	5 - 9	6 - 9	2 - 9

Our results also indicated that there was a significant difference in writing speed (captured during the copied sentence subtest) amongst participants who achieved the lines task requirements, mean=109 (SD=28.2) and those who failed, mean=88.9 (SD=28.2); ($t=3.9$, $df=118$, $p<.001$). Participants who achieved the requirements of the task wrote 20.1 more letters per minute (95% CI 9.9 to 30.4) than those who did not.

For the self-composed sentence subtest, there was also a significant difference in writing speed amongst participants who achieved the requirements of the lines task, mean=105 (SD=27.3) and participants who did not, mean=87.3 (SD=25.8); (t=3.6, df=118, p<.001). Participants who achieved the lines task requirements wrote 17.7 more letters per minute (95% CI 8 to 27.4) than those who did not achieve the requirements.

Discussion

This cross sectional study found that older adults may fail the UL-MAS lines and dots tasks due to their age and individual skill level. Therefore, for stroke survivors, reduced motor control post-stroke may not be the only reason that a person fails the UL-MAS pencil tasks. For younger and older stroke survivors, the lines and dots tasks are more difficult to complete than other UL-MAS advanced hand activities (K. J. Miller et al., 2010; Pickering et al., 2010). Our study is the first to investigate the performance of healthy adults on these tasks. The lines task in particular was too difficult for many individuals in our study. Consequently, it is recommended that clinicians interpret scores achieved by stroke survivors for the lines and dots subtests of the UL-MAS with caution. Furthermore, we suggest the following modifications be made to scoring procedures for the lines and dots tests.

First, we recommend abandoning the dichotomous scoring procedure, or at least adding a continuous measure of task performance, since many participants failed the lines task. A continuous measure of performance is more useful, clinically and for research purposes, to demonstrate change. For the lines task, the number of total and ‘accurate’ lines produced should be recorded (up to a maximum of 10), as shown in Table 3, providing a continuous measure of upper limb performance that is sensitive to changes in function. For

the dots task, we recommend recording the number of dots produced in five seconds, up to a maximum of 10 dots.

Second, improved administration procedures for the lines task are recommended. Original MAS procedures do not specify the desired length of horizontal lines, nor the space to be provided on a piece of paper for line drawing. In previous studies and in clinical practice, the length of horizontal lines drawn has not been standardised. However, the length of lines drawn would presumably be associated with the number of lines an individual can produce in the 20 second timeframe. We recommend use of a prepared sheet of paper with two pre-marked vertical lines (each 250mm in length), 175mm apart for line drawing to occur. Future use of the 175mm space between vertical lines would allow for comparison of performance against results of this study. Presenting two pre-marked vertical lines also accommodates for choice of direction of line drawing. In the current study, we observed one left-handed participant who drew lines from right to left. The direction of line drawing used by a participant when completing the assessment should be indicated (with an arrow) at the time of testing, allowing line accuracy to be scored using the appropriate target vertical line. Chapter Four, Appendix 1 and Chapter Four, Appendix 2 (presented at the end of this chapter) detail the recommended scoring and administration modifications.

Participants who achieved the requirements of the lines task wrote faster than those who failed. For handwriting to be functional, writing speed is important because individuals often need to complete written tasks quickly, within a limited time (Ferrier et al., 2013; Wallen et al., 2013) for example transcribing telephone messages, or information heard on the radio. In rehabilitation settings, measuring the number of lines drawn in the lines task

may help therapists and patients determine therapy goals and measure progress related to handwriting speed.

A potential limiting factor of our study was the cross-sectional (observational) design. Although this design is commonly used in health research to determine prevalence, we acknowledge that a cross sectional design does not permit distinction between cause and effect (Mann, 2003). Therefore, it is possible that our results are reflective only of individual variations in task performance and not the effects of ageing. A well-funded longitudinal study is warranted to confirm these findings. A second limitation is that participants in our study were recruited through convenience sampling, which may have resulted in a non-representative sample of older Australians, as opposed to a randomly selected sample. Third, no standardised screening instruments were used to exclude people with major depression, impaired cognition, vision or hand function. It is therefore possible that individuals with mild dementia, depression, or other health conditions may have participated and these conditions may have reduced their writing speed. However we have previously reported that all participants were able to self-generate then write a short self-composed sentence, with 97% of sentences considered legible (Dettrick-Janes et al., 2015). Finally, although our study provides descriptive data on the total number of lines drawn by participants who failed the lines task (see Table 3), a well-funded study with a larger sample size of healthy adults is warranted to provide normative values for comparison with a cohort of stroke survivors.

Regardless of these limitations, the study provides the first set of descriptive data for healthy older adults completing the UL-MAS lines and dots tasks, with results suggesting that patients may not achieve test requirements due to age and individual skill levels, and not

due to stroke-related impairments alone. This finding is significant to rehabilitation therapists and researchers using the MAS or UL-MAS as an outcome measure.

Descriptive data presented in this study were obtained from healthy older adults who completed the UL-MAS lines and dots tasks using their dominant writing hand. In previous research, and in practice, patients with stroke use their stroke-affected arm to complete the UL-MAS, regardless of hand dominance. Although the lines and dots hand activities provide a measure of upper limb performance, researchers and therapists need to consider the validity and clinical utility of conducting pencil-use tests with the non-dominant hand - unless the goal is training hand dominance transfer. If stroke survivors continue to complete the UL-MAS pencil tasks using their non-dominant hand, future research is required to investigate performance of healthy adults using their non-dominant hand to provide descriptive data for comparison during rehabilitation. Further research examining the performance of left-handed individuals on these pencil tasks is also warranted. In this study only two participants were left-handed; no comparisons of left-and righted-handed performance were possible. Finally, research to investigate the performance of healthy younger adults is also required to allow comparison with younger individuals following stroke.

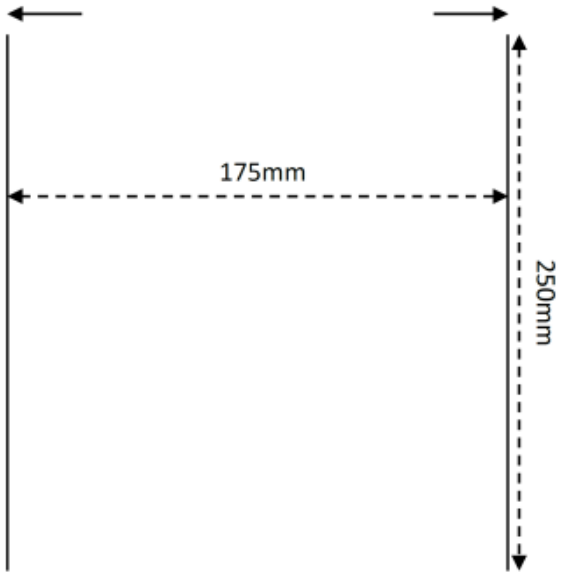
In conclusion, findings of the present study show that many healthy older adults cannot achieve the requirements of the lines and dots tasks due to age and individual skill level. Findings suggest that stroke-related disability may not be the only factor contributing to stroke survivors failing the UL-MAS pencil tasks. It is recommended that administration and scoring procedures be modified to include the range of lines and dots achieved during the allocated test period.

Chapter Four, Appendix 1

Lines task (modified)

Test set up:

1. Prepare three sheets of plain paper with two vertical lines (each 250mm in length), spaced 175mm apart. Place arrows pointing toward each line at the top of each line. These arrows are used for noting the direction of line drawing preferred by the participant. Three sheets of paper need to be prepared as the task should be repeated three times to ensure the participants 'best attempt' is captured. An example (not to scale) is below.



Equipment Required:

1. Three prepared sheets of paper (as above)
2. Pencil for line drawing
3. Ruler for measuring line accuracy

Administration Procedure:

1. Instruction: *'Draw as many horizontal lines as possible in 20 seconds on the sheet of paper provided. Lines should be drawn between the two vertical lines and stop accurately at a vertical line. You are timed from the moment you put the pencil on the paper to start the assessment. You will be stopped once the 20 second time period has elapsed. You are able to have three attempts at the test, and your best attempt will be scored'.*
2. Participants can draw from left to right or right to left. Circle the appropriate arrow provided on the prepared page to indicate the direction of line drawing.
3. Offer a practice attempt (which is not timed) to draw some horizontal lines. Mark practice lines 'P' next to each practice line. Provide clarification that the lines should stop accurately at a vertical line if required.
4. Repeat the task three times, using the three separate pieces of paper.

Scoring procedure:

1. Count and record on the page the total number lines drawn for each attempt. Count up to 10 lines, if more than 10 lines were drawn record '10' regardless (practice attempts are not counted)
2. Count and record on the same page the number of 'accurate' lines drawn. Lines that finish within 2mm either side (before or after) of the vertical line at which the line was intended to stop are considered 'accurate'. Count up to 10 lines.
3. Record the number of total lines and the number of accurate lines (both up to a maximum of 10) drawn on the best attempt. The 'best attempt' is defined as the attempt with the greatest number of accurate lines drawn.

Chapter Four, Appendix 2

Dots task (modified)

Equipment Required:

1. Three blank sheets of plain paper
2. Pencil for dot making
3. Ruler for measuring diameter of dots

Administration Procedure:

1. Instruction: *'Holding a pencil, make as many rapid consecutive dots as possible in 5 seconds on the sheet of paper provided. You must make 'dots' not 'strokes'. A dot with a 'tail' counts as a stroke. To be considered an accurate dot, the dot must not be more than 1mm 'thick' at any point in its diameter. You must pick up the pencil and position it without assistance and hold the pencil as for writing. You are timed from the moment you put the pencil on the paper to start the assessment. You are able to have three attempts at the test, and your best attempt will be scored.'*
2. Offer a practice attempt (which is not timed) to make some dots on the page. Circle the practice attempt and mark 'P' next to the circle. Provide clarification of the definition of a dot by demonstrating making a dot, then making a 'stroke' if participant has difficulty understanding the instruction.

Scoring procedure:

1. Count the number of dots produced until 10 dots are tallied. To distinguish between a 'dot' and a 'stroke', use a transparent ruler to measure the diameter of each 'dot' at its

widest point. If the dot diameter was 1mm or less, the dot is counted. If the dot diameter was greater than 1mm it was considered a ‘stroke’ and is not counted.

2. Record the number of dots produced up to 10. If more than 10 dots were produced, record 10 regardless. (Practice attempts are not counted.)

CHAPTER FIVE: DISCUSSION

In this chapter I discuss the overall conclusions from the research project, the implications of the research and limitations of this research. Finally, aspects of handwriting assessment requiring future research are discussed.

Introduction

The overall aims of the studies presented in this thesis were to describe (a) the range of legibility scores across a variety of tasks, in healthy adults aged 60 to 99 years and (b) the performance of healthy older adults' (without stroke) on the 'lines' and 'dots' tasks of the Motor Assessment Scale (MAS), an instrument commonly used in research and practice to measure motor performance following stroke (Askim et al., 2010; Carr et al., 1985; Hayward et al., 2013; Olaleye et al., 2014).

Specifically, the two studies presented in this thesis were established to examine older adults' handwriting legibility and performance in tasks requiring pencil control and manipulation. Handwriting legibility samples were obtained through four writing subtests and evaluated using the Modified Four Point Scale—version 2 (mFPS-v2). Pencil control was examined through the 'lines' and 'dots' tasks, two 'advanced hand activities' from the MAS which are also included in the Handwriting Assessment Battery for Adults (HAB) (Faddy et al., 2008; McCluskey & Lannin, 2003).

Several key findings emerged from these studies. First, healthy older adults were able to handwrite with high global (overall) legibility when completing all subtests, regardless of

increasing age. Second, many healthy older adults were not able to 'pass' or achieve the requirements of the 'lines' task of the MAS. Third, performance of both the 'lines' and 'dots' tasks of the MAS was poorer in the oldest participant group.

These key findings have important implications for use and interpretation of these measurement methods when evaluating stroke survivors' handwriting legibility and pen / pencil control. Following a brief discussion of findings from each study, these implications will be discussed in detail.

Handwriting Legibility in Healthy Older Adults

Almost all participants in this study wrote a short self-composed sentence, a copied sentence and a self-generated shopping list with high global and word legibility. Global legibility scores were similar across age groups for all writing subtests. Findings from this study suggest that increasing age does not impact upon global handwriting legibility outcomes. This finding is consistent with an earlier study where older and younger participants had similar levels of overall legibility (Baxter, 2004).

