Université de Montréal

Factors related to braille acquisition among adult and senior learners: Establishing evidence-based practice

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Factors related to braille acquisition among adult and senior learners:

Establishing evidence-based practice

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Résumé

Les difficultés de lecture sont les raisons les plus fréquentes pour lesquelles des personnes sont orientées vers un service de réadaptation visuelle. Bien qu'il existe une base historique solide à propos de l'enseignement du braille chez les enfants aveugles, il existe très peu de données probantes concernant l'apprentissage du braille chez les personnes en âge de travailler et les personnes âgées. De surcroît, bien qu'il soit clair que le vieillissement est associé à un déclin des capacités tactiles, motrices et cognitives, on sait peu de choses sur la manière dont ces variables peuvent influencer les résultats de la lecture du braille.

Pour examiner cette problématique, une étude en quatre phases a été conceptualisée. Dans la première phase, une étude de la portée a été menée afin de synthétiser les connaissances existantes concernant la relation entre le déclin des capacités lié au vieillissement et la performance de la lecture en braille. La seconde a voulu étudier les obstacles et les facilitateurs rencontrés par les adultes qui suivent une formation en braille. La troisième a exploré les variables qui sont en corrélation avec la performance de lecture en braille à l'âge adulte. Enfin, la dernière phase a voulu se pencher sur l'influence du support de lecture sur la performance de lecture des adultes ayant une sensibilité tactile réduite.

Les preuves antérieures concernant le braille et le vieillissement restent rares. Il existe une variété de facteurs personnels, sociaux et institutionnels qui façonnent le processus d'apprentissage du braille chez les adultes, incluant la stigmatisation envers le braille et le vieillissement perçue par certains praticiens, des services inadéquats et des difficultés à l'accès aux équipements brailles. Des données soulignent la nécessité de commencer l'apprentissage du braille le plus tôt possible, d'évaluer des mesures objectives de l'acuité tactile tout en considérant le rôle de la fonction du toucher, de fournir une formation accrue en matière de perception tactile et d'envisager une plus grande intégration d'appareils braille.

Les résultats font également ressortir la nécessité d'augmenter le financement et les services ; de définir des critères d'éligibilité qui tiennent compte des réalités uniques des clients âgés et l'accès au braille ; et d'étudier plus avant le rôle de la stigmatisation vis-à-vis du braille et du vieillissement. En somme, tous ces éléments réunis peuvent influencer à la fois les décisions cliniques et les résultats d'apprentissage.

Mots-clés : cécité, déficience visuelle, braille, adulte, vieillissement, sensibilité tactile

Abstract

Reading difficulties are the most common reasons for referral to vision rehabilitation. Though there is a strong historical basis for the provision of braille instruction among blind children, there is little evidence-based research on the needs of working-age and older adults. Aging is associated with declines in tactile, motor and cognitive capacities. Moreover, learning in adulthood is distinct from childhood learning, owing to differences in cortical plasticity and development. Little is known about how these variables may influence braille reading outcomes, but such knowledge is needed to inform the design of evidence-based strategies. For example, low-cost braille devices incorporate dots of greater height and density, but the extent to which such approaches may enhance reading performance for older adults with reduced tactile sensitivity remains unexplored. These questions are especially imperative as the prevalence of age-related vision loss continues to increase.

A four-phase study was devised to synthesize prior evidence on the interrelationship between factors known to decline with age and braille reading performance; to investigate the barriers and facilitators encountered by working-age and older adults who pursue braille training; to identify variables that correlate with braille reading performance in adulthood; and to explore the influence of reading medium on the reading performance of adults with reduced tactile sensitivity.

This thesis confirms that prior evidence on braille and aging remains scant, heightening the imperative for further research in this domain. Moreover, there are a variety of personal, social and institutional factors which shape the adult braille learning process, including perceived stigma towards braille and aging among some practitioners, inadequate services and access to braille devices. Braille learning age, frequency of usage, and measures of active tactile acuity emerged as significant correlates of braille reading speed. Preliminary evidence suggests that using braille displays with greater dot height enhances performance for those with reduced tactile sensitivity, while also enabling immediate access to relevant reading content.

Collectively, these findings point to the need for rehabilitation practitioners to introduce braille as early as possible, evaluate objective measures of tactile acuity while also considering the role of functional touch, provide increased training in tactile perception, and consider a wider integration of braille devices. Findings also highlight the need for increased funding and services, eligibility criteria which takes into account the unique realities of older braille clients, and the need to further explore the role of stigma towards braille and aging which may influence both clinical decisions and learning outcomes.

Keywords: blindness, visual impairment, braille, adult, aging, tactile sensitivity

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List of Acronyms and Abbreviations

ANCOVA	analysis of covariance
ANOVA	analysis of variance
cpm	characters per minute (as a measure of braille reading speed)
CNIB	Canadian National Institute for the Blind (now operating as Vision Loss Rehabilitation Canada and the CNIB Foundation)
CVRT	Certified Vision Rehabilitation Therapist
DSI	dual-sensory impairment (typically a combined vision and hearing loss)
EHI	Edinburgh Handedness Inventory
fMRI	functional magnetic resonance imaging
GOT	Grating Orientation Task
ICEB	International Council on English Braille
IReST	International Reading Speed Tests
JVIB	*Journal of Visual Impairment & Blindness*
MCI	mild cognitive impairment
MoCA	Montreal Cognitive Assessment
MoCA-B	Montreal Cognitive Assessment, adapted for blind and visually impaired individuals
TBI	traumatic brain injury
UEB	Unified English Braille
WHO	World Health Organization
wpm	words per minute (as a measure of reading speed)

Impossible is just a big word thrown around by small [people] who find it easier to live in the world they've been given, than to explore the power they have to change it. Impossible is not a fact. It's an opinion. Impossible is not a declaration. It's a dare. Impossible is potential. Impossible is temporary. Impossible is nothing.

- Muhammad Ali

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Chapter 1 – Global introduction and overview

1.1. Braille and visual impairment - Description of the population

The World Health Organization (WHO) estimates that there are approximately 253 million individuals living with a congenital or acquired visual impairment worldwide. Based on the acuity and field definitions provided by the WHO,[1] of these 253 million people, 36 million are blind and 217 million have moderate or severe visual impairments. Most definitions of visual impairment are derived from objective measurements of visual acuity (the ability to view detail at various distances) or visual field (the area an individual is able to see when their eyes are open).[2] Many industrialized countries have adopted a legal definition of blindness based on acuity and fields to determine who is eligible for specialized services (including vision rehabilitation) and programs (including social security and financial support for the purchase of assistive devices).[3] Legal blindness is often defined as a central visual acuity of 20/200 or less in the better eye with best standard correction, or a visual field that subtends an angular distance no greater than 20 degrees in the better eye.[2,3] In the 2012 Canadian Survey on Disability, conducted by Statistics Canada, 756,300 respondents self-identified as having a "seeing disability" that limited their daily activities, of whom 5.8% (43,866) self-reported as being legally blind.[4] In the United States, it is estimated that 1.02 million individuals are legally blind, and a further 7.2 million live with some form of uncorrectable vision impairment.[5,6] In the United Kingdom, there are at least 147,000 individuals who are registered as legally blind.[7]

Although clinical measures of acuity and field provide a common starting point for discussing visual impairment, practitioners in the field of vision rehabilitation underscore that such definitions reveal little about how individuals actually use their vision or how well they function visually for different tasks.[2,8] For these reasons, proponents have advanced a definition of 'low vision' to describe that an individual may experience functional limitations, even if they do not meet the criteria for legal blindness. Low vision generally refers to a person who has measurable vision (is not totally blind) but who has difficulty accomplishing visual tasks even with best correction, and who can enhance their ability to perform certain visual tasks through the use of compensatory visual strategies, environmental modifications or optical devices.[2] Individuals with some functional vision may struggle with certain daily tasks, either due to environmental conditions (poor or too bright lighting), fluctuating vision (vision that may change depending on the time of day or the stability of other health disorders), or the nature of the visual stimulus (colour, degree of contrast).[2] For example, it is possible that an individual may have the capacity to read shorter texts (such as labels and instructions) but exhibit visual fatigue when engaged in sustained or longer reading tasks (such as the reading of textbooks or professional correspondence).[9] Likewise, it is possible that an individual may be able to visually access information when colour, contrast and size are ideal, but struggle when reading texts that incorporate fine print (such as newspapers) or cursive fonts (such as restaurant menus).[2] Moreover, individuals with low vision may have degenerative visual conditions that deteriorate over time, and may thus use sight substitution methods (such as braille) in preparation for future vision loss.[10]

In addition to visual impairment, there is also a segment of the population with either congenital or acquired dual sensory (concurrent vision and hearing) impairment (DSI). Like visual impairment, DSI can be measured objectively based on information about visual acuity and fields (for vision) and pure tone average (for hearing), and can range from mild to more profound.[11] It is estimated that 0.2% of the population (or approximately 15 million people worldwide) live with severe deaf-blindness.[12] In Canada, there are roughly 1 million Canadians with some form of DSI.[11] Depending on the degree of vision or hearing loss, these individuals may struggle with print reading for some or all tasks, and may also be unable to functionally rely upon text-to-speech software if the auditory output is not ideal or if hearing is severely impaired.[13]

1.2. Aging and changing demographics

Although congenital visual impairment was historically most prominent, the prevalence of acquired vision loss is rapidly expanding in all industrialized countries, due to both population growth and aging.[6,11] Today, the population of older adults above the age of 65 already exceeds that of children and youth in most western countries, including Canada.[14] As lifespans continue to increase, it is projected that the population of older adults with age-related vision loss will double in Canada and triple world wide over the next two decades.[6] As shown in Figure 1, the prevalence of visual impairment and blindness greatly increases with age, ranging from 5.7% and 0.2% respectively for those age 18-44 to 21.1% and 1.5% respectively among those over age 75.

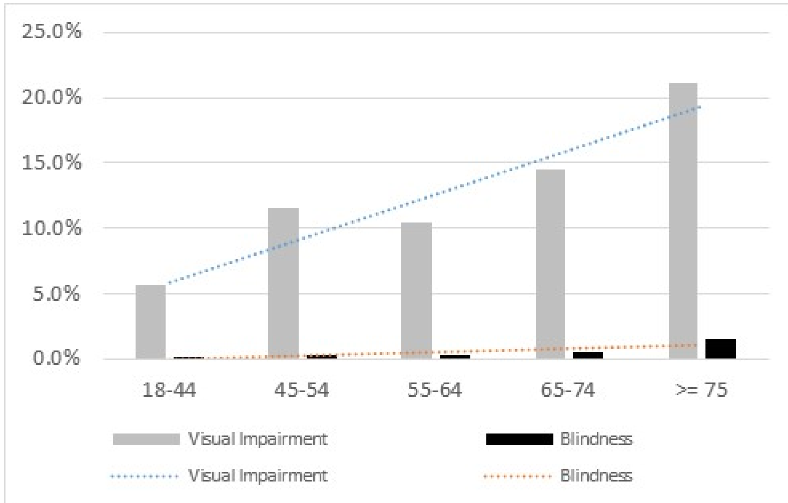


Figure 1. – Prevalence of visual impairment and blindness by age group[15]

In addition, there is a growing prevalence of acquired dual sensory impairment among working-age and older adults: between 1998 and 2005 alone, the estimated proportion of those over age 65 with dual vision and hearing impairments increased from 21.6% to 45.4%,[16] and these numbers are projected to rise substantially as baby-boomers age.[17] Between 69 and 85 percent of individuals having DSI who access vision rehabilitation services are over age 65.[18] These clients include those with Usher's Syndrome who may have developed one or both sensory impairments early in life, as well as those who acquire both sensory impairments as they age.[16]

Unlike past decades, when congenital conditions such as retinopathy of prematurity predominated,[3] the most common conditions encountered in vision rehabilitation today are those acquired later in life (glaucoma, diabetic retinopathy, retinitis pigmentosa and age-related macular degeneration).[19] Glaucoma and retinitis pigmentosa can be acquired at any age but are both progressive conditions that often lead to functional or total blindness, due to increasingly restrictive visual fields.[8] Diabetic retinopathy is the most common visual diagnosis among working-age adults and leads to the deterioration of the retina and scotomas that obscure the visual field.[20] Age-related macular degeneration (AMD) is the most common age-related condition among those above the age of 60,[21] and affects the macula, thereby impairing central vision needed for tasks that require fine vision, such as reading.[22]

Within the adult braille rehabilitation context, three main categories of clients are therefore encountered. The first are those with congenital visual impairments who learned braille early in life, and who may seek rehabilitation for changing needs as they age (for example, the attribution of new braille devices). The second are those with congenital visual impairments who did not learn braille when they were young, due either to their level of vision at the time or a lack of adequate services, and who therefore seek braille training as adults. The third, a growing majority, are those with acquired visual impairment or DSI who require braille training to maintain or regain their functional independence after adventitious vision loss.[10,23] It is not surprising that reading-related difficulties are the most common reason for referral to vision rehabilitation services today.[24]

There is a growing awareness of the global cost that acquired vision loss will have on economies, societies and on existing healthcare systems. As the Canadian population continues to age, it is projected that acquired vision loss will cost more than $16 billion per year in direct healthcare and rehabilitation expenditures by 2032.[25] While there is a vast body of knowledge on how to assess, train and support children who learn braille,[26] little remains known about how to address the unique needs of aging braille clients. As vision rehabilitation professionals continue to encounter a growing number of working-age and older adults with acquired vision loss, it will become imperative to develop evidence-based strategies that effectively and efficiently meet the needs of this quickly aging demographic. There remains a continual call for research on braille, adulthood and aging to help inform clinical decision-making, given the relative lack of knowledge in this domain.[23]

1.3. Evolution of the braille code

The braille code was devised by Louis Braille in 1821, at the age of 15.[27] Blinded at the age of 3 from an accident in his father's workshop, Louis Braille attended the first school for the blind in the world, located in Paris, France and established by Valentin Hauy.[3,28] Braille was inspired by

Charles Barbier, a retired artilleryman, who was invited to present his “écriture nocturne” (Night Writing) code to the teachers and students at the school (see Figure 2).

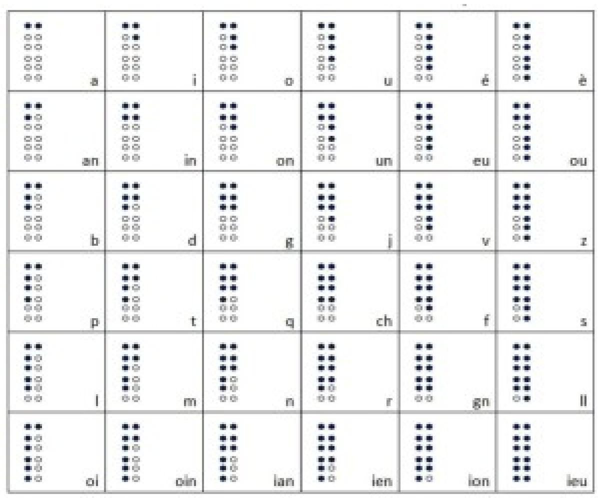
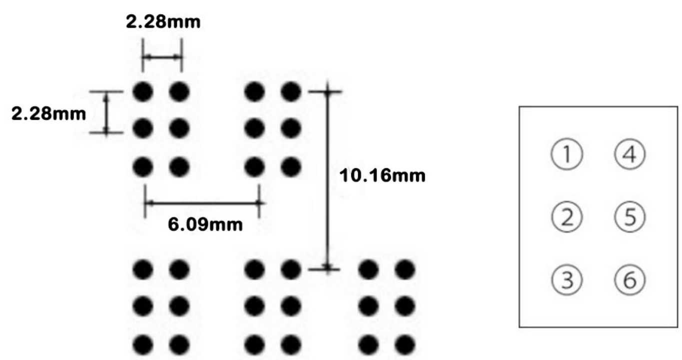


Figure 2. – Charles Barbier’s “Night Writing” alphabet [29]

Barbier’s tactile code, created to facilitate communication among soldiers at night, consisted of a 6 x 2 matrix, where combinations of dots were used to represent each of the phonemic sounds of the French language.[28] Louis Braille was inspired by the notion of a raised dot-based system, but recognized several limitations in Barbier’s code which he addressed in his development of braille. Among these limitations, the phonemic nature of Night Writing made the learning of spelling impossible; the code did not include symbols for punctuation or numerals; and writing was complex due to the need for numerous dots in each symbol. From a perceptual standpoint, Night Writing was also cumbersome to perceive because the 6 x 2 matrix extended beyond what fit comfortably beneath the distal pads of the fingers, requiring the reader to move vertically to capture the full configuration.[3] This presented the same limitations imposed by the raised Roman letters that students at the school (including Louis Braille) had been using prior to the braille code. Indeed, several perceptual studies have found that raised Roman alphabets are slower to decipher than punctiform systems such as braille, due in part to the fact that raised Roman letters are inherently larger, requiring the perceiver to piece together the symbol.[30]

In the braille code, each braille character (or "cell") consists of a 2x3 matrix of 6 raised dots which fit comfortably beneath the pads of the reading fingers, activating the cutaneous and subcutaneous mechanoreceptors responsible for tactile perception.[31] While there are some slight variations in production, the dots of the braille cell have a base diameter of 1.5mm, a height above the page of approximately 0.46mm, and the centers of adjacent dots within a cell are placed 2.28mm apart.[32] For these reasons, a minimum ability to perceive two separate dots at a distance of 2.28mm is considered to be theoretically important for braille reading,[33] but there is some evidence that those with poorer tactile acuity can nonetheless read braille.[34] For reference purposes, the dots in the braille cell are numbered 1 through 6 based on their position within the braille cell (see Figure 3).



(Adapted from Tiresias[32])

Figure 3. – Diagram depicting the dimensions of the braille cell and spacing between dots, cells, and lines of braille, as well as the organization and numbering system utilized to describe dot positions in the braille cell.

The ingenuity of the braille code is that, although the braille cell only consists of 6 dots, a total of 63 unique configurations can be formed to represent all the letters, numerals and punctuation needed to write in 133 languages today.[28] For example, the letter *c* contains dots 1-4 (the top left and right dots of the braille cell: ⠉). Similarly, dots 2-5-6 are used to write the "period" punctuation sign: ⠲. In this way, braille written in its uncontracted form contains a tactile equivalent for each print letter of the alphabet, as shown in Figure 4.

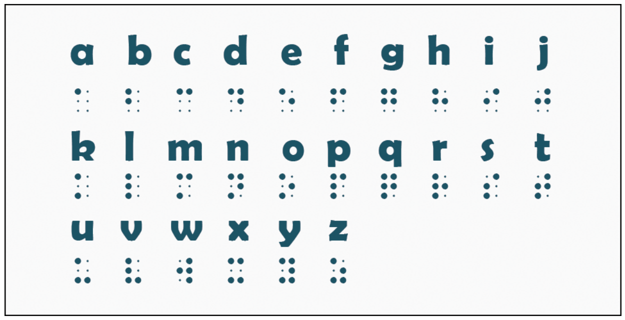


Figure 4. – The braille alphabet, as used in English braille

Ironically, though braille is often perceived by sighted non-readers to be difficult to learn,[35] it is in actuality more logical and predictable than the arbitrary nature of print letters. As demonstrated in Figure 4, the first ten letters of the braille alphabet (*a* through *j*) only use a combination of dots in the upper portion of the braille cell (dots 1, 2, 4, and 5). The next ten letters (*k* through *t*) are precisely the same as letters *a* through *j*, except for the fact that they add dot 3 to each configuration. For example, the letter *a* is represented by dot 1 (⠁), while the letter *k* is represented by dots 1-3 (⠅). The final 6 letters of the alphabet (*u* through *z*) are analogous to letters *a* through *j* again, except for the addition of dots 3-6 to each configuration. Note from Figure 4 that the letter *w* is the only symbol that does not follow this logical sequence. Louis Braille had not thought to include the letter *w* in his original alphabet, as it was not part of the French language.[28] Moreover, the letters *a* through *j* are interpreted as numerals if preceded by the numeric indicator (⠼), such that *a* through *i* become numbers 1 through 9, and *j* becomes 0 (i.e. 70 = ⠼⠛⠚). As a result, individuals who memorize the configuration of the first ten braille letters can easily learn the remainder of the alphabet and all numerals once this logic is understood.

In addition to uncontracted braille, where each print letter has a direct braille equivalent, contracted braille refers to a condensed form of braille in which specific symbols are employed as a space-saving mechanism to represent common words or commonly reoccurring groups of letters within a given language. For example, the letter *c* in contracted English braille when standing alone refers to the word *can*. The letters *ab* when standing alone represent the word *about*. Contracted English braille contains approximately 180 of these short form symbols, but this varies according to the braille code of a given language.[31,36] Contracted French braille, for instance, contains around 1,168 such abbreviations.[37] Learners who are expected to use braille for extensive purposes (such as for lifelong use, education or employment) are often encouraged to learn contracted braille for efficiency, and because many longer hard copy braille texts are only produced in contracted braille.[36,38] These contractions afford both a speed and a space saving advantage. For example, Legge, Madison and Mansfield reported reading speeds in contracted braille that were approximately 28.5% faster than in uncontracted braille; the texts themselves were approximately 25% shorter when contracted.[39] Of note, while many past braille reading studies compute reading speed based solely on words per minute (wpm), this information is of limited use if one is measuring the rate at which braille characters are perceived, as some words in braille may be contractable to a single letter. For this reason, authors such as Legge[33] have advocated for the use of *per-character* measures (characters per second or characters per minute), to control for the effect of contractions.

Though the braille code was the first tactile system to fully enable both reading and writing for the blind, it was unfortunately not officially adopted in France until 1854, 2 years after the death of Louis Braille, who never knew of the global impact of his code.[40] For several decades, a number of other tactile typographies (both raised Roman letter and dot-based systems) were developed and championed around the world. In the United States, several tactile systems were being simultaneously produced and taught alongside braille in the early 20th century, an era now known as the "war of the dots."[41] Fully contracted braille was officially adopted as the sole code in the United States in 1932, at which point it became the primary tactile system in both Europe and North America.[41,42] In 2004, the International Council on English Braille (ICEB) adopted Unified English Braille (UEB) which eliminated any differences in the braille code used in all English-speaking countries.[43] From an adult learner perspective, UEB facilitates the sharing of braille across subject domains and international borders, providing readers with access to a wider range of materials in the years ahead.[28]

Although braille has traditionally been produced in hard copy, embossed format, the evolution of electronic braille displays provide increased options for braille readers today.[44] These devices can be paired to accessible computers, tablets and smartphones and translate what is displayed on the screen into braille through refreshable pins that fall and rise to form braille symbols.[45] It should be noted that these devices are still primarily restricted to a single line of text, and therefore hard copy braille remains vital for any text that requires spatial layout (such as math). Commercial multi-line braille displays such as the Canute developed by Bristol Braille have recently entered the market, but are still at the early stages of development and not yet widely available. Although traditional paper braille is often bulky and costly to produce, braille devices can store large amounts of information in a portable format, and thus such tools significantly expand the amount of reading material available.[44] Unfortunately, braille devices have traditionally been expensive (costing $3000 or more).[46] While funding programs are available in some jurisdictions, they are often limited to students or to adults who are employed, and are thus not available to working-age and older adults who are experiencing vision loss, and who may neither be working nor studying.[47] The recent proliferation of lower cost braille displays presents promising new options for working-age and older adult braille learners.[46,48] These devices incorporate dots that are of slightly greater density and height (.63mm-.80mm) than paper braille (.46-.48mm) and provide access to reading materials that are often more motivating than those available for children.[32] While some initial studies have explored the efficacy of incorporating braille displays within braille instruction,[49,50] these have focused on the added motivation provided by these devices and have centered on young children. To date, no studies have explored the outcomes of using electronic braille displays within the adult braille rehabilitation context, or whether such devices could enhance training outcomes among those with reduced tactile sensitivity.

1.4. Braille literacy rates

It is difficult to provide an accurate estimate of current braille literacy rates (that is, the number of persons with blindness, low vision or deaf-blindness who use braille, either alone or in combination with other modes of access, such as large print or text-to-to-speech software). The most commonly cited statistic is that fewer than 10% of blind people currently use braille;[51,52] however, these numbers stem from articles in popular media and not from scientific research. The earliest cited example of this statistic is found in an article published in the United States in 1935.[53] Among the limitations highlighted in later research, this statistic is primarily based on convenience samples and the number of students who are registered to obtain hard copy braille materials from a designated institution, and therefore does not take into account those who may be using electronic braille.[54] Moreover, it is worth noting that this statistic does not include braille reading rates among adults who are no longer within the educational system, nor does it exclude the high prevalence of children with additional disabilities for whom traditional literacy may not be possible.[54,55] While based on a sample, the 2012 Canadian Survey on Disability reported that 0.8% (6,050 people) of the 756,300 people who self-identified as having a “seeing disability” and 13.8% of the 43,866 people who self-identified as being “legally blind” used braille reading materials or braillewriters.[4]

Given that those with severe or profound visual impairments constitute only one segment of the overall visually impaired population, it is logical to assume that braille literacy rates will be reflective of this; however, practitioners in the field of blindness also point to a number of circumstances that have contributed to low braille literacy rates even among those who would benefit from it.[55] While focused on children, these factors have been shown to include inadequate access to qualified professionals, inaccurate or negative perceptions about braille as a viable method, and heavy caseloads which may dictate professional decisions.[55] While a comprehensive investigation of the barriers encountered within adult braille rehabilitation has, to date, not been conducted, preliminary evidence[56] suggests that similar concerns likely shape the extent to which braille training is provided to this population. When discussing braille literacy rates, an emphasis is thus often placed on ensuring that braille is available to all those who need it, rather than relying solely on statistics as an indication of its functional importance as a reading and writing medium.[55,57]

1.5. Functional impact of braille

While text-to-speech software provides auditory access to information, practitioners within the field of blindness (including braille readers themselves) continue to underscore the importance of braille as a literacy medium that is equivalent to print for the sighted.[28] For early literacy development, braille provides blind children with a physical means of understanding components of written language (such as spelling, punctuation, and spatial layout) that would be difficult or impossible to grasp through auditory methods alone.[45] For example, the homonyms *there* and *their* sound the same but are spelled differently, a concept that is grasped through direct access to written text. For these same reasons, braille literacy is often crucial for advancing in subjects that rely heavily on spatial information, such as math, science, music notation, and computer programming.[58]

Unlike young children, adults who acquire vision impairments later in life already bring with them accumulated literacy competencies that they acquired as print readers. Nonetheless, braille provides an additional mode of access to supplement other methods such as screen magnification or auditory-based technologies.[59] The ability to draw on multiple modes of access provides adults with the option to choose the method that is best for a given task. For example, braille may be used to more subtly refer to notes during a presentation or meeting (as compared to speech-output software or large print), to access information even in the absence of costly assistive technologies, and for quickly reading and storing personal communications (such as phone numbers and lists) in a private format.[60] Research also demonstrates that, in the absence of additional learning disabilities, having physical access to text (through braille) is associated with higher levels of retention and reading comprehension than passively listening to text that is read aloud.[61] From an aging perspective, a growing body of research also suggests that engaging in mentally stimulating activities, such as reading, can slow cognitive aging.[62] This is especially pertinent given the apparent association that exists between acquired sensory impairment and mild cognitive impairment.[63-66]

At the personal level, acquired vision loss is associated with higher levels of depression and social isolation, often stemming from the inability to maintain meaningful activities of daily living and social participation.[67] Braille can be used to perform both basic reading tasks (identifying household products, reading prescriptions, instructions, recipes, lists and phone numbers) and for more advanced reading tasks (such as reading textbooks and professional correspondence). While some adults use braille for extensive purposes, others rely on braille for targeted tasks, such as reading elevator buttons or engaging in social and leisure activities that may not otherwise be possible with the use of residual vision.[10] Although the unemployment rate for the blind continues to hover at 70%, there is a consistent association between braille literacy and higher levels of education, income and employment among blind adults, particularly in more advanced technical fields.[68-70] Moreover, for the growing number of adults with acquired dual sensory impairment,[71] braille may be the only viable mode of written communication.