The more complex task of transcribing an audio-taped message returned lower scores for word legibility than the other three subtests (test statistics for word legibility between subtests; chi-square=26.63, df=3, p=0.001). Reviewed literature purports that transcribing auditory information is cognitively demanding, requiring quick, fluent handwriting and good language comprehension (Peverly, 2006), challenging the working memory of older adults (Hoskyn & Lee Swanson, 2003). Furthermore, during data collection, many older participants (aged over 80 and 90 years) were observed to have difficulty hearing the audio message, even when the message was turned up very loudly. This problem is not surprising, as hearing loss

is a common difficulty faced by individuals in older age. As detailed in the published paper (Chapter Three, Table 3), the audio-taped message subtest yielded 100 samples of handwriting data from the 120 participants tested. Based on my observations as the onsite researcher, the main reason for these missing data was that many participants experienced difficulty hearing the audio message. For individuals who did complete the task, it is also possible that difficulty hearing the audio message may have increased the cognitive load and impacted on handwriting processes and word level legibility.

In summary, the key findings from this study were that global legibility was high across all subtests, and legibility was not related to increasing age.

Healthy Older Adults' Performance on the 'Lines' and 'Dots' Tasks

Many healthy older adults in this study (54%) were unable to successfully complete the Motor Assessment Scale (MAS) 'lines' task. Differences in line drawing performance across age groups was statistically significant (chi-square = 9.02, df=3, p=.03.). While many participants failed the test, more participants from the 90 to 99 years age group failed (20 of the 30 participants). Additionally, eleven of the 120 participants (9%) failed the 'dots' task of the MAS, nine of whom were aged 90 to 99 years of age. This suggests that the requirements of the 'lines' and 'dots' tasks of the MAS are too challenging for many older adults due to age and individual skill level, although only two older adults aged 60 to 89 years were unable to pass the 'dots' test.

Participants who passed the 'lines' task (which required participants to draw 10 horizontal lines across a page within a 20 second timeframe) also wrote sentences faster than those who failed ($p<.001$). This finding is consistent with previous research investigating

handwriting processes in healthy older adults; over the last 10 years several researchers have concluded that, adults write more slowly and less fluently with increasing age (i.e. they spend more time with the pen in the air and not on the paper) (Burger & McCluskey, 2011; Engel-Yeger et al., 2012; Rosenblum & Werner, 2006). Our study is the first to investigate an association between handwriting speed and performance on the time-limited 'lines' task of the MAS. The study found that older adults with faster writing can also produce more lines across a page in a 20 second time limit, compared to older adults who write more slowly.

In summary, the key finding of this study was that many healthy older adults cannot achieve the requirements of the 'lines' and 'dots' tasks of the MAS due to age and individual skill level. These results have implications for the use (and scoring) of these tasks in the context of handwriting assessment and rehabilitation following stroke. These implications are discussed in detail in the following section.

Implications for Handwriting Assessment and Rehabilitation of Stroke Survivors

Healthy older adults in this study were generally able to produce legible handwriting under the test conditions described. Therefore, when the handwriting tasks and methods of rating legibility presented in this study are used to test handwriting in individuals after stroke, poor overall legibility is likely to be a consequence of stroke impairment, or pre-stroke individual skill level, rather than due to 'normal ageing'.

When using methods described in this study for measuring legibility and pen control, several issues should be considered. First, the handwriting subtests used to collect writing samples may not be relevant to many older individuals wishing to improve their handwriting

following stroke. For example, due to hearing loss, older adults may no longer attempt to listen to recorded phone messages, or take down handwritten information from a recorded phone message (as described earlier in this conclusion chapter). Furthermore, changes in technological communication systems may result in some older adults preferring to receive text messages or email, to avoid missing telephone calls. Thus the 'audio message' subtest may not be a familiar or relevant task for older adults. Another example of a subtest that may not be relevant to some older adults is the shopping list test. Some older adults may make regular shopping lists using pen and paper, others may use their 'smart phone' to record lists electronically, while others may not ever make a list, or even go shopping. While standardised tests are important, therapists need to consider the relevance of the handwriting subtests to the individual when interpreting test results. Do the tested handwriting tasks reflect those that an individual needs or wants to do regularly? Is the individual hoping to perform the task in the future? In clinical practice, it is important to enquire if the handwriting tasks contained in an assessment are unfamiliar or irrelevant to the individual, thus assisting with interpretation of test results and providing direction for setting therapy goals.

Second, interpreting the legibility of handwriting when using the mFPS-v2 to measure legibility, requires caution. In this study, two independent raters did not achieve acceptable inter rater agreement using the mFPS-v2, and a systematic bias in the measurement error was identified affecting inter rater reliability. One rater consistently rated handwriting legibility more severely than the other. Differences in inter rater agreement when rating legibility were not unexpected as evaluation of handwriting legibility is inherently subjective (Rosenblum et al., 2003) and may be influenced by background knowledge (Murray et al., 2012). Poor inter rater reliability when using the mFPS-v2 could possibly result in the problem of handwriting

being inadvertently misclassified by individual therapists as illegible. However, intra rater reliability was acceptable (close agreement for global legibility rating = 100%), suggesting that the mFPS-v2 method of rating global legibility is clinically useful if repeated assessments are completed by the same rater. However, a reliable instrument for measuring handwriting legibility by different raters remains elusive and a more nuanced method of measuring handwriting legibility, as well as other aesthetic aspects of handwriting may be required. The low inter rater reliability of the mFPS-v2 should also be taken into consideration when comparing assessment results against information presented in this study.

Third, printing was used as a preferred writing style by more than 10% of participants per subtest, for subtests other than the copied sentence (which was instructed to be written in cursive). Printing should not be discouraged when assessing and retraining handwriting. Previous studies have found that printing or mixed print handwriting styles (printing and cursive within the same writing sample or word) are more legible than cursive writing alone (Gozzard et al., 2012; Graham, Weintraub, et al., 1998; van Drempt et al., 2011a). Therapists retraining handwriting legibility may consider encouraging the use of printed letters as a strategy to ensure that first, last and ascender/descender letters in words are well-formed as easy recognition of first and last letters in a word, and recognition of overall word shape increases a reader's ability to read handwritten words (Schomaker & Segers, 1999).

Furthermore, educating individuals to increase contextual cues may increase a reader's ability to decipher handwriting which is difficult to read. As described in Chapter 2 of this thesis, increased contextual cues improves readability of text (Morton, 1964). Raters involved in the current study also noted that handwriting was easier to decipher when expected context was provided, for example when five shopping items of a similar category

were written (such as five types of vegetables), rather than items with little relation to each other (such as socks, tinned tomatoes and magazine). For adults whose writing has been affected by stroke, strategies to increase contextual cues, such as grouping shopping list items under categories (e.g. ‘frozen items’ or ‘fruit and vegetables’) may assist the intended reader.

Fourth, no differences in handwriting legibility were found between writing tools (pen/pencil) for any handwriting subtests. Pen and pencil writing produced similar legibility ratings in this study. Although handwriting speed is generally faster when a pen is used compared to a pencil (Burger & McCluskey, 2011), adult handwriting assessment and retraining could involve use of preferred writing tools, multiple writing tools and those which optimise an individual’s performance.

Fifth, there were no significant global legibility differences between men and women across handwriting subtests. Although women did achieve a higher percentage of legible words for the self-composed sentence subtest when written in pencil ($p=.042$), this finding is puzzling as no differences in legible words were found when the self-composed sentence was written in pen. Nonetheless, in our study, the handwriting of older men was, overall, as legible as the handwriting of older women. These results do not support the finding from an earlier study where women produced more legible handwriting than men when writing a standardised 48-letter sentence, but stopped writing after only 10 seconds (Berwick & Winickoff, 1996). Given these results, further exploration of gender differences in handwriting legibility may be required.

Sixth, as many healthy older adults in our study failed the ‘lines’ task, and some failed the ‘dots’ task, performance difficulties experienced by stroke survivors on these tasks may

be related to a combination of ageing, pre-existing individual skill level and stroke related disability. Therefore more nuanced scoring methods (as opposed to the dichotomous 'pass' / 'fail' ratings used in the MAS) might be required when using the 'lines' and 'dots' tasks. We recommend that scoring procedures be modified to include the range of lines and dots achieved during the allocated test period. A continuous measure of performance will also be more useful clinically to demonstrate change in performance over time. An alternate method of administration procedures for the 'lines' task and a continuous scoring method for both the 'lines' and 'dots' tasks are suggested in our published paper (chapter 4, appendix 1 and 2 of the paper).

Finally, descriptive data presented in this study were obtained from healthy older adults who completed the subtests using their dominant writing hand. In previous research, and in practice, stroke survivors use their stroke-affected arm to complete upper limb activities of the Motor Assessment Scale, regardless of hand dominance. While the 'lines' and 'dots' tasks provide a measure of hand activity performance, researchers and therapists need to consider the validity and clinical utility of conducting pencil-use tasks with the non-dominant hand, unless the goal is training hand dominance transfer. Alternatively, it may be useful for future research to explore the performance of healthy older adults on these assessments when using their non-dominant hand. This research would provide useful information as a comparison, because handwriting legibility and pencil control skills will be poorer when using the non-dominant hand.

Limitations

First, although the cross-sectional (observational) design used in this study is commonly used in health research to determine prevalence, it does not permit distinction

between cause and effect (Mann, 2003). Therefore, it is possible that results of the study reflect only individual variations in task performance and are not due to the effects of aging. To confirm these findings would require a well-funded longitudinal study. Second, the convenience sampling method of recruitment may have resulted in a non-representative sample of older Australians. It is therefore possible that without replication, results of this research may not be applicable to the wider population of Australian older adults. Furthermore, findings of this study cannot be applied to non-English speaking Australian populations, as non-English speaking individuals were not included in the sample. Third, self-report methods were used to determine pre-existing health conditions, rather than standardised health screening instruments. It is therefore possible that individuals with depression, mild dementia or other health conditions may have participated in the study. These conditions may have impacted on participants' performance on the subtests and tasks included in this study. Study limitations have been discussed in detail in relation to handwriting legibility in healthy older adults and healthy older adults' performance on the lines and dots tasks of the Motor Assessment Scale in the two published research papers (Chapters Three and Four).

Implications for Future Research

The main key findings from this research were that (a) under test conditions, healthy older adults were able to handwrite with high global legibly regardless of increasing age, (b) many healthy older adults were not able to achieve the requirements of the 'lines' task of the MAS and (c) increasing age was associated with an inability to complete the requirements of the 'lines' and 'dots' pencil use tasks.

Investigation of the revised scoring method for the 'lines' and 'dots' tasks

Further research is needed to evaluate the proposed changes to scoring methods for the 'lines' and 'dots' tasks of the MAS. Our recommendation is that therapists record the number and range of lines and dots achieved during the allocated test period. A continuous measure of performance is potentially more clinically useful for demonstrating change over time than the current dichotomous measure 'achieved/not achieved'. If an individual with stroke draws five or six lines in 20 seconds due to improved motor recovery, compared to one line initially, the score for the MAS 'lines' task should reflect this improvement. Current scoring methods would still report this person as having 'not achieved' 10 lines in 20 seconds. Further research will help inform therapists about the number and range of lines and dots that can be achieved, and establish norms for this population. Appendices 1 and 2 in Chapter Four of this thesis detail the recommended changes to scoring.