Numerous studies also point to the psychosocial benefits of braille, often resulting from the feelings of independence that are derived from having the flexibility to choose among different modes of access depending on the task and circumstance. In a study of adult braille users, for instance, Schroeder[72] observed that feelings towards braille are often closely intertwined with feelings of self-esteem and more positive perceptions of blindness. Despite these considerations, vision rehabilitation professionals have, at times, questioned whether braille is still necessary, given recent technological advancements that provide new forms of access to information.[73-75] Initial evidence suggests that practitioners who lack adequate braille competencies may be less likely to consider braille as an intervention option.[76] In the absence of research on braille, adulthood and aging, there is a risk that clinical decisions may be made based on such personal beliefs about braille and not on what may be most beneficial for clients.

1.6. Provision of adult braille rehabilitation

The earliest iterations of braille instruction in the 19th century and first half of the 20th century focused on blind children who attended schools for the blind.[3,42] The emphasis on children was a consequence of the social realities of that time. Prior to braille, the blind were neither educated nor employed. They could neither read nor write, and relied entirely on charitable asylums and religious institutions which reflected public views on blindness.[3] The notion that the blind could be literate was not seriously contemplated before the time of Louis Braille, due, in part, to the belief that the blind were intellectually inferior, coinciding with contemporary negative perceptions about disability.[77]

For these reasons, the first chapter of braille instruction centered on establishing basic levels of initial education, providing blind children with the first true form of literacy, and gradually transitioning them from an education that focused on manual crafts to one that expanded to include more intellectual pursuits.[3,28] Kenneth Jernigan, who served as the President of the National Federation of the Blind in the United States from 1968 until 1986, called this period one of “satisfying hunger”[78], wherein blind children were provided with the basic levels of literacy (spelling, grammar, punctuation, numeracy) needed to eventually pursue more gainful avenues of employment and participate more fully in society. However, at a broader level, the introduction of braille within the education of blind children opened many doors that would eventually demonstrate to society that even those who lose their vision later in life could continue to read and write.[26,42]

Many of the forerunners of early adult braille rehabilitation were thus themselves blind. Some had learned braille as children through specialized schools and were now in a position to become the first ‘home teachers’ (precursors to contemporary vision rehabilitation therapists), able to teach braille reading and writing to recently blinded adults.[3,10,79] Others were blinded veterans from the first and second world wars who had been heavily involved in public life prior to their battle injuries and thus advocated for the services they would need to continue living meaningfully after the wars.[42]

While congenital blindness continued to have a significant impact on braille instruction throughout the 20th century, the field also had to evolve to accommodate the numerous veterans who returned home. The first adult vision rehabilitation agency in Canada was the Montreal Association for the Blind (MAB), established by Philip E. Layton, a blind adult, in 1909.[42] In addition to the two world wars, the Halifax explosion of 1917 had the effect of significantly expanding access to braille and other rehabilitation training to adults. A munitions explosion on a ship at the harbour led to close to 600 adults instantly suffering eye injuries, many having one or both eyes enucleated, and spurring the creation of the Canadian National Institute for the Blind (CNIB) in 1918 as the first nationwide rehabilitation centre for the blind in Canada.[80] Notably, 5 of the 7 signatories were blind adults, several of whom had connections to the blindness consumer movement taking shape in the United States.[42] Thus the field of adult braille rehabilitation in Canada evolved alongside the blindness rehabilitation profession taking root in the U.S.[79]

Braille training for adults, like that for children, has been primarily premised on trial and error and on the use of techniques passed down through oral tradition from the earliest home teachers, rather than on empirical evidence or standardized practice.[57,79] The continued need for professional practice ultimately gave way to the first professional certification standards for home teachers in the 1940s, and the first personnel preparation program in vision rehabilitation at Western Michigan University in 1963, which included a course on teaching braille to adults.[79] In the first few years of the 21st century, the title of Rehabilitation Teacher, held by professionals who provide braille training to adults, was changed to what is now the Certified Vision Rehabilitation Therapist (CVRT).[79]

The transition from rehabilitation teacher to vision rehabilitation therapist serves to acknowledge the interdisciplinary expertise that professionals must have and the broader psychosocial reality in which rehabilitation takes place.[79] However, the persistent shortage of professionals coupled with the growing number of working-age and older adults who require service necessitates that professionals become proficient in multiple domains (braille, activities of daily living, and a vast variety of assistive technologies). The consequence is that braille becomes only one of many specialized skills that a CVRT must possess. While no comprehensive studies on the state of adult braille rehabilitation have been conducted, evidence suggests that referrals to braille are low despite its potential utility.[81] In the Canadian context, the decentralized nature of health care services and the disparities between rural and urban environments has resulted in significant differences from one province to another in terms of funding models, eligibility determinations, and the level of service provided.[82] As a consequence, while there are general principles that guide braille instruction, no standardized practices have been established across centres.

At a broad level, the provision of adult braille rehabilitation follows a sequence of stages. Clients with reading related difficulties are referred to vision rehabilitation. Braille may or may not be considered, depending on visual diagnosis, the tasks that require support and the professional judgment of clinicians. In Canada, the most common curriculum used[83] begins with uncontracted braille instruction, but may or may not progress to contracted braille depending on whether it is recommended or part of the client's individualized program plan.[10] Some practitioners may incorporate a prebraille training component, where tactile perception is developed prior to the introduction of braille symbols,[84] but no data on specific procedures or assessment and training tools used across centres exist. The most recent attempt to catalog existing adult braille training textbooks was published in 1996.[85]

1.7. Learning braille in childhood vs. adulthood: the problem

Blind children with congenital visual impairments learn braille through the process of acquiring literacy.[57] Braille, like print for the sighted child, merely becomes the vehicle through which reading skills are acquired.[86] The process of braille instruction, like print, thus begins by learning to read, and once adequate skills are attained, reading to learn.[26,57] For these reasons, braille literacy instruction emphasizes developing fundamental literacy skills, including phonemic awareness (letter-sound associations), syntax, semantics, orthography, grammar, punctuation and other components of written language. As a consequence, practitioner resources for early braille instruction are heavily focused on literacy acquisition for children. For example, the *Building on Patterns* curriculum[87] introduces braille symbols and contractions according to grade level, building on the concepts and vocabulary that children learn as they develop. It is more accurate to state that blind children learn to read, rather than to say that they learn braille.

The learning of braille in children who are blind typically occurs over a long period of time, and is interwoven with and reliant upon comprehensive early intervention supports. Research on the characteristics of proficient braille readers focuses heavily on young children with congenital vision impairments and on the development of early preliteracy concepts and skills.[88] For example, a wide body of research underscores the importance of early concept-development and providing pre-braille reading children with hands-on opportunities to learn about the visual world around them.[89] Blind children who lack these emergent literacy opportunities may exhibit reading comprehension difficulties when themes unfamiliar to them are encountered in the stories they read. Koenig and Farrenkopf[90] examined more than 250 stories from three basal reading series and identified more than 20 themes (e.g. interactions with living creatures, going to a farm, etc.) that would be meaningful to blind children only if they had had the opportunity to directly *engage* in those activities (rather than, for example, seeing them on a television program, as would be the case for most sighted children). For this reason, in early pre-braille and braille literacy instruction, a considerable emphasis is placed on concept development, hands-on experiences, and on the use of strategies such as “story boxes” which incorporate manipulatives and objects for children to feel in the stories they read.[84]

Intuitively, it would not be appropriate to apply the same learning strategies to the instruction of adults who arrive after vision loss with a lifetime of visual experience and literacy competencies, and who require greater emphasis on developing the mechanics of braille reading.[91] In the absence of evidence-based adult braille instruction curricula, practitioners are at times left to adapt strategies designed for children to the adult rehabilitation context.[56] Among the differences between children and adult readers is the inherent distinction between childhood development and aging. While children experience gradual improvements in different capacities as they develop and learn, adults will experience gradual declines in tactile, motor and cognitive abilities as they age.[92] Moreover, numerous functional magnetic resonance imaging (fMRI) studies demonstrate that children who learn braille early in life, especially before the age of 12,[93] exhibit greater cortical magnification of the braille reading fingers and greater activation of the visual cortex during braille reading.[94,95] Though some studies observe similar cross-modal plasticity in adult learners of braille,[96] they do not directly explore the potential role of tactile, motor and cognitive capacities that are known to decline with age.

Physiological differences aside, ample research underscores the distinction between pedagogy (childhood learning) and andragogy (adult learning) and the implications this carries for the design of interventions.[97] According to the andragogical framework advanced by Knowles,[97,98] adult learners: (1) need to know *why a skill* is important before they expend the effort to learn it; (2) need to be treated as self-directed, capable, and independent beings with personal responsibility for their learning; (3) require individualized instructional plans that take into account their lifetime of experience and circumstances; (4) become ready to learn what they can apply in the present to cope with their current lived realities; (5) are very problem-centered and task-oriented, and demand that learning have a defined purpose; and (6) are most strongly motivated by intrinsic factors (e.g. self-esteem, a desire for greater job satisfaction, etc.). Evidence from other fields indicates that tailoring efforts to address these unique characteristics of adult learners improves outcomes,[99] but the extent to which this is applicable to braille, and the particular strategies that would assist in working towards an andragogical approach to braille rehabilitation, have not been directly explored.

1.8. Impact of aging on reading performance among the sighted

There is ample evidence illustrating the ways in which normal age-related changes effect different facets of reading performance among the sighted.[100-102] For healthy, younger sighted readers (age 18-35), the average print reading rate as measured by the standardized International Reading Speed Test (IReST) is 228 words per minute (wpm), but these norms are reduced by approximately 19% to 185 wpm for those age 65-80.[103] Efficient print readers engage in minimal short but regular saccadic pauses, stable return sweeps with no regressive ocular movements, and draw on the integrated coordination of multiple cognitive processes.[102,104] Decreases in reading rate are thought to be due in part to normal age-related changes in vision (such as reduced visual acuity and contrast sensitivity) which begin in middle age and are exacerbated in older adulthood, contributing to longer fixations and more frequent regressions during print reading.[105,106] However, sensory-cognitive processes are closely interrelated, such that physiological deficits in one mechanism may lead to apparent functional deficits in others [107]. For example, older adults who have lower levels of vision than what is typically expected with age, such as those with age-related visual conditions, may allocate greater cognitive resources to perceiving visual text, at the expense of the cognitive reserve required for comprehension of that text.[108]

At the cognitive level, normal age-related declines in processing speed, working-memory and attention caused by age-related changes to gray and white matter are associated with deficits in print reading comprehension.[109] Additionally, age-related declines in visual efficiency contribute to less precise sensory inputs[110,111] and a reduced ability to attend to information.[112,113] Though gray matter deterioration in the prefrontal cortex and hippocampus is observable starting at age 50,[114] certain cognitive domains are especially impacted by normal aging while other declines remain undetected until later advancing age.[92] For example, there is a steady decline in fluid abilities (the ability to rapidly process and manipulate new information, such as when reading) from 20 to 80 years of age,[115] with one large cohort study reporting a nearly linear decline in processing speed with a standard deviation of -0.02 decline per year.[116] Conversely, crystallized intelligence (prior information that is accumulated throughout life, including vocabulary) remains largely intact in the absence of cognitive disease.[63,117] In fact, numerous studies demonstrate that there is a gradual improvement in crystallized abilities until age 60, followed by a plateau until 80 years of age.[115] While such historical and episodic memory remains largely intact, working-memory and retrieval of newly acquired information will become increasingly impaired, and memory-based tasks that require immediate recall (such as retaining text that is being read) may become more difficult. For example, older adults experience greater difficulties with tasks that require the ability to exceed normal primary storage capacities (the ability to retain more than 6 or 7 items at one time).[115]

Comprehension, the ultimate goal of reading, demands moving beyond phonological decoding and mere word recognition and requires higher-order cognitive processing of larger textual units (e.g. sentences, paragraphs).[118] Deficits in working-memory are correlated with difficulties in print reading comprehension, though the nature of the text that is being read may play a significant role. For example, de Beni[119] found that, although working-memory declined with age among participants, older adults (aged 75-85) demonstrated poorer reading comprehension when assessed using an expository but not a narrative text. Moreover, students with poor print reading comprehension not due to poor decoding or word reading skills are often shown to exhibit deficits in working-memory.[120] In this way, difficulties in reading comprehension may in fact mask deficits in working-memory which limit the ability for the reader to recall new information that has been read. For these reasons, several authors underscore the importance of controlling for working-memory ability when assessing reading comprehension in older adults.[121]

1.9. Distinctions between print and braille reading

To understand how the aging process might influence braille reading ability, it is necessary to first examine how print and braille reading align and differ in the underlying capacities that are recruited (see Table 1 on the following page). Braille reading requires tactile perception and the movement of the reading fingers across a line of text. Specifically, Merkel discs are activated when a stimulus touches the skin, and these receptors are primarily responsible for perceiving fine touch (much like the fovea in the eye), including individual braille symbols. Meissner corpuscles are activated through vibration as the fingers move across a surface, as is the case for braille.[30] For these reasons, both touch perception and haptics are vital components of braille reading.[104]

There is a larger density of sensory receptors on sites of the body where tactile perception is most acute, such as the fingers, lips and tongue. The number and density of Merkel discs and Meissner corpuscles is greatest in the index fingers, which in most cases are therefore the leading fingers in braille reading, and gradually decreases on each proceeding digit.[30] Finger size may play a mediating role, as previous research has suggested that larger fingers do not have more mechanoreceptors – they are simply spaced further apart.[122] As a result, while tactile acuity can be improved with practice and training, that improvement is asymptotic toward a theoretical optimum threshold determined by finger size.[123]

Table 1. – Comparison of characteristics of visual and braille reading

Characteristic	Visual Reading	Braille Reading
Pauses	Short saccadic pauses during which perception occurs	Pauses are rare “rallying points” that interrupt perception
Movement	No perception through movement	Perception *only* through movement
Perception	Several letters/words in parallel	Individual characters perceived successively and processed in chunks
Cues	Letter/word shapes	First 1-3 letters used to predict / anticipate
Sensory Channel	Both eyes together, moving involuntarily	One or both hands, under direct voluntary control

Adapted from Wormsley and D’Andrea[57] Table 1-1 (p. 7)

While braille reading can occur with one hand, the greatest reading speeds are associated with two-handed reading. Much like binocular vision, bimanual braille reading provides a collaborative advantage, and thus requires coordination among the fingers and hands.[124] Information from tactile receptors in both hands are transmitted contralaterally to the central nervous system, where this is processed by the somatosensory cortex (responsible for sensory perception), the visual cortex (particularly for the early blind) and the same linguistic and cognitive domains required for print reading, including the visual word area.[30] Tactile perception is highly practice dependent, such that those with greater tactile experience (such as the early blind and pianists) exhibit better tactile acuity thresholds.[125,126] This is revealed on the somatotopic map of the cortex, which illustrates the amount of real estate devoted to processing tactile perception from each site of the body, and where the area for the reading fingers is magnified in the early blind compared to that of others.[126]

While experienced print readers unconsciously and autonomously collect several words in the span of a single saccadic pause,[57,104,127] novice or less proficient braille readers retain each symbol in memory as each successive character is perceived until a complete word is assembled.[86,95,128] Rather like auditory comprehension, the information arrives serially and the reader has no ability to look ahead to prepare for what is coming.[129] The smaller sensory window of the braille reading fingers therefore slows the overall reading process and inherently increases the cognitive load as characters are held in working memory for processing and integration.[130,131] Conversely, experienced and more proficient braille readers routinely use the first few symbols in a word (called the 'critical' or 'uniqueness point') to predict what they will read next based on context, significantly increasing reading rate.[104,132] Thus a distinction is made between the sensory-window (the amount the fingers are able to perceive at one time) and the perceptual window (the amount braille readers are able to "chunk" and process at one time), which is greater among more experienced readers.[133]

Reading braille draws on the integration of both tactile sensitivity and voluntary motor functions. While reading braille is thought to best occur when a constant, smooth motion is maintained, a closer inspection of the reading process reveals that there are significant variations in the acceleration, velocity, and deceleration of the reading fingers across a line of text.[134,135] In fact, what appear as smooth reading movements are actually a series of very small adjustments, with the changes in velocity stemming from the motor system's "necessary construction of slow movements from more elementary sub-movements."[136 (p. 726)] As such, deficits in both the motor and cognitive domains may be expected to impact braille reading performance.

For all these reasons, braille reading is distinguishable from print reading in that performance is dependant on tactile, motor, and cognitive variables. The braille reading process is, as Hughes[135] describes it, “best modeled as a complex perceptual-cognitive-motor skill” (p. 370). As will be discussed in significant detail in Chapter 2, the existing literature predominantly examines braille reading performance one domain at a time (e.g. hand movements, or tactile acuity, or working memory), without sufficient attention paid to these overarching interrelationships.

1.10 Aging and braille reading performance

The normal aging process is associated with a progressive decline in tactile, motor, and cognitive abilities;[137-139] however, the existing literature does not expressly address the extent to which such age-related declines may influence braille reading performance or the extent to which these might be improved through training interventions.

1.10.1. Tactile acuity

Tactile acuity is typically measured as the smallest gap in a stimulus whereby an individual is able to detect that there are two contact points with their finger, rather than a single contact point.[30] A myriad of different measures and assessments have been developed to evaluate tactile acuity, among which two broad categories emerge. Passive measures (such as the Two-Point Discrimination Test[140] and the Grating Orientation Task[141]) assess acuity by applying a fixed stimulus to the stationary finger, activating Merkel discs which respond to pressure or deformation of the skin.[142] Active measures (such as Legge’s “Dot” and “C” Charts[33,141]) assess acuity when the finger is being moved across a stimulus, stimulate the Meissner corpuscles which respond to mechanical vibrations.[142] Investigations of tactile acuity in both the passive and active regimes reveal that among otherwise healthy participants, tactile acuity declines at a rate of approximately 1% per annum.[33,143,144] In blind, braille-reading individuals, absolute thresholds similarly decline but are typically 15% lower across all ages.[141,144] Table 19 in Appendix D summarizes the acuity thresholds that have been reported for blind and sighted participants in different age groups for each of these four common evaluations.

1.10.2. Motor dexterity

Motor dexterity, and particularly fine motor skills, decline as a consequence of normal aging.[111,135,145] Moreover, motor declines can be a secondary effect of cognitive declines. The prefrontal cortex gradually deteriorates with age[113] and as this region of the brain is responsible for executing instructions related to voluntary movement, declines in processing speed may disrupt or delay movements such as those required for efficient braille reading.

While fine-motor dexterity declines with age, several different assessments exist to measure such motor declines, most of which have been employed with sighted participants. Yancosek and Howell[146] conducted a narrative review of dexterity assessments and identified 14 different measures of adult hand/finger dexterity. Of those 14 evaluations, the Purdue Pegboard Test has been commonly employed in studies involving blind or visually impaired participants.[147-150] While the validity and reliability of the Purdue Pegboard Test has been extensively studied in a variety of normally healthy and clinical populations,[151] there are no published age-linked norms for those who are functionally blind and who complete the assessment tactually. However, among the sighted, Agnew et al.[152] and Yeudall et al.[153] report norms for fine-motor dexterity (using the Purdue Pegboard test) for those in their 8th decade (dominant hand/non-dominant hand/both hands together) that are 22.5%/28.9%/33.1% lower than for a 21-25 year old woman, and 30.0%/29.7%/34.5% lower than for a 21-25 year old man. Wittich and Nadon[148] have reported, in respect of older adults with low vision, significant declines between the 6th and 9th decade (in the dominant/non-dominant/both hands conditions) of 14.1%/28.7%/20.3% for men and 37.1%/39.7%/49.7% for women (although the difference based on sex was not statistically significant). Of interest is that in many other studies, biological sex appears to influence fine-motor dexterity, with females achieving greater performance than males. Merritt and Fisher[154] (citing a variety of other studies) suggest gender differences, whereby women have, at least historically, spent more time performing daily household activities that involve fine manipulation and therefore may have historically had more experience in these tasks. Whether normal declines in fine-motor ability due to age are significant to braille reading performance remains unexplored.

1.10.3. Cognitive capacity

While decreases in cognitive functioning may be readily observable in severe cases,[155] more subtle mild cognitive impairments may also exist and impact reading performance. A variety of screening tests have been developed to identify individuals with mild cognitive impairments, including the Mini-Mental State Examination, the Middlesex Elderly Assessment of Mental State, the Informant Questionnaire on Cognitive Decline, the Geriatric Depression Scale, the Montreal Cognitive Assessment (MoCA), and other indirectly related tests (such as the Word Reading Threshold).[156]

Assessments of working memory typically require participants to recall and repeat stimuli in the order they were presented. *Span* is most commonly measured as the longest series that has been correctly recalled.[157] In *reading span* tests, participants might read a group of sentences and answer several questions about those sentences – while being tasked with remembering the last word of each sentence for later repetition.[121,158] *Listening span* tasks involve listening to sentences, answering a question about the sentences, and later repeating the last word in each sentence [159,160]. *Digit span* tests, like listening span tests, involve hearing and repeating a series of individual digits [161]. Finally, *computational* tests demand that a participant perform a series of arithmetic problems while remembering the last digit of each problem [159,160].

Of interest is that, while each of these evaluations engages slightly different combinations of sensory and information processing modalities, the results from each have found to be comparable.[157] Nonetheless, they are not necessarily suitable for assessing working memory capacity where braille reading performance is of interest. There is some evidence that tactile working memory functions differently than working memory associated with visual or auditory stimuli. Rex, Koenig, Wormsley and Baker[86] suggest that the more rapid decay of tactual information, owing to the fact that more of the cortex is dedicated to visual rather than tactile input, contributes to initial difficulties in retaining braille symbols for some learners. Moreover, when assessing braille reading performance, examining correlations with a working memory test that involves the reading of braille words or sentences creates an unworkable circularity: poor reading performance may lead to a poor working memory test result, without establishing that working memory is the cause of that poor performance. Likewise, some tactile working memory assessments have found better results among congenitally blind subjects than subjects with residual vision, suggesting that plasticity might increase tactile working memory capabilities that would not be reflected in the results of listening or computational assessments.[162]

One example of a purer tactile working memory assessment (that does not depend on reading ability or linguistic processing) is that devised by Papagno et al.[163] Described in more detail in Study 3 (specifically §4.3.6) and Appendix D1, in this evaluation participants tactually examine a grid-based pattern containing an equal number of "smooth" and "rough" textures and then re-create that same pattern. No knowledge of braille is required, insulating the evaluation from potential linguistic processing deficits. For comparative purposes, Table 2 presents the norms for the participants in Papagano et al. and Della Sala et al.'s examinations. However, research is needed to directly explore whether declines in tactile working-memory may influence braille reading performance.

Table 2. – Distribution of Visual Pattern Test/Tactile Pattern Test scores in prior research

Variable	Della Sala et al. [(a)]	Papagno et al. [(b)]
N	345 (159 male, 186 female) healthy British participants	15 blind participants
Age	M = 41.95 (SD = 21.99), range 13-92	Mdn = 49.5
Correlation to age	r = -0.55, p < .01	n/r
Mean	9.08	n/r
Median	9.00	3.33
SD	2.25	n/r
Min, Max	2, 15	n/r, 8
Simple range	13	n/r
Lower, upper quartile	8, 11	3.16, 4.33
Interquartile range	3	1.17

[(a)] Scores are reported as "pattern span": the number of "filled" squares in the largest correctly completed matrix
[(b)] Scores are reported as "tactile span": the mean number of "rough" squares among the three largest correctly completed matrices
n/r: Not reported

1.10.4. Interaction among capacities

There is mounting evidence of a correlation between sensory impairment and cognitive decline in old age, even when sensory impairment is accommodated during the testing procedure.[63-66] One hypothesis, centered on the allocation of scarce cognitive resources, suggests that older individuals with impaired sensory abilities (such as reduced tactile acuity) may need to allocate more attentional resources to perceive sensory input and fewer resources remain for other cognitively demanding tasks as a consequence.[164] An alternative hypothesis is that the sensory and cognitive declines result from age-related degeneration of the central nervous system, which reduces both cognitive and non-cognitive capacities.[66,164] Irrespective of the cause, it is clear that age-related declines in any of these mechanisms could be expected to disrupt the functioning of others in this closely interrelated pathway.[165] However, as the existing research typically investigates the relationship between braille reading performance and measures of only one of these capacities, the interrelated impacts of declines in other areas have not been explored. Studies on learning and aging among the sighted provide some evidence that deficits in specific age-related domains might be improved through compensatory techniques or targeted training.[166] Given the nascent state of the existing research on the influence of age-related declines on older braille readers, these questions require greater attention as the population of both those with congenital and acquired visual impairments continues to increase.

1.11. Objectives and hypotheses

1.11.1. Purpose of this research

The overview in this chapter serves to highlight that, while formal adult braille rehabilitation services have existed since World War I, little remains empirically known about the process of learning braille later in life, or how to best support working-age and older adult braille clients. These questions are especially imperative now as the population continues to age, placing new demands on existing rehabilitation systems. Understanding correlates of braille reading performance among working-age and older adults will pinpoint what components are especially important to target within adult braille rehabilitation paradigms. There are ongoing calls for research to understand whether specific underlying capacities could be used to predict braille reading ability in prospective aging braille clients, or whether remedial activities could be designed to enhance the underlying capacities that are shown to be especially important to braille reading ability among older braille learners.

Beyond these physiological and cognitive questions, environmental factors, such as inadequate access to services and psychosocial adjustment to vision loss, are also known to shape the vision rehabilitation process generally. However, no previous research has directly explored the facilitators and barriers encountered by working-age and older adults who pursue braille training, in order to pinpoint the external factors which might shape their training outcomes. Such insights would provide vital information to inform policy and practice recommendations, by highlighting where current gaps in service delivery exist. Research that does not aim to explore both the intrinsic and extrinsic factors which bear upon braille learning outcomes will at best be incomplete. Collectively, this dissertation will thus paint the first comprehensive portrait of the variables that shape the adult braille learning process, providing a vital foundation for future research and practice to build upon.

The goal of this thesis is to add to the relatively insubstantial body of research on braille learning and usage among individuals across the adulthood age spectrum. While the studies presented in each chapter of this dissertation stand on their own as individual contributions, they were also deliberately designed to build upon one another, with each informing the subsequent studies. Collectively, these investigations provide insight into fundamentally interlinked questions about braille, adulthood and aging. More broadly, this research will shed much-needed light on the unique experience of braille usage in adulthood and will contribute to the development of evidence-based recommendations to better meet the unique needs of a rapidly aging population.

1.11.2. Research context and stakeholder engagement

This research was conducted at the Université de Montréal, School of Optometry. The protocols for the studies described in Chapters 3, 4 and 5 were approved by the Centre for Interdisciplinary Research in Rehabilitation of Greater-Montreal (CRIR), as a prerequisite to recruiting clients through the network of vision loss rehabilitation services in the Montreal region. Given the difficulties that are often encountered when seeking larger sample sizes in braille research,[167] concerted efforts were made to expand recruitment as widely as possible. Additional ethics approval was obtained through the Canadian National Institute for the Blind (CNIB), the largest provider of vision rehabilitation services outside of Quebec, which enabled recruitment at the national level. The protocol for the study in Chapter 5 was also approved by the Université de Montréal, to enable participation of on-campus students.