Development of a comprehensive handwriting instrument for adults to evaluate legibility and neatness

In the current study, handwriting legibility scores were consistently high for global legibility, yet raters noted individual differences in handwriting 'neatness'. The general aesthetic character of handwriting has long been considered an important aspect of handwriting (Bailey, 1988). 'Neatness' has previously been described as a legibility component, thought to affect the overall legibility of children's handwriting (Graham, 1986; Graham & Weintraub, 1980). However, in subsequent research, Graham et al. (1989) suggested that neatness may not influence actual readability, but perceptions of legibility in children's handwriting. That study aimed to investigate the validity of a paediatric handwriting measure (the Handwriting Scale from the Test of Written Language) and described neatness as writing which was free of erasures (error corrections), smudges and

strikeouts; used ‘appropriate’ paragraph indentations and margins and had good ‘letter line quality’ such that letters did not appear too dark or light (Graham et al., 1989). Neatness was found to significantly contribute to raters’ predictions of legibility scores but not the actual legibility scores (Graham et al., 1989). Error corrections, erasures and strikeouts, are penalised in many paediatric handwriting assessments (e.g., Amundson, 1995). However error corrections such as overwriting, retouching, inserting or crossing out letters seem to be relatively common when healthy adults handwrite in real-world scenarios. In a study describing the handwriting practices of 30 healthy older adults, error corrections were identified in 106 of 268 real-world handwriting samples (39.5%), averaging 3.2 corrections per 100 words (van Drempt et al., 2011a). Legibility of these handwriting samples was not investigated. Another study which used self-report methods found that 89% of healthy adults (n=73) aged 20 to 70 years made error corrections (Hennessy, 1997). Reasons for error corrections included trying to write at increased speed (n=29), pen or surface problems (n=29), carelessness (n=26), lapses in concentration (n=15) and external distractions (n=15). Error corrections, therefore, seem relatively common for adults when writing and some instances of error correction could be considered ‘typical’ for adult hand writers.

Only one known study has investigated both ‘neatness’ and legibility in adult handwriting (Baxter, 2004). That study found that older adults rated significantly lower for neatness than younger adults, but both groups had similar scores of legibility (Baxter, 2004). Handwriting samples were obtained from 26 older adults aged 60 to 92 years and 32 younger adults aged 21 to 59 years, then self-rated by participants and two independent raters for both legibility and neatness on a scale of one to 100. In that study, ‘neatness’ was not defined and it is assumed individual raters used their own definition of neatness when awarding ratings. Results showed that older adults awarded themselves significantly lower ratings for neatness

than the younger adults. Older adults were also rated significantly lower for neatness by one of the two raters, suggesting that individuals may use their own definitions of 'neatness', a definition which may or may not be explicit to others. Despite lower ratings of handwriting neatness, there were no significant differences between the age groups in terms of overall legibility (Baxter, 2004).

In my own clinical practice, individuals with stroke would often express dissatisfaction with their handwriting 'legibility', yet their writing could still be read and understood. These individuals remained dissatisfied with the appearance of their written text and 'legibility acceptability'. During the course of this study, I became convinced that the handwriting parameters of size, alignment, 'line quality' and spacing; referred to as 'legibility components' in children's handwriting literature (as discussed in chapter 2 of this thesis), probably relate more to adult handwriting *quality*, *aesthetics* or *neatness* than legibility. This view is consistent with findings from three recent Australian studies (published after the data collection phase of my study) (Gozzard et al., 2012; Simpson et al., 2016; van Drempt et al., 2011a). Two of those studies explored the handwriting behaviours of healthy adults, types of handwriting activities performed regularly by adults, and characteristics of writing such as speed, style and legibility (Gozzard et al., 2012; van Drempt et al., 2011a). Both of these studies found that variations in 'handwriting legibility components' (space, size and alignment) did not impact upon overall handwriting legibility in healthy adults (Gozzard et al., 2012; van Drempt et al., 2011a). A third study investigated the feasibility of delivering a handwriting retraining program and using the modified Evaluation Tool of Children's Handwriting – Words (mETCH-W) to measure handwriting legibility, in adult stroke survivors (Simpson et al., 2016). This exploratory pilot study had a very small sample size of seven participants, which is a methodological limitation. Nonetheless, the researchers

concluded that while participants' writing was readable and thus awarded high legibility scores, most participants expressed concern that their handwriting was still untidy or of poor quality since the stroke (Simpson et al., 2016). Simpson et al. (2016) also found that participants' handwriting goals reflected their concerns about handwriting quality; for example, one participant wanted to 'write a neat Christmas card'. Common changes to individuals' handwriting following stroke included larger and/or inconsistent sized letters, alignment problems and 'shaky' rather than 'smooth' straight and curved strokes of letters. These handwriting changes were often perceived by the writer as 'illegible', 'unsatisfactory' or 'childlike', despite the letters remaining well-formed and the handwriting rated 'legible' (readable) by a single blind rater (Simpson et al., 2016). The researchers concluded that:

> [F]eatures of handwriting that may contribute to writing quality such as straightness of lines, consistency of spacing and evenness of letters, are not addressed in the mETCH-W. An additional outcome measure that can evaluate handwriting neatness or quality is recommended for future studies. (Simpson et al., 2016, p. 681)

These studies, combined with results from my own study, confirmed my view that a new, more comprehensive handwriting instrument is needed for use with adult stroke survivors. The instrument needs to measure change in adult handwriting appearance / aesthetics / neatness, in addition to legibility, pen control and speed, and inform handwriting rehabilitation goals. Neatness may not be related to overall legibility, when legibility is defined as readability, yet the assessment of neatness, especially self-appraised neatness, may represent an important factor to measure in order to capture important changes in handwriting over time. I developed, but have not yet pilot tested nor validated, the 'Handwriting Appearance and Satisfaction Index' (HASI) for use with individuals who wish to improve

their handwriting following stroke (see Appendix 3). The HASI aims to measure two distinct handwriting constructs, (a) self-rated *quality* of aspects of handwriting appearance (such a letter size, letter alignment, error corrections and so on) and (b) self-reported *satisfaction* with each aspect of handwriting following stroke. Discussions with paediatric occupational therapists regarding the limitations of paediatric handwriting assessments led me to believe that a modified version of the HASI may also be useful for paediatric therapists assessing handwriting in children who identify, or are identified by others, as having 'poor, messy or unsatisfactory' handwriting (see Appendix 4).

Therefore, future studies are needed to pilot and assess the measurement properties of the HASI, a new instrument for measuring handwriting quality and satisfaction following stroke. A modified instrument for use with a variety of populations, not just adults who have had a stroke, could also be investigated through future research.

Future research might also use the HASI to investigate if increasing age is associated with deterioration in line quality and other aesthetic aspects of handwriting. As downward pen pressure (Engel-Yeger et al., 2012) and letter size consistency (Yoon et al., 2013) have been shown to reduce with increasing age it is reasonable to assume that while handwriting remains functional in terms of legibility, as individual's age, the aesthetic appearance of handwriting may deteriorate. However, research is required to support this assumption.

Conclusions

Improving handwriting is an important goal for many stroke survivors. However, limitations in current knowledge about healthy older adults' performance on handwriting tasks has, until now, limited assessment and rehabilitation in this area. This thesis addresses that lack of knowledge by providing information about healthy older adults' performance on several commonly-used handwriting assessments. Published research contained in this thesis provides new knowledge that informs handwriting assessment and rehabilitation for stroke survivors. Future researchers can build on this foundational work, particularly the inter rater reliability of handwriting legibility assessments, the validation of more nuanced scoring methods for the 'lines' and 'dots' tasks of the MAS and the development of an instrument to measure handwriting appearance and satisfaction.

REFERENCES

Aamodt, G., Kjendahl, A., & Jahnsen, R. (2006). Dimensionality and scalability of the Motor Assessment Scale (MAS). *Disability and Rehabilitation, 28*, 1007-1013. doi:10.1080/09638280500476188

Adak, C., Chaudhuri, B.B., & Blumenstein, M. (2017). Legibility and aesthetic analysis of handwriting. *2017 14th IAPR International Conference on Document Analysis and Recognition (ICDAR), 01*, 175-182.

Alston, J. (1983). A Legibility Index: can handwriting be measured? *Educational Review, 35*, 237-242. doi:10.1080/0013191830350305

American Foundation for the Blind. (2010). Glossary of eye conditions. Retrieved from http://www.afb.org/info/living-with-vision-loss

Amundson, S. J. (1995). *Evaluation of children's handwriting: ETCH Examiner's Manual*. Homer, AK: OT Kids.

Amundson, S. J. (2005). Prewriting and handwriting skills. In J. Case-Smith (Ed.), *Occupational therapy for children* (5th ed., pp. 587-614). St Louis, MO: Elsevier/Mosby.

Askim, T., Mørkved, S., Engen, A., Roos, K., Aas, T., & Indredavik, B. (2010). Effects of a community-based intensive motor training program combined with early supported discharge after treatment in a comprehensive stroke unit: a randomized, controlled trial. *Stroke, 41*, 1697-1703. doi:10.1161/STROKEAHA.110.584284

Au, E. H., McCluskey, A., & Lannin, N. A. (2012). Inter-rater reliability of three adult handwriting legibility instruments. *Australian Occupational Therapy Journal, 59*, 347-354. doi:10.1111/j.1440-1630.2012.01035.x

Bailey, C. A. (1988). Handwriting: Ergonomics, assessment and instruction. *British Journal of Special Education, 15*, 65-71. doi:10.1111/j.1467-8578.1988.tb00318.x

Barnett, A. L., Henderson, S. E., Scheib, B., & Schulz, J. (2010). *Detailed assessment of speed of handwriting for 17-25 (DASH 17+)*. London: Peason Assessment.

Barnett, A. L., Henderson, S. E., Scheib, B., & Schulz, J. (2011). Handwriting Difficulties and Their Assessment in Young Adults with DCD: Extension of the DASH for 17-to 25-Year-Olds. *Journal of Adult Development, 18*, 114-121. doi:10.1007/s10804-011-9121-3

Baxter, S. (2004). Perceptions of handwriting deterioration in older adults *PSIGE Newsletter* (Vol. 87).

Beech, J. R., & Mayall, K. A. (2005). The word shape hypothesis re-examined: Evidence for an external feature advantage in word recognition. *Journal of Research in Reading, 28*, 302-319. doi:10.1111/j.1467-9817.2005.00271.x

Berchmans, D., & Kumar, S. S. (2014). *Optical character recognition: An overview and an insight*. Paper presented at the International Conference on Control, Instrumentation, Communication and Computational Technologies (ICCICCT), Kanyakumari, India.

Berninger, V. W. (2012). *Evidence-based developmentally appropriate writing skills K to 5: Teaching the orthographic loop of working memory to write letters so developing writers can spell words, and express ideas*. Paper presented at the Handwriting in the 21st Century?: An Educational Summit, Washington, D.C., Newseum, Washington, D.C.

Berwick, D. M., & Winickoff, D. E. (1996). The truth about doctor's handwriting: A prospective study. *British Medical Journal, 313*, 1657-1658.

Bland, J. M., & Altman, D. G. (1996). Measurement error. *BMJ, 313:744*.

Blote, A., & Hamstr-Bletz, L. (1991). A longitudinal study on the structure of handwriting. *Perceptual and Motor Skills, 72*, 983-994.

Bonney, M.-A. (1992). Understanding and assessing handwriting difficulty: Perspectives from the literature. *Australian Occupational Therapy Journal, 39*, 7-15. doi:10.1111/j.1440-1630.1992.tb01751.x

Brasse, B. (1991). *The influence of global word contour during visual recognition: a comparison between machine print and script*. Netherlands: Nijmegen University.

Brossard-Racine, M., Mazer, B., Julien, M., & Majnemer, A. (2012). Validating the use of the Evaluation Tool of Children's Handwriting-manuscript to identify handwriting difficulties and detect change in school-age children. *American Journal of Occupational Therapy, 66*, 414-421. doi:10.5014/ajot.2012.003558

Burger, D. K., & McCluskey, A. (2011). Australian norms for handwriting speed in healthy adults aged 60-99 years. *Australian Occupational Therapy Journal, 58*, 355-363. doi:10.1111/j.1440-1630.2011.00955.x

Carlson, K., & Cunningham, J. (1990). Effect of pencil diameter on the graphomotor skills of preschoolers. *Early childhood Ressearch Quarterly, 5*, 279-293.

Carr, J. H., & Shepherd, R. B. (2003). *Stroke rehabilitation: Guidelines for exercise and training to optimize motor skill*. London: Butterworth-Heinemann.

Carr, J. H., Shepherd, R. B., Nordholm, L., & Lynne, D. (1985). Investigation of a new motor assessment scale for stroke patients. *Physical Therapy, 65*, 175-180.

Case-Smith, J., Holland, T., Lane, A., & White, S. (2012). Effect of a co-teaching handwriting program for first graders: One-group pretest–posttest design. *American Journal of Occupational Therapy, 66*, 396-405. doi:10.5014/ajot.2012.004333

Chapparo, C., & Ranka, J. (2005). *The percieve recall plan and perform system of task analysis intervention course*. Lidcombe, NSW: OP Network.