Concerted efforts were made throughout this research to foster stakeholder engagement at each stage, to ensure the relevance of results and that the questions adequately respond to practitioner concerns. Graham et al.[168] highlight that research findings are not often transferred to practise settings, and the lack of such evidence-based, cost-effective and accountable knowledge transfer often leads to the inefficient use of limited healthcare resources. Consultations with rehabilitation service providers from the Centre de réadaptation Lethbridge-Layton-Mackay du CIUSSS du Centre-Ouest-de-l'Île-de-Montréal, the CNIB, Institut Nazareth et Louis-Braille du CISSS de la Montérégie-Centre and the Quebec-based Jacques Ouellette School for the Blind served to refine the protocol for each study (including the design of research questions and methodological decisions). For example, stakeholders noted that oral reading performance may not be indicative of actual reading ability, given that most readers will not, in their day to day activities, need to read other than silently to themselves. This observation led to the exploration in study 3 of reading in both the oral and silent modalities.

To provide feedback to these practitioners, the findings from this work have been communicated through presentations offered to clinicians, conference workshops and journal talks geared towards practitioners, and have been published (or are being published) through open-access articles in peer-reviewed scientific journals to expand outreach. At a broader level, this stakeholder engagement serves to better ensure that the recommendations stemming from this work can contribute to ongoing discussions on braille, adulthood and aging and be implemented to improve current practice. Of note, this has recently culminated in the acceptance of a resolution at the 2020 General Assembly of the International Council on English Braille (ICEB), the international body which regulates and reviews the braille code across all English-speaking countries, to focus on cataloging existing braille learning resources for working-age and older adults, a project I have been appointed to oversee (see Appendix A).

1.11.3. Study 1: Scoping review (Chapter 2)

A variety of instruments have been developed to measure tactile, motor and cognitive capacities in blind individuals, and to explore the relationship between these measures and braille reading outcomes.[33,144,169,170] However, these studies are sparse and have given rise to inconsistent findings depending on the instruments that are used, even when those instruments purportedly measure the same underlying capacity. From a clinical perspective, over-reliance on the findings of a single study or the use of a specific instrument may lead to uninformed clinical decisions, such as wrongly assuming that performance on a specific measure will predict braille reading capacity in older braille clients. Given the lack of research on braille and aging, a scoping review therefore functioned as a necessary first step for clarifying existing knowledge and highlighting where current gaps exist. To summarize the breadth, nature and extent of research addressing the identified questions, the capacities examined in the eligible articles (and the corresponding measurement instruments) were categorized into three domains (tactile, motor and cognitive). The results from the scoping review[171], including the identification of the most common tactile, motor, and cognitive assessments, informed the methodological design of study 3 in this thesis.

1.11.4. Study 2: Qualitative research (Chapter 3)

In addition to the physiological and cognitive capacities of aging braille clients, a variety of environmental facilitators and barriers may significantly influence the braille learning process for working-age and older adults. Acknowledging the role of these potential factors, the second study explored the experience of learning braille later in life to describe, through a qualitative phenomenological approach, the enablers and obstacles encountered by working-age and older adults within this context. In-depth, semi-structured interviews were conducted with 14 working-age and older adults who had pursued braille training outside of the educational system (i.e. after age 21), and a bottom-up inductive thematic content analysis[172] was used to identify overarching themes. Of note, these findings highlighted the need to explore the use of electronic braille displays within adult braille rehabilitation training, further examined in study 3 and 4 of this thesis.

1.11.5. Study 3: Cross-sectional correlational study (Chapter 4)

This study served to address the gaps identified in the scoping review on braille and aging. The aim of this study was to explore correlates of braille reading performance within a single sample of working-age and older adult braille users, and to consider the influence of age within this context. Given the potential for reduced tactile acuity among older readers, and the concerns raised by stakeholders that oral and silent reading may be materially different, reading speed based on medium (paper vs. braille display) and mode (oral vs. silent) was also explored. It was hypothesized, based on previous norms from other studies, that tactile, motor and cognitive measures would decline with age, and that the age braille was learned would emerge as a significant predictor of braille reading speed. The specific measurement instruments used were based on the findings from the scoping review, taking into account which had been used most often in previous work and which might have clinical relevance as tools that could be used in clinical settings. The results of selected tests also assisted in substantially narrowing the number and range of assessments that would ultimately be used as a part of study 4.

1.11.6. Study 4: Pilot case series intervention study (Chapter 5)

The results from the first 3 studies in tandem with stakeholder discussions led to the fourth and final study of this research: a case series training intervention study to explore differences in paper-based vs. braille display usage on the initial braille learning outcomes of younger and older adults otherwise naïve to braille. It was hypothesized that, given the crisper, firmer dots on a braille display (compared to paper braille): (1) learning letters on a display would lead to greater accuracy and speed than learning on paper; (2) transitioning from use of a display to reading on paper would lead to a decrease in speed or accuracy; and (3) differences in tactile acuity would influence the speed and accuracy of reading. A subset of the evaluations that study 3 found to be most relevant to reading performance in that sample were conducted. This study permitted an examination not only of reading performance on both paper and display, but the difference observed when transitioning from one format to the other. The findings from this pilot study provide valuable insights about the efficacy of using braille displays within interventions designed for older adults who may exhibit reduced tactile sensitivity, and add to the results from the previous study which focuses more heavily on experienced braille readers.

1.12. Contributions and authorship

The protocols for each of the four studies in this research program were designed, developed and implemented by Natalina Martiniello ("NM") under the supervision of Prof. Walter Wittich, PhD ("WW"). Mahadeo Sukhai, PhD ("MS"), Head of Research and Chief Accessibility Officer at CNIB (a MITACS partner organization) helped to arrange recruitment of participants for the second and third studies and provided general guidance throughout the process.

Fatima Tangkhpanya ("FT") and Camille Demers ("CD"), students at the Université de Montréal recruited as research assistants to NM, assisted with study 1 and 2. Leila Haririsanati ("LH"), then a Masters student in the Wittich Lab co-supervised by NM and WW, assisted with study 2. Karine Elalouf, M.Sc ("KE"), and Norman Robert Boie ("NRB"), research assistants in the Wittich Vision Impairment Research Lab ("Wittich Lab"), assisted with data collection in study 3. Meaghan Barlow, PhD ("MB") provided assistance with data collection and guidance on statistical analysis in study 3. Eleanor Diamond and Emilia Milheiro (of the Braille Production Service at the Lethbridge-Layton-Mackay Rehabilitation Centre ("LLMRC")) arranged for the production of the braille reading passages (used in study 3) and tactile acuity charts (used in studies 3 and 4).

1.12.1. Study 1: The association between tactile, motor and cognitive capacities and braille reading performance: a scoping review of primary evidence to advance research on braille and aging (published in *Disability & Rehabilitation*; NM and WW as authors)

NM identified the research questions, defined the inclusion and exclusion criteria, performed the database searches, charted the data, and wrote the resulting manuscript. Atul Jaiswal, PhD, a post-doctoral fellow in the Wittich Lab, provided guidance on the process for conducting a scoping review. NM collected articles from electronic databases and paper sources, and NM and FT independently screened titles and abstracts, and then full-text articles, against the eligibility criteria. NM summarized the results, interpreted the data, and wrote the manuscript. NM and WW reviewed and revised the manuscript for publication.

1.12.2. Study 2: Enablers and barriers encountered by working-age and older adults with vision impairment who pursue braille training (published in *Disability & Rehabilitation*; NM, LH, and WW as authors)

NM identified the research questions, developed the interview guide, and was primarily responsible for conducting the interviews, five of which LH also attended. CD produced verbatim transcriptions of the audio-recorded interviews. NM conducted the thematic analysis of the interviews (with CD as a secondary coder), summarized the results, and wrote the manuscript. NM and WW revised and finalized the article for publication.

1.12.3. Study 3: Exploring correlates of braille reading performance in working-age and older adults with visual impairments (submitted to *Scientific Studies on Reading*; NM, MB, and WW as authors)

NM devised the research questions, identified the measurement instruments to be used based on the comprehensive scoping review, and oversaw management of the participant recruitment and testing procedures. Michel Pepin (Canada Sales Director, Humanware) arranged for the loan of a BrailleNote Touch Plus braille notetaker for evaluation purposes and use during data collection. Sara Brennan (a Vision Rehabilitation Therapist at LLMRC), Charles André-Labbé (Vision Impairment Resource at École Jacques-Ouellette), Chantal Robillard (Director of Research at LLMRC), and Chantal Nicole (a VRT at L'institut Nazareth et Louis Braille) provided feedback on the protocol, assistance with recruitment of participants, and served as liaisons with their respective organizations. KE and MB performed data collection, with NM providing training on the testing protocol and attending and supervising in all cases. KE and MB performed the initial data entry. NM conducted the data analysis, with MB providing guidance with respect to the regression and ANCOVA modeling. Guidance (and assistance with recruitment of participants through CNIB) was provided throughout by MS. The manuscript was prepared by NM, with reviews by MB and WW prior to finalization.

1.12.4. Study 4: Exploring the influence of reading medium on braille learning outcomes: A case series of 6 working-age and older adults (accepted for publication in the *British Journal of Visual Impairment*; NM and WW as authors)

Based on findings from the prior studies, NM devised the research questions and hypotheses, and prepared the braille reading materials. NM conducted data collection, analyzed the data, and drafted the manuscript. NM and WW reviewed and revised the article to finalize it for publication.

1.13. References

1. Ackland P, Resnikoff S, Bourne R. World blindness and visual impairment: despite many successes, the problem is growing. Community eye health. 2017; 30(100):71-3.

2. Corn AL, Erin JN. Foundations of low vision: Clinical and functional perspectives: American Foundation for the Blind; 2010.

3. Koestler FA. The Unseen Minority: A Social History of Blindness in the United States. American Foundation for the Blind2004.

4. Bizier C, Contreras R, Walpole A. Seeing disabilities among Canadians aged 15 years and older, 2012 (Canadian Survey on Disability, 2012) (No. 89-654-X). Ottawa: Statistics Canada; 2016.

5. Centre for Disease Control and Prevention. Vision Health Initiative (VHI): Fast Facts of Common Eye Disorders: Centre for Disease Control and Prevention; 2020 [updated June 9, 2020. Available from: https://www.cdc.gov/visionhealth/basics/ced/fastfacts.htm#:~:text=Approximately%2012%20 million%20people%2040,due%20to%20uncorrected%20refractive%20error.

6. Varma R, Vajaranant T, Burkemper B. Visual impairment and blindness in adults in the United States: Demographic and geographic variations from 2015 to 2050. Journal of the American Medical Association: Opthalmology. 2016; 134(7):802-9.

7. Morris C. Visual Impairment. In: Atkinson P, Delamont A, Cernat A, Sakshaug JW, Williams RA, editors. SAGE Research Methods Foundation: SAGE Publishing; 2019.

8. Corn AL, Lusk KE. Perspectives on Low Vision (Chapter 1). Foundations of Low Vision: Clinical and Functional Perspectives. New York: American Foundation for the Blind; 2010. p. 3-34.

9. Presley I, D'Andrea FM. Assistive technology for students who are blind or visually impaired: a guide to assessment. New York: American Foundation for the Blind; 2009.

10. Ponchillia PE, Ponchillia SV. Foundations of Rehabilitation Teaching with Persons Who Are Blind or Visually Impaired. New York: American Foundation for the Blind; 1996.

11. Mick P, Hämäläinen A, Kolisang L, Pichora-Fuller MK, Phillips N, Guthrie D, et al. The prevalence of hearing and vision loss in older Canadians: An analysis of Data from the Canadian Longitudinal Study on Aging. PsyArXiv Preprints; 2019.

12. Sense International. At risk of exclusion from CRPD and SDGs implementation: Inequality and Persons with Deafblindness. 2018.

13. St-Amour L, Jarry J, Wittich W. The Audibility of Low Vision Devices with Speech Output Used by Older Adults with Dual Sensory Impairment. Optometry and Vision Science. 2019; 96(5):345.

14. Statistics Canada. Canada's population estimates: Age and sex, July 1, 2020 Ottawa: Statistics Canada; 2020 [Available from: https://www150.statcan.gc.ca/n1/en/daily-quotidien/200929/dq200929b-eng.pdf?st=E0pVHjk6.

15. Ryskulova A, Turczyn K, Makuc DM, Cotch MF, Klein RJ, Janiszewski R. Self-reported age-related eye diseases and visual impairment in the United States: results of the 2002 national health interview survey. American Journal of Public Health. 2008; 98(3):454-61.

16. Wittich W, Watanabe DH, Gagné J-P. Sensory and demographic characteristics of deafblindness rehabilitation clients in Montréal, Canada. Ophthalmic and Physiological Optics. 2012; 32(3):242-51.

17. Brennan M, Bally SJ. Psychosocial adaptations to dual sensory loss in middle and late adulthood. Trends in amplification. 2007; 11(4):281-300.

18. Fraser SA, Southall KE, Wittich W. Exploring Professionals’ experiences in the rehabilitation of older clients with dual-sensory impairment. Canadian Journal on Aging/La Revue canadienne du vieillissement. 2019; 38(4):481-92.

19. Maberley DAL, Hollands H, Chuo J, Tam G, Konkal J, Roesch M, et al. The prevalence of low vision and blindness in Canada. Eye. 2006; 20(3):341-6.

20. Kobrin Klein BE. Overview of Epidemiologic Studies of Diabetic Retinopathy. Ophthalmic Epidemiology. 2007; 14(4):179-83.

21. Hernández-Zimbrón LF, Zamora-Alvarado R, Ochoa-De la Paz L, Velez-Montoya R, Zenteno E, Gulias-Cañizo R, et al. Age-Related Macular Degeneration: New Paradigms for Treatment and Management of AMD. Oxidative Medicine and Cellular Longevity. 2018; 2018:8374647.

22. Lee H, Ponchillia SV. Low Vision Rehabilitation Training for Working-Age Adults. In: Erin J, Corn AL, editors. Foundations of Low Vision: Clinical and Functional Perspectives. 2nd ed. New York, NY: AFB Press; 2010. p. 760-98.

23. Cryer H, Home S. Final report: Feasibility of developing a diagnostic touch test to determine braille reading potential. United Kingdom: RNIB Centre for Accessible Information; 2011.

24. Rubin GS. Measuring reading performance. Vision Research. 2013; 90:43-51.

25. Cruess AF, Gordon KD, Bellan L, Mitchell S, Pezzullo ML. The cost of vision loss in Canada. 2. Results. Can J Ophthalmol. 2011; 46(4):315-8.

26. Holbrook MC, McCarthy T, Kamei-Hannan C. Foundations of Education: Volume I: History and Theory of Teaching Children and Youths with Visual Impairments. 3rd ed: AFB Press; 2017.

27. Mellor CM. Louis Braille: A touch of genius: National Braille Press; 2006.

28. Dixon J, editor. Braille into the next milennium. Washington, DC: National Library Service for the Blind and Physically Handicapped; 2000.

29. Australian Braille Authority. International Braille Honour Roll: Australian Braille Authority; n.d. [Available from: http://brailleaustralia.org/about-braille/international-honour/.

30. Heller MA, Gentaz E. Psychology of Touch and Blindness: Psychology Press; 2013.

31. Foulke E. Reading braille. Tactual Perception: A Sourcebook. New York: Cambridge University Press; 1982. p. 168-208.

32. Tiresias. Braille cell dimensions 2009 [Available from: http://www.arch.mcgill.ca/prof/klopp/arch678/fall2008/3%20Student%20exchange/Team%20Surface/Connexion%20Surface%20Folder/MA%20files/Braille%20cell%20dimensions.pdf.

33. Legge GE, Madison CM, Vaughn BN, Cheong AMY, Miller JC. Retention of high tactile acuity throughout the lifespan in blindness. Perception & Psychophysics. 2008; 70(8):1471-88.

34. Harley RK, Pichert JW, Morrison M. Braille instruction for blind diabetic adults with decreased tactile sensitivity. Journal of Visual Impairment & Blindness. 1985; 79(1):12-7.

35. Johnson L. The braille literacy crisis for children. Journal of Visual Impairment & Blindness. 1996; 90(3):276-8.

36. D'Andrea FM. A History of Instructional Methods in Uncontracted and Contracted Braille. Journal of Visual Impairment & Blindness. 2009; 103(10):585-94.

37. Laroche L, Boulé J, Wittich W. Reading speed of contracted French braille. Journal of Visual Impairment & Blindness. 2012; 106(1):37-42.

38. Emerson RW, Holbrook MC, D'Andrea FM. Acquisition of literacy skills by young children who are blind: Results from the ABC Braille Study. Journal of Visual Impairment & Blindness. 2009; 103(10):610-24.

39. Legge GE, Madison CM, Mansfield JS. Measuring braille reading speed with the MNREAD test. Visual Impairment Research. 1999; 1(3):131-45.

40. Herie E. Six Dots that Changed the World: In Remembrance of Louis Braille (1809 – 2009). 7th World Blind Union General Assembly; January 4; Geneva, Switzerland: World Blind Union; 2008.

41. Irwin RB. The war of the dots: American Foundation for the Blind; 1983.

42. Herie E. Journey to Independence: Blindness - The Canadian Story: Dundurn Publishing; 2005.

43. D'Andrea FM. Unified English Braille: The future of braille in the United States. Journal of Visual Impairment & Blindness. 2013; 107(3):243-6.

44. Cryer H, Home S. Use of braille displays. 2011.

45. Massof RW. The Role of Braille in the Literacy of Blind and Visually Impaired Children. Archives of Ophthalmology. 2009; 127(11):1530-1.

46. Adnan ME, Dastagir NM, Jabin J, Chowdhury AM, Islam MR, editors. A cost effective electronic braille for visually impaired individuals. 2017 IEEE Region 10 Humanitarian Technology Conference (R10-HTC); 2017: IEEE.

47. Tariff for insured visual aids and related services, CQLR c A-29, r 8.1 (Health Insurance Act), (2018).

48. Nadeem M, Aziz N, Sajjad U, Aziz F, Shaikh H, editors. A comparative analysis of Braille generation technologies. 2016 International Conference on Advanced Robotics and Mechatronics (ICARM); 2016 18-20 Aug. 2016.

49. Bickford JO, Falco RA. Technology for early braille literacy: Comparison of traditional braille instruction and instruction with an electronic notetaker. Journal of Visual Impairment & Blindness. 2012; 106(10):679-93.

50. Cooper HL, Nichols SK. Technology and early braille literacy: Using the Mountbatten Pro Brailler in primary-grade classrooms. Journal of Visual Impairment & Blindness. 2007; 101(1):22-31.

51. Alam H. The end of braille? Why fewer people are reading by touch: CTV News; 2019 [Available from: https://www.ctvnews.ca/lifestyle/the-end-of-braille-why-fewer-people-are-reading-by-touch-1.4447543.

52. Aviv R. Listening to Braille. The New York Times Magazine. 2010 Jan. 3.

53. Heyer HE. Statistical survey of the blind in New Jersey. Journal of Visual Impairment & Blindness. 1935; 29(3):107-35.

54. Graves A. Braille literacy statistics research study: History and politics of the "braille reader statistic": A summary of AFB Leadership Conference Session on Education. Journal of Visual Impairment & Blindness. 2018; 112(3):328-31.

55. Spungin SJ, D'Andrea FM. Braille Literacy. In: Dixon JM, editor. Braille into the next millennium. braille edition ed. Washingon, DC: National Library Service for the Blind and Physically Handicapped; 2000. p. 537-71.

56. Martiniello N, Haririsanati L, Wittich W. Enablers and barriers encountered by working-age and older adults who pursue braille training. Disability and Rehabilitation. 2020.

57. Wormsley DP, D'Andrea FM. Instructional Strategies for Braille Literacy. New York: American Foundation for the Blind; 1997.

58. Nemeth A, Mathematics JUBCSo. Nemeth code of braille mathematics: American Print. House for the Blind; 1958.

59. Huebner KM. Daily uses of braille as told by 4 adult braille users. Journal of Visual Impairment & Blindness. 1989; 83:308-9.

60. Mack C. How Useful is Braille? Reports of Blind Adults. Journal of Visual Impairment & Blindness. 1984; 78(7):311-3.

61. Stepien-Bernabe NN, Lei D, McKerracher A, Orel-Bixler D. The Impact of Presentation Mode and Technology on Reading Comprehension among Blind and Sighted Individuals. Optometry and Vision Science. 2019; 96(5):354-61.

62. Finkel D, Andel R, Gatz M, Pedersen NL. The role of occupational complexity in trajectories of cognitive aging before and after retirement. Psychology and Aging. 2009; 24(3):563-73.

63. Baltes PB, Schaie KW. On the plasticity of intelligence in adulthood and old age: Where Horn and Donaldson fail. American Psychologist. 1976; 31(10):720-5.

64. Ghisletta P, Lindenberger U. Exploring structural dynamics within and between sensory and intellectual functioning in old and very old age: Longitudinal evidence from the Berlin Aging Study. Intelligence. 2005; 33:555-87.

65. Wittich W, Phillips N, Nasreddine ZS, Chertkow H. Sensitivity and specificity of the Montreal Cognitive Assessment modified for individuals who are visually impaired. Journal of Visual Impairment & Blindness. 2010; 104(6):360.

66. Lindenberger U, Baltes PB. Sensory functioning and intelligence in old age: a strong connection. Psychology and Aging. 1994; 9(3):339-55.

67. Tuttle DW, Tuttle NR. Self-esteem and adjusting with blindness: The process of responding to life's demands. Springfield, IL: Charles C. Thomas Publisher Ltd.; 2004.

68. Ryles R. The impact of braille reading skills on employment, income, education, and reading habits. Journal of Visual Impairment & Blindness. 1996; 90(3):219-26.

69. Bell EC. Competitive employment for consumers who are legally blind: a 10-year retrospective study. Journal of Rehabilitation Research & Development. 2010; 47(2):109-16.

70. Martiniello N, Wittich W. Employment and visual impairment: Issues in adulthood. In: Ravenscraft J, editor. Routledge Handbook of Visual Impairment: Routledge; 2019. p. 415-37.

71. Mick PT, Hämäläinen A, Kolisang L, Pichora-Fuller MK, Phillips N, Guthrie D, et al. The Prevalence of Hearing, Vision, and Dual Sensory Loss in Older Canadians: An Analysis of Data from the Canadian Longitudinal Study on Aging. Canadian Journal on Aging/La Revue canadienne du vieillissement. 2020:1-22.

72. Schroeder FK. Perceptions of braille usage by legally blind adults. Journal of Visual Impairment & Blindness. 1996; 90(3):210-8.

73. Stone J. Has Braille had its day? British Journal of Visual Impairment. 1995; 13(2):80-1.

74. Franks J. To braille, or not to braille? That is the question. British Journal of Visual Impairment. 1998; 16(2):57-60.

75. Wiazowski J. Can Braille be revived? A possible impact of high-end Braille and mainstream technology on the revival of tactile literacy medium. Assistive Technology. 2014; 26(4):227-30.

76. Ponchillia PE, Durant PA. Teaching behaviors and attitudes of braille instructors in adult rehabilitation centers. Journal of Visual Impairment & Blindness. 1995.

77. Jernigan K. Blindness: Is Literature Against Us? Chicago: National Federation of the Blind; 1974.

78. Jernigan K. The Day After Civil Rights. National Federation of the Blind Annual Convention; July 4; New Orleans, LA: National Federation of the Blind; 1997.

79. Academy for Certification of Vision Rehabilitation & Educational Professionals. Vision Rehabilitation Therapist Certification (CVRT) Handbook, Section 4, History of Vision Rehabilitation Therapy Certification Tucson, AZ: Academy for Certification of Vision Rehabilitation & Educadtional Professionals (ACVREP); n.d. [Available from: https://www.acvrep.org/certifications/cvrt-history.

80. McAlister CN, Murray TJ, Lakosha H, Maxner CE. The Halifax disaster (1917): eye injuries and their care. The British journal of ophthalmology. 2007; 91(6):832-5.

81. Bernbaum M, Albert SG, McGarry JD. Diabetic neuropathy and braille ability. Archives of Neruology. 1989; 46:1179-81.

82. Greenland C. Vision Canada: The Unmet Needs of Blind Canadians. Toronto: Canadian National Institute for the Blind; 1976.

83. Rodrigues M, Carter F. Celebrating Braille - UEB - A Canadian Approach. Toronto: CNIB; 2013.

84. Swenson AM. Beginning with Braille: Firsthand experiences with a balanced approach to literacy: American Foundation for the Blind; 1999.

85. Rex E, Richesin C. Report on a review of textbooks to teach Braille to blind adults. Journal of Visual Impairment & Blindness. 1996; 90(3):266-8.

86. Rex E, Koenig A, Wormsley DP, Baker R. Foundations of braille literacy. New York: American Foundation for the Blind; 1995.

87. Caton HR, Pester E, Bradley EJ. Patterns: The primary braille reading program. Louisville: American Printing House for the Blind; 1982.

88. Clark C, Stoner JB. An investigation of the spelling skills of braille readers. Journal of Visual Impairment & Blindness. 2008; 102(9):553-63.

89. Lamb G. Dots for tots: emergent literacy and braille reading. British Journal of Visual Impairment. 1998; 16(3):111-5.

90. Koenig AJ, Farrenkopf C. Essential experiences to undergird the early development of literacy. Journal of Visual Impairment & Blindness. 1997; 91(1):14-24.

91. McGill-Franzen A. Literacy for All Children:" I Could Read the Words!": Selecting Good Books for Inexperienced Readers. The Reading Teacher. 1993; 46(5):424-6.

92. Kandel ER, Schwartz JH, Jessell TM, Siegelbaum SA, Hudspeth AJ, Mack S. Principles of neural science. 2013.

93. Grant AC, Thiagarajah MC, Sathian K. Tactile perception in blind braille readers: A psychophysical study of acuity and hyperacuity using gratings and dot patterns. Perception & Psychophysics. 2000; 62(2):301-12.

94. Sadato N, Okada T, Honda M, Yorekura Y. Critical period for cross-modal plasticity in blind humans: a functional MRI study. Neuroimage. 2002; 16:389-400.

95. Hannan CK. Review of research: Neuroscience and the impact of brain plasticity on braille reading. Journal of Visual Impairment & Blindness. 2006; 100(7).

96. Sterr A, Müller M, Elbert T, Rockstroh B, Taub E. Development of cortical reorganization in the somatosensory cortex of adult Braille students. Electroencephalography and Clinical Neurophysiology. 1999; 49:292-8.

97. Knowles MS. Andragogy: Adult Learning Theory in Perspective. Community College Review. 1978; 5(3):9-20.

98. Knowles MS, Holton EF, Swanson RA. The adult learner : the definitive classic in adult education and human resource development. 2015.

99. May L, Day R, Warren S. Perceptions of patient education in spinal cord injury rehabilitation. Disability and Rehabilitation. 2006; 28(17):1041-9.

100. Gordon PC, Lowder MW, Hoedemaker RS. Reading in normally aging adults. In: Wright HH, editor. Cognition, language and aging. Amsterdam: John Benjamins B.V.; 2016. p. 165-91.

101. Paterson KB, McGowan VA, Jordan TR. Effects of adult aging on reading filtered text: evidence from eye movements. PeerJ. 2013; 1:e63.

102. Warrington KL, McGowan VA, Paterson KB, White SJ. Effects of aging, word frequency, and text stimulus quality on reading across the adult lifespan: Evidence from eye movements. Journal of Experimental Psychology: Learning, Memory, and Cognition. 2018; 44(11):1714.

103. Hahn G, Penka D, Gehrlich C, Messias A, Weismann M, Hyvärinen L, et al. New standardised texts for assessing reading performance in four European languages. British Journal of Ophthalmology. 2006; 90(4):480-4.

104. Kusajima T. Visual reading and braille reading: an experimental investigation of the physiology and psychology of visual and tactual reading. New York: American Foundation of the Blind; 1974.

105. Kemper S, Liu C-J. Eye movements of young and older adults during reading. Psychology and Aging. 2007; 22(1):84-93.

106. Kemper S, McDowd J. Eye movements of young and older adults while reading with distraction. Psychology and Aging. 2006; 21(1):32.

107. Wingfield A, Tun PA, editors. Spoken language comprehension in older adults: Interactions between sensory and cognitive change in normal aging. Seminars in hearing; 2001: Copyright© 2001 by Thieme Medical Publishers, Inc., 333 Seventh Avenue, New ….