Chu, S. (1997). Occupational Therapy for Children with Handwriting Difficulties: A Framework for Evaluation and Treatment. *British Journal of Occupational Therapy, 60*, 514-520. doi:10.1177/030802269706001202

Contreras-Vidal, J. L., Teulings, H., & Stelmach, G. (1998). Elderly subjects are impaired in spatial coordination in fine motor control. *Acta Psychologica, 100*, 25-35. doi:10.1016/S0001-6918(98)00023-7

Cornhill, H., & Case-Smith, J. (1996). Factors that relate to good and poor handwriting. *American Journal of Occupational Therapy, 50*, 732-739. doi:10.5014/ajot.50.9.732

Daniel, M. E., & Froude, E. H. (1998). Reliability of occupational therapist and teacher evaluations of the handwriting quality of grade 5 and 6 primary school children. *Australian Occupational Therapy Journal, 45*, 48-58.

Dean, C., & Mackey, F. (1992). Motor assessment scale scores as a measure of rehabilitation outcome following stroke. *Australian Physiotherapy, 38*, 31-35.

Dennis, J. L., & Swinth, Y. (2001). Pencil grasp and children's handwriting legibility during different-length writing tasks. *American Journal of Occupational Therapy, 55*, 175-183. doi:10.5014/ajot.55.2.175

Denton, P. L., Cope, S., & Moser, C. (2006). The effects of sensorimotor-based intervention versus therapeutic practice on improving handwriting performance in 6- to 11-year-old children. *American Journal of Occupational Therapy, 60*, 16-27. doi:10.5014/ajot.60.1.16

Department of Education Queensland. (1984). *The teaching of handwriting: a handbook*. Brisbane: Queensland Government.

Dettrick-Janes, M., McCluskey, A., Lannin, N., & Scanlan, J. (2015). Handwriting legibility in healthy older adults. *Physical & Occupational Therapy In Geriatrics, 33*. doi:10.3109/02703181.2015.1037978

Duff, S., & Goyen, T.-A. (2010). Reliability and validity of the Evaluation Tool of Children's Handwriting-Cursvie (ETCH-C) using the general scoring criteria. *The American Journal of Occupational Therapy, 64*, 37-46.

Engel-Yeger, B., Hus, S., & Rosenblum, S. (2012). Age effects on sensory-processing abilities and their impact on handwriting. *Canadian Journal of Occupational Therapy, 79*, 264-274. doi:10.2182/cjot.2012.79.5.2

Exner, C. E. (1996). Development of hand skills. In J. C. Case-Smith, A.S.Allen, & P. N. Pratt (Eds.), *Occupational therapy for children* (3rd ed., pp. 269-306). St Louis, MO: Mosby.

Faddy, K., McCluskey, A., & Lannin, N. A. (2008). Interrater reliability of a new handwriting assessment battery for adults. *American Journal of Occupational Therapy, 62*, 595-599. doi:10.5014/ajot.62.5.595

Feder, K. P., & Majnemer, A. (2003). Children's handwriting evaluation tools and their psychometric properties. *Physical & Occupational Therapy In Pediatrics, 23*, 65-84. doi:10.1080/J006v23n03_05

Feder, K. P., & Majnemer, A. (2007). Handwriting development, competency, and intervention. *Developmental Medicine and Child Neurology, 49*, 312-317. doi:10.1111/j.1469-8749.2007.00312.x

Federmeier, K. D., & Kutas, M. (1999). A rose by any other name: Long-term memory structure and sentence processing. *Journal of Memory and Language, 41*, 469-495. doi:10.1006/jmla.1999.2660

Ferrier, J., Horne, J., & Singleton, C. (2013). Factors affecting the speed of free writing. *Journal of Research in Special Educational Needs, 13*, 66-78.

Firth, U. (1985). Beneath the surface of developmental dyslexia. In K. Patterson, J. C. Marshall, & M. Coltheart (Eds.), *Surface dyslexia: Neuropsychological and cognitive studies of phonological reading* (pp. 301-330). Hillsdale, NJ: Lawrence Erlbaum.

Fleiss, J. L. (1986). *The Design and Analysis of Clinical Experiments*. New York: John Wiley & Sons.

Ghali, B., Thalanki Anantha, N., Chan, J., & Chau, T. (2013). Variability of grip kinetics during adult signature writing. *PLOS ONE, 8*, e63216. doi:10.1371/journal.pone.0063216

Government of South Australia. (2007). *Handwriting in the South Australian Curriculum*. Adelaide: The State of South Australia.

Gozzard, M., McCluskey, A., Lannin, N., & van Drempt, N. (2012). Handwriting in healthy adults aged 20 to 24 years: Informing handwriting rehabilitation. *International Journal of Therapy and Rehabilitation, 19*, 31-41.

Graham, S. (1986). A review of handwriting scales and factors that contribute to variability in handwriting scores. *Journal of School Psychology, 24*, 63-72.

Graham, S., Berninger, V., Weintraub, N., & Schafer, W. (1998). Development of handwriting speed and legibility in grades 1-9. *The Journal of Educational Research, 92*, 42-52. doi:10.1080/00220679809597574

Graham, S., Boyer-Shick, K., & Tippets, E. (1989). The validity of the handwriting scale from the Test of Written Language. *The Journal of Educational Research, 82*, 166-171. doi:10.1080/00220671.1989.10885886

Graham, S., Struck, M., Santoro, J., & Berninger, V. W. (2006). Dimensions of good and poor handwriting legibility in first and second graders: Motor programs, visual–spatial arrangement, and letter formation parameter setting. *Developmental Neuropsychology, 29*, 43-60. doi:10.1207/s15326942dn2901_4

Graham, S., & Weintraub, N. (1980). Handwriting research and practice: A unified approach. *Focus on Exceptional Children, 13*, 1-16.

Graham, S., & Weintraub, N. (1996). A review of handwriting research: Progress and prospects from 1980 to 1994. *Educational Psychology Review, 8*, 7-87. doi:10.1007/bf01761831

Graham, S., Weintraub, N., & Berninger, V. W. (1998). The relationship between handwriting style and speed and legibility. *The Journal of Educational Research, 91*, 290-297. doi:10.1080/00220679809597556

Hackel, M. E., Wolfe, G. A., Bang, S. M., & Canfield, J. S. (1992). Changes in hand function in the aging adult as determined by the Jebsen test of hand function *Physical Therapy, 72*, 373-377. doi:10.1093/ptj/72.5.373

Hadavandkhani, F., Bahrami, H., Behnia, F., Farahbod, M., & Salehi, M. (2008). Handwriting Difficulties: Introducing an Instrument. *Iranian Rehabilitation Journal, 6*, 39-46.

Hammerschmidt, S. L., & Sudsawad, P. (2004). Teachers' survey on problems with handwriting: Referral, evaluation, and outcomes. *American Journal of Occupational Therapy, 58*, 185-192. doi:10.5014/ajot.58.2.185

Hayward, K. S., Barker, R., N., Brauer, S. G., Lloyd, D., Horsley, S. A., & Carson, R. G. (2013). SMART arm with outcome-triggered electrical stimulation: A pilot randomized clinical trial *Topics in Stroke Rehabilitation, 20*, 289-298. doi:10.1310/tsr2004-289

Hennessy, D. L. (1997). Touch-ups in authentic writing. *Journal of Forensic Document Examination, 10*, 53-57.

Hooper, S. R., & Montgomery, J. W. (1993). Prevalence of writing problems across three middle school samples. *School Psychology Review, 22*, 610.

Hoskyn, M., & Lee Swanson, H. (2003). The relationship between working memory and writing in younger and older adults. *Reading and Writing: An Interdisciplinary Journal, 16*, 759-784.

Hoy, M. M. P., Egan, M. Y., & Feder, K. P. (2011). A systematic review of interventions to improve handwriting. *Canadian Journal of Occupational Therapy, 78*, 13-25. doi:10.2182/cjot.2011.78.1.3

Hsueh, I.-P., & Hsieh, C.-L. (2002). Responsiveness of two upper extremity function instruments for stroke inpatients recieving rehabilitation. *Clinical Rehabiliation, 16*, 617-624.

IBM Corp. Released 2011, IBM SPSS Statistics for Windows, Version 20.0. Armonk, NY: IBM Corp.

Jaffe, L. (1987). *Influence of grip on legibility, speed, and fatigue in adult handwriting*. Unpublished manuscript. Boston University.

Jebsen, R. H., Taylor, N., Trieschman, R. B., Trotter, M. J., & Howard, L. A. (1969). An objective and standardised test of hand function. *Archives of Physical Medicine and Rehabilitation, 50*, 311-319.

Jones, D., & Christensen, C. A. (1999). Relationship between automaticity in handwriting and students' ability to generate written text. *Journal of Educational Psychology, 91*, 44-49. doi:10.1037/0022-0663.91.1.44

Kendeou, P., Muis, K. R., & Fulton, S. (2011). Reader and text factors in reading comprehension processes. *Journal of Research in Reading, 34*, 365-383. doi:10.1111/j.1467-9817.2010.01436.x

Khan, A., Chien, C.-W., & Brauer, S. G. (2013). Rasch-based scoring offered more precision in differentiating patient groups in measuring upper limb function. *Journal of Clinical Epidemiology, 66*, 681-687. doi:10.1016/j.jclinepi.2012.12.014

Kong, K.-H., Chua, K. S. G., & Lee, J. (2011). Recovery of upper limb dexterity in patients more than 1 year after stroke: Frequency, clinical correlates and predictors. *NeuroRehabilitation, 28*, 105-111. doi:10.3233/Nre-2011-0639

Koziatek, S. M., & Powell, N. J. (2002). A validity study of the Evaluation Tool of Children's Handwriting–Cursive. *American Journal of Occupational Therapy, 56*, 446-453. doi:10.5014/ajot.56.4.446

Kwakkel, G., & Kollen, B. (2007). Predicting improvement in the upper paretic limb after stroke: a longitudinal prospective study. *Restorative Neurology and Neuroscience, 25*, 453-460.

Lamme, L. L., & Ayris, B. M. (1983). Is handwriting of beginning writers influenced by writing tools? *Journal of Research and Development in Education, 17*, 32-38.

Lane-Brown, A., & Tate, R. (2009). Interventions for apathy after traumatic brain injury. *Cochrane Database of Systematic Reviews*. doi:10.1002/14651858.CD006341.pub2

Lannin, N. A. (2004). Reliability, validity and factor structure of the upper limb subscale of the Motor Assessment Scale (UL-MAS) in adults following stroke. *Disability and Rehabilitation, 26*, 109-115. doi:10.1080/0963828032000157970

Larsen, S., & Hammill, D. (1989). *Test of legible handwriting*. Austin, TX: Pro-Ed.

Lavidor, M. (2011). Whole-word shape effect in dyslexia. *Journal of Research in Reading, 34*, 443-454. doi:10.1111/j.1467-9817.2010.01444.x

Lavrenko, V., Rath, T. M., & Manmatha, R. (2004). Holistic word recognition for handwritten historical documents. *Procedings of the First International Workshop on Document Image Analysis for Libraries* (pp. 278-287). Palo Alto: IEEE.

Levine, M. B. (1992). Neurodevelopment variation and dysfunction in school aged children. In M. Levine, W. Carey, & A. Crocker (Eds.), *Developmental-behavioral pediatrics* (2nd ed., pp. 477-490). Philadelphia: W.B. Saunders.

Lohman, J. W. (1993). *Factors influencing handwriting legibility.* (University Honors Program), Southern Illinois University Carbondale. Retrieved from opensiuc.lib.siu.edu/cgi/viewcontent.cgi?article=1030&context=uhp_theses (Paper 22)

Lowe, S. (1999). *The complete idiot's guide to handwriting analysis*. New York: Macmillan.

Mann, C. J. (2003). Observational research methods. Research design II: cohort, cross sectional, and case-control studies. *Emergency Medicine Journal, 20*, 54-60. doi:10.1136/emj.20.1.54

Marr, D., Windsor, M.-M., & Cermak, S. (2001). Handwriting readiness: Locatives and visuomotor skills in the kindergarten year. *Early Childhood Research & Practice: An Internet Journal on the Development, Care, and Education of Young Children, 3*, n/a.