108. Varadaraj V, Lesche S, Ramulu PY, Swenor BK. Reading speed and reading comprehension in age-related macular degeneration. American Journal of Ophthalmology. 2018; 186:138-43.

109. Van der Linden M, Hupet M, Feyereisen P, Schelstraete M-A, Bestgen Y, Bruyer R, et al. Cognitive Mediators of Age-Related Differences in Language Comprehension and Verbal Memory Performance. Aging, Neuropsychology, and Cognition. 1999; 6(1):32-55.

110. Gutchess A. Plasticity of the aging brain: New directions in cognitive neuroscience. Science. 2014; 346(6209):579-82.

111. Voelcker-Rehage C. Motor-skill learning in older adults—a review of studies on age-related differences. European Review of Aging and Physical Activity. 2008; 5:5-16.

112. Norden J. Neuroscience of Learning and Memory I. International Academy for Professional Development: Centre for Neuroscience; 2014.

113. Kandel ER, Schwartz JH, Jessell TM, Siegelbaum SA, Hudspeth AJ. Principles of Neural Science: McGraw-Hill Companies Inc.; 2013.

114. Pirchoa-Fuller MK. Processing speed and timing in aging adults: psychoacoustics, speech perception, and comprehension. International Journal of Audiology. 2003; 42:S59-S67.

115. Murman DL. The Impact of Age on Cognition. Semin Hear. 2015; 36(3):111-21.

116. Salthouse TA. Selective review of cognitive aging. Journal of the International Neuropsychological Society: JINS. 2010; 16(5):754.

117. Isingrini M, Vazou F. Relation between fluid intelligence and frontal lobe functioning in older adults. International Journal of Aging and Human Development. 1997; 45(2):99-109.

118. Sesma HW, Mahone EM, Levine T, Eason SH, Cutting LE. The contribution of executive skills to reading comprehension. Child Neuropsychology. 2009; 15(3):232-46.

119. de Beni R, Borella E, Carretti B. Reading comprehension in aging: The role of working memory and metacomprehension. Aging, Neuropsychology and Cognition. 2007; 14:189-212.

120. Arrington CN, Kulesz PA, Francis DJ, Fletcher JM, Barnes MA. The Contribution of Attentional Control and Working Memory to Reading Comprehension and Decoding. Scientific Studies of Reading. 2014; 18(5):325-46.

121. Daneman M, Carpenter PA. Individual differences in working memory and reading. Journal of Verbal Learning and Verbal Behaviour. 1980; 19:450-66.

122. Peters RM, Hackeman E, Goldreich D. Diminutive digits discern delicate details: fingertip size and the sex difference in tactile spatial acuity. Journal of Neuroscience. 2009; 29(50):15756-61.

123. Wong M, Peters RM, Goldreich D. A physical constraint on perceptual learning: tactile spatial acuity improves with training to a limit set by finger size. Journal of Neuroscience. 2013; 33(22):9345-52.

124. Wormsley DP. Hand Movement Training in Braille Reading. Journal of Visual Impairment and Blindness. 1981; 75(8):327-31.

125. Legge GE, Granquist C, Lubet A, Gage R, Xiong YZ. Preserved tactile acuity in older pianists. Atten Percept Psychophys. 2019; 81(8):2619-25.

126. Hamilton R, Keenan JP, Catala M, Pascual-Leone A. Alexia for Braille following bilateral occipital stroke in an early blind woman. Neuroreport. 2000; 11(2):237-40.

127. Verhoeven L, Reitsma P, Siegel LS. Cognitive and linguistic factors in reading acquisition. Reading and Writing. 2011; 24(4):387-94.

128. Hall AD, Newman SE. Braille learning: Relative importance of seven variables. Applied Cognitive Psychology. 1987; 1:133-41.

129. Bertelson P. Language by touch: the case of braille reading. Speech and Reading: A Comparative Approach. East Sussex: Erlbaum (UK) Taylor & Francis; 1995. p. 91-108.

130. Knowlton M, Wetzel R. Braille reading rates as a function of reading tasks. Journal of Visual Impairment & Blindness. 1996; 90(3).

131. Nolan CY, Kederis JC. Perceptual Factors in Braille Word Recognition (Research Series No. 20). New York: American Foundation for the Blind; 1969.

132. Bertelson P, Mousty P, Radeau M. The time course of braille word recognition. Journal of Experimental Psychology: Learning, Memory, and Cognition. 1992; 18(2):284-97.

133. Simón C, Huertas JC. How blind readers perceive and gather information written in braille. Journal of Visual Impairment & Blindness. 1998; 92(5):322-30.

134. Hughes B, McLelland A, Henare D. On the nonsmooth, nonconstant velocity of braille reading and reversals. Scientific Studies of Reading. 2014; 18(2):94-113.

135. Hughes B. Movement kinematics of the braille-reading finger. Journal of Visual Impairment & Blindness. 2011; 105(6):370-81.

136. Hughes B, Van Gemmert AWA, Stelmach GE. Linguistic and perceptual-motor contributions to the kinematic properties of the braille reading finger. Human Movement Science. 2011; 30(4):711-30.

137. Willis SL. Cognitive training and everyday competence. Annual Review of Gerontology and Geriatrics. 1987; 7(1):159-88.

138. Melzer I, Benjuya N, Kaplanski J. Age-Related Changes of Postural Control: Effect of Cognitive Tasks. Gerontology. 2001; 47(4):189-94.

139. Dinse HR, Kleibel N, Kalisch T, Ragert P, Wilimzig C, Tegenthoff M. Tactile coactivation resets age-related decline of human tactile discrimination. Annals of Neurology. 2006; 60(1):88-94.

140. Lundborg G, Rosen B. The Two-Point Discrimination Test – Time For a Re-Appraisal? Journal of Hand Surgery. 2004; 29(5):418-22.

141. Bruns P, Camargo CJ, Campanella H, Esteve J, Dinse HR, Röder B. Tactile acuity charts: a reliable measure of spatial acuity. PloS One. 2014; 9(2):e87384.

142. Sawada H, Zhao F, Uchida K, editors. Displaying Braille for Mobile Use with the Micro-vibration of SMA Wires. 2012 5th International Conference on Human System Interactions; 2012 6-8 June 2012.

143. Stevens JC. Aging and spatial acuity of touch. Journal of Gerontology. 1992; 47(1):35-40.

144. Stevens JC, Foulke E, Patterson MQ. Tactile acuity, aging, and braille reading in long-term blindness. Journal of Experimental Psychology: Applied. 1996; 2(2):91-106.

145. Lorimer P. Hand techniques in reading braille; synthesis of spatial and verbal elements of reading. British Journal of Visual Impairment. 2002; 20(2):76-9.

146. Yancosek KE, Howell D. A narrative review of dexterity assessments. Journal of Hand Therapy. 2009; 22(3):258-70.

147. Maxfield KE, Perry JD. Performance of blind vocational rehabilitation clients on the purdue pegboard. Perceptual and Motor Skills. 1960; 11(2):139-46.

148. Wittich W, Nadon C. The Purdue Pegboard test: Normative data for older adults with low vision. Disability and Rehabilitation: Assistive Technology. 2015; 12(3).

149. Jacko JA, Scott IU, Sainfort F, Barnard L, Edwards PJ, Emery VK, et al., editors. Older adults and visual impairment: What do exposure times and accuracy tell us about performance gains associated with multimodal feedback? Proceedings of the SIGCHI conference on Human factors in computing systems; 2003.

150. Tobin M, Greenhalgh R. Normative data for assessing the manual dexterity of visually handicapped adults in vocational rehabilitation. Journal of Occupational Psychology. 1987; 60(1):73-80.

151. Buddenberg LA, Davis C. Test–Retest Reliability of the Purdue Pegboard Test. American Journal of Occupational Therapy. 2000; 54(5):555-8.

152. Agnew J, Bolla-Wilson K, Kawas CH, Bleecker ML. Purdue pegboard age and sex norms for people 40 years old and older. Developmental Neuropsychology. 1988; 4(1):29-35.

153. Yeudall LT, Fromm D, Reddon JR, Stefanyk WO. Normative data stratified by age and sex for 12 neuropsychological tests. Journal of Clinical Psychology. 1986; 42(6):918-46.

154. Merritt BK, Fisher AG. Gender differences in the performance of activities of daily living. Archives of physical medicine and rehabilitation. 2003; 84(12):1872-7.

155. Petersen RC. Mild cognitive impairment. The New England Journal of Medicine. 2011; 364:2227-34.

156. Nasresddine ZS, Phillips NA, Bédirian V, Charbonneau S, Whitehead V, Collin I, et al. The Montreal Cognitive Assessment, MoCA: a brief screening tool for mild cognitive impairment. Journal of the American Geriatric Association. 2005; 53(4):695-9.

157. Bopp KL, Verhaeghen P. Aging and verbal memory span: A meta-analysis. Journal of Gerentology. 2005; 60B(5):P223-P33.

158. Hartley JT. Reader and text variables as determinants of course memory in adulthood. Psychology and Aging. 1986; 1:150-8.

159. Babcock RL, Salthouse TA. Effects of increased processing demands on age differences in working memory. Psychology and Aging. 1990; 5:421-8.

160. Salthouse TA, Babcock RL. Decomposing adult age differences in working memory. Developmental Psychology. 1991:765-76.

161. Mehta MA, Goodyer IM, Sahakian BJ. Methylphenidate improves working memory and set-shifting in AD/HD: Relationships to baseline memory capacity. Journal of Child Psychology and Psychiatry. 2004; 45(2):293-305.

162. Cohen H, Scherzer P, Viau R, Voss P, Lepore F. Working memory for braille is shaped by experience. Communication & Integrative Biology. 2011; 4(2):227-9.

163. Papagno C, Minniti G, Mattavelli GC, Manatovan L, Cecchetto C. Tactile short-term memory in sensory-deprived individuals. Experimental Brain Research. 2017; 235(2):471-80.

164. Valentijn SAM, von Boxtel MPJ, von Hooren SAH, Bosma H, Beckers HJM, Ponds RWHM, et al. Change in sensory functioning predicts change in cognitive functioning: results from a 6-year follow up in the Maastricht Aging Study. Journal of the American Geriatric Society. 2005; 53:374-80.

165. Mahncke H, Bronstone A, Merzenich MM. Brain plasticity and functional losses in the aged: scientific bases for a noval intervention. Progress in Brain Research. 2006; 157:81-109.

166. Faubert J. Visual perception and aging. Canadian Journal of Experimental Psychology. 2002; 56:164-76.

167. Wright T. Looking for power: The difficulties and possibilities of finding participants for braille research. Journal of Visual Impairment & Blindness. 2010; 104(12):775-80.

168. Graham ID, Logan J, Harrison MB, Straus SE, Tetroe J, Caswell W, et al. Lost in knowledge translation: time for a map? Journal of Continuing Education in the Health Professions. 2006; 26(1):13-24.

169. Goldreich D, Kanics IM. Performance of blind and sighted humans on a tactile grating detection task. Perception & Psychophysics. 2006; 68(8):1363-71.

170. Nolan CY, Morris JE. Development and validation of the Roughness Discrimination Test. The International Journal for the Education of the Blind. 1965; 15(1):1-6.

171. Martiniello N, Wittich W. The association between tactile, motor and cognitive capacities and braille reading performance: a scoping review of primary evidence to advance research on braille and aging. Disability & Rehabilitation. 2020.

172. Braun V, Clarke V. Thematic analysis. APA handbook of research methods in psychology, Vol 2: Research designs: Quantitative, qualitative, neuropsychological, and biological. APA

handbooks in psychology®. Washington, DC, US: American Psychological Association; 2012. p. 57-71.

Chapter 2 – Study 1: The association between tactile, motor and cognitive capacities and braille reading performance: a scoping review of primary evidence to advance research on braille and aging

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2.1. Abstract

As the prevalence of age-related visual impairment increases, a greater understanding of the physiological and cognitive capacities that are recruited during braille reading and the potential implications of age-related declines is required. Methods: This scoping review aimed to identify and describe primary studies exploring the relationship between tactile, motor and cognitive capacities and braille reading performance, the instruments used to measure these capacities, and the extent to which age is considered within these investigations. English peer-reviewed articles exploring the relationship between these capacities and braille reading performance were included. Articles were screened by two researchers, and 91% agreement was achieved (*kappa* = .84 [.81,.87], $p<.01$). Results: 2405 articles were considered of which 36 met the inclusion criteria. Fifteen investigated the relationship between tactile capacities and braille reading performance, 25 explored motor capacities, and 5 considered cognitive capacities. Nineteen instruments were used to measure tactile capacity, 4 for motor dexterity, and 7 for cognitive capacity. These studies focus on younger participants and on those who learned braille early in life. Conclusions: Although this overview underscores the importance of tactile perception and bimanual reading, future research is needed to explore the unique needs of older adults who learn braille later in life.

Keywords: aging; blindness; braille; reading; rehabilitation; vision, low

2.2. Introduction

Tactile sensitivity, manual dexterity and cognitive capacities are vital components of efficient braille reading.[1,2] Many of these physiological and cognitive capacities are known to decline as part of the typical aging process.[3] While there is a broad scope of literature centered on braille literacy and childhood,[2,4-6] there is insufficient evidence on the extent to which age-related declines in these capacities will effect braille reading outcomes. In recent decades, various instruments have been developed to measure tactile, motor and cognitive capacities in blind individuals and to explore the relationship between these measures and braille reading outcomes.[7-10] However, these studies are sparse and have given rise to inconsistent findings depending on the instruments that are used, even when those instruments purportedly measure the same underlying capacity. For example, both Bola[11] and Veispak[12,13] explored the association between passive tactile acuity (using the Grating Orientation Test[14]) and braille reading speed, though Veispak observed a relationship while Bola did not. Thus far, there is no research which describes and summarizes these findings within a single comprehensive review. As the prevalence of age-related visual impairment continues to increase,[15,16] there are growing calls for research on braille and aging and for the development of evidence-based practices that best support the needs of older adults who pursue braille.[17] It is possible that older adults with impaired tactile, motor or cognitive capacities may benefit from specific pre-braille readiness activities designed to target their unique needs.[17] Similarly, research is needed to ensure that clinical decisions are not based upon conjecture and overarching generalizations about aging, such as the prevailing belief among some prospective clients and rehabilitation practitioners that older adults are unable to pursue braille due to reduced tactile sensitivity.[17,18] The objectives of this review are to provide an overview of primary studies that explore the relationship between tactile, motor and cognitive capacities and braille reading performance in order to consolidate available research as a precursor to future studies that will build upon this evidence.

The ability to read is necessary for the completion of common daily tasks, from identifying household products to reading prescriptions, documents and instructions, and is closely tied to feelings of self-competence and independence for individuals who acquire a visual impairment [19,20]. In fact, reading-related difficulties are among the most common reasons for referral to low vision rehabilitation services.[21,22] Braille, a tactile system of reading and writing, provides a non-visual alternative to print for those with significant or fluctuating visual impairments or for those who have a degenerative visual condition.[19] As a literacy medium, it provides access to spelling, punctuation and other grammatical nuances that are often difficult to access through auditory-based methods alone.[23] Moreover, for the growing population of individuals with acquired dual sensory impairment (concurrent vision and hearing loss), braille may be the *only* vehicle through which communication becomes possible.[24]

The reading of braille draws on the somatosensory cortex responsible for processing tactile perception, the motor cortex for fine movements of the fingers and hands and, much like visual reading, the cognitive functions of memory, sustained attention, information processing and comprehension.[25] Tactile information is perceived by a variety of peripheral touch receptors that transmit information from the distal pads of the fingertips to the central nervous system. The combined information when readers lightly slide their fingers across a page of braille leads to the ability to discriminate braille characters.[3] Unlike print reading, braille reading can only occur haptically, through the smooth and constant movements of the reading hands, and disruption to movement will necessarily impede perception.[1,26] Impairments in one or both hands or instability stemming from degenerative disease may consequently impede tactual perception and reading speed.[27] Braille reading differs from print in that characters are read sequentially as the fingers move across a line rather than being perceived simultaneously during a single saccadic gaze. New or less proficient braille readers must retain each successive symbol in working memory to build a representation of the word in question,[23,28-31] initially placing a greater emphasis on working-memory.[17,32] Conversely, more proficient or experienced braille readers with greater reading fluency are able to draw on lexical, perceptual and contextual cues to facilitate faster reading and comprehension.[33-35]

Normal aging is associated with steady declines in tactile acuity, fine motor dexterity, and cognitive functions, including working-memory and sustained attention.[3] Tactile acuity of the fingertips has been shown to decrease with age,[7,36] particularly among the sighted who lack a lifetime of tactile experience,[37] and this can be further impaired by neuropathic comorbidities such as diabetes.[25] Declines in fine and gross motor dexterity are also observable with advancing age. In particular, fine-motor dexterity appears to be most effected by the aging process, gradually impacting the use of fingers and hands during tasks that require pinching, grasping or the manipulation of objects, finger strength, or the coordinated use of the fingers and hands.[38] Similarly, gray and white matter deterioration is observable after the fifth decade of life.[39,40] Among sighted print readers, a correlation exists between degree of hippocampal shrinkage, performance on memory-based tasks (such as word retention) and overall memory decline.[40] Though the relationship between working-memory and braille reading performance has not been directly explored, it has been shown that age-related declines in short-term working memory are significantly correlated with reading comprehension difficulties among the sighted.[41]

Although increased age is generally correlated with declines in tactile, motor and cognitive capacities, these characteristics have been measured using a wide range of instruments.[42,43] Moreover, tactile perception, motor dexterity and cognitive functioning are broad descriptors of capacities that may refer to different underlying components that are not directly comparable.[44] These considerations may therefore give rise to inconsistencies among results, depending on the specific capacity that is being assessed and the measurement instrument that is used. For example, tactile sensation can be passively perceived (without any movement between the stimulus and the skin) or actively perceived (where there is movement or friction between the stimulus and the skin), each of which activate different receptors.[43,44] The passive 2-point discrimination test, originally pioneered by E.H. Weber in the mid-19th century,[45] is routinely employed within medical and research domains but has been called into question due to its purportedly poor test-retest reliability. Alternative measurements of passive tactile acuity (such as the Grating Orientation Test) which emphasize the ability to discern groove orientation rather than the ability to perceive two individual points have therefore also been devised.[43] Quite apart from the specific instrument used to measure different facets of tactile acuity, the question of whether methods used to measure passive and active touch acuity are interchangeable remain the subject of debate.[25,43,46] Reliance on the findings of a single study or the use of a specific instrument may therefore lead to uninformed clinical decisions, such as wrongly assuming that performance on a specific measure will predict braille reading capacity.

While congenital visual impairments were historically prevalent,[4,47] there has been a steady increase of working-age and older adults with acquired visual impairment over recent decades. It is projected that the prevalence of age-related visual impairment will double in Canada and triple worldwide over the next two decades, due to both population growth and aging.[15] This raises critical new questions for rehabilitation practitioners, including the need to understand how older populations and those who learn braille later in life differ from children in underlying mechanisms that influence their braille training outcomes, and whether specific remedial activities or supports would enhance their braille reading performance. For example, a report on braille and aging compiled by Cryer[17] synthesized several existing methods used to test and train tactile ability among adult braille clients. Though vital in that it answered some initial questions, this report did not include a systematic overview of all existing primary literature and did not consider the contribution of motor and cognitive capacities within the braille reading context. Recognizing this, the authors concluded by explicitly emphasizing the need to explore these themes in greater depth as a first step towards developing methods to better support older adults who learn braille.[17]

The aims of this review are to (1) identify and describe existing literature on the relationship between tactile, motor and cognitive capacities and braille reading performance; (2) summarize the range of instruments that have been used to measure these capacities, and (3) describe the extent to which the relationship between age and braille reading performance is considered within these investigations. This overview will clarify the current state of knowledge on braille and aging within a field that has traditionally focused almost exclusively on braille learning in childhood,[5,48] and will set future research agendas on braille and aging by highlighting where current knowledge gaps exist.

2.3. Methods

A scoping review[49] that summarizes all relevant primary studies was deemed to be optimal, rather than alternative review methodologies that exclude articles on the basis of sample or effect size. Following the scoping review methodology outlined by Arskey and O'Malley[49] and Levac, Colquhoun & O'Brien[50], this study consisted of five separate stages, each of which is described below. This review also complies with the methodological recommendations outlined within the Joanna Briggs Institute manual for conducting systematic scoping reviews.[51]

2.3.1. Stage 1: Identifying the research questions

This scoping review is based on the following research questions:

(1) What is known about the relationship between tactile, motor and cognitive capacities and braille reading performance?
(2) What are the instruments that have been used to measure these capacities?

(3) To what extent is the relationship between age and braille reading performance considered within these investigations?

The search strategy for this study was guided by the following parameters:

2.3.1.1. Population

This review focuses on the study of participants who read braille tactually with their fingers. Studies with braille readers who are described as blind, low vision or visually impaired are included, even if specific acuities and fields are not reported. Braille readers of any age and any braille level are included, as long as the study in question explores the relationship with at least one of the identified capacities (tactile, motor or cognitive) and at least one of the braille reading measures (reading speed, accuracy or comprehension).

2.3.1.2. Concept

- Tactile capacity: may includes studies of passive acuity, where a stimulus is applied to the fingertip without any movement between the finger and the stimulus, or active (haptic) acuity, where such movement is permitted or required (as with the reading of braille).[42]
- Motor capacity: may include measures of fine or gross motor dexterity,[52] as well as studies that examine the use of fingers and hands and the relationship of these patterns to braille reading outcomes.[53]
- Cognitive capacity: refers to domain-specific cognitive mechanisms that are known to decline with age, such as working-memory, sustained attention and information processing.[54] Notably, this does not include level of education, phonological awareness, orthography or other literacy-based competencies. While prior education and literacy experiences are important considerations, the present investigation focussed on the physiological and cognitive capacities that are known to decline with age.
- Braille reading performance is divided into the following subcomponents, in line with measures usually considered when assessing braille reading skills:[2] speed (characters or words per minute), accuracy (number of misread characters or words) and comprehension (understanding of the text, typically assessed through the use of comprehension questions

or methods such as the closed procedure).[2] Studies which examine at least one of these reading outcomes in relation to tactile, motor or cognitive capacities were included. Both oral and silent reading measures were deemed eligible as was the reading of uncontracted (alphabetic) or contracted (abbreviated) braille.

- Age: To address the final research question on the extent to which the relationship between age and braille reading performance is explored within the eligible studies, three age-related variables are considered: chronological age, age of onset, and age when braille was learned.

2.3.1.3. Context

No limitations were placed on geographic location or date of publication. Only peer-reviewed articles published in English were considered.

2.3.2. Stage 2: Identifying relevant articles

A comprehensive search of four peer-reviewed academic databases (PsycInfo, ERIC, Cochrane and PubMed) was conducted in August 2019 and updated in July 2020, in accordance with the Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) Checklist: see Appendix B1) for details. Given the limited size of the research base relating to braille, the decision was made to simply search for the word "braille" and to rely on the inclusion criteria to narrow the analysis (see Table 3 for inclusion/exclusion criteria). Second, a manual search in the JVIB online database was conducted in July 2020, due to the relevance of this publication to the field of braille and blindness. Given the focus on braille and blindness within JVIB, specific key words were used to narrow the search: (keyword: 'braille AND (speed OR accuracy OR comprehension)'. Finally, the reference lists of all included articles were reviewed to ensure that no relevant articles were omitted. All relevant citations and abstracts were downloaded and imported into a Microsoft Excel worksheet. Duplicates were flagged (based on their title and author list) with a custom macro and then manually reviewed prior to being removed.

Table 3. – Inclusion and exclusion criteria

Inclusion Criteria	Exclusion Criteria
● studies which explore the relationship between tactile, motor and/or cognitive capacities and braille reading performance (speed, accuracy and/or comprehension), regardless of whether a relationship is found ● study samples comprised of tactual braille readers irrespective of age or braille level, including blind participants and blindfolded sighted participants who learned braille entirely through touch ● peer-reviewed articles published in English ● no restrictions placed on geographic location or date of publication ● any quantitative study designs that consider a correlation between capacities and braille reading outcomes, including cross-sectional and longitudinal studies	● studies which explore tactile, motor or cognitive capacities but that do not examine a correlation between these capacities and braille reading performance ● studies that explore a relationship between braille reading performance and other demographic variables (education, gender, employment level, etc.) rather than tactile, motor or cognitive capacities; ● studies focused specifically on the relationship between literacy skills rather than tactile, motor or cognitive capacities (such as orthography, phonetics, vocabulary) and braille reading outcomes ● study samples comprised of sighted participants who read braille visually ● studies that explore the relationship between tactile, motor or cognitive capacities and performance on tactile recognition tasks rather than reading performance (such as the ability to differentiate between different tactile symbols) ● studies not available in English ● non-peer-reviewed materials, such as opinion pieces, literature reviews, conference proceedings, books and dissertations ● secondary research not reporting on primary data or findings ● qualitative studies about braille that do not consider correlations

2.3.3. Stage 3: Article selection

Articles were screened by two reviewers (the first author and an additional research assistant). Screening consisted of a two-stage process, beginning with the screening of titles and abstracts and finally with the review of the full texts of those articles which had not been excluded at the first stage. Inclusion/Exclusion decisions were marked in separate files by each reviewer and then compared and discussed.

Figure 5 shows the flow of article selection and number of excluded articles at each stage of the process (including results from both the initial search and the July 2020 update).

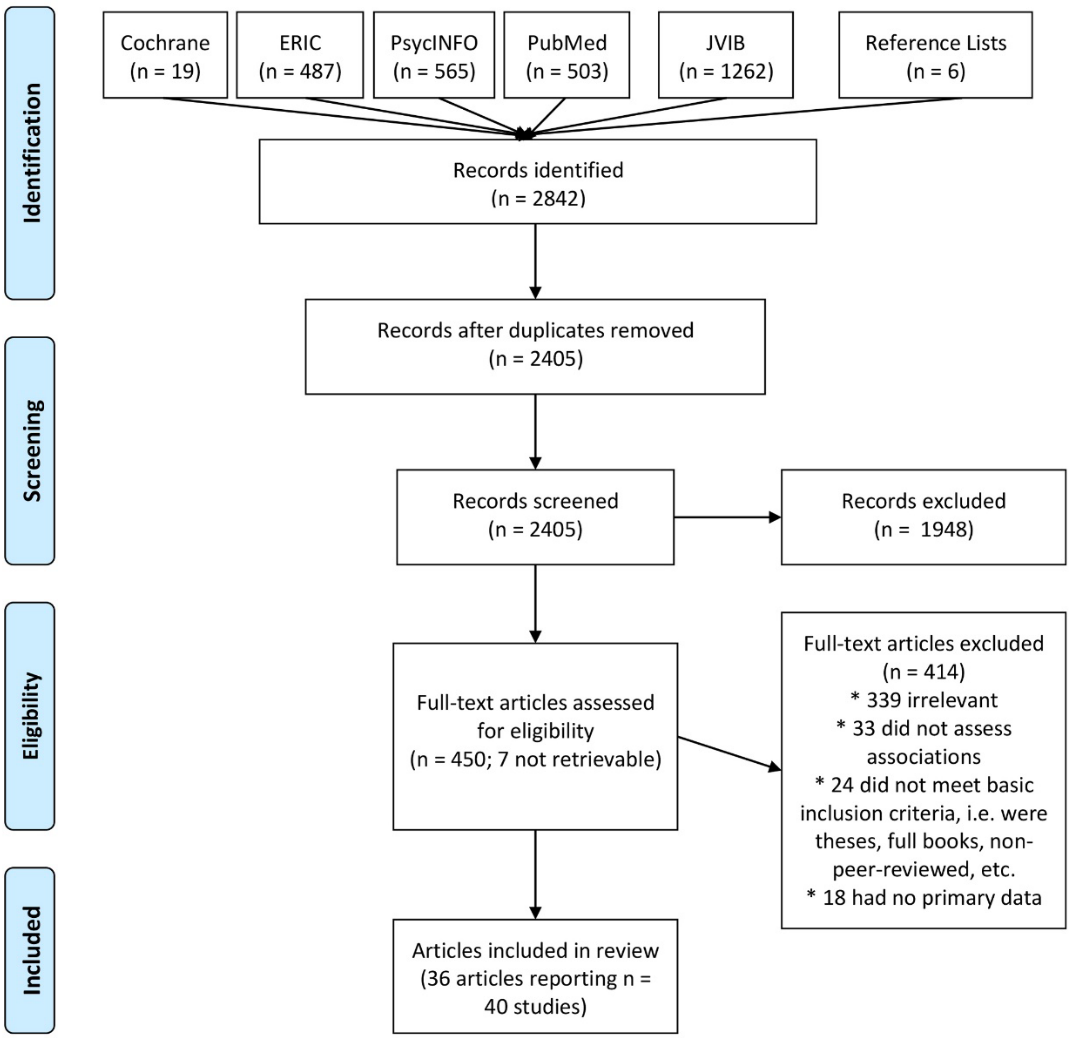

Figure 5. – Diagram showing flow of included studies (review updated as of June 2020)

The search identified 2,405 articles after duplicates were removed (including 6 additional articles identified through manual review of the reference lists of included articles). Some articles report on multiple studies and where that occurred, the results of each study are addressed individually for the purpose of this scoping review.