McCluskey, A., & Lannin, N. (2003). *Handwriting Assessment Battery for Adults.* Unpublished manuscript. School of Exercise and Health Sciences, University of Western Sydney.

McMahon, R. (2008). *Examining handwriting and communication technology use by Australian adults aged between 18 and 54 years.* (Unpublished thesis, Bachelor of Applied Science (Occupational Therapy) with honours), The University of Sydney, Sydney, Australia.

Miller, B., Juhasz, B. J., & Rayner, K. (2006). The orthographic uniqueness point and eye movements during reading. *British Journal of Psychology, 97*, 191-216. doi:10.1348/000712605X66845

Miller, K. J., Slade, A. L., Pallant, J. F., & Galea, M. P. (2010). Evaluation of the psychometric properties of the upper limb subscales of the Motor Assessment Scale using a Rasch analysis model. *Journal of Rehabilitation Medicine, 42*, 315-322. doi:10.2340/16501977-0519

Morris, K. J. (2014). *Does paper presentation affect grading: Examining the possible educational repercussions of the quality of student penmanship.* (BS(Hons)), Salem State University. Available from https://digitalcommons.salemstate.edu/honors_theses/30.

Morton, J. (1964). The effects of context on the visual duration threshold for words. *British Journal of Psychology, 55*, 165-180. doi:10.1111/j.2044-8295.1964.tb02716.x

Murray, S., Boylan, G., O'Flynn, S., O'Tuathalgh, C., & Doran, K. (2012). Can you read this? Legibiity and hospital records: a multi-stakeholder analysis. *Clinical Risk, 18*, 95-98.

National Institute of Neurological Disorders and Stroke. (2011). NINDS dysgraphia information page. Retrieved from https://www.ninds.nih.gov/

Oehler, E., DeKrey, H., Eadry, E., Fogo, J., Lewis, E., Maher, C., & Schilling, A. (2000). The effect of pencil size and shape on the pre-writing skills of kindergartners. *Physical and Occupational Therapy in Pediatrics, 19*, 53-60.

Olaleye, O. A., Hamzat, T. K., & Owolabi, M. O. (2014). Stroke rehabilitation: should physiotherapy intervention be provided at a primary health care centre or the patients' place of domicile? *Disability and Rehabilitation, 36*, 49-54. doi:10.3109/09638288.2013.777804

Peat, J. K., Williams, K., Xuan, W., & Mellis, C. M. (2001). Chapter 4: Calculating the sample size. *Health Science Research: A handbook of quantitative methods.* (pp. 128-147). Sydney: Allen and Unwin.

Peverly, S. T. (2006). The importance of handwriting speed in adult writing. *Developmental Neuropsychology, 29*, 197-216. doi:10.1207/s15326942dn2901_10

Peverly, S. T., Vekaria, P. C., Reddington, L. A., Sumowski, J. F., Johnson, K. R., & Ramsay, C. M. (2013). The relationship of handwriting speed, working memory,

language comprehension and outlines to lecture note-taking and test-taking among college students. *Applied Cognitive Psychology, 27*, 115-126. doi:10.1002/acp.2881

Phelps, J., & Stempel, L. (1988). The Children's Handwriting Evaluation Scale for manuscript writing. *Reading Improvement, 25*, 247-254.

Pickering, R. L., Hubbard, I. J., Baker, K. G., & Parsons, M. W. (2010). Assessment of the upper limb in acute stroke: The validity of hierarchal scoring for the Motor Assessment Scale. *Australian Occupational Therapy Journal, 57*, 174-182. doi:10.1111/j.1440-1630.2009.00810.x

Plamondon, R., & Srihari, S. N. (2000). Online and off-line handwriting recognition: a comprehensive survey. *IEEE Transactions on pattern analysis and machine intelligence, 22*, 63-84. doi:10.1109/34.824821

Poole, J. L., & Whitney, S. L. (1988). Motor assessment scale for stroke patients: Concurrent validity and interrater reliability. *Arhives of Physical Medicine and Rehabilitation, 69*, 195-197.

Portney, L., & Watkins, M. (2009). *Foundations of clinical research: Applications to practice* (3rd ed.). Upper Saddle River, NJ: Pearson Prentice Hall.

Powalka, R. K., Sherkat, N., & Whitrow, R. J. (1994). The use of word shape information for cursive script recognition *Procedings of the Fourth International Workshop on Frontiers of Handwriting Recognition* (pp. 67-76): Available from https://pdfs.semanticscholar.org/0f16/a160fb6cb8d72dfe9f06b0d073b648c18197.pdf.

Rapcsak, S. Z. (1997). Disorders of writing. In L.J.G. Rothi & K. M. Heilman (Eds.), *Apraxia: The neuropsychology of action* (pp. 149-172). Hove, UK: Psychology Press.

Reisman, J. E. (1993). Development and reliability of the research version of the Minnesota Handwriting Test. *Physical and Occupational Therapy in Pediatrics, 13*, 41-55.

Reisman, J. E. (1999). *Minnesota Handwriting Assessment*: San Antonio, TX: The Psychological Corporation.

Rodríguez-Vera, F. J., Marín, Y., Sánchez, A., Borrachero, C., & Pujol, E. (2002). Illegible handwriting in medical records. *Journal of the Royal Society of Medicine, 95*, 545-546.

Rosenblum, S., Goldstand, S., & Parush, S. (2006). Relationships among biomechanical ergonomic factors, handwriting product quality, handwriting efficiency, and computerized handwriting process measures in children with and without handwriting difficulties. *American Journal of Occupational Therapy, 60*, 28-39. doi:10.5014/ajot.60.1.28

Rosenblum, S., Weiss, P. L., & Parush, S. (2003). Product and process evaluation of handwriting difficulties. *Educational Psychology Review, 15*, 41-81. doi:10.1023/A:1021371425220

Rosenblum, S., & Werner, P. (2006). Assessing the handwriting process in healthy elderly persons using a computerized system. *Aging: Clinical and Experimental Research, 18*, 433-439. doi:10.1007/BF03324840

Rusu, A., & Govindaraju, V. (2006). *The Influence of Image Complexity on Handwriting Recognition*. Paper presented at the 10th IAPR Internation Workshop on Frontier of Handwriting Recognition, La Baule, Centre de Congres Atlantia, France

Ryan, S. E., Rigby, P. J., & Campbell, K. A. (2010). Randomised controlled trial comparing two school furniture configurations in the printing performance of young children with cerebral palsy. *Australian Occupational Therapy Journal, 57*, 239-245. doi:10.1111/j.1440-1630.2009.00831.x

Sabari, J. S., Lim, A. L., Velozo, C. A., Lehman, L., Kieran, O., & Lai, J.-S. (2005). Assessing arm and hand function after stroke: A validity test of the hierarchical

scoring system used in the motor assessment scale for stroke. *Archives of Physical Medicine and Rehabilitation, 86*, 1609-1615. doi:10.1016/j.apmr.2004.12.028

Schneider, K. A., Murray, C. W., Shadduck, R. D., & Meyers, D. G. (2006). Legibility of doctors' handwriting is as good (or bad) as everyone else's. *Quality and Safety in Health Care, 15*, 445-445. doi:10.1136/qshc.2006.018911

Schomaker, L., & Segers, E. (1999). Finding features used in the human reading of cursive handwriting. *International Journal on Document Analysis and Recognition, 2*, 13-18. doi:10.1007/s100320050031

Schwellnus, H., Carnahan, H., Kushki, A., Polatajko, H., Missiuna, C., & Chau, T. (2012). Effect of Pencil Grasp on the Speed and Legibility of Handwriting in Children. *American Journal of Occupational Therapy, 66*, 718-726. doi:10.5014/ajot.2012.004515

Shah, L. J., & Gladson, B. L. (2015). The relationship of pencil grasp on college students' handwriting speed and legibility. *Journal of Occupational Therapy, Schools, & Early Intervention, 8*, 180-191. doi:10.1080/19411243.2015.1040673

Simpson, B., McCluskey, A., Lannin, N., & Cordier, R. (2016). Feasibility of a home-based program to improve handwriting after stroke: a pilot study. *Disability and Rehabiliation, 38*, 673-682. doi:10.3109/09638288.2015.1059495

Stott, D. H., Moyes, F. A., & Henderson, S. E. (1985). *Diagnosis and remediation of handwriting problemsAssociates.* Fairwater, Cardiff, Wales: DRAKE Educational

Stroke Foundation. (2017). Clinical guidelines for stroke management 2017. Retrieved from https://informme.org.au/Guidelines/Clinical-Guidelines-for-Stroke-Management-2017

Sudsawad, P., Trombly, C. A., Henderson, A., & Tickle-Degnen, L. (2001). The relationship between the Evaluation Tool of Children's Handwriting and teachers' perceptions of

handwriting legibility. *American Journal of Occupational Therapy, 55*, 518-523. doi:10.5014/ajot.55.5.518

Summers, J., & Catarro, F. (2003). Assessment of handwriting speed and factors influencing written output of university students in examinations. *Australian Occupational Therapy Journal, 50*, 148-157. doi:10.1046/j.1440-1630.2003.00310.x

Sweedler-Brown, C. O. (1992). The effect of training on the appearance bias of holistic essay graders. *Journal of Research and Development in Education, 26*, 24-29.

The Macquarie Dictionary. (Ed.) (2004) Macquarie Concise Dictionary (Revised Third ed.). The Macquarie Library Pty Ltd.

Treiman, R., Gordon, J., Boada, R., Peterson, R. L., & Pennington, B. F. (2014). Statistical learning, letter reversals, and reading. *Scientific Studies of Reading, 18*, 383-394. doi:10.1080/10888438.2013.873937

Tseng, M. H. (1998). Development of pencil grip position in preschool children. *Occupational Therapy Journal of Research, 18*, 207–224. doi:10.1177/153944929801800406

Tseng, M. H., & Cermak, S. A. (1993). The Influence of Ergonomic Factors and Perceptual–Motor Abilities on Handwriting Performance. *American Journal of Occupational Therapy, 47*, 919-926. doi:10.5014/ajot.47.10.919

Tucha, O., Mecklinger, L., Walitza, S., & Lange, K. W. (2006). Attention and movement execution during handwriting. *Human Movement Science, 25*, 536-552. doi:https://doi.org/10.1016/j.humov.2006.06.002

Turner, O. G. (1930). The Comparative Legibility and Speed of Manuscript and Cursive Handwriting. *The Elementary School Journal, 30*, 780-786. doi:10.1086/456502

van Drempt, N. (2010). *Handwriting in healthy people ages 65 years and older.* (MAppSc Thesis), The University of Sydney, Sydney. Retrieved from

https://ses.library.usyd.edu.au/bitstream/2123/6623/1/NA_van_Drempt_2010_Thesis.pdf

van Drempt, N., McCluskey, A., & Lannin, N. A. (2011a). Handwriting in healthy people aged 65 years and over. *Australian Occupational Therapy Journal, 58*, 276-286. doi:10.1111/j.1440-1630.2011.00923.x

van Drempt, N., McCluskey, A., & Lannin, N. A. (2011b). A review of factors that influence adult handwriting performance. *Australian Occupational Therapy Journal, 58*, 321-328. doi:10.1111/j.1440-1630.2011.00960.x

Viera, A. J., & Garrett, J. M. (2005). Understanding interobserver agreement: The kappa statistic. *Family Medicine, 37*, 360-363.

Wallen, M., Duff, S., Goyen, T. A., & Froude, E. (2013). Respecting the evidence: Responsible assessment and effective intervention for children with handwriting difficulties. *Australian Occupational Therapy Journal, 60*, 366–369. doi:10.1111/1440-1630.12045

Watson, G. R., Wright, V., Wyse, E., & De l'Aune, W. (2004). A Writing Assessment for Persons with Age-related Vision Loss. *Journal of Visual Impairment & Blindness, 98*, 160-167.

Weintraub, N., Drory-Asayag, A., Dekel, R., Jokobovits, H., & Parush, S. (2007). Developmental trends in handwriting performance among middle school children. *OTJR: Occupation, Participation and Health, 27*, 104-112. doi:10.1177/153944920702700304

Williams, B. K., Galea, M. P., & Winter, A. T. (2001). What is the functional outcome for the upper limb after stroke? *Australian Journal of Physiotherapy, 47*, 19-27.

Yancosek, K. E., & Calderhead, W. J. (2012). Efficacy of handwriting for heroes, a novel hand dominance transfer intervention. *Hand Therapy, 17*, 15-24.