Titles and abstracts of an initial 250 articles were reviewed by the two reviewers, with 83% agreement as to inclusion (Cohen's *kappa* = .76 [.71, .81], $p < .01$). Differences were resolved between the reviewers through discussion, and after screening all 2,405 titles and abstracts, 91% agreement was achieved (*kappa* = .84 [.81, .87], $p < .01$). Where doubt remained about inclusion, articles were kept.

Screening of the titles and abstracts left 457 which met the criteria for a full-text review. The full text of 450 of these papers was then acquired (7 could not be obtained) and assessed against the inclusion criteria by the two reviewers, with 83.1% agreement achieved (*kappa* = .57 [.46, .68], $p < .01$). It became evident that the most common disagreement related to articles that reported on relevant tactile, motor or cognitive capacities, but did not actually consider any of those characteristics in the analysis. With those articles removed, 93.2% agreement was achieved (*kappa* = .81, [.76, .86], $p < .01$), and the remaining disagreements were resolved through discussion between the two reviewers, resulting in 36 articles selected for inclusion. All analyses for interrater reliability were conducted using the *irr*[55] and *psych*[56] packages from the computer program R (The R Foundation for Statistical Computing, Vienna, Austria, version 3.4.4).

2.3.4. Stage 4: Charting the data

The 36 articles that met the inclusion criteria[8-12,27,57-86] were then subject to data extraction following the guidelines outlined by Peters et al.[51]. The extracted data for each study are summarized in Appendix B2.

2.3.5. Stage 5: Collating, summarizing, and reporting the results

(A) Descriptive numerical analysis: Numerical analysis (percentage, range, central tendency, variation) was computed to describe the nature and distribution of all included studies.

(B) Qualitative thematic analysis: Following the procedure for qualitative thematic analysis outlined by Braun et al[87] the 36 included studies were coded by the two reviewers into one of three categories according to whether they examined tactile, motor or cognitive capacities in relation to braille reading performance. The studies were further categorized into subthemes to describe the underlying tactile, motor and cognitive capacities investigated in the studies. Each reviewer coded the articles separately and this was then compared through discussion, where no disagreements were observed.

2.4. Results

The 36 articles (representing 40 unique studies) that met the inclusion criteria were published between the years of 1934 and 2019. Figure 6 depicts the number of articles published in each decade. It can be seen that between 1954 and 1994, the number of publications steadily increased, resulting in more than half (58%) of the included studies published during this time frame. Of interest, n=9 articles were published between 1984 – 1994, making this the most prolific decade.

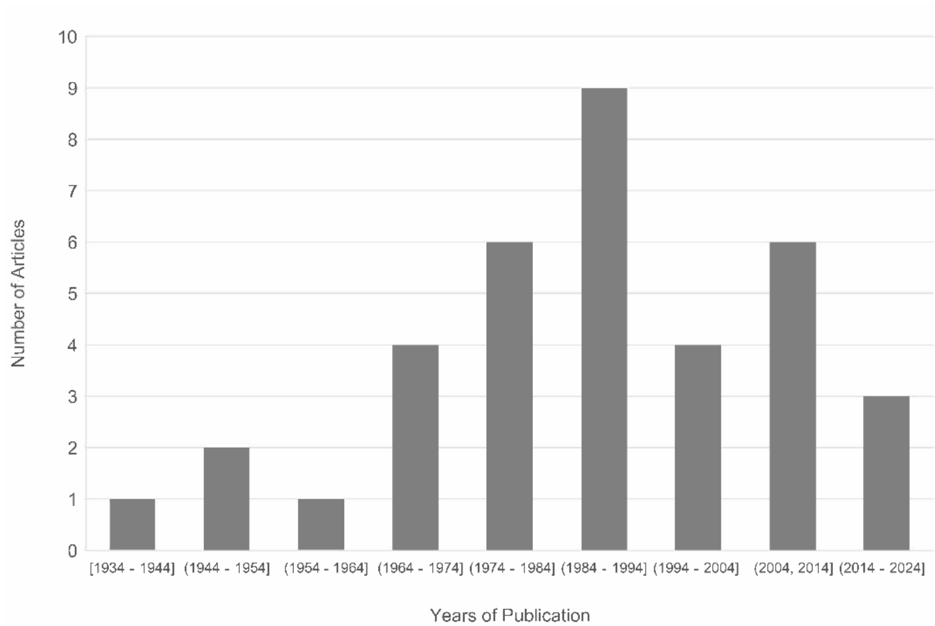

Figure 6. – Histogram depicting the number of published articles appearing in each decade since 1934

As shown in Figure 7, the top three represented journals were the Journal of Visual Impairment & Blindness (n = 9), Research in Developmental Disabilities (n = 4), and Neuropsychologia (n = 3). Table 4 (below, on p. 60) summarizes the characteristics of the 36 articles (40 studies), and the detailed data extracted is provided in Appendix B2.

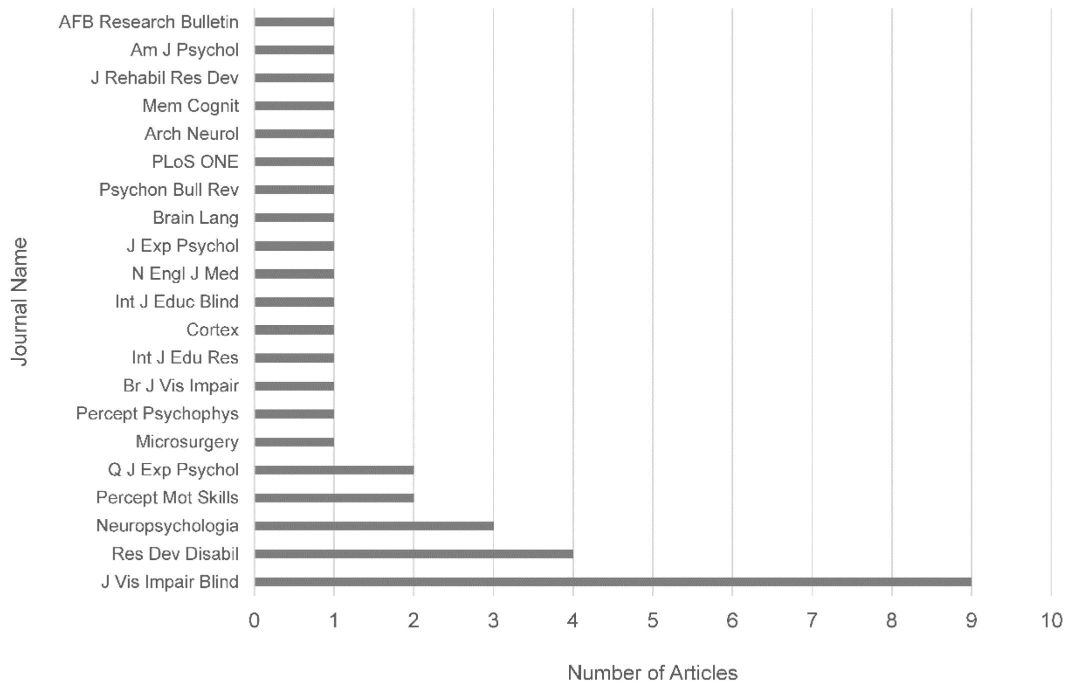

Figure 7. – Graph depicting the number of articles published by journal of publication

As will be discussed, two notable characteristics of the included studies were their sample size and the range of included participant ages (depicted in Figure 8 below, on p. 61). The sample size for the 40 studies ranges between 6 and 73 participants (with two outliers having *n* = 120 and *n* = 256 respectively, both focused on young children). The mean sample size among the 40 studies is 37.1 (SD=46.8) (removing the two outliers: mean=26.4, SD=14.1) and only four have *n* >= 50. Collectively the studies included participants between the age of 3 and 82 (mean=30.1, SD=14.2); however, the *average* lower and upper bounds of the age groups represented (where this information was available) were 14.3 and 40.1 respectively. Among the 32 studies that reported sufficient information to determine the age range of participants, 32.5% (n=13) studies included participants over the age of 60, and 25% (n=10) included only participants below the age of 21. Importantly, 20% (n=8) did not provide enough information to determine the age range of participants, and a full 47.5% (n=19) did not report the mean or median age of participants.

Table 4. – Summary of characteristics of included studies

Characteristic	N	% of Studies
Study location		
United States	20	50%
Canada	3	7.5%
Holland	3	7.5%
Japan	2	5%
Belgium	1	2.5%
China	1	2.5%
England	1	2.5%
Estonia	1	2.5%
France	1	2.5%
Greece	1	2.5%
Poland	1	2.5%
Spain	1	2.5%
Nature of investigation		
Cross-sectional	29	72.5%
Prospective	10	25%
Longitudinal	1	2.5%
Capacities explored		
Motor	25	62.5%
Tactile	15	37.5%
Cognitive	5	12.5%
Exploring multiple capacities	6	15%
Braille reading measures explored		
Speed	33	82.5%
Accuracy	14	35%
Comprehension	3	7.5%
Capacity [a]	3	7.5%
Exploring multiple measures	13	32.5%
Age groups represented in sample		
Indeterminate [b]	8	20%
Children (< 10)	11	27.5%
Youth (10 – 18)	20	50%
Adults (19 – 59)	16	40%
Older adults (60+)	13	32.5%

[a] These studies measured braille reading performance on a binary “can vs cannot read” basis, or described reading performance as “poor/fair/very good” without any further explanation as to the meaning of these descriptions

[a] Insufficient information was provided in these studies to determine the age range of participants

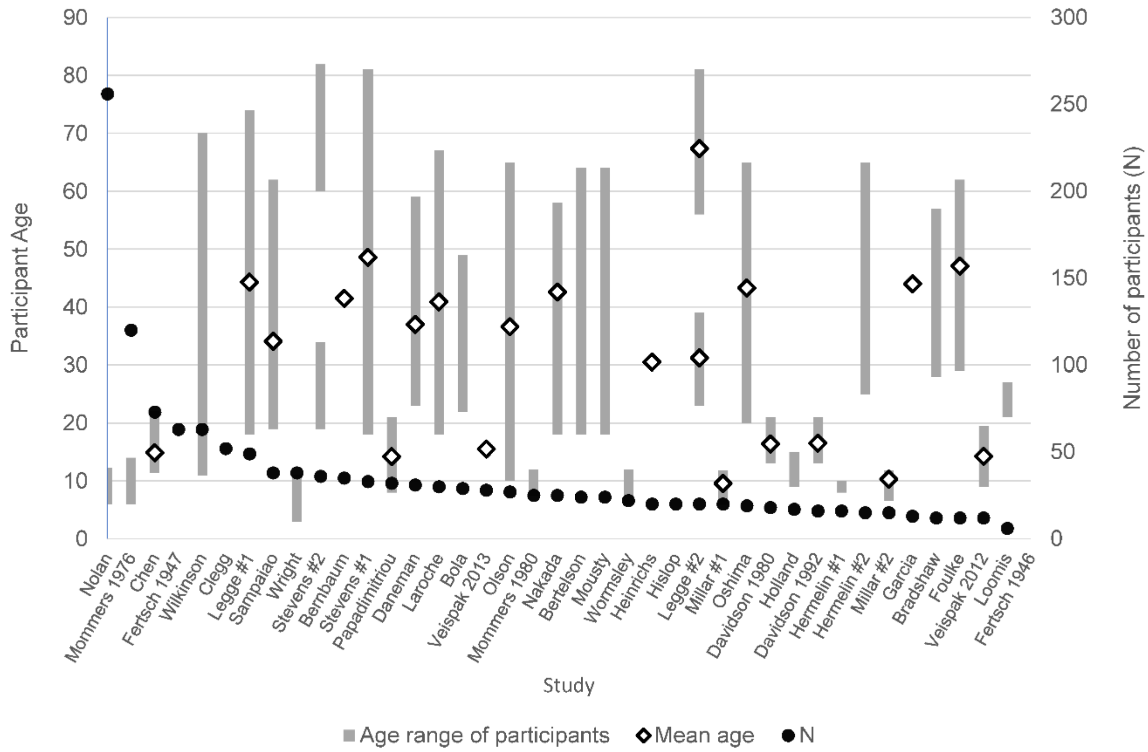

Figure 8. – Graph summarizing the age range, sample size, and mean age of participants in each study

2.4.1. Relationship between Capacities, Braille Reading and Instruments Used

2.4.1.1. Tactile capacities

Among the 40 studies (36 articles), 15 studies (13 articles) explored the relationship between tactile capacity measures and braille reading performance (see Table 5). Of these, 8 studies (7 articles) examined passive (or static) acuity and 7 studies (6 articles) explored active (or haptic) acuity. In total, 19 different instruments were used to measure tactile capacity (11 for passive and 8 for active). Only 6 of the instruments were used in more than one study (Grating Orientation Test, Static Two-point Discrimination Test, Two-point Gap Discrimination Test, Nylon Filament Test, Roughness Discrimination Test, and Legge Dot Chart). Overall, 12 studies (10 articles) explored the relationship between tactile capacity and reading speed, 4 studies (4 articles) for reading accuracy, and 3 of the studies (3 articles) explored the relationship between tactile capacity and a more general can read/cannot read measure. None of the articles explored the relationship between tactile capacity and reading comprehension.

Table 5. – Tactile capacities and relationship to braille reading performance.

Instrument	Speed	Accuracy	Capacity
Passive Tests			
Distinguishing between two points at various distances			
Two-Point Discrimination Test (Static)	N = 1; Not sig = 1[10 (Study #1)]		N = 2; Sig = 1[78*]; Not Sig = 1[27◊]
Two-Point Discrimination Test (Moving)			N = 1; Sig = 1[78*]
Identification of the presence/absence of a gap			
Disk Gap Detection	N = 1; Sig = 1[10* (Study #1)]		
Two-Point Gap Discrimination Test	N = 1; Sig = 1[10* (Study #2)]		N = 1; Sig = 1[68♦]
Identification of the orientation of a stimuli on the finger			
Grating Orientation Test	N = 3; Not sig = 1[11]; Sig = 2[12*; 83*]	N = 2; Not sig = 2[83, 12]	
Line Orientation	N = 1; Not sig = 1[10 (Study #2)]		
Two-Point Orientation Test	N = 1; Sig = 1:[10* (Study #2)]		
Differentiating the length of stimuli			
Length Discrimination	N = 1; Not sig = 1[10 (Study #2)]		
Identifying the sensation of touch or vibration			
Nylon Filament Test			N = 2; Sig = 1[68♦]; Not sig = 1[78]
Vibro-Tactile Detection			N = 1; Sig = 1[68♦]
Measurement of electrical impulses transmitted through the nerve			
Nerve Conduction Study			N = 1; Not sig = 1[27◊]
Active Tests			
Differentiating and categorizing based on size / shape / texture			
Haptic Figure Orientation Test	N = 1; Not sig = 1[75◊]		
Haptic Object Discrimination Test	N = 1; Not sig = 1[75◊]		
Haptic Size Discrimination Test	N = 1; Not sig = 1[75◊]		
Roughness Discrimination Test	N = 2; Sig = 1[8*]; Not sig = 1[76◊]	N = 1; Sig = 1[8*]	

Instrument	Speed	Accuracy	Capacity
Tactual Discrimination Test	N = 1; Sig = 1: [60]*	N = 1; Sig = 1: [60]*	
Tactile Kinesthetic Form Discrimination Test	N = 1; Not sig = 1[75]◊		
Determining orientation of tactile figures (logarithmically decreasing size)			
Legge "Dot Chart"	N = 2; Not sig = 2[9 (Study #1); 80]		
Legge "Ring Chart"	N = 1; Not sig = 1[9 (Study #2)]		

*Study found a reportedly significant relationship between the assessment and the identified reading performance metric (typically at the .05 level).
♦ Study described the results as being 'significant' but did not report statistical significance tests or results.
◊ Study did not report statistical significance tests or results, and did not describe the results as being 'significant'.

2.4.1.2. Motor capacities

25 of the studies (23 articles) examined motor capacities in relation to braille reading performance, with 22 studies (20 articles) investigating reading speed, 9 studies (8 articles) examining accuracy, and 5 studies (5 articles) exploring reading comprehension (see Table 6 on the following page).

The measurement of motor capacities in these studies relied upon the observation of fingers and hand usage during braille reading. Among the 25 studies, 2 examined the relationship between contact force (the amount of pressure applied by the reading fingers) and braille reading performance; 5 focused on the use of specific fingers during braille reading; 9 focused on hand usage (left vs. right hand); and 13 focused on the use of specific hand reading patterns (whether the hands move together across the line or whether they employ the more advanced scissors technique, where one hand reads the remainder of the current line while the other begins reading the next line).

Table 6. – Motor capacities and relationship to braille reading performance

Capacity	Speed	Accuracy	Comprehension
Contact Force (Pressure)	N = 1; Not sig = 1[71]	N = 1; Not sig = 1[73◊]	
Hand Movement Patterns	N = 11; Sig = 10[72*, 59*; 63*, 64♦, 67*, 74 (Study #2)*, 77*, 85♦, 86*, 88*]; Not sig = 1[70◊]	N = 2; Sig = 1[81*]; Not sig = 1[62◊]	N = 4; Not sig = 4[72, 59, 62◊, 67]
Hand Used (Left/Right)	N = 10; Sig = 7[65*, 69* (Study #1 & #2), 74* (Study #1), 76*, 82*, 84*]; Not sig = 3[58, 66, 77]	N = 6; Sig = 3[69* (Study #1 & #2), 84*]; Not sig = 3[58, 66, 74 (Study #1)]	N = 1; Not sig = 1[84]
Finger(s) Used	N = 5; Sig = 3[66*, 69* (Study #1), 79*]; Not sig = 2[76, 84]	N = 3; Sig = 2[66*, 69* (Study #1)]; Not sig = 1[84]	N = 1; Not sig = 1[84]

*Study found a reportedly significant relationship between the assessment and the identified reading performance metric (typically at the .05 level).
♦ Study described the results as being 'significant' but did not report statistical significance tests or results.
◊ Study did not report statistical significance tests or results, and did not describe the results as being 'significant'.

2.4.1.3. Cognitive capacities

In total, 5 of the studies (reported in 5 articles) explored the correlation between cognitive capacities and braille reading performance, with 5 investigating speed, 3 investigating accuracy, and 1 exploring comprehension (see Table 7 on the following page). Overall, 7 instruments were used, which fall into one of three broad categories: intelligence or IQ tests; tests of processing speed (the speed at which a participant is able to process information being perceived); and tests relating to short-term working memory (the ability to retain and recall information that is just perceived).

2.4.2. The relationship between age and reading performance

Table 8 (on the following page) provides an overview of the extent to which age-related variables were considered across the 40 studies. The 11 studies (in 10 articles) which directly explored the relationship between age-related variables (chronological age, age of onset or braille learning age) and braille reading performance included between 13 and 73 participants (mean 31.9, SD 16.8) ranging in age from 11 to 74 (mean 36.9, SD 9.5).

Table 7. – Cognitive capacities and relationship to braille reading performance

Capacity	Speed	Accuracy	Comprehension
		Intelligence	
IQ	N = 2 Not sig = 2[80◊, 85]	N = 1; Not sig = 1[80◊]	
		Processing Speed	
Rapid Automatic Naming	N = 2; Sig = 2[12*, 83*]	N = 2; Sig = 1[83*]; Not sig = 1[12]	
		Short-Term Working Memory	
Braille Span Test	N = 1; Not sig = 1[61]		N = 1; Sig = 1[61*]
Listening Span	N = 1; Not sig = 1[61]		N = 1; Sig = 1[61*]
Listening Comprehension Test	N = 1; Not sig = 1[61]		N = 1; Sig = 1[61*]
Speech-in-Noise Test	N = 2; Not sig = 2[12, 83]	N = 2; Sig = 2[12*, 83*]	
Verbal Short-Term Memory Tests (Digit Span, Non-word Repetition)	N = 3; Not sig = 3[12, 61, 83]	N = 2; Sig = 2[12*, 83*]	N = 1; Sig = 1[61*]

*Study found a reportedly significant relationship between the assessment and the identified reading performance metric (typically at the .05 level).

Table 8. – Relationship between various measures of age and measures of braille reading performance (speed, accuracy, comprehension)

Measure of Age	Speed	Accuracy	Comprehension	Capacity
Chronological age	N = 4; Sig = 1: [61*]; Not sig = 3[9◊, 11, 79]		N = 2; Sig = 1[79♦]; Not sig = 1[61]	N = 1; Sig = 1 [78*]
Age of onset of blindness	N = 5; Sig = 4[80*, 61*■, 77*, 82*■]; Not sig = 1[59■]	N = 1; Not sig = 1[80]	N = 2; Not sig = 2[59■, 61■]	
Age braille first learned	N = 2; Sig = 2[72*, 67*]	N = 1; Sig = 1[72*] (when reading aloud)	N = 2; Not sig = 2[72◊, 67]	N = 1; Sig = 1[78*]

* Study found a statistically significant relationship between the factor and this reading performance metric.
◊ Study did not report detailed statistical significance test results.
■ Study distinguished only between individuals with "adventitious" or "congenital" vision loss. Categorical definitions for age of onset: Chen[59]: Congenital (0-10 months), Adventitious: 1-13 years; Daneman[61]: Congenital (at birth), Adventitious: "early childhood to middle adulthood"; Mousty[77]: Congenital (at birth), Adventitious: after birth (60% before age 6, 20% before age 10, 13% before age 11, 7% before age 19); Oshima[80]: Early onset (0 to 3), Late onset: 6-52; Sampaio[82]: Birth (0), Early childhood: 1.5-6

Overall, 5 of the studies (in 5 articles) explored the relationship between chronological age and braille reading performance, with 4 examining reading speed; 0 exploring reading accuracy; 2 for reading comprehension, and 1 exploring general braille reading capacity.

In total, 5 of the studies (in 5 articles) explored the relationship between age of onset and braille reading performance. All 5 explored the relationship between age of onset and reading speed; 1 also explored reading accuracy; and 2 also explored reading comprehension. It is impossible to provide a lower and upper age of onset range for these studies collectively, as sufficient information is not provided and different definitions of "age of onset" are used across these studies. While some articles provided continuous age of onset values, others simply categorized participants into dichotomous groups (e.g. congenital vs. adventitious). The specific definitions used for age of onset for these studies are indicated in the legend found at the end of Table 8.

In total, 3 of the studies explored the relationship between the age at which braille was learned and braille reading performance. Of these, 2 examined braille learning age and reading speed; 1 examined reading accuracy; 2 explored the relationship with reading comprehension, and 1 explored the relationship between braille learning age and general 'braille reading capacity'. Note that the definition of braille learning age varied across these 3 studies. Garcia[67] did not specifically identify the age at which participants learned braille (except to note that participants had between 1 and 55 years reading experience); Laroche[72] divided participants into two groups (learned *before* age 10 and learned *after* age 10); and in Nakada[78], participants had completed two years of braille rehabilitation training yielding braille learning ages of between 18 and 58 (mean 42.6, SD 10.2).

2.5. Discussion

The aim of this scoping review was to summarize the breadth and nature of research exploring the relationship between tactile, motor and cognitive capacities and braille reading performance, the instruments used to measure these capacities, and the extent to which age has been considered within these investigations. Spanning 4 databases and 85 years of published literature, this review is noteworthy not merely for the insights it affords, but also for heightening the discrepancies that remain. Though no restrictions were placed on year of publication, only 36 articles (representing 40 studies) published between 1934 and 2019 were deemed eligible. Of note, although braille reading draws on multiple capacities,[1] none of the included studies explore the relationship between tactile, motor and cognitive capacities and braille reading measures within a single sample. This may lead to an over-simplification of the braille reading process, and the misinterpretation of findings which obscure the potential influence of other confounding age-related variables. Similarly, though a wide range of instruments have been used to measure these capacities, most of these tools have only been employed within a single study, highlighting the need for replication. As the prevalence of age-related visual impairment continues to increase, there is an evident need for research focusing on older adults and on those who learn braille beyond childhood.

2.5.1. Relationship between capacities and braille reading and the range of instruments used

2.5.1.1. Tactile capacities

It can be seen that among the 15 studies (13 articles) in Table 5, there is a clear focus on whether passive acuity measures could be used to predict current or future braille reading capacity. This trend persists across the decades, with the earliest passive tactile acuity study published in 1969 and the most recent in 2016.

The interest in passive acuity originates from the medical domain where such tools are routinely employed to assess neurological damage, including diabetic neuropathy of the fingertips.[43] From a clinical perspective, several authors have also highlighted that passive acuity instruments are often portable and simple to administer.[17] In the static two-point discrimination test, for example, the points of the calipers are applied to the pad of the stationary finger at different distances from each other, in order to determine the minimal distance at which the participant is able to distinguish the presence of one or two points.[10] Given that the center-to-center distance between dots in the standard braille cell is approximately 2.28 mm,[9] it is unsurprising that researchers would contemplate whether 2-point threshold measures could be used to predict braille reading ability or whether individuals with a 2-point threshold above 2.28 mm would find it difficult to read standard braille.[27,68,78]

Despite these considerations, the studies in this review differ drastically in the extent to which a relationship between passive acuity and braille reading performance is reported. Among the two most commonly used passive acuity tests within this review (two-point and Grating Orientation), two-point is only related to braille reading performance in 1 of 3 studies, and Grating Orientation in 2 of the 3 studies. These inconsistent findings partially stem from the fact that although the Grating Orientation Test has been found to be a reliable measure of passive tactile perception,[42] the two-point discrimination test depends heavily on the examiner's ability to maintain consistent force with both points across all trials, and is associated with poor test-retest reliability.[42,89] Importantly, it is also difficult to draw specific comparisons across these passive acuity studies, as sufficient demographic information (such as previous braille experience) is not always available, and 3 of the passive acuity studies simply evaluate braille reading performance using a subjective, qualitative scale (cannot read/can read with difficulty/can read well) without specific information about reading rate, accuracy or comprehension.[27,68,78]

Several authors have also highlighted that passive acuity measures reveal little about activities that draw on active tactile perception,[17] leading to an interest in active acuity measures. Indeed, the focus on passive acuity seems counterintuitive given that braille reading is impaired when the fingers remain static or when ineffective movements (such as vertical scrubbing) are employed.[2,53,90] Braille reading activates the nerve endings of sensory receptors, but also the muscles, joints and tendons of the fingers, hands, wrists, arms and shoulders.[2,44,53] Moreover, active tactile perception provides greater control to the participant over the stimulus being perceived and enables the use of strategies to move across symbols more effectively.[9,17]

While there is no doubt that proficient braille reading requires the ability to actively perceive tactile symbols, there are 8 different active acuity instruments used across the studies in this review and only two (Roughness Discrimination Test and Legge Dot Chart) are used in more than one study. Of interest, the Legge Dot Chart is a tactile analogue to the Snellen chart used to measure the threshold of visual perception among the sighted, but is not related to braille reading speed in either of the two studies where it is used.[9,80] This tactile chart consists of nine lines of four randomly presented braille-like symbols (corresponding to the letters *d*, *f*, *h*, and *j*) where the distance between the dots in each symbol decreases logarithmically from one line to the next. Though it can be seen that blind subjects outperformed sighted age-matched subjects in Legge's study,[9] no relationship between active acuity threshold and braille reading speed (using a braille version of the MN Read) is reported. Of relevance is that the blind participants in this study were all experienced braille readers with early blindness and with active acuity thresholds well below the 2.28mm distance required for braille reading.[9] As with visual reading, it may be that further increases in acuity do not accord any additional advantage to reading speed when the acuity is already below the threshold required for successful reading.[9] It is possible that a more significant relationship between speed and acuity measures might be observed among late blind participants and among those whose tactile acuities are closer to the 2.28mm braille threshold.

2.5.1.2. Motor capacities

A majority of the studies in this review are devoted to the motor capacities recruited during braille reading, with 25 studies (22 articles) falling within this domain (see Table 6). Of interest, this research focuses heavily on observations of finger and hand usage during braille reading, rather than on underlying measures of fine or gross motor capacities that may decline with age.

Several of the earliest studies examined whether the use of specific fingers correlate with better braille reading outcomes, and confirm the superiority of the index fingers for tactile perception.[43] Foulke[66] tested braille reading speed on 8 separate fingers for each participant (all but the two thumbs) and found that performance was best on the index fingers of both hands. This is unsurprising given that the index fingers contain the greatest density of sensory receptors (much like the fovea of the eye) and the number of these receptors gradually declines with each digit.[44] While the superiority of the index fingers for tactile perception is undisputed, it is now also recognized that multiple fingers are often recruited during the braille reading process.[2] Even if the index fingers are the most dominant, students are often encouraged to perceive the braille reading line with multiple fingers as this can facilitate reading by confirming what is being processed.[2,76] From an aging perspective, it is possible that readers with damage or disease in the index fingers may develop a preference for relying more heavily on alternative fingers during braille reading and especially benefit from the use of multiple fingers where tactile perception is impaired, contributing to cortical magnification in the preferred reading fingers.[27,44] As such, studies that test braille reading without taking into account preferred reading fingers and habits may not provide a realistic measure of reading performance in such cases.

Much of the motor literature focuses heavily on hand dominance and hand reading patterns, and the question of whether the left or right hand is best for braille reading. Several studies from the 1970s and 1980s are premised on evidence suggesting that sighted participants who are unfamiliar with braille recruit the right hemisphere during braille reading (believed to be responsible for spatial processing) and will therefore perform best when using the left hand. Alternatively, it was believed that experienced braille readers show a right hand dominance because they recognize braille symbols for their linguistic properties and in turn reveal a left hemispheric superiority.[58,69,82] Despite the appeal of arguments based on cortical asymmetry, these studies result in inconsistent findings and confirmed that there is no universally best hand for braille reading. Instead, multiple parts of the cortex (including the occipital cortex) are recruited during the braille reading process, and two-handed reading is associated with faster reading rates.[53]

A total of 13 studies in this review explore the influence of specific hand reading patterns. These patterns are typically categorized as one-handed reading, where either the left or right hand is used alone; two-handed reading where both hands move together with the index fingers spaced slightly apart from each other; and disjointed reading whereby the two hands read together until the midpoint, after which the right hand reads the remainder of the line while the left hand moves diagonally to locate the start of the following line.[1] The latter pattern is virtually always associated with the fastest reading rates, owing in part to the time saved in transitioning from one line to the next.[57] There is considerable evidence that when two hands are used collaboratively, each hand is independently contributing to the reading process. Mommers,[76] for example, observed that when both hands are used, the left hand is used to confirm what has just been read with the right, and in some cases even regresses to re-read passages for confirmation while the right hand continues reading ahead. It has likewise been observed that where large disparities exist between the performance of the left and right hand individually for a particular subject, this disparity limits the potential two-handed reading performance [77].

While two-handed reading is associated with faster reading rates, Wormsley[53] underscores that even where readers use advanced two-handed reading techniques, reading rates do not necessarily improve where tactile recognition skills are deficient.[53] Indeed, poor tactile perception may adversely effect hand reading strategies.[71] These considerations raise the limitations of studies that examine motor capacities in isolation from other factors (such as tactile perception) that may influence overall braille reading rates. Of interest is that, in this review, only the study by Mommers[75] included both measures of tactile perception and motor capacities within the same sample.

Finally, it is well established that motor dexterity, and particularly fine motor skills, decline as a result of the normal aging process and may carry additional consequences that should be considered within the training context.[26,38,90] Though manual dexterity training has led to performance gains among older sighted adults, the degree to which such gains are possible appears to depend on the complexity of the task.[38] Importantly, none of the studies in this review measure fine motor dexterity or whether age-related changes may influence the hand movements which support braille reading.

2.5.1.3. Cognitive capacities

In total, 5 of the articles (representing 5 studies) in this review directly explore the relationship between cognitive capacities and braille reading performance (see Table 7). Most of these studies explore the influence of short-term working memory on braille reading outcomes, with a total of 4 studies falling within this domain. Despite an evident relationship between working memory and aspects of braille reading performance, the studies in this review employ a wide range of working memory instruments including those which require the completion of auditory or braille reading span tasks, but none specifically evaluated tactile short-term working memory. While this is not inconsistent with research on sighted readers (where measures of listening comprehension have been shown to be associated with reading comprehension ability, for example[61]), care must be taken when using such measures to ensure that other impairments (such as undiagnosed hearing loss) are not confounding results. Furthermore, assessing braille reading performance against a task which itself requires the reading of braille (in the case of 'braille span' measures, for example[61]) will potentially disadvantage those with poor braille skills who may read slower and who experience greater cognitive load during reading. Instruments such as the one described in Papagno et al.[91] may be worth further exploration as a method for better isolating tactile short-term working memory performance from the potential influence of reading ability.

Prior research also highlights the need to assess comprehension independently of short-term working memory. Of interest, these cognitive aspects are not considered within the studies of this review, save for Daneman[61] where a comprehension monitoring exercise was proposed to permit assessment of comprehension even in the presence of degraded short-term working memory. These factors are important to control in future research particularly given that cognitive processing errors common among older adults may be masked by apparent poor performance on other measures (such as tactile acuity assessments).[92]

2.5.2. Consideration of age

It is apparent that, although the studies in this review examine different aspects of braille reading performance, this research focuses heavily on younger readers and on those who learn braille early in childhood. Of the 40 studies, only 13 include participants who are above the age of 60, most of whom learned braille early in life. Moreover, where braille learning age is directly explored in relation to reading performance measures, insufficient information is often available. For example, Laroche[72] merely divides participants between those who learn before and after the age of 10. This limits the degree to which results can be meaningfully interpreted, given that the abilities of adults differ drastically from those in older adulthood who experience greater age-related declines.[3] Though it is understood that the typical aging process contributes to declines in tactile, motor and cognitive capacities,[3] evidence also indicates that individuals with extensive tactile exposure and practice maintain tactile perception abilities as they age.[9] For these reasons, the chronological age of participants should not be examined in isolation from their braille learning age or frequency of braille usage. Despite these considerations, none of the studies in this review consider these age-related variables in unison.

2.5.3. Limitation and weaknesses of this study

This is the first study to synthesize primary research on the relationship between physiological and cognitive capacities and braille reading performance. It is possible that some relevant articles have been omitted if the titles and abstracts did not clearly map onto the inclusion criteria. The search was limited to four academic databases, and to peer-reviewed articles published in English. Nonetheless, a manual search through the *Journal of Visual Impairment and Blindness* and through the reference lists of all included articles was conducted, and there were no restrictions on date of publication.

Second, as with other scoping reviews, this overview does not aggregate research findings nor eliminate studies on the basis of quality, sample size and effect size. Given the low prevalence of blindness which often contributes to smaller sample sizes, it was believed that a meta-analysis would significantly restrict the scope of research considered. Future studies are needed to build upon this knowledge base and to assess the reliability of specific measurement instruments.

Third, restricted this review was restricted to the physiological and cognitive capacities known to decline with age. Importantly, this did not consider external factors which may further influence the braille learning experience. Research points to a persistent shortage of specialized teachers who serve blind children, and access to rehabilitation services for adults may be constrained by geographic location, funding programs and restrictive eligibility criteria.[18] Future research is needed to explore the facilitators and barriers encountered by adults and seniors who pursue braille training, in order to understand the influence of external factors on the adult braille learning process.

2.6. Conclusion

Collectively, the studies in this review underscore the importance of developing tactile perception and efficient hand reading strategies throughout the learning process. However, they do not directly explore the potential influence of age-related declines in fine-motor and short-term working memory. Moreover, this research focuses heavily on younger participants and on individuals who learned braille early in life. As rehabilitation practitioners encounter a growing number of older adults with acquired visual impairments, it will be vital to understand how the aging process may uniquely shape their braille learning experiences. This context would highlight where areas of difficulties may exist, and what specific remedial activities will help to support the success of older clients who are served.

2.7. Declaration of interest

The authors report no conflicts of interest.

2.8. Data sharing

The authors confirm that the data supporting the findings of this study are available within the article. Readers interested in accessing our selected articles for specific purposes related to their respective research are invited to do so by contacting the corresponding author through the provided email address.

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2.11. References

1. Kusajima T. Visual reading and braille reading: an experimental investigation of the physiology and psychology of visual and tactual reading. New York: American Foundation of the Blind; 1974.

2. Wormsley DP, D'Andrea FM. Instructional Strategies for Braille Literacy. New York: American Foundation for the Blind; 1997.

3. Kandel ER, Schwartz JH, Jessell TM, Siegelbaum SA, Hudspeth AJ, Mack S. Principles of neural science. 2013.

4. Holbrook MC, McCarthy T, Kamei-Hannan C. Foundations of Education: Volume I: History and Theory of Teaching Children and Youths with Visual Impairments. 3rd ed: AFB Press; 2017.

5. Ferrell KA, Mason L, Young J, Cooney J. Forty Years of Literacy Research in Blindness and Visual Impairment. Colorado: University of Northern Colorado; 2006 December 31, 2006.

6. Steinman BA, LeJeune B, Kimbrough B. Developmental stages of reading processes in children who are blind and sighted. Journal of Visual Impairment & Blindness. 2006; 100(1):36-46.

7. Goldreich D, Kanics IM. Performance of blind and sighted humans on a tactile grating detection task. Perception & Psychophysics. 2006; 68(8):1363-71.

8. Nolan CY, Morris JE. Development and validation of the Roughness Discrimination Test. The International Journal for the Education of the Blind. 1965; 15(1):1-6.

9. Legge GE, Madison CM, Vaughn BN, Cheong AMY, Miller JC. Retention of high tactile acuity throughout the lifespan in blindness. Perception & Psychophysics. 2008; 70(8):1471-88.

10. Stevens JC, Foulke E, Patterson MQ. Tactile acuity, aging, and braille reading in long-term blindness. Journal of Experimental Psychology: Applied. 1996; 2(2):91-106.

11. Bola L, Siuda-Krzywicka K, Paplinska M, Sumera E, Hanczur P, Szwed M. Braille in the sighted: Teaching tactile reading to sighted adults. PloS One. 2016; 11(5):e0153394.

12. Veispak A, Boets B, Ghesquière P. Differential cognitive and perceptual correlates of print reading versus braille reading. Research in Developmental Disabilities. 2013; 34:372-85.

13. Veispak A, Boets B, Ghesquière P. Parallel versus sequential processing in print and braille reading. Research in Developmental Disabilities. 2012; 33:2153-63.

14. Van Boven RW, Johnson KO. The limit of tactile spatial resolution in humans: grating orientation discrimination at the lip, tongue, and finger. Neurology. 1994; 44(12):2361-.

15. Varma R, Vajaranant T, Burkemper B. Visual impairment and blindness in adults in the United States: Demographic and geographic variations from 2015 to 2050. Journal of the American Medical Association: Opthalmology. 2016; 134(7):802-9.

16. Cruess AF, Gordon KD, Bellan L, Mitchell S, Pezzullo ML. The cost of vision loss in Canada. 2. Results. Can J Ophthalmol. 2011; 46(4):315-8.

17. Cryer H, Home S. Final report: Feasibility of developing a diagnostic touch test to determine braille reading potential. United Kingdom: RNIB Centre for Accessible Information; 2011.

18. Ponchillia PE, Durant PA. Teaching behaviors and attitudes of braille instructors in adult rehabilitation centers. Journal of Visual Impairment & Blindness. 1995.

19. Ponchillia PE, Ponchillia SV. Foundations of Rehabilitation Teaching with Persons Who Are Blind or Visually Impaired. New York: American Foundation for the Blind; 1996.

20. Schroeder FK. Perceptions of braille usage by legally blind adults. Journal of Visual Impairment & Blindness. 1996; 90(3):210-8.

21. Rubin GS. Measuring reading performance. Vision Research. 2013; 90:43-51.

22. Brown JC, Goldstein JE, Chan TL, Massof R, Ramulu P. Characterizing functional complaints in patients seeking outpatient low-vision services in the United States. Ophthalmology. 2014; 121(8):1665-2, e51.

23. Rex E, Koenig A, Wormsley DP, Baker R. Foundations of braille literacy. New York: American Foundation for the Blind; 1995.

24. Ozioko O, Hersh MA, editors. Development of a Portable Two-Way Communication and Information Device for Deafblind People. AAATE Conf; 2015.

25. Heller KW, D'Andrea FM, Forney PE. Determining reading and writing media for individuals with visual and physical impairments. Journal of Visual Impairment & Blindness. 1998; 92(3).

26. Hughes B. Movement kinematics of the braille-reading finger. Journal of Visual Impairment & Blindness. 2011; 105(6):370-81.

27. Bernbaum M, Albert SG, McGarry JD. Diabetic neuropathy and braille ability. Archives of Neruology. 1989; 46:1179-81.

28. Hall AD, Newman SE. Braille learning: Relative importance of seven variables. Applied Cognitive Psychology. 1987; 1:133-41.

29. Hannan CK. Review of research: Neuroscience and the impact of brain plasticity on braille reading. Journal of Visual Impairment & Blindness. 2006; 100(7).

30. Knowlton M, Wetzel R. Braille reading rates as a function of reading tasks. Journal of Visual Impairment & Blindness. 1996; 90(3).

31. Nolan CY, Kederis JC. Perceptual Factors in Braille Word Recognition (Research Series No. 20). New York: American Foundation for the Blind; 1969.

32. Bopp KL, Verhaeghen P. Aging and verbal memory span: A meta-analysis. Journal of Gerentology. 2005; 60B(5):P223-P33.

33. Millar S. Perceptual and task factors in fluent braille. Perception. 1987; 16:521-36.

34. Argyropoulos V, Papadimitriou V. Braille reading accuracy of students who are visually impaired: The effects of gender, age at vision loss, and level of education. Journal of Visual Impairment & Blindness. 2015; 109(2):107-18.

35. Simón C, Huertas JC. How blind readers perceive and gather information written in braille. Journal of Visual Impairment & Blindness. 1998; 92(5):322-30.

36. Stevens JC. Aging and spatial acuity of touch. Journal of Gerontology. 1992; 47(1):35-40.

37. Goldreich D, Kanics IM. Tactile acuity is enhanced in blindness. J Neurosci. 2003; 23(8):3439-45.

38. Voelcker-Rehage C. Motor-skill learning in older adults—a review of studies on age-related differences. European Review of Aging and Physical Activity. 2008; 5:5-16.

39. Gunning-Dixon F, Brickman AM, Cheng JC, Alexopoulos GS. Aging of cerebral white matter: A review of MRI findings. International Journal of Geriatric Psychiatry. 2009; 24(2):109-17.

40. Persson J, Pudas S, Lind J, Kauppi K, Nilsson L-G, Nyberg L. Longitudinal structure-function correlates in elderly reveal MTL dysfunction with cognitive decline. Cerebral Cortex. 2012; 22:2297-304.

41. Siegel L. Working memory and reading: A life-span perspective. International Journal of Behavioural Development. 1994; 17:109-24.

42. Bruns P, Camargo CJ, Campanella H, Esteve J, Dinse HR, Röder B. Tactile acuity charts: a reliable measure of spatial acuity. PloS One. 2014; 9(2):e87384.

43. Foulke E. Reading braille. Tactual Perception: A Sourcebook. New York: Cambridge University Press; 1982. p. 168-208.

44. Heller MA, Gentaz E. Psychology of Touch and Blindness: Psychology Press; 2013.

45. Weber EH. E. H. Weber on the tactile senses, 2nd ed. Ross HE, Murray DJ, editors. Oxford, England: Erlbaum (Uk) Taylor & Francis, Publ; 1996. xii, 260-xii, p.

46. Schwartz AS, Perey AJ, Azulay A. Further analysis of active and passive touch in pattern discrimination. Bulletin of the Psychonomic Society. 1975; 6(1):7-9.

47. Corn AL, Lusk KE. Perspectives on Low Vision (Chapter 1). Foundations of Low Vision: Clinical and Functional Perspectives. New York: American Foundation for the Blind; 2010. p. 3-34.

48. Dixon J, editor. Braille into the next milennium. Washington, DC: National Library Service for the Blind and Physically Handicapped; 2000.

49. Arksey H, O'Malley L. Scoping studies: towards a methodological framework. International Journal of Social Research. 2005; 8:19-32.

50. Levac D, Colquhoun H, O'Brien KK. Scoping studies: advancing the methodology. Implementation Science. 2010; 5:69.

51. Peters MD, Godfrey CM, Khalil H, McInerney P, Parker D, Soares CB. Guidance for conducting systematic scoping reviews. International journal of evidence-based healthcare. 2015; 13(3):141-6.

52. Tiffin J, Asher EJ. The Purdue Pegboard: norms and studies of reliability and validity. Journal of Applied Psychology. 1948; 32(3):234-47.

53. Wormsley DP. Hand Movement Training in Braille Reading. Journal of Visual Impairment and Blindness. 1981; 75(8):327-31.

54. Murman DL. The Impact of Age on Cognition. Semin Hear. 2015; 36(3):111-21.

55. Gamer M, Lemon J, Fellows I, Singh P. Package 'irr': Various coefficients of interrater reliability and agreement (version 0.84). 2012.

56. Revelle W. Package 'psych': Procedures for psychological, psychometric, and personality research (version 1.7.8). 2017.

57. Bertelson P, Mousty P, D'Alimonte G. A study of braille reading: 2. Patterns of hand activity in one-handed and two-handed reading. The Quarterly Journal of Experimental Psychology Section A. 1985; 37(2):235-56.

58. Bradshaw JL, Nettleton NC, Speir K. Braille reading and left and right hemispace. Neuropsychologia. 1982; 20(4):493-500.

59. Chen X, Liang L, Lu M, Potměšil M, Zhong J. The effects of reading mode and braille reading patterns on braille reading speed and comprehension: A study of students with visual impairments in China. Research in Developmental Disabilities. 2019; 91:103424.

60. Clegg GD. A study of the Tactual Discrimination Test for measuring tactual ability of the visually handicapped. Research Bulletin No 25 - January 1973. New York: The American Foundation for the Blind; 1973. p. 259-60.

61. Daneman M. How reading braille is both like and unlike reading print. Memory & Cognition. 1988; 16(6):497-504.

62. Davidson PW, Wiles-Kettenmann M, Haber RN, Appelle S. Relationship between hand movements, reading competence and passage difficulty in braille reading. Neuropsychologia. 1980; 18(6):629-35.

63. Davidson PW, Appelle S, Haber RN. Haptic scanning of braille cells by low-and high-proficiency blind readers. Research in Developmental Disabilities. 1992; 13(2):99-111.

64. Fertsch P. An analysis of braille reading. Outlook for the blind and the teachers forum1946. p. 128.

65. Fertsch P. Hand dominance in reading braille. The American Journal of Psychology. 1947; 60(3):335-49.

66. Foulke E. Transfer of a complex perceptual skill. Perceptual and Motor Skills. 1964; 18:733-40.

67. Garcia LG. Assessment of text reading comprehension by Spanish-speaking blind persons. The British Journal of Visual Impairment. 2004; 22(1):4-12.

68. Heinrichs R, Moorhouse J. Touch-perception thresholds in blind diabetic subjects in relation to the reading of Braille type. New England Journal of Medicine. 1969; 280(2):72-5.

69. Hermelin B, O'Connor N. Functional asymmetry in the reading of Braille. Neuropsychologia. 1971; 9(4):431-5.

70. Hislop DW, Zuber BL, Trimble JL. Text-scanning patterns of blind readers using Optacon and braille. Journal of Rehabilitation Research and Development. 1985; 22(3):54-65.

71. Holland BF. Speed and Pressure Factors in Braille Reading. Journal of Visual Impairment & Blindness. 1934; 28(1b):13-7.

72. Laroche L, Boulé J, Wittich W. Reading speed of contracted French braille. Journal of Visual Impairment & Blindness. 2012; 106(1):37-42.

73. Loomis JM. Tactile recognition of raised characters: A parametric study. Bulletin of the Psychonomic Society. 1985; 23(1):18-20.

74. Millar S. Is there a "best hand" for braille? Cortex. 1984; 20:75-87.

75. Mommers MJC. Braille Reading: Factors Affecting Achievement of Dutch Elementary School Children. Journal of Visual Impairment & Blindness. 1976; 70(8):332-40.

76. Mommers MJC. Braille Reading: Effects of Different Hand and Finger Usage. Journal of Visual Impairment & Blindness. 1980; 74(9):338-43.

77. Mousty P, Bertelson P. 1. A study of braille reading: Reading speed as a function of hand usage and context. The Quarterly Journal of Experimental Psychology. 1985; 37A:217-33.

78. Nakada M, Dellon L. Relationship between sensibility and ability to read braille in diabetics. Microsurgery. 1989; 10:138-41.

79. Olson M, Harlow SD, Williams J. Rapid Reading in Braille and Large Print: An Examination of McBride's Procedures. Journal of Visual Impairment & Blindness. 1975; 69(9):392-5.

80. Oshima K, Arai T, Ichihara S, Nakano Y. Tactile sensitivity and braille reading in people with early blindness and late blindness. Journal of Visual Impairment & Blindness. 2014; 108(2):122-31.

81. Papadimitriou V, Argyropoulos V. The effect of hand movements on braille reading accuracy. International Journal of Educational Research. 2017; 85:43-50.

82. Sampaio E, Philip J. Influences of age at onset of blindness on braille reading performances with left and right hands. Perceptual and Motor Skills. 1995; 81\:131-41.

83. Veispak A, Boets B, Männamaa M, Ghesquière P. Probing the perceptual and cognitive underpinnings of braille reading: An Estonian population study. Research in Developmental Disabilities. 2012; 33:1366-79.

84. Wilkinson JM, Carr TH. Strategic hand use preferences and hemispheric specialization in tactual reading: Impact of the demands of perceptual encoding. Brain and Language. 1987; 32:97-123.

85. Wormsley DP. Reading rates of young braille-reading children. Journal of Visual Impairment & Blindness. 1996; 90(3).

86. Wright T, Wormsley DP, Kamei-Hannan C. Hand movements and braille reading efficiency: Data from the Alphabetic Braille and Contracted Braille Study. Journal of Visual Impairment & Blindness. 2009; 103(10):649-61.

87. Braun V, Clarke V. Thematic analysis. APA handbook of research methods in psychology, Vol 2: Research designs: Quantitative, qualitative, neuropsychological, and biological. APA handbooks in psychology®. Washington, DC, US: American Psychological Association; 2012. p. 57-71.

88. Bertelson P. Language by touch: the case of braille reading. Speech and Reading: A Comparative Approach. East Sussex: Erlbaum (UK) Taylor & Francis; 1995. p. 91-108.

89. Golub DB. A model of successful work experience for employees who are visually impaired: The results of a study. Journal of Visual Impairment & Blindness. 2006; 100(12):715-25.

90. Lorimer P. Hand techniques in reading braille; synthesis of spatial and verbal elements of reading. British Journal of Visual Impairment. 2002; 20(2):76-9.

91. Papagno C, Minniti G, Mattavelli GC, Manatovan L, Cecchetto C. Tactile short-term memory in sensory-deprived individuals. Experimental Brain Research. 2017; 235(2):471-80.

92. Daneman M, Carpenter PA. Individual differences in working memory and reading. Journal of Verbal Learning and Verbal Behaviour. 1980; 19:450-66.

Chapter 3 – Study 2: Enablers and barriers encountered by working-age and older adults who pursue braille training

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3.1. Abstract

Purpose: This study explored the experiences of working-age and older adults with acquired vision loss who pursued braille rehabilitation training and the facilitators and barriers they encountered throughout this process.

Methods: Semi-structured interviews of up to 90 minutes in length were conducted with 14 participants from across Canada who learned braille between the ages of 33 and 67 (Mdn=46). Transcripts were analyzed by two researchers using interpretive phenomenological analysis.

Results: A variety of personal, social and institutional factors characterize the adult braille learning experience. Among these, participants highlight the role of prior identity and experience, the impact of access to resources and the cost of materials and devices needed to maintain braille skills. Findings also emphasize invisible barriers, including the role of societal perceptions towards braille, the level of support provided by family and friends, and the influence of unconscious biases towards braille and aging held by both adult learners and those around them.

Conclusions: These findings provide important context to improve policies and practice in adult braille rehabilitation. As the prevalence of age-related vision loss continues to increase, it will become imperative to understand the unique needs of working-age and older adults with acquired vision loss who pursue braille.

Keywords: braille, rehabilitation, blindness, vision loss, adult learning

3.2. Introduction

Considering that the training of new or compensatory skills is often at the heart of vision loss rehabilitation,[1] it is curious that so little attention has been devoted to directly engaging with the knowledge gained from other domains on the adult learning process,[2] or the implications of adult learning theory and practice within the rehabilitation context. Questions on how to best serve adults with acquired vision loss, whose experiences differ intrinsically from those born with congenital visual impairment, become more imperative to address as the prevalence of age-related vision loss continues to increase. It is estimated that the population of people with vision impairment (that is, those who are blind or who have low vision) will triple worldwide over the next 30 years due to both population growth and aging. This continues to place new burdens on existing healthcare and rehabilitation systems.[3] In the United States alone, the prevalence of age-related vision loss is expected to double by 2050.[4] This raises the need for innovative evidence-based approaches and policies that can respond to these evolving priorities.

Braille is among the skills taught to adults with visual impairments who pursue rehabilitation training, as it provides a tactile alternative to visual print.[1] Although reports indicate that fewer than 10% of individuals who are blind are braille readers,[5] these rates remain greatly contested (for example, see Graves[6]). Practitioners within the field of blindness as well as braille readers themselves accentuate that these figures do not reflect the individual benefits of braille as a literacy medium.[7] Braille carries benefits for adults who are functionally blind or who have fluctuating vision, and can be vital for the growing number of older adults with dual sensory (combined vision and hearing) impairment.[8] Best practices and prior research on braille learning centers heavily on blind children who acquire braille as a literacy medium through the educational system, given the historically high prevalence of congenital visual impairment.[9] Comparatively less is known about the unique experience of learning braille in adulthood after acquired vision loss or about the facilitators and barriers encountered by older clients who pursue braille rehabilitation training. The present study therefore explores the experience of learning braille in adulthood and the enablers and obstacles encountered, as a catalyst for future policy and practice recommendations.

There is ample evidence demonstrating the ways in which adults can and do learn differently from children. Within the braille context, blind children typically learn braille through the process of acquiring literacy, and an emphasis is placed on the development of spelling, phonetics and underlying concept development.[10] In these instances, braille is merely the means through which literacy is attained, just as print is the vehicle through which literacy is acquired for children with sight. Adults and seniors, on the other hand, are already literate as print readers prior to age-related vision loss and do not seek rehabilitation training to acquire fundamental literacy skills. Rehabilitation training for these older clients therefore places emphasis on the development of tactile perception and fine-motor skills needed to effectively use braille later in life.[11]

Studies directed explicitly at exploring the experiences of working-age and older adults who learn braille are rare, but typically centre on the physiological and cognitive implications of acquiring new skills after childhood. For example, a wide body of research explores the degree of learning plasticity that can be expected as individuals age. These investigations reveal that those who learn braille early in life recruit the otherwise unused visual cortex during braille reading and exhibit cortical magnification in the regions associated with the braille reading fingers.[12,13] Some isolated studies also suggest that, with ample exposure and practice, this cortical plasticity might also be observable in adult learners of braille.[14] Others have explored tactile sensitivity declines as individuals age and the potential relationship between tactile acuity and braille reading performance, resulting in mostly inconsistent findings.[15-20] These findings are essential because they consider the effect of the aging process on the skills needed to use braille; However, they fail to account for the subjective implications of learning something new as an adult after the onset of a diagnosis, or the factors which influence this experience.

Other studies explore the impact of braille among adults who learned it early in life. Schroeder[21] interviewed eight legally blind adult braille users and observed that self-esteem, self-identity and the meanings ascribed to being a person with a disability were closely intertwined with expressed feelings towards braille. In comparing outcomes among congenitally legally blind adults who learned braille versus print as their primary medium in childhood, Ryles[22] found that those who learned braille had higher levels of education and income and engaged in more extensive reading as adults. In a study of 443 legally blind adults, Silverman and Bell[23] observed that adults who had learned braille as either a primary or secondary medium expressed more positive perceived well-being and life satisfaction as compared to legally blind adults who had not learned braille at all. These investigations are valuable in that they reveal the ways in which braille may impact quality of life for legally blind adults who already know it, but they do not explicitly focus on the experience of learning braille beyond childhood.

Though not centered on braille in particular, prior literature is replete with examples of how adjustment to vision loss later in life can effect both the decision to initially pursue rehabilitation and overall training outcomes.[24,25] Barriers to seeking vision loss rehabilitation have been shown to include practical factors such as lack of transportation[24] but also the denial to accept a visual diagnosis and the stigma often associated with blindness.[26] Adults with acquired vision loss may carry a lifetime of misconceptions about blindness that must be untangled and confronted throughout the rehabilitation process and beyond. These psychosocial considerations may further impede adjustment to vision loss.[24] Such stigma is evidenced by the many inaccurate and problematic depictions of blindness in both literary and visual culture which habitually portray the blind as symbols of pity and charity.[27-29]

Recognizing the role of stigma as an impediment, some service organizations have removed the term 'blind' from their name to instead highlight that the majority of those who seek rehabilitation today do not have total blindness.[30,31] It is worth noting, however, that the reluctance to use the term 'blind' may work to further deepen the stigmatization of blindness and the symbols closely associated with it. Traditional assistive devices which disclose an otherwise invisible visual impairment, for instance, are often abandoned or under-used despite their potential utility.[32] The white cane, arguably the most recognizable symbol of blindness, identifies the user as someone who is blind and can be attached to unwanted attention for those still adjusting to vision loss.[33,34] Adults with remaining functional vision may postpone the adoption of such tools until it is deemed to be necessary, due to fears of being judged or misunderstood. Though the role of braille within this discussion has not been directly examined, it is possible that braille could conjure similar feelings of reluctance for those still adjusting to vision loss, given its role as a prominent symbol of blindness.

It is, however, from the field of adult learning rather than rehabilitation that the greatest insight on the uniqueness of the adult learning process can be gained. Coined by Malcolm Knowles in the 1970's, andragogy as a field of inquiry accentuates the factors which uniquely influences the learning experiences of adults, and which proponents argue should be taken into consideration in any adult training context.[2] Based on empirical research and observations, the andragogical framework is structured around six core assumptions of adult learners.[35] An emphasis is placed on self-directed learning and the notion that the motivation to learn in adulthood is greatly driven by a perceived need to know in order to fill a gap or improve quality of life.[2] In a series of related investigations, Tough[36] observed that adults who undertake to learn something on their own are especially cognizant of the potential benefits as well as the negative consequences that might arise if that learning is abandoned. The model further accentuates the role of prior life experiences which adults bring with them into any learning situation, as a consequence of having lived longer than children. It implies that the richest resources for learning in adulthood reside in the adult learners themselves and in harnessing their previous experiences.[2]

Above and beyond these considerations, a variety of other factors may influence the experiences of adult learners generally. These factors may include anxiety about returning to school (or adopting the often long-shed role of learner), resistance to change, poor past academic success which may effect self-confidence and locus of control, rigid schedules and limited time due to family, finances and other adult responsibilities.[37] Such insights have led to the development of paradigms that better respond to the needs of adult learners, such as Universal Design for Learning (premised on the importance of flexibility),[38] transformational learning theory (which acknowledges the relevance of world views),[39] and constructivism (which harnesses the value of prior experience),[40] but such frameworks have gained little attention in the field of braille rehabilitation.

To date, a lack of ample evidence has contributed to ongoing inconsistencies in the ways in which adult and senior braille clients are assessed, trained and supported among rehabilitation centres generally.[11] This is especially true in countries like Canada, where rehabilitation services may vary drastically due to geography and the resulting discrepancies among provincial or regional healthcare and rehabilitation systems.[41] Moreover, questions on improving service delivery have garnered renewed attention in recent years due to legislative efforts at the macro level. The United Nations Convention on the Rights of Persons with Disabilities (UNCRPD), ratified by 181 countries, calls upon states to provide adequate educational and rehabilitation services, including the provision of braille and other alternative format training where required.[42] As rehabilitation agencies encounter a growing number of adults and seniors who may pursue braille training, it will become imperative to understand how the experience of learning braille in adulthood might align or veer from childhood learning, and whether specific enablers or barriers influence this process.

This study aims to explore the experience of learning braille as an adult or senior with acquired vision loss, and to identify the facilitators and barriers that manifest in different ways throughout this process. A phenomenological approach to analysis was therefore deemed to be most appropriate, given the desire to understand the essence of a shared or common experience that is not yet well understood.[43] Recognizing the importance of foregrounding the first-hand experiences of participants, it is believed that such a qualitative approach will raise aspects of the adult and senior braille rehabilitation experience that might otherwise be overlooked through other methods of inquiry. It is also hoped that the insights gained from this study will serve as the impetus for future tangible recommendations that begin to tackle the obstacles that emerge.

3.3. Methods

3.3.1. Eligibility and recruitment

The data for this study are drawn from the transcripts of semi-structured interviews conducted between July 2018 and January 2019. To take part in the study, participants had to reside anywhere in Canada, had to have learned braille anytime after the age of 21 (the age at which braille would no longer fall under the purview of the educational system), had to have completed their formal braille training at least one year before participation, and self-identify as meeting the legal definition of blindness; that is, a visual acuity of 20/200 or less or a visual field of 20 degrees or less in the better eye with best correction.[44]

The invitation to participate was circulated internally through the Lethbridge-Layton-Mackay Rehabilitation Centre, Vision Loss Rehabilitation Canada, The Quebec Federation of the Blind, the Canadian Council of the Blind, Braille Literacy Canada, Balance for Blind Adults, the Pacific Training Centre for the Blind, and the Alliance for Equality of Blind Canadians. The invitation was also posted publicly, with prior permission from moderators, onto social media platforms geared towards blind and low vision Canadians. Snowball sampling, whereby participants were invited to share the invitation with others in their circles who may be interested, provided additional reach beyond these means.[45]

3.3.2. Study design

The creation of the semi-structured interview guide applies the process described by Smith[46] and other qualitative researchers engaged in interpretive phenomenological analysis (IPA).[43,47] The first and second authors developed an outline through discussion to delineate the general parameters of the interview. It was agreed that the questions guiding the interviews should explore the experience of learning braille in adulthood from three successive time-points (before, during and after formal braille training), in order to acknowledge the circumstances both before and after braille training that may also play a role.[48] Recognition of the continuing nature of this process helps to contextualize the decisions which lead participants to pursue braille training and the ways in which braille is applied and understood once formal training has ended. This is especially pertinent given the emphasis in rehabilitation research on understanding the factors which lead some to abandon or under-use seemingly effective assistive devices and techniques as an important component of the overall rehabilitation experience.[49-51]

In designing this study, the authors also recognize that self-perception as a construct is dynamic in nature.[48] Adequate distance from the time when a health or rehabilitation intervention occurs is sometimes warranted to more effectively reflect and look back upon its impact, as the overcharge of emotions or fatigue experienced immediately afterwards may bias the lens through which the experience is contextualized.[48] It is for these reasons that eligibility to participate required that participants had completed their formal braille training at least one year before.

Questions were developed based broadly on the categories of the International Classification of Functioning, Disability and Health (ICF) model.[52] The interview questions generated with this framework in mind therefore consider both the person at the centre of the learning process and the environments in which they are situated.

3.3.3. Data collection and sample size

Prior to the start of the interview, participants were provided with a copy of the Information and Consent form in their preferred format (large print, braille, electronic, or read aloud to them on the phone). Informed consent was either provided verbally and audio-recorded or obtained in written form, in accordance with *The Declaration of Helsinki and Public Health*.[53] The option to provide recorded verbal consent offered an accessible alternative for blind and low vision participants who could not or who preferred not to indicate their consent through written signature or trust in a third party,[54] an option which all participants selected. The individual interviews (which were recorded with participant consent) required roughly 90 minutes of the participants' time, and in all cases, both the first and second author were present. The interviews could be completed either by phone or by visiting one of the approved research sites, though all participants chose to take part by phone. The merits of ensuring flexibility during the data collection phase have been discussed in other research with diverse populations,[55] and is especially important for people with disabilities and older adults who may not easily be able to travel to a research site or personally and directly respond to invitations to participate.[56]

The methodological approach of interpretive phenomenological analysis, as with other qualitative paradigms, is concerned with understanding and foregrounding participant perspectives, and values above all else the richness of data stemming from participant stories.[43,46,57] It is this in-depth exploration of the essence of an experience that phenomenology as an epistemological tradition seeks to unearth.[43] Rigor in phenomenology is therefore cultivated not through achieving statistical power but through the quality and richness of data provided by each participant.[58] The valuing of such first-hand voices gives rise to vital testimony which informs research and practice and gives prominence to what can be overlooked when these first-hand perspectives remain absent from the conversation. This is especially noteworthy given the enduring criticism that the voices of people with disabilities are generally ignored or silenced in the scientific and healthcare research that directly impacts them.[59,60] For these reasons, it was decided that data collection would conclude not when an *a priori* sample size was achieved, but with theoretical saturation, when no new themes emerged.[58] The resulting sample size was consistent with many prior examples of phenomenological inquiry, where sample sizes of between 10 and 15 are common.[43,61]

3.3.4. Data analysis

A bottom-up inductive approach to thematic content analysis (following the steps put forth by Braun & Clarke[62]) was applied in order to ensure that emerging themes were driven by the data:

1. The recorded interviews were transcribed verbatim by a research assistant. InqScribe[63] software was employed for transcription purposes, as it inserts time stamps at the start of each statement to facilitate later analysis. All participant names and identifying details (such as geographic location and the rehabilitation centre where braille training was pursued) were removed from the transcripts to ensure anonymity.
2. The first three transcripts were read and reread several times by the first and second authors to gain a general sense of the participants' observations. During this early stage, notes about significant statements as well as author reflections were compared and discussed.
3. These initial transcripts were reread and both authors began to generate initial codes based on significant statements of relevance to the research questions. These codes were then reviewed and discussed. Emerging themes which cluster common threads across transcripts were identified, recognizing that these themes would continue to evolve through an iterative process.[64]
4. Each successive transcript was reviewed by both authors respectively and the codes as well as the names and boundaries of themes were discussed and revised through reflection and consensus.

The resulting themes and codes provide a description of the essence of the shared experience of learning braille in adulthood, as well as the meanings and contexts which shape the experience.[43]

3.4. Validity, rigor, and trustworthiness

In recognizing that researchers bring with them their own unconscious biases and preconceptions which colour the interpretation of any data,[65] the authors made deliberate efforts to engage in a bracketing process through ongoing dialogue with each other; However, it is acknowledged that no act of interpretation is completely free of unconscious bias.[43] Data collection and analysis were conducted jointly by the first and second author. Their distinct yet complimentary backgrounds as a blind braille user and rehabilitation specialist (author 1) and sighted low vision rehabilitation specialist (author 2) ensured that the interpretation of data was not merely a reflection of one specific viewpoint. The third author (doctoral supervisor of author one, internship supervisor for author two) provided additional feedback throughout the project. Where disagreements in codes emerged, these were discussed and consensus was reached collaboratively, leading to an inter-coder agreement coefficient of >98%: Gwet's agreement coefficient = .988 (range .959 –1.0).

In discussing the impact of insider epistemology, Asselin posits that it is crucial for the insider researcher to proceed carefully during data collection and analysis, because though the researcher may be intimately connected to an aspect of the topic under study, "she might not understand the subculture, which points to the need for bracketing assumptions."[66] Here, the first author was innately aware of her role as insider, specifically as a person who is both blind (like the participants being interviewed) and a braille user who has navigated the rehabilitation system available to Canadians with visual impairments, both as a rehabilitation specialist and past service recipient. It emerged that the role as insider led to a perceived sense of unspoken connection with participants that contributed to a heightened degree of trustworthiness during information-sharing, in a way that may not have transpired had both researchers been perceived as 'outsiders' to the community. Here the first author observed inklings of what Mingus calls 'access intimacy', "that elusive, hard to describe feeling when someone else 'gets' your access needs."[67] Though consciously aware of the insider label attributed to her by participants, and the need to self-check any unconscious biases that arose because of this, the first author equally considered her role as 'outsider' – as someone who learned braille early in life and can therefore not ever fully comprehend the experience of learning braille in adulthood after acquired vision loss. It is this tension that exists when navigating between the insider and outsider role that required the researchers to engage in a process of regularly "reining in and reflexively interrogating their own understandings."[64]

3.5. Results

Fourteen participants from Canada took part in this study (7 male, 7 female; 3 from Quebec, 5 from Ontario, 6 from British Columbia). Participants ranged between the ages of 40 and 72 at the time of the interviews (Mdn=55) and began learning braille between the ages of 33 and 67 (Mdn=46). Table 9 outlines the age of onset and cause of visual impairment, the age when braille was learned, frequency of braille instruction and the braille codes learned for each participant. Note that while some report a childhood visual diagnosis, these are progressive conditions that deteriorate over time. Three of the participants had additional disabilities above and beyond vision loss: one self-reported a learning disability, one had a severe hearing impairment, and one had fused fingers which prevented him from using a regular keyboard for typing. In total, 9 of the participants had a Bachelor's degree, 2 had a Master's, 1 obtained a Ph.D. and 2 completed a High School diploma. Only two participants reported being unemployed, with 6 retired, 3 working full-time, and 3 working in part-time positions. Prior to learning braille, most participants relied on regular and large print, but also indicated the use of audio for some reading tasks.

Table 9. – Participant descriptors

				Codes Learned				
#	**Diagnoses**	**Age of onset**	**Age braille learned**	**Uncontracted**	**Contracted**	**Nemeth**	**Music**	**Chess**
1 'Margaret'	Retinitis pigmentosa	22	52	✓	✓			
2 'Kelly'	Glaucoma, Angiomas	43	44	✓	✓			
3 'Stephanie'	Progressive cones dystrophy	20	42	✓				

#	Diagnoses	Age of onset	Age braille learned	Codes Learned				
				Uncontracted	Contracted	Nemeth	Music	Chess
4 ‘Jacob’	Bilateral enucleation	46	47	✓				
5 ‘Toby’	Optic nerve hypoplasia	Birth	59	✓	✓			
6 ‘Rachel’	Retinitis pigmentosa	20	47	✓	✓			✓
7 ‘Brian’	Lebers	35	37	✓	✓	✓	✓	
8 ‘Thomas’	Congenital cataracts, Glaucoma, Lorneledemia	Birth	51	✓				
9 ‘Paul’	Retinitis pigmentosa	19	36	✓				
10 ‘Seth’	Retinitis pigmentosa	12	67	✓				
11 ‘Barbara’	Congenital cataracts, retinal detachment	13	33	✓				
12 ‘Ellen’	Retinitis pigmentosa	Birth	36	✓				
13 ‘Sharon’	Congenital cataracts, glaucoma, nystagmus	Birth	51	✓	✓			
14 ‘Eric’	Retinitis pigmentosa	27	46	✓				

Twelve of the participants learned braille through a rehabilitation centre, and 2 pursued correspondence courses through adult blindness agencies. Of the 12 who attended a rehabilitation centre, 3 attended a residential program that required them to live in residence throughout the duration of training. Braille training ranged from 5 months to 2.5 years depending on the availability of services and the level of instruction required (whether the participant went on to learn contracted braille or additional braille codes). Training for most participants followed a similar progression, beginning with the alphabet. Activities typically began with short words comprised of the letters learned, and progressed to phrases and passages. Some participants were introduced to braille writing at the start of training, while others began using writing tools once half of the alphabet had been learned. Most used a structured textbook designed for adult braille learners during training sessions. Following their braille training, 5 participants report now using braille on a daily basis; 4 use it several times per week; 3 use it once per week, and 2 participants report using braille a few times per month. Table 10 (on the following page) summarizes the tasks where braille is currently being used for each participant. Of interest is that only 2 participants report using braille for longer reading tasks such as reading novels, but all expressed that they value braille as an essential skill and do not regret having learned it.

Analysis of the transcripts reveal that the braille learning process for adults and seniors with acquired vision loss is characterized by personal, social and institutional factors (see Figure 9 below on p. 97). The present section defines and provide examples of each of these three broad themes. First name pseudonyms have been used to protect confidentiality.

3.5.1. Theme 1: Personal Factors

The first broad theme highlighted by participants related to the personal factors attributed to their personality, emotions or intrinsic characteristics that influenced their braille learning journey in different ways. Four categories of interest fall under the theme of personal factors: the personal motivations to learn and use braille; psychosocial responses to blindness and braille; the role of prior learning experiences; and the physical capacities needed to use braille.

Table 10. – Tasks for which participants utilize braille

Task / Participant No.:	**1** Marg aret	**2** Kelly	**3** Step hanie	**4** Jacob	**5** Toby	**6** Rach el	**7** Brian	**8** Tho mas	**9** Paul	**10** Seth	**11** Barb ara	**12** Ellen	**13** Shar on	**14** Eric
Address Book	●	●	-		○	○	○	○	○	●	●	○	○	○
Course/ Work/ Volunteer	●	-	○		-	-	○	-	-	-	●	●	-	-
Education Reading	-	-	-		-	-	○	-	-	-	-	-	-	-
Household Items	●	●	●		●	●	●	○	●	●	○	●	●	○
Letters/ Mail	●	●	●		○	○	●	○	○	○	●	●	○	○
Newspaper/ Magazine	●	●	○		○	○	○	○	○	○	○	○	○	○
Novels	●	●	○			○	○	○	○	○	○	○	○	○
Personal Notes	●	●	●		●	●	●	○	○	○	●	●	●	○
Phone Numbers	●	●	●		○	●	●	○	○	○	●	●	○	●
Reading to Children	○	○	○		○	●	○	○	○	○	●	●	○	○
Recipes	●	●	●		○	●	○	○	○	○	○	●	●	-
Work Reading	-	-	○		-	-	○	○	○	○	-	●	-	●

● Braille used for this task; ○ Braille not used for this task; - Participant does not perform this task.
NOTE: Participant #4 learned braille solely for the purpose of typing on a computer and did not use braille for any reading activities.

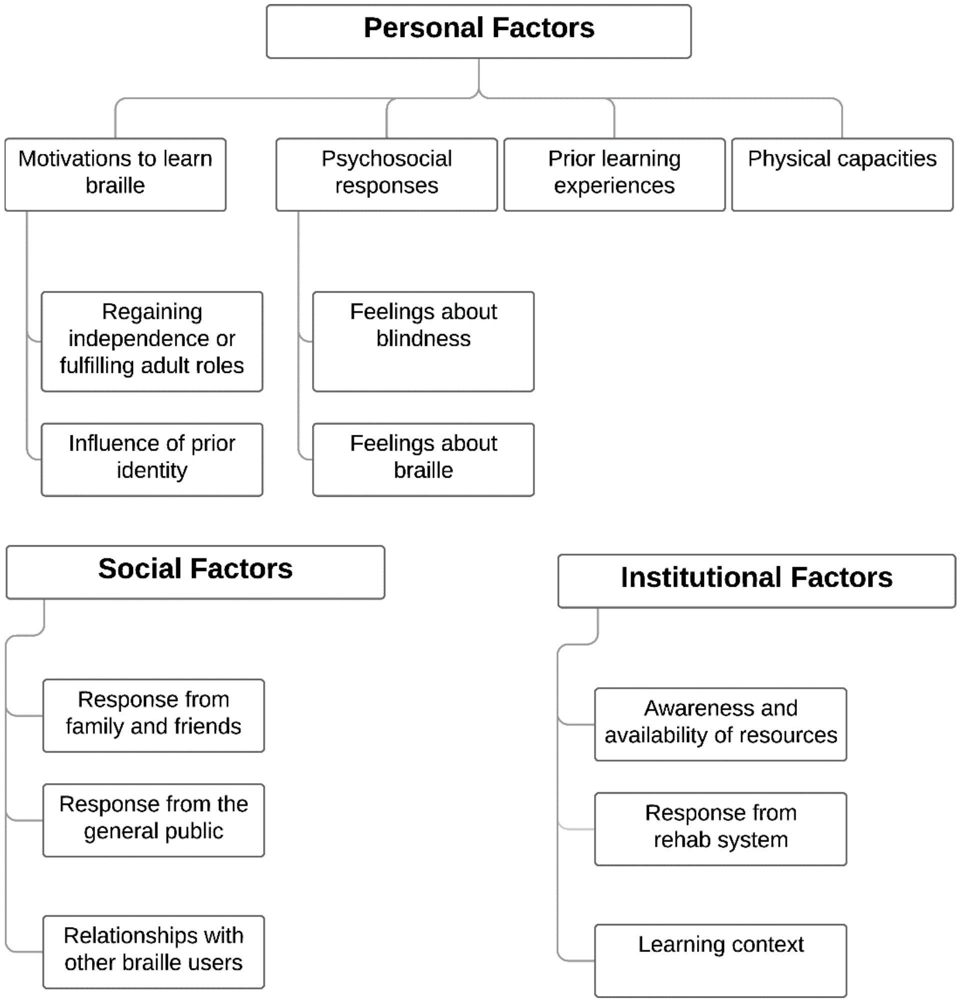

Figure 9. – Diagram depicting the hierarchy of personal, social, and institutional themes that characterize the adult braille learning experience

3.5.1.1. Motivations to learn braille

Although others may have influenced the decision to learn braille (as will be discussed in later themes), this decision was ultimately one that was personally motivated and that participants made on their own in order to maintain personally meaningful adult labels. This motivation was described as either a practical necessity to regain independence or as a means of reconnecting with a core part of identity, and was sometimes prompted by a moment characterized as a turning point.

Regaining independence or fulfilling adult roles. For a majority of participants, the personal motivation to learn braille stemmed from an inability to engage in a meaningful home or work activity. The learning of braille was described as being necessary to regain or maintain a label closely tied to adulthood identity (such as employee or parent) and in re-establishing confidence after vision loss:

> Margaret: I felt helpless because I couldn’t do things on my own. I was dependent on always asking others. I couldn’t make little notes to myself. Making voice memos didn't work out so well for me. So when I could start writing telephone numbers, shopping lists and notes to myself… Oh my God! I felt absolutely fantastic... It felt a little bit like Lazarus rising.

One participant explained that it was only in her adult years that she made the personal choice to learn braille, in order to fulfill her role as a parent.

> Barbara: by the time I started braille, I had three kids… around the time my boy started kindergarten, that's when I started realising I had problems. Spelling lists, homework. I couldn't remember how to spell. I wanted to help my kids more and make it so they had a good education.

Another participant described the personal decision to learn braille as simply a practical necessity in order to maintain his job title, regardless of any feelings he may have had about braille at the time:

> Jacob: I guess I might have been my own biggest obstacle in starting to learn it but once I realized that I was going to need a set of tools if I wanted to go back to work, that obstacle went away pretty quickly.

Participants with low vision expressed this same notion; However, their decision was attached to the personal realization that, although certain tasks could still be done with functional vision, learning braille would eliminate perceived inconveniences:

> Stephanie: I was just really struggling with magnification, and it was taking me a very long time to look at things. I just eventually thought that, for around the home and things, it would be easier if I could learn braille as opposed to running around my house looking for a magnifying glass and then dealing with the struggle and the strain of trying to focus.

For some participants, the motivation was prompted by the need to take on an entirely new adult role, due to the loss of an integral support system or other drastic life change.

> Toby: If there was some materials that I needed to read, I would ask my wife but my wife died at the same time that I retired, so I had to learn braille to fill in those gaps.

Some shared a pivotal or memorable moment that represented a turning point that finally instigated their decision to learn braille. For example, one participant described learning braille (and the broader acceptance of her blindness) as a means of regaining control:

> Kelly: Every single week, and sometimes every single day, there was something I could no longer do… that was very, very traumatic. So for me, the process of losing my sight in that way slowly over time was much more traumatic than just being blind. It got to a point where I hurt myself… I felt so stupid. I just walked into a closed door, with a very hot coffee, and I lost it. So I cried and I said… enough ! I just want to be blind. If it's going to happen, then I want to be blind now . And when I did become blind it felt like being in a pool, hitting the bottom, and from then on, everything I did would be a positive, a recovery. (…) Blindness is not fun but you know what? Now that I'm blind and so many doors are closed, I'm going to reopen all the doors. As many of them as I can… because I was not going to be a sorry blind person … stuck in her apartment, never coming out again… I couldn't just give up on my life.

Influence of prior identity. Prior identity emerged as a second important personal factor that either helped or hindered the decision to learn braille. Here, participants who perceived themselves as 'readers' as a core part of their identity prior to vision loss viewed the learning of braille as a means of regaining a fundamental part of themselves they felt they had lost. In this way, an interesting juxtaposition was drawn by some between identity before and after vision loss, and the disconcerting period 'in between', before braille was learned.

> Margaret: Well when I read print I had an internal voice that read along with me. And when I read braille, I get my internal voice back. It's just … My existential self is kind of reaffirmed. I feel like I am not losing anything (…) It's that crisis that happens when you have yourself taken away, the things you identify with strongly. Like in my case, reading… and then all of a sudden that's gone. People say "well do something else". But remember I'm an adult and you don't become "something else" readily.

For these participants, the learning of braille afforded them something that could not be gained through other formats alone (such as audio), because they spoke of braille as a form of literacy that is equivalent to the print they may remember as sighted readers. This perception served as a motivator for learning braille.

> Kelly: I love paper, I love the feel of paper, I love touching paper, I love writing on paper… and I loved the smell of paper, like the smell of a new book…

> Margaret: And I placed very high value on things like spelling form, the functions of grammar, and it was hard for me to live in a world that was only audio, and not have contact with commas and paragraphs

One participant used the analogy of a land-line to explain the need for braille, even when audio is available.

> Jacob: My daughter and son-in-law do not have a landline in their house. I have a cell phone and a landline… What happens if something goes wrong with the cell? I could still use my phone, I have a landline. So for me it's knowing that I have something to fall back on.

On the other hand, participants who did not view themselves as ‘readers’ as a core component of their identity prior to vision loss expressed feeling initially uncertain about the need for braille.