Yancosek, K. E., & Howell, D. (2011). Systematic review of interventions to improve or augment handwriting ability in adult clients. *OTJR: Occupation, Participation and Health, 31*, 55-63. doi:10.3928/15394492-20100722-03

Yoon, J. H., Kim, H. H., Kim, J. W., Park, E., & Kim, S. R. (2013). Size variability of handwriting in healthy Korean older adults. *Geriatrics and Gerontology International, 14*, 458-463. doi:10.1111/ggi.12106

Zesiger, P., Mounoud, P., & Hauert, C.-A. (1993). Effects of lexicality and trigram frequency on handwriting production in children and adults. *Acta Psychologica, 82*, 353-365. doi:10.1016/0001-6918(93)90020-R

Ziviani, J., & Elkins, J. (1984). An evaluation of handwriting performance. *Educational Review, 36*, 249-261. doi:10.1080/0013191840360304

Ziviani, J., & Elkins, J. (1986). Effects of pencil grip on handwriting speed and legibility. *Educational Review, 38*, 247-257. doi:10.1080/0013191860380305

Ziviani, J., & Watson-Will, A. (1998). Writing speed and legibility of 7–14-year-old school students using modern cursive script. *Australian Occupational Therapy Journal, 45*, 59-64. doi:10.1111/j.1440-1630.1998.tb00783.x

APPENDIX 1: ETHICS APPROVALS, PARTICIPANT INFORMATION STATEMENT AND CONSENT FORMS

2009/12407 (P)

ETHICS OFFICE
14 JUL 2010
DATE RECEIVED

Address for correspondence:
OFFICE OF ETHICS ADMINISTRATION
LEVEL 6
JANE FOSS RUSSELL BUILDING – G02
THE UNIVERSITY OF SYDNEY NSW 2006

APPROVED
16/7/10

THE UNIVERSITY OF SYDNEY

HUMAN RESEARCH ETHICS COMMITTEE
REQUEST FOR MODIFICATION

Note: please refer to section 3.3.4 of application which includes an undertaking to forward letter of permission from any organisation where testing is to be conducted

1. **Principal Investigator:** Dr Annie McCluskey
   Department: Postdoctoral Research Fellow, Faculty of Health Sciences, The University of Sydney
   Address: PO Box 170, Lidcombe, NSW 1825
2. **Project Title:** An investigation of normative handwriting performance in healthy older adults.
3. **HREC Approval No.:** 12-2009/12407
4. **Names of Students/Co-Investigators:** Dr Annie McCluskey, Miss Donne Kelly Burger
5. **Project Description:**
   Please provide a one paragraph lay summary of your original project

Handwriting is an important occupation for adults. Activities such as signing your name, writing notes and preparing a shopping list are common. For functional handwriting, legibility and speed are required. The aim of this descriptive cohort study is to obtain normative data on handwriting performance in healthy older adults aged 60 years and older. Primary data collection methods include completion of three handwriting assessments, a self-report survey and videotaping of a handwriting task. A sample of up to 120 healthy older adults will be recruited using convenience and snowball sampling, and via local seniors groups. Descriptive statistics, correlations and logistic regression will be used for analysis. Study findings will help to inform clinicians who measure and retrain handwriting following stroke.

6. **Any previously approved minor amendments?** ☐ Yes ☒ No
   If YES, please briefly outline

7. **Nature of and reasons for amendment(s)**
   Please provide details of the changes you propose to make to the project and explain why they are necessary. Please justify any increase in sample size.

1. Add Masters Student as researcher
2. Add 2nd supervisor as associate supervisor
3. Increase sample size to 150 (increase by 30 people) to accommodate further analysis of data for Masters project
4. Extend data collection to all states and territories within Australia, to allow increased data collection for Masters project.

8. **Adding New Staff Member / Student / Research Assistant** ☒ Yes ☐ No
If YES, provide the following *(If more than one, please copy this page)*

Name	Michelle Dettrick-Janes
Title: (e.g: Mr, Ms, Dr, Associate Professor)	Ms.
Faculty/Department/School/Centre/Institution	Clinical and Rehabilitation Research Group, The University of Sydney
Address	2/5 Bardsley Gardens, North Sydney, 2060
Telephone Number	9955 0523
Facsimile Number	
Email Address	Mdet5563@usyd.edu.au
Position (ie lecturer, PhD student)	Masters Student
Qualifications (if PhD indicate field of study)	B. App. Sc. (Occ Therapy)
Role in the project	Master of Applied Science Student, Researcher
Has the new staff member received a copy of the approved application?	☒ Yes ☐ No
Signature of new staff member	Signature **Michelle Dettrick-Janes** Print Name **4/ 7 / 2010** Date

8. **Adding New Staff Member / Student / Research Assistant** ☒ Yes ☐ No
If YES, provide the following *(If more than one, please copy this page)* – 2nd Staff Member

Name	Natasha Lannin
Title: (e.g: Mr, Ms, Dr, Associate Professor)	Dr
Faculty/Department/School/Centre/Institution	Rehabilitation Studies Unit, Sydney Medical School, The University of Sydney
Address	PO Box 6, Ryde NSW 1680
Telephone Number	02 9808 9236
Facsimile Number	02 9809 9037
Email Address	natasha.lannin@sydney.edu.au
Position (ie lecturer, PhD student)	Lecturer
Qualifications (if PhD indicate field of study)	PhD
Role in the project	Associate research supervisor
Has the new staff member received a copy of the approved application?	☒ Yes ☐ No
Signature of new staff member	Signature **Dr Natasha Lannin** Print Name 11 / 7 / 2010

Modification Form

	Date

9. **Removing Staff Member / Student / Research Assistant** ☐ Yes ☒ No
If YES, provide the following *(If more than one, please copy this page)*

Name	
Faculty/Department/School/Centre/Institution	
Position (ie lecturer, PhD student)	
Role in the project	
Date of Departure	_____ / _____ / _____

10. **Possible inconveniences or risks to subjects:** ☐ Yes ☒ No
If Yes, please outline any inconvenience or possible risks that the changes you propose may create for participants (eg changes to confidentiality provisions, physical or psychological risks, increased time commitments etc).

11. **Actions to be taken by researchers to reduce risks:** ☐ Yes ☒ No
If Yes, please provide details of any additional actions and / or support that you will need to provide to participants as a result of the proposed changes.

12. **Expected date of implementation of amendments to research:**

Date: 1 August 2010

13. **Time Extension** ☐ Yes ☒ No
If Yes, state new finishing date

Date:

14. **Whether funding arrangements for the research been affected by the changes** ☐ Yes ☒ No

15. **Implications for compliance with legislative requirements:** ☐ Yes ☒ No
Please check current legislation and related requirements, if appropriate – including, for example Privacy Act 1998 (please refer to Guidelines under Section 95 of the Privacy Act produced by the NHMRC) and Children and Young Persons Act 1989.

16. **Attach copies of amended surveys, questionnaires or interview questions** ☐ Yes ☒ No

17. **Attach copies of the amended advertisement, participant information statement and consent form.** ☒ Yes ☐ No
Participants need to be advised of changes to procedures, time commitments, etc. You will need to update the participant information statement to reflect the changes

Please find attached patient information sheet and consent form.

18. **Details of other permission or approvals required as a result of your proposed changes**

Not Applicable

19. **Other Amendments**
If you require an additional title to be added to the HREC Database (Grant for application)

Title:

Granting Body:

20. **Declaration of Researchers**

M. A. McCluskey

Signature of Chief Investigator: Date: 05/07/2010

Signature of Student/Co-Investigators: Date: 07/07/2010

Signature of Student/Co-Investigators: Date: 07/07/2010

Signature of Associate Supervisor: Date: 11/07/2010

Signature of Student/Co-Investigators: Date:

Signature of Student/Co-Investigators: Date:

Signature of Head of Faculty/Department/School:

The University of Sydney

Discipline of Occupational Therapy
Faculty of Health Sciences

ABN 15 211 513 464

Annie McCluskey
Postdoctoral Research Fellow

Room J122, J Block
Cumberland Campus
East St Lidcombe
The University of Sydney NSW 1825
AUSTRALIA
Telephone: +61 2 9351 9834
Email: annie.mccluskey@sydney.edu.au

PARTICIPANT INFORMATION STATEMENT

Project Title: An investigation of normative handwriting performance in healthy older adults.

1) What is the study about?
We are aiming to collect up to 150 handwriting samples from older adults aged 60 years and over, to help understand the range of writing speeds and legibility in this population. Normative data are collected to help us learn about typical writing speeds and legibility. Occupational therapists and others can then use this information during rehabilitation, to make comparisons with people who have slow and illegible handwriting, for example after a stroke.

2) Who is carrying out the study?
The study is being conducted by Donné Burger (occupational therapy honours student), Michelle Dettrick-Janes (Master of Applied Science student), Dr Annie McCluskey and Dr Natasha Lannin.

3) Why have you been approached to participate in the study?
You are eligible to participate because you are aged 60 years or older, have indicated interest in participating, you can read and write in English, and have no pain or other symptoms which stop you from writing.

4) What does the study involve?
If you choose to participate, you will be asked to complete some writing tests at your home, at a local club or hall or at the Lidcombe campus of the University of Sydney. You may choose the location. The study will be explained to you, and a signed consent form completed. During this **30 minute** session you will be asked to complete:

- A handwriting survey which will tell us about your age, level of education and usual handwriting activities. Your writing hand, but not your face, will be videotaped during this activity.
- Three short handwriting tests which examine pen control, writing speed and legibility. During these tests, you are asked to write the alphabet and copy some sentences.
- A written telephone message, which you will be asked to write while listening to the message.

5) What are the benefits and risks of participating in the study?
There are no known risks associated with this study. Participation will not directly benefit you. It will, however, provide valuable information for clinicians who measure and retrain adult handwriting. You can receive a 1-page written summary of the study results if you wish when the research is finished.

6) Can I withdraw from the study?
Yes, you can withdraw at any time, even after your writing samples have been obtained. Participation is voluntary, and you are not obliged to participate. If you do choose to take part, you may withdraw at any time without prejudice or penalty. Any data collected will be destroyed if you wish. Whatever your decision, it will not affect your relationship with the University of Sydney or the researchers.

7) Will anyone else know the results?
All data collected during this study, including the results, will remain confidential. Only the research team will have access to information on participants, which will be stored in a locked filing cabinet by the Chief investigator. Additional copies of data will be saved to a computer memory stick and will only contain de-identified data to maintain anonymity and confidentiality. Video footage and writing samples may be presented at future conferences or included in published reports of the study; however, individual participants will not be identified. All data collected will be stored for 7 years at the University of Sydney before being destroyed.

8) Can I tell other people about the study?
Yes, you are welcome to tell other people about the study, and to pass on the researcher's contact details to other people who may be interested in participating.

9) What if I require further information?
If you have any questions, please contact any of the researchers below:

Donné Kelly Burger
Occupational Therapy
Honours Student
The University of Sydney
Ph: 0405176351
Email: dbur3170@uni.sydney.edu.au

Dr Annie McCluskey
Postdoctoral Research Fellow
Faculty of Health Sciences
The University of Sydney
Ph: (02) 9351 9834
Email: annie.mccluskey@sydney.edu.au

Michelle Dettrick-Janes
Master of Applied Science student
The University of Sydney
Ph: 0410327716
Email: mdet5563@usyd.edu.au

Dr Natasha Lannin
Lecturer
Rehabilitation Studies Unit
Sydney Medical School
The University of Sydney
Ph: 9808 9236
Email: natasha.lannin@sydney.edu.au

10. What if I have a complaint or concerns?

Any person with concerns or complaints about the conduct of a research study can contact the Deputy Manager, Human Ethics Administration, University of Sydney on (02) 8627 8176 (Telephone); (02) 8627 8177 (Facsimile) or human.ethics@usyd.edu.au (Email).

The University of Sydney

Discipline of Occupational Therapy
Faculty of Health Sciences

ABN 15 211 513 464

Annie McCluskey
Postdoctoral Research Fellow

Room J122,
J-Block, Location C42
Cumberland Campus
East St Lidcombe
The University of Sydney NSW 1825
AUSTRALIA
Telephone: +61 2 9351 9834
Facsimile: +61 2 9351 9197
Email: annie.mccluskey@sydney.edu.au

PARTICIPANT CONSENT FORM

I.....(please print your name) give my consent to participate in the research project: *An investigation of normative scores on handwriting speed in healthy older adults.*

In giving my consent I acknowledge that:

1. The procedures required for the project, and the time involved (up to 30 minutes), 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 from the study at any time, without affecting my relationship with the researchers or the University of Sydney, now or in the future.

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

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

7. I consent to my writing and hand being videotaped during the assessments:
   YES ☐ NO ☐

Signed: .....
Name: .....
Date: .....

APPENDIX 2: DATA COLLECTION BOOKLET

ID No: Date:

‘An investigation of handwriting performance in healthy older adults’

Data Collection Booklet

Handwriting Survey

Date: ID No:

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

Thank you for your time – Donné Kelly Burger and Dr Annie McCluskey

---

1. What is your gender?
   - ❒ Male
   - ❒ Female

2. What is your age?_____

3. In what language do you most commonly write?

   - ❒ English
   - ❒ Other

If you have ticked 'Other', please give details:

_____

4. What is your highest level of education?

Please choose <u>oneoptiononly</u>

- □ Primary School or below
- □ Year 10 or below
- □ Year 10 Equivalent
- □ Year 12 Equivalent
- □ Year 12 Equivalent but currently studying a degree
- □ Certificate (i.e. TAFE certificate)
- □ Post-graduate degree
- □ Advanced diploma/Diploma
- □ Bachelor Degree
- □ Graduate Diploma/ Certificate
- □ Other Education (please specify):

_____

_____

5 a) Have you retired from paid employment? (If yes answer 5b) and if no go to question 6).

   - ❒ Yes
   - ❒ No

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

_____

_____

(Go to question 7)

6. If in paid employment are you working full or part time?

   - ❒ Full time
   - ❒ Part time

If you ticked 'Part time', how many hours do you work? _____

7. What is your primary occupation now? (include any, paid, unpaid or voluntary work)

_____

_____

8. Which is your writing hand?

   - ❒ Right
   - ❒ Left

_____

9. Do you have any health condition which affects your arms or ability to write (e.g. neurological condition, arthritis, low vision)?
   - ❒ No
   - ❒ Yes

If you have ticked 'Yes', please give details:

_____

_____

10. How often have you completed the following handwriting activities in the past year? Please tick all options that apply

Writing Tasks	Frequency				
	Not at all	Infrequently		Frequently	
		Once or more in the past year	Once or more in the past month	Once or more in the past fortnight	Once or more in the past 3 days
To do list					
Diary/planner (e.g. day to day events, appointments)					
Personal journal (e.g. Thoughts, feelings and reflections etc)					
Telephone messages					
Shopping list					
Notes / ideas / personal reminders					
Cheques / Finances (e.g. bank deposit)					
Puzzles (e.g. Sudoku, crosswords)					
Letters / cards					
Forms (e.g. applications, claims)					
Signature					
Calendar (e.g. on the wall, fridge or other)					
Writing a number/message on your hand					
Whiteboard (e.g. on the wall or fridge)					
Editing documents (e.g. assignments, homework tasks, minutes)					
Other writing task (please specify):					

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

0	5	10
Not at all Important	Somewhat Important	Extremely Important

Please give reasons for your answer:

_____

_____

12. How often have you used the following modes of communication in the past year?
Please tick <u>all</u> options that apply

Modes of Communication		Frequency				
		Not at all	Infrequently		Frequently	
			Once or more in the past year	Once or more in the past month	Once or more in the past fortnight	Once or more in the past 3 days
Telephone	Made a Call					
	Received a Call					
Mobile Phone	Made a Call					
	Received a Call					
SMS text message via mobile phone	Sent a message					
	Received a message					
Email	Sent a message					
	Received a message					
Used a PDA/Palm Pilot or similar device						
Face-to-face communication (e.g. talking)						
Handwritten Communication						
Video conferencing (e.g. web cam)						
Internet (e.g. to pay bills, book tickets, look up factual information)						
Internet Telephoning (eg skype)						
Used other messenger services (e.g. MSN, Yahoo Messenger, Face Book)						
Other mode of Communication: (please specify) _____						

13. Do you have any further comments regarding handwriting?

_____

_____

_____

_____

Thank you for taking time to complete this survey.

Pen Control and Manipulation (Horizontal Lines Task)

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 (pencil)

Pen Control and Manipulation (Horizontal Lines Task)

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 (pencil)

Pen Control and Manipulation (Horizontal Lines Task)

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 (pencil)

Pen Control and Manipulation (Dots Task)

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 (pencil)

Pen Control and Manipulation (Dots Task)

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 (pencil)

Pen Control and Manipulation (Dots Task)

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 (pencil)

Jebsen Speed Test: Copied Sentence

- 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 examiner will turn the card over for you.
- When the therapist says 'go' copy the sentence in cursive writing, not printing.
- You will be timed from the word 'Go' until you have completed the sentence.
- Please write the sentence as quickly and as neatly as possible:

Pencil:

TIME:

Pen:

TIME:

Attempt 2 (Only if required):

Pencil:

TIME:

Pen:

TIME:

Sentence Composition

Think of sentence that you would like to write. Make sure the sentence has only five words.
I will give you a few seconds to think of the sentence and then you can write it down
If you don't know how to spell a word in the sentence, just do the best you can.
You may write in cursive or printed text or a mixture of both-whichever is normal writing for you.

Pencil:

TIME:

Pen:

TIME:

Audio Taped Message

ID No: _____

Date: _____

Aim: To transcribe the key information from the audio taped telephone message, in order to examine legibility during a functional task.

Attached to the telephone receiver is tape recorder. You will hear a brief telephone message only once. As soon as the message starts, write down the key information in the message as you hear it

Pencil:

Shopping List

ID No: _____

Date: _____

Aim: To generate then write 5 single word items that you might write down on a shopping list. You will perform this task twice once in pencil and once in pen using different shopping items for each list. This assessment will examine writing speed and legibility during a functional task.

You will be timed from the word 'Go' until you have completed the shopping list.

Pencil:

Shopping List

ID No: _____

Date: _____

Aim: To generate then write 5 single word items that you might write down on a shopping list. You will perform this task twice once in pencil and once in pen using different shopping items for each list. This assessment will examine writing speed and legibility during a functional task.

You will be timed from the word 'Go' until you have completed the shopping list.

Pen:

APPENDIX 3: HANDWRITING APPEARANCE AND SATISFACTION INDEX

Handwriting Appearance and Satisfaction Index

To be rated by the stroke survivor with assistance from a therapist or carer if required. It is recommended to ***have more than one handwriting sample available to assist you to fill in this index***

1. The overall **appearance** or 'look' of your handwriting

1A. Compared with your pre-stroke handwriting, is the overall appearance of your handwriting now worse?

☐ Not at all, the overall appearance of my handwriting is the same or better

☐ The appearance of my handwriting is a little worse

☐ The appearance of my handwriting is moderately worse

☐ The appearance of my handwriting is a lot worse

1B. How satisfied are you now with the overall appearance or 'look' of your handwriting?

☐	☐	☐	☐	☐	☐
Very satisfied	Moderately satisfied	Somewhat satisfied	Somewhat dissatisfied	Moderately dissatisfied	Very dissatisfied

1C. Do you want to improve the overall look of your handwriting *with advice from a therapist*?

☐ Yes

☐ No

---

2. The **size** of your handwritten **letters**

2A. Compared with your pre-stroke handwriting, is the size of your handwritten letters now worse? For example the letters are too big, too small or a combination of these.

☐ Not at all, the size of my handwritten letters is the same or better

☐ The size of my handwritten letters is a little worse

☐ The size of my handwritten letters is moderately worse

☐ The size of my handwritten letters is a lot worse

2B. How satisfied are you now with the size of your handwritten letters?

☐	☐	☐	☐	☐	☐
Very satisfied	Moderately satisfied	Somewhat satisfied	Somewhat dissatisfied	Moderately dissatisfied	Very dissatisfied

2C. Do you want to improve the size of your handwritten letters *with advice from a therapist*?

☐ Yes

☐ No

3. The **spacing** between your handwritten **letters**

3A. Compared with your pre-stroke handwriting, is the spacing between your handwritten letters now worse? For example the letters are too close together, overlapping, too far apart, or a combination of these

- ☐ Not at all, the spacing between my handwritten letters is the same or better
- ☐ The spacing between my handwritten letters is a little worse
- ☐ The spacing between my handwritten letters is moderately worse
- ☐ The spacing between my handwritten letters is a lot worse

3B. How satisfied are you now with the spacing between your handwritten letters?

☐	☐	☐	☐	☐	☐
Very satisfied	Moderately satisfied	Somewhat satisfied	Somewhat dissatisfied	Moderately dissatisfied	Very dissatisfied

3C. Do you want to improve the spacing between your handwritten letters *with advice from a therapist*?

- ☐ Yes
- ☐ No

---

4. The **spacing** between your handwritten **words**

4A. Compared with your pre-stroke handwriting, is the spacing between your words now worse? For example the words are too close together, overlapping, too far apart, or a combination of these

- ☐ Not at all, the spacing between my handwritten words is the same or better
- ☐ The spacing between my handwritten words is a little worse
- ☐ The spacing between my handwritten words is moderately worse
- ☐ The spacing between my handwritten words is a lot worse

4B. How satisfied are you now with the spacing between your handwritten words?

☐	☐	☐	☐	☐	☐
Very satisfied	Moderately satisfied	Somewhat satisfied	Somewhat dissatisfied	Moderately dissatisfied	Very dissatisfied

4C. Do you want to improve the spacing between your handwritten words *with advice from a therapist*?

- ☐ Yes
- ☐ No

5. The **alignment** of your handwriting

Alignment refers to the letters and words appearing 'in line' in relation to each other, regardless of whether the writing is on lined paper or blank paper

5A. Compared with your pre-stroke handwriting, is the alignment of your handwriting now worse? For example, the letters and/or words move up or down the page or are not in line with each other.

- ☐ Not at all, the alignment of my handwriting is the same or better
- ☐ The alignment of my handwriting is a little worse
- ☐ The alignment of my handwriting is moderately worse
- ☐ The alignment of my handwriting is a lot worse

5B. How satisfied are you now with the alignment of your letters and words?

☐	☐	☐	☐	☐	☐
Very satisfied	Moderately satisfied	Somewhat satisfied	Somewhat dissatisfied	Moderately dissatisfied	Very dissatisfied

5C. Do you want to improve the alignment of your handwriting *with advice from a therapist*?

- ☐ Yes
- ☐ No

---

6. The **slant** or **angle** of your handwriting

6A. Compared with your pre-stroke handwriting, is the slant or angle of your handwritten letters now worse? For example the letters slant too far towards clockwise, too far towards anticlockwise or the slant of the writing is not uniform

- ☐ Not at all, the slant or angle of my letters is the same or better
- ☐ The slant or angle of my letters is a little worse
- ☐ The slant or angle of my letters is moderately worse
- ☐ The slant or angle of my letters is a lot worse

6B. How satisfied are you now with the slant or angle of your letters and words

☐	☐	☐	☐	☐	☐
Very satisfied	Moderately satisfied	Somewhat satisfied	Somewhat dissatisfied	Moderately dissatisfied	Very dissatisfied

6C. Do you want to improve the slant or angle of your handwritten letters *with advice from a therapist*?

- ☐ Yes
- ☐ No

7. The **quality or appearance** of the **lines and curves** of your **letters**

7A. Compared with your pre-stroke handwriting, is the quality of the lines and curves now worse? For example the letter lines and curves appear too dark, too light, jerky or shaky or the letter curves are not smooth, and have abrupt directional changes

- ☐ Not at all, quality of the lines and curves of my letters is the same or better
- ☐ The quality of the lines and curves of my letters is a little worse
- ☐ The quality of the lines and curves of my letters is moderately worse
- ☐ The quality of the lines and curves of my letters is a lot worse

7B. How satisfied are you now with the quality of the lines and curves of your letters?

☐	☐	☐	☐	☐	☐
Very satisfied	Moderately satisfied	Somewhat satisfied	Somewhat dissatisfied	Moderately dissatisfied	Very dissatisfied

7C. Do you want to improve the quality of the lines and curves of your handwritten letters *with advice from a therapist*?