> Stephanie: I wasn't sure if I'd really use it, because I am not a reader. I don't really sit down and read books. So for me at that time, I was like, well I don't really see how it would be helpful to me, because I'm not interested in sitting down and reading a braille book.

3.5.1.2. Psychosocial responses

A second category of personal factors that either served as a facilitator or barrier before, during and after braille training related to internalized feelings that participants held about braille and blindness.

Feelings about blindness. Participants either described vision loss as something they accepted as a part of who they are, or as a barrier that prevented them from initially seeking braille and other rehabilitation training. For some participants, vision loss was tied to feelings of denial which prevented them from wanting to adopt tools or behaviours that would disclose their visual impairment to others. In these cases, the reluctance to use a white cane was often used as a comparison.

> Stephanie: I didn’t really accept it (vision loss) up until a few years ago (…) I just didn't let on that I was really struggling. (…) I felt at the time it (white cane) was already drawing attention to myself and then everybody was going to know why I can’t see.

On the other hand, a few participants described accepting their vision loss early on as one part of who they are. Participants in this situation typically had low vision for a longer period of time before it deteriorated further, and may have known others with vision loss over the years. For these participants, a direct connection was made between their blind identity and their understanding of braille as a logical next step.

> Ellen: I've always been extremely positive about my blindness. I was lucky to have a wonderful mother and a supportive family. I just always thought of it [being blind] as another way of being and it's part of who I am. Braille is just a part of my life.

Some participants explained how their feelings about vision loss changed as a consequence of their braille learning experiences.

> Brian: I kind of see the struggles that I've had, and I want to make them better for other people, so that was my motivation to pursue my degree and career. I just want to kind of share that with other people so that I can help them get through the struggles that they have and lead an independent and as full of a life as they can. So my feelings [about vision loss] certainly have ... actually become more positive in that I feel like I want to take my strengths and help others.

Others emphasized that adjustment to vision loss is an ongoing process, especially if that vision loss occurred later in life. This acknowledgment is different from an altogether denial of vision loss that may postpone the use of tools such as braille.

> Jacob: Well [sighs] I'm going from somebody who could see, and I drove, and I played sports and I did a lot of stuff. I went in one minute from seeing to not seeing… You know, that was 15 years ago, and I'm still not over it. I'm not happy that I'm blind, unlike some of my [congenitally] blind friends (…) I know what I miss (…) I know what it was like to drive… I know what it is not to see my grand daughter's face. and those are things that I miss. So, yeah I'm not happy that I'm blind, but am I going to sit in the corner and cry about it ? No. I'm going to live my life to the fullest, to the best that I can.

Feelings about braille. Feelings about braille prior to training functioned as an enabler or obstacle, depending on whether those feelings were attached to certain misconceptions. In particular, beliefs about braille being only for those who are totally blind, that it would be too hard to learn, or that it is only for those who engage in extensive reading emerged as important and reoccurring considerations.

While some participants understood that braille could be used by both people who are blind and those who have low vision, some expressed that they initially held the misconception that braille was only for those who were fully blind. This stereotype served to delay the start of training, especially if the person in question felt a sense of stigma towards blindness as a whole.

> Seth: I knew where to go. I had good contacts [to learn braille]. There was a group at the time and I went to a couple of meetings, but I was kind of turned off because they were all blind… and I didn't think that I was that bad yet.

The notion that braille would be too hard to learn or that one has to be exceptionally smart to learn it also played an influential role. For some, this misperception ironically served as a motivator – a challenge to overcome – particularly if they viewed intelligence as a positive attribute.

> Margaret: Most of the people were fairly educated people who liked to read (…) So I'd say that what these two ladies have in common is that they're really smart [laughing] so I don't know if that plays in anything but they're really intellectually bright…

On the other hand, others described that they feared braille would be hard to learn initially, but that this misconception dissipated once the logic of the braille system was revealed to them through training. Understanding the rationale behind the code served as a helpful motivator.

> Thomas: I actually came to enjoy it. At first I thought it was going to be really hard. Then I started learning the logic [behind the symbols]… I realized that made it easier.

Finally, some participants described that the delay in initially learning braille or even fully engaging with the learning process stemmed from the misconception that braille was primarily for extensive reading. In these cases, there was a lack of awareness of the different ways in which braille could be applicable to their lives.

> Stephanie: I didn't go into it with a great understanding but it has helped me tons now that I know (…) I didn't realize all of the uses there were for braille. Especially labeling. That's something that I hadn't really thought about. I really just thought it was for reading books

3.5.1.3. The role of prior learning experiences

Prior learning experiences served as invisible enablers or barriers to learning, depending on whether they were associated with positive or negative memories. For participants who held positive memories of learning and who looked back upon their previous learning experiences with fondness, these other learning contexts served as examples to motivate learning. For example, some participants used the analogy of first learning the alphabet or first learning to tie shoelaces as reference points to motivate their braille learning.

> Margaret: Remember when you were a kid learning print.. when you start in kindergarten, you start slow and then the next thing you know, after a number of years, you won't even notice the task and you'll be reading easily… It's like when you're a kid with your shoelace, the first time you tie your shoelace, you're a little kid and you don't think about it you're just, 'oh my god, my laces are done!' that was a giant leap forward, then you know all kinds of things are possible, you're heading down the right road.

Some used the analogy of learning other skills even as adults as positive reference points

> Jacob: I'm just old enough that I remember getting one of the first computers… All of a sudden… this contraption called a computer landed on my desk with a keyboard and they said "You're going to learn how to use this" and I went "what is that?" [laughs]… so I had to learn how to type… So after losing my eyesight…. I thought well I'm going to have to communicate. So how will I do that? Well, braille.

These positive learning reference points influenced not only feelings towards learning a new skill in adulthood, but also the specific learning strategies applied. For example, one participant described herself as a visual learner in the past, and drew on visual memory strategies to facilitate braille learning.

> Rachel: Because I had eyesight, there was a visual connection I saw. I would say "Okay, the letter "a" is like a circle… and the letter "d" in braille faces the correct way [like the letter d in print] (…) I knew that helped me.

Another participant described the lack of self-checking study tools as an impediment to learning braille, based on his past study habits.

> Toby: I wished we had… the answers at the back of the book… So when you're doing your [braille] exercises you could… look ahead, test yourself. I used to always work ahead in school [because of my low vision] so that when the class reached a lesson, I had some idea what the lesson was about, even if I couldn't see the blackboard.

On the other hand, some participants shared negative previous learning experiences and the fact that they did not view themselves as strong learners. For example, when asked whether her fear of braille or her confidence as a learner held her back initially, one participant said:

> Stephanie: Me as a learner. I really thought that would hold me back a little bit. I would think "I don't know if I can do this!"

3.5.1.4. Physical capacities

Though physical capacities such as the role of tactile perception were mentioned by some, it is worth noting that these were by no means the most frequently highlighted personal factors. Here, some participants expressed the frustration they felt at the start of training when developing the tactile skills needed to recognize braille symbols, or the hand movements needed to maintain position on a braille page. For some participants, this frustration served as a discouragement at the start of training.

> Stephanie: For me, it was quite frustrating at first. I had a really hard time staying on the lines. I still struggle with it a little bit. Because I end up with bad posture and I rub a little bit where I shouldn't be rubbing, I should be gliding. So I found it a bit challenging.

Some participants highlighted that difficulties with tactile perception were greatest at the start of training, but also returned when learning more advanced symbols that were not being encountered outside of training sessions.

> Barbara: Learning the alphabet, numbers and punctuation was easy. The basic things you use every day. But stuff I don't use, like some of the contractions, I wouldn't put in my long-term braille memory. It made it harder for me. My mental capacity to hold it was harder, because I was older.

Finally, all participants highlighted that the frustration related to tactile perception diminished over time as proper techniques developed.

> Jacob: Trying to memorize it at first was difficult... I won't say it was easy, it was not. I got frustrated with it… because I was a visual learner… before I lost my eyesight I would learn stuff by watching it get done… Eventually I figured out how to do it and it started going well. Once I got it, then it became pretty easy.

3.5.2. Theme 2: Social Factors

The second broad theme related to the social factors which influenced the braille learning process. Here, participants emphasized the role of sighted family and friends, the response from the general public, and the influence of knowing other more experienced braille users.

3.5.2.1. Response from family and friends

Participants highlighted the influence of biases or misconceptions held by family and friends about braille, and the role of family support during the braille learning process.

> Margaret: There was a presumption that I would learn Braille... And I have to say it's really funny, people think "Oh, so you lose your vision, you know how to read Braille!" like it comes with the vision loss... I was a little frustrated because, at that point... I was having difficulty finding someone to teach braille to me! I would say that people expecting that you will learn braille is not the same thing as encouraging you.

Other participants shared comments from family members who felt that braille would be too difficult to learn, and this may have deepened the level of discouragement felt.

> Brian: Some of the people maybe saw that I was getting a little frustrated with how I wasn't able to apply it as quickly as I thought, or read as much as I wanted to, and at that point they maybe got a little discouraging, and would say, "Well you don't really need it, if it's that difficult". I think they were trying to be helpful to me, but I don't think that was really helpful.

On the other hand, for some, comments from family and friends who felt impressed because they held the belief that braille would be too difficult to learn served as a source of motivation or pride.

> Kelly: there are many things that I needed help with, or that I couldn't do as quickly... but this I can do and they can't!

Some participants with low vision made the point that family members may not have been aware of the need for braille once training began, especially if the learner still outwardly appeared to be coping visually.

> Stephanie: I think a lot of my family and friends didn't realize how much I really needed it - because I did things well - I'm very bubbly and just didn't let on that I was really struggling.

Other participants highlighted that, though well-meaning, response from family members were influenced by the feelings towards braille that those family members carried with them based on their own past experiences.

> Barbara: I asked them [at the time] why they wanted me to learn print. Later on I learned from my mom that she didn't want me getting headaches. She told me that she could sit in a dark room and read braille, but as soon as there was light, it would give her headaches. She didn't want me to have those same problems. She didn't discourage me from learning it, but didn't want me to learn it too soon.

Other participants highlighted that the learning of braille was not as consequential to family members as adjusting to the new label of blindness.

> Jacob: You know when you are six and you come home from school, you kind of explode out of your clothes.. books fly, shoes fly, and you go play.... We had the experience where I tripped over some stuff and she realized "oh I can't do that because that's going to hurt dad"... So for her it wasn't so much me learning braille, it was adjusting to a father who was sighted and is now blind.

Many participants described the impact of family and friends who provided tangible positive support throughout the learning process and beyond. This support may have included driving them to training interventions, learning some braille to facilitate household communication, or simply showing a level of awareness.

> Toby: well, for instance, I needed somebody to tell me what my CDs were [so that I could label them in braille]. I had a neighbour who would come and go through my CDs with me at the time.

> Jacob: my wife was supportive and said "you take the time you need to do what it takes to get back to work"... She made sure that if I had to go to the rehab centre, she was there to take me... Our lives to some extent were put on hold.

> Margaret: I think that when people are familiar then they are much more likely to be respectful with the [braille] material itself. Not to leave it out or put it in an obscure place... I find even now having friends who come over and if they bring me something and take the time to label it in braille, that's fantastic! Very small things make it really easy... I do think it's helpful if they know some braille… just Grade One braille.

Above all else, participants highlighted the need to provide resources to family members during the braille learning process. For example, one participant describes how the lack of informational resources for family members influenced his learning experience:

> Brian: I think a supportive environment really helps encourage someone to stick with it and to learn. had my family members been exposed to any kind of information about why it was important to learn braille, maybe they would have encouraged it more. I mean, they didn't discourage it, but they didn't encourage it either. Education for family members might help and so the advice I would give is to have that available to them, or point the blind individual to resources they can share with their family to help.

3.5.2.2. Response from the general public

Participants overwhelmingly described reactions from the general public. Some participants drew a distinction between the white cane or guide dog and braille as symbols that put the user on display, and connected this to their broader acceptance of blindness.

> Thomas: The cane is more obvious, but if you’re reading braille in public it is the same thing. I’m not concerned about that anymore. In the beginning you kind of have to decide to accept that [attention] or not.

Others highlighted that the usual social contract is broken in some interactions, where members of the public behave in ways that would normally seem inappropriate.

> Kelly: Sometimes people will comment. One time a man (this was when I was beginning to learn braille) he said "if you're going to be that slow I don't even know why you bother!"

This same participant described an interaction with a stranger who physically removed a braille book from her hands, an experience which she described as distressing as a new braille user.

> Kelly: I said, "what's happening? what's happening?" and this woman said "oh, I wanted to show my grandson!" and I said "you can't do that! Do you do that to sighted people, come to them and remove their book from out of their hands?" (...) She gave it back to me and said "read to him?" and I said "please don't do that."

Participants overwhelmingly highlighted that the misconceptions held by the general public remain a pervasive problem. For some, these social interactions translated into a source of empowerment and raised their own awareness of their visible platform.

> Ellen: You know how people take sign language just for fun? So I thought, why don’t people learn braille like that? I like to bring braille to people… Try to get rid of all those misconceptions.

3.5.2.3. Influence of other braille users

Most participants revealed the ways in which knowing (or not knowing) other braille users influenced their braille learning experiences. For example, one participant highlighted the influence of seeing first-hand examples of braille being used before she began learning braille:

> Rachel: This one lady, she completed a degree and (…) she read all her books in braille. I think that was very important for me, to understand that if you have that background in braille, it allows you to have a lot more opportunity.

Others highlighted the value of knowing other braille users during the learning process, as a useful resource or point of reference for the ways in which braille could be used in daily life.

> Brian: I think if you can bounce ideas off other people of what they're using braille to do, there is value in that for sure. I don't think it's the be all and end all but I think just having a connection with other people who are using braille is important if you want to make that a part of your life.

On the other hand, some participants expressed that the lack of these social connections functioned as an early barrier, especially if a lack of information or stigma delayed the learning of braille.

> Stephanie: I hadn't really met a lot of blind people myself so you know I didn't really have any interaction, which is something personally I think is a lacking feature in Canada.

Above and beyond the influence of having these practical reference points, an interesting thread emerged related to the experience of identifying with a larger braille or blindness community and the influence this had on identity formation during the braille learning process. Here, some participants described the notion that remaining a non-braille reader in a sighted world was more disabling than being a braille reader in a blind world.

> Ellen: I knew totally blind people who knew braille and read it extraordinarily well. You know, it was the weirdest experience. I went to a restaurant with a totally blind friend… and they read the menu to me. I couldn't read the menu. So I'm stuck in this nowhere land, because I'm in the middle. I can't read print, but I can't read braille. It was like when I had blind friends that would play [braille] Scrabble, but… I couldn't do it. Then finally when I learned braille… I could do these things. It felt so empowering.

Linked to this, some participants touched on the influence of coming to identify with a braille or blindness community during the braille learning process and the broader impact this had on them as adult braille learners.

> Kelly: In a funny way it felt good to be part of a very select club… For me, it was proof positive that there is a need for expression, that there is a need for literacy… that blind people could persevere… I was so proud to be part of that group.

For participants who acknowledged feeling this sense of community, the learning and use of braille often came to be viewed through an identity-based perspective.

> Ellen: It was so liberating… I know I sound a bit over the top, but it was almost like being given my heritage, finally. Being given what I felt I should have been given because I was born blind. Braille is the reading mode of the blind, but I was deprived of that, and it made me really upset and sad.

3.5.3. Theme 3: Institutional Factors

The final theme emphasized by participants underscored the institutional factors which considerably shaped the adult braille learning journey. Overwhelmingly, participants highlighted that they encountered institutional barriers at different points of the learning trajectory. Specifically, participants emphasized the role of awareness and availability of resources, the response from the rehabilitation system, and the influence of learning context.

3.5.3.1. Awareness and availability of resources

Several participants described that once they decided to pursue braille training, they encountered difficulties in securing that training, due to a lack of resources, long wait lists or a lack of awareness of where to go. One participant described having to turn to a correspondence course because he could not find training where he lived.

> Brian: Looking back now, I probably would have preferred to have either group or one-on-one instruction which would have been much more effective but due to the lack of services that was not an option.

Another participant described that even now that she has learned braille, she is unaware of training resources in her region to further her skills:

> Margaret: I had difficulty finding someone who would teach me braille! Even now… I don't know right now how to learn, if I wanted to learn today. For somebody with my enthusiasm, you think I'd be able to easily find out about braille continuing education but no.

On the other hand, participants who lived in regions where rehabilitation fell under provincial healthcare jurisdiction did not encounter difficulties when seeking training. However, long wait lists often postponed the start of training where these services were more readily available.

Most participants expressed that they could not find reading materials to maintain their braille skills during and after training, either due to a lack of resources for adults or a lack of awareness about where to search.

> Brian: One of the biggest obstacles is that I wanted to order some braille books to practice when I first started learning. I remember it took almost a year for me to even get anything mailed to me (…) So that first year of taking courses, I didn't really have any material to practice with beyond the textbook and I think that discouraged me.

A final recurring thread related to lack of access to braille devices, due to cost and the lack of funding programs specifically for adults. For example, one participant describes having seen electronic braille displays during training and how having access to one of his own would have facilitated learning.

> Thomas: We did see a braille display and it was really neat, but it was so expensive. I probably would have used braille more if I actually would have had my own braille display.

Another participant highlighted that having access to such a tool would have been a beneficial supplement to her as an adult learner with decreased tactile sensitivity.

> Stephanie: I have a friend here now that has been letting me play with his braille display and I, for one, struggle feeling the dots, and found the braille display so much easier. It is a cost issue.

3.5.3.2. Response from rehabilitation system

In telling their stories, several participants often returned to what they viewed as a perceived reluctance to provide braille training among some rehabilitation specialists, due to their beliefs about braille and aging. For example, a participant highlighted the strong emotional response she experienced when she was told that she should wait for further vision loss before pursuing braille:

> Kelly: I could not see the dots themselves, but I could see the shadow of the dots. And because I could see the shadow of the dots, he said “No, you’re not ready” and I almost cried. I thought ‘is this it?’ I could learn. I could learn to read a new code. Write a new code. I could touch paper again… And you’re saying no? I was devastated.

Some participants felt that their advanced age led rehabilitation specialists to believe that they would be unable to succeed to the same degree as younger clients:

> Toby: He was quite doubtful [about me taking the braille test]. He said “I don’t know… some younger people can't do it”

Others emphasized the perceived support they encountered from rehabilitation specialists and the positive impact this had during braille learning. One participant with deafblindness spoke about his rehabilitation specialists’ dedication to accommodate his unique communication needs:

> Seth: The instructor is wonderful. She has a keyboard and a laptop, and she types everything that she says… I really appreciate it. It saves me from having to interrupt her to repeat herself. She is very inclusive.

3.5.3.3. Learning context

Participants described how learning context (the inclusion or exclusion of different learning approaches) influenced their training experiences. Specifically, participants emphasized the role of relevant and motivating materials for adults, and the impact of learning alone or with others.

There was a consensus among participants that it is difficult to remain motivated as an adult learner when materials used in training are either deemed to be irrelevant or too below the age level of adult learners. For example, one participant described the positive impact of selecting her own reading material during training sessions. In her case, this book also provided her with valuable information as a newly blinded adult:

> Kelly: This book had a dual purpose. Allowing me to practice braille in an unstructured way and of course there was a lot of information in there for somebody who was very recently blind.

Another participant expressed that the lack of relevant materials prevented him from reading braille between sessions. Here, he felt that access to a braille display would have permitted him to read personally meaningful material, such as emails and websites:

> Brian: I think it would have made a huge difference because if I had the braille display I probably would have made myself use it more with the computer and practiced a lot more. It would have opened a lot of doors to me but of course we don't have any source of funding in Canada for that.

On the other hand, other participants highlighted that the need for relevant materials for adults must be balanced with those that are at an appropriate level. For example, one participant described that it was helpful for her to read books that were familiar to her from her childhood. This allowed her to encounter new braille symbols but within the context of familiar content:

> Rachel: I chose a book that I was particularly interested in… Black Beauty, Because I knew the story. It helped to rote learn the new contractions.

Another participant noted that the inclusion of personally meaningful projects during sessions helped her develop an appreciation for braille and the role it could play in her own life.

> Ellen: In our braille class, they wanted us to do a project. I ended up making a braille menu for a restaurant that didn't have one. I had them email me the text and my project was to put it all together… learn the braille contractions and I printed it out and I had to bind it. And that made it more relevant, more personal.

Finally, participants highlighted the impact of either learning braille alone or with other adult clients. For many participants, learning in a group context provided a level of support and a sense of unified community that they felt they had been lacking.

> Margaret: The atmosphere was really informal and I would say that we were all unified by a common cause (…) It also really helped with motivation to punctuate our progress with little celebrations of achievement.

Another participant highlighted that learning in a group context provided her with mentors, but also allowed her to develop her own confidence through the process of helping less advanced learners.

> Stephanie: Having other peers in the class who were a bit further ahead helped me. And I was helping the new person, and that was kind of a little bit of an encouragement for me too because I was so new to braille yet at the same time I was able to help someone.

On the other hand, some participants emphasized the value of maintaining different options for adult learners, who may have other responsibilities or impairments that require them to learn at home or on a one-on-one basis:

> Jacob: I'm glad that I learned it privately. As a kid it's not so bad, but as an adult I needed to learn in a quiet space and I needed to be with somebody who was very patient. Not judgmental about it and who would let me learn at my own pace.

3.6. Discussion

The purpose of this study was to explore the experiences of working-age and older adults who pursue braille rehabilitation training, and to identify the enablers and barriers which may influence this process. Participants describe that the adult braille learning journey is shaped by a variety of personal, social, and institutional factors. Their insights provide important context for future research and practice, and help to work towards the development of evidence-based recommendations to address existing gaps.

3.6.1. Personal Factors

Among the personal factors that emerged, it can be seen that the motivation to learn braille is typically instigated by a perceived 'need to know' in order to maintain a life activity or meaningful adult label. It is true that this echoes the andragogical assertion that learning is most effective when the decision to learn is made deliberately in order to tangibly improve some aspect of life.[35] However, a barrier appears to arise when the prospective learner is operating upon misconceptions about what braille is and whom it can serve. This is evidenced by participants who expressed initial misconceptions that may have delayed their training, such as the belief that braille is only for those who are fully blind or for those who engage in extensive reading. The onus therefore remains with the rehabilitation specialist to be cognizant of unspoken misconceptions that prospective braille clients might hold, and to foreground the practical usage of braille in daily life during any learning situation.

Prior identity also emerged as an important personal factor that either motivated or impeded the decision to pursue braille, regardless of its potential utility. Here, a subtle but seemingly important distinction is drawn between those who attached the 'reader' label to their identity prior to vision loss, and those who did not. For individuals who viewed themselves as readers and who felt a personal connection to the physicality of reading, braille enables them to reconnect with a part of themselves they feel they had lost. This concept is echoed in comments from participants who speak of braille literacy as "the self reaffirmed" or "like Lazarus rising" (Margaret).

The concept of the perceived loss of self-identity that accompanies acquired impairment has been explored in other studies in the field of rehabilitation, though not specifically in relation to braille. Levack et al.[68], for instance, describes how some participants with acquired traumatic brain injury (TBI) feel that their self-identity becomes fragmented or disrupted following diagnosis, leading them to speak of the 'self' before and after TBI as two separate identities. In a similar way, braille for some participants appears to bridge the gap between their identity before and after the onset of vision loss. The implication of this is that while other alternative formats (such as audio) may equally enable the completion of tasks, they will not address the identity gap felt by some clients. Rehabilitation specialists must therefore consider not only what tools may be best to complete a specific task, but also the holistic experiences attached to literacy that adults carry with them as important sources of motivation.

Previous learning experiences, whether positive or negative, appear to also influence both the motivation to learn braille and the views adults have of themselves as learners, echoing the notion that experience is the adult learners living textbook.[35] participants describe the use of past learning tactics which served them well, such as drawing on visual imagery (Rachel) or the use of self-checking study methods (Toby). Others turn to examples of previous learning experiences as positive reference points to motivate learning (as with Margaret who uses the analogy of learning to tie her shoelaces or Jacob who remembers the initial learning curve when computers were introduced to the workplace). On the other hand, we can see that prior learning experiences can also serve as invisible impediments to learning if they are associated with failure.

Though little attention has been devoted to previous learning within the adult braille rehabilitation context, a wide body of research from other domains explores the role of past learning memories on adult motivation and self-efficacy. According to expectancy-value theory, for instance, learning motivation is a function of both the expectancy of success ("Can I do this?") and the subjective value ascribed to a learning task ("Do I want to do this?"), and it is influenced by a variety of preceding variables including affective learning memories.[69] In a sample of 300 adults, for example, Gorges illustrates how previous education and the memories associated with it function as important predictors of adult learning engagement.[69] Research also suggests that adults whose metacognitive skills are well developed are more able and motivated to learn.[70] In this way, adult learners gain a sense of self-agency when they are included in the assessment process (by asking them what works and what could be done differently) and by directly incorporating learning tactics that have worked effectively for them in the past. Our findings demonstrate that prior experiences should be considered as part of the often invisible baggage that adults carry with them, and that positive learning experiences (including accumulated interests and expertise) should be harnessed to enhance training outcomes.

3.6.2. Social Factors

At the level of social factors, it is evident that reactions from family and friends play an influential role during the braille learning process, even though they are not physically in the room when learning takes place. Participants highlight the value of tangible support that family members provide, but also the negative impact of misconceptions held by family and friends. The stories shared illustrate the ways in which family and friends may also be adjusting to vision loss in the background. They may either not be aware of the need for braille if the client is 'passing' as sighted or may themselves discourage the use of braille based on their unconscious biases. Participants accentuated the need for greater information geared towards family and friends, such as basic awareness to dispel myths about braille and (in some cases) exposure to the braille alphabet to facilitate communication. In fact, rehabilitation research is replete with examples of how support from those in a client's inner circle can influence training outcomes or contribute to the abandonment or under-use of compensatory tools.[71] While the role of family members (and in particular, parents) is an integral consideration during childhood braille learning,[72] it is clear that a greater emphasis should be placed on providing adult clients with resources to share with family and friends, and that these social networks can function as positive supports when considered.

Moving to the macro level, these findings also point to the potential influence of societal perceptions of braille and blindness during the adult braille learning process. Through the anecdotes of participant interactions with members of the public, a subtle yet clinically significant distinction begins to emerge. When blindness is viewed through a medical model lens[73] (as a stigma or impediment), braille is by extension also viewed as an outward symbol of deficit: "I didn't think I was that bad yet" (Seth); "I felt at the time it (white cane) was already drawing attention to myself" (Stephanie). On the other hand, when blindness comes to be viewed through a social model lens[73] or as "simply a part of who [you are]" (Ellen), then braille by extension is perceived as a symbol of independence that empowers the user: "it [learning braille] felt so liberating…almost like being given my heritage finally" (Ellen). What participants illustrate through their comments is that braille can become entangled and inseparable from the self-identity that adult braille learners with acquired vision loss must negotiate.

Though theoretical on the surface, these insights carry important implications for adult braille learning. Ellen, for example, described that what disabled her prior to learning braille was not her blindness, but her inability to access information. She shared the feeling of being 'disabled' in the presence of her braille-using friends who could read the restaurant menu. Coming to this understanding reinforces that braille is not an impediment but instead an empowering tool that enabled her to achieve her goals (because her braille-using blind friends were not disabled in this moment, though she was). Though adjustment to vision loss is an ongoing process, these stories raise the importance of fostering the understanding of braille as a tool that ultimately minimizes the disabling impact of blindness. Several participants describe that this social definition of blindness is often forged through the connections made with other experienced braille users during the learning process, or in coming to feel as though they are part of a larger blindness community. Although participants highlight the need to ensure flexible learning options, they also stress that access to other braille users as mentors and sources of peer-support helps to address many of the emotions attached to braille as a symbol of blindness. It therefore becomes imperative to consider the value of group training paradigms for those who would benefit from it,[74] and the inclusion of peer-support initiatives to bridge learning both during and once training concludes.

The influence of societal responses