- ☐ Yes
- ☐ No

---

8. **Extra marks** around your writing

8A. Compared with your pre-stroke handwriting, are the number of extra pen or pencil marks on or around the writing now worse? For example there are extra blotches, dashes, smudges or corrections?

- ☐ Not at all, the overall appearance of my handwriting is the same or better
- ☐ The appearance of my handwriting is a little worse
- ☐ The appearance of my handwriting is moderately worse
- ☐ The appearance of my handwriting is a lot worse

8B. How satisfied are you now with the number of extra pen or pencil marks on or around your handwriting?

☐	☐	☐	☐	☐	☐
Very satisfied	Moderately satisfied	Somewhat satisfied	Somewhat dissatisfied	Moderately dissatisfied	Very dissatisfied

8C. Do you want to reduce the number of extra pen or pencil marks on or around your writing *with advice from a therapist*?

- ☐ Yes
- ☐ No

9. The **formation** of your handwritten **letters**

9A. Compared with your pre-stroke handwriting, is the formation of your handwritten letters now worse? For example letter parts are not joined up, letters are incomplete, letters are distorted, stretched, squashed or reversed

- ☐ Not at all, the formation of my handwritten letters is the same or better
- ☐ The formation of my handwritten letters is a little worse
- ☐ The formation of my handwritten letters is moderately worse
- ☐ The formation of my handwritten letters is a lot worse

9B. How satisfied are you now with the formation of your handwritten letters?

☐	☐	☐	☐	☐	☐
Very satisfied	Moderately satisfied	Somewhat satisfied	Somewhat dissatisfied	Moderately dissatisfied	Very dissatisfied

9C. Do you want to improve the formation of your letters *with advice from a therapist*?

- ☐ Yes
- ☐ No

---

10. Use of the **writing space**

10A. Compared to your pre-stroke handwriting, is your use of the writing space now worse? For example the writing is squashed up to one side

- ☐ Not at all, my use of the writing space is the same or better
- ☐ My use of the writing space is a little worse
- ☐ My use of the writing is moderately worse
- ☐ My use of the writing space is a lot worse

10B. How satisfied are you now with your use of the writing space?

☐	☐	☐	☐	☐	☐
Very satisfied	Moderately satisfied	Somewhat satisfied	Somewhat dissatisfied	Moderately dissatisfied	Very dissatisfied

10C. Do you want to improve your use of the writing space *with advice from a therapist*?

- ☐ Yes
- ☐ No

11. The **overall neatness** of your handwriting

11A. Compared with your pre-stroke handwriting, is the overall neatness of your handwriting now worse?

- ☐ Not at all, the overall neatness of my handwriting is the same or better
- ☐ The overall neatness of my handwriting is a little worse
- ☐ The overall neatness of my handwriting is moderately worse
- ☐ The overall neatness of my handwriting is a lot worse

11B. How satisfied are you now with the overall neatness of your handwriting?

☐	☐	☐	☐	☐	☐
Very satisfied	Moderately satisfied	Somewhat satisfied	Somewhat dissatisfied	Moderately dissatisfied	Very dissatisfied

11C. Do you want to improve the overall neatness of your handwriting *with advice from a therapist*?

- ☐ Yes
- ☐ No

---

12. The **overall legibility** of your handwriting

12A. Compared to your pre-stroke handwriting, the overall legibility of your handwriting now worse?

- ☐ Not at all, the overall legibility of my handwriting is the same or better
- ☐ The overall legibility of my handwriting is a little worse
- ☐ The overall legibility of my handwriting is moderately worse
- ☐ The overall legibility of my handwriting is a lot worse

12B. How satisfied are you now with the overall legibility of your handwriting?

☐	☐	☐	☐	☐	☐
Very satisfied	Moderately satisfied	Somewhat satisfied	Somewhat dissatisfied	Moderately dissatisfied	Very dissatisfied

12C. Do you want to improve the overall legibility of your handwriting *with advice from a therapist*?

- ☐ Yes
- ☐ No

Other Aspects of Your Handwriting

13. **Spelling** when handwriting

13A. Are you satisfied with your spelling when handwriting?

☐ Yes

☐ No

13B. Do you want to improve your spelling when handwriting *with advice from a therapist*?

☐ Yes

☐ No

14.Writing speed

14A. Are you satisfied with your writing speed?

☐ Yes

☐ No

14B. Do you want to improve your writing speed *with advice from a therapist*?

☐ Yes

☐ No

---

15. **Pen grip** when writing

15A. Are you satisfied with your pen grip?

☐ Yes

☐ No

15B. Do you want to improve your pen grip *with advice from a therapist*?

☐ Yes

☐ No

---

16. Is there **any other aspect of your handwriting** you are unsatisfied with and would like to improve?

☐ Yes

☐ No

Please List:

APPENDIX 4: HANDWRITING APPEARANCE AND SATISFACTION INDEX (GENERAL USE)

Handwriting Appearance and Satisfaction Index

(General Use)

A child may require assistance from a parent, carer, therapist or teacher to fill in this form. Parents, carers, therapists or teachers may also wish to fill in the form separately and discuss comparisons of the handwriting with the child. ***It is recommended to have more than one handwriting sample available to assist you to fill in this index.***

1. The overall **appearance** or 'look' of your handwriting

1A. How satisfied are you now with the overall appearance or 'look' of your handwriting?

☐	☐	☐	☐	☐	☐
Very satisfied	Moderately satisfied	Somewhat satisfied	Somewhat dissatisfied	Moderately dissatisfied	Very dissatisfied

1B. Do you want to improve the overall look of your handwriting *with help from a therapist or teacher*?

☐ Yes

☐ No

---

2. The **size** of your handwritten **letters**

Your handwritten letters may be too big, too small, a combination of these or the size of your letters may be 'just right'

2A. How satisfied are you now with the size of your handwritten letters?

☐	☐	☐	☐	☐	☐
Very satisfied	Moderately satisfied	Somewhat satisfied	Somewhat dissatisfied	Moderately dissatisfied	Very dissatisfied

2B. Do you want to improve the size of your handwritten letters *with help from a therapist or teacher*?

☐ Yes

☐ No

3. The **spacing** between your handwritten **letters**

Your handwritten letters may be too close together, overlapping, too far apart, a combination of these or the spacing between letters may be 'just right'

3A. How satisfied are you now with the spacing between your handwritten letters?

☐	☐	☐	☐	☐	☐
Very satisfied	Moderately satisfied	Somewhat satisfied	Somewhat dissatisfied	Moderately dissatisfied	Very dissatisfied

3B. Do you want to improve the spacing between your handwritten letters *with advice from a therapist or teacher*?

☐ Yes

☐ No

---

4. The **spacing** between your handwritten **words**

Your handwritten words may be too close together, overlapping, too far apart, a combination of these or the spacing between your words may be 'just right'

4A. How satisfied are you now with the spacing between your handwritten words?

☐	☐	☐	☐	☐	☐
Very satisfied	Moderately satisfied	Somewhat satisfied	Somewhat dissatisfied	Moderately dissatisfied	Very dissatisfied

4B. Do you want to improve the spacing between your handwritten words *with advice from a therapist or teacher*?

☐ Yes

☐ No

5. The **alignment** of your handwriting

Your letters and words may not appear 'in line' with each other, the writing may move up the page, down the page, or may appear 'in line' (for older children or adults alignment may be considered when writing on blank paper - with no writing lines)

5A. How satisfied are you now with the alignment of your letters and words?

☐	☐	☐	☐	☐	☐
Very satisfied	Moderately satisfied	Somewhat satisfied	Somewhat dissatisfied	Moderately dissatisfied	Very dissatisfied

5B. Do you want to improve the alignment of your handwriting *with advice from a therapist or teacher*?

☐ Yes

☐ No

---

6. The **slant** or **angle** of your handwriting

Your letters may slant too far towards clockwise, too far towards anticlockwise, the slant of the writing may not be uniform, or the writing slant may be 'just right'

6A. How satisfied are you now with the slant or angle of your letters and words

☐	☐	☐	☐	☐	☐
Very satisfied	Moderately satisfied	Somewhat satisfied	Somewhat dissatisfied	Moderately dissatisfied	Very dissatisfied

6B. Do you want to improve the slant or angle of your handwritten letters *with advice from a therapist or teacher*?

☐ Yes

☐ No

7. The **quality or appearance** of the **lines and curves** of your **letters**

The appearance of each letter line, stroke or curve may appear too dark, too light, jerky, shaky or not smooth, may have abrupt directional changes, or the quality of the lines and curves may be 'just right'

7A. How satisfied are you now with the quality of the lines and curves of your letters?

☐	☐	☐	☐	☐	☐
Very satisfied	Moderately satisfied	Somewhat satisfied	Somewhat dissatisfied	Moderately dissatisfied	Very dissatisfied

7B. Do you want to improve the quality of the lines and curves of your handwritten letters *with advice from a therapist or teacher*?

☐ Yes

☐ No

---

8. **Extra marks** around your writing

Your writing may have extra pen or pencil marks on or around the writing, there may be extra blotches, dashes, smudges or corrections, or the marks or corrections of your writing may be 'just right'

8A. How satisfied are you now with the number of extra pen or pencil marks on or around your handwriting?

☐	☐	☐	☐	☐	☐
Very satisfied	Moderately satisfied	Somewhat satisfied	Somewhat dissatisfied	Moderately dissatisfied	Very dissatisfied

8B. Do you want to reduce the number of extra pen or pencil marks on or around your writing *with advice from a therapist or teacher*?

☐ Yes

☐ No

9. The **formation** of your handwritten **letters**

Some letters may not look like the letter they are supposed to be, some letter parts may not be joined up, some letters may be incomplete, some letters may be distorted, stretched, squashed or reversed, or your letter formation may be 'just right'

9A. How satisfied are you now with the formation of your handwritten letters?

☐	☐	☐	☐	☐	☐
Very satisfied	Moderately satisfied	Somewhat satisfied	Somewhat dissatisfied	Moderately dissatisfied	Very dissatisfied

9B. Do you want to improve the formation of your letters *with advice from a therapist or teacher*?

☐ Yes

☐ No

Please list any particular letters that you know you have trouble writing:

---

10. Use of the **page or writing space**

Your writing may be squashed up to one side, you may not use the margin space 'correctly', you may not use the whole page when writing or your writing may be 'just right' on the page (or within another writing space, such as on a card or in a speech bubble)

10A. How satisfied are you now with your use of the writing space?

☐	☐	☐	☐	☐	☐
Very satisfied	Moderately satisfied	Somewhat satisfied	Somewhat dissatisfied	Moderately dissatisfied	Very dissatisfied

10B. Do you want to improve your use of the writing space *with advice from a therapist or teacher*?

☐ Yes

☐ No

11. The **overall neatness** of your handwriting

11A. How satisfied are you now with the overall neatness of your handwriting?

☐	☐	☐	☐	☐	☐
Very satisfied	Moderately satisfied	Somewhat satisfied	Somewhat dissatisfied	Moderately dissatisfied	Very dissatisfied

11B. Do you want to improve the overall neatness of your handwriting *with advice from a therapist or teacher*?

☐ Yes

☐ No

---

12. The **overall legibility** of your handwriting

12A. How satisfied are you now with the overall legibility of your handwriting?

☐	☐	☐	☐	☐	☐
Very satisfied	Moderately satisfied	Somewhat satisfied	Somewhat dissatisfied	Moderately dissatisfied	Very dissatisfied

12B. Do you want to improve the overall legibility of your handwriting *with advice from a therapist or teacher*?

☐ Yes

☐ No

Other Aspects of Your Handwriting

13. **Spelling** when handwriting

13A. Are you satisfied with your spelling when handwriting?

☐ Yes

☐ No

13B. Do you want to improve your spelling when handwriting *with advice from a therapist*?

☐ Yes

☐ No

14.Writing speed

14A. Are you satisfied with your writing speed?

☐ Yes

☐ No

14B. Do you want to improve your writing speed *with advice from a therapist*?

☐ Yes

☐ No

15.**Pen grip** when writing

15A. Are you satisfied with your pen grip?

☐ Yes

☐ No

15B. Do you want to improve your pen grip *with advice from a therapist*?

☐ Yes

☐ No

---

16. Is there **any other aspect of your handwriting** you are unsatisfied with and would like to improve?

☐ Yes

☐ No

Please List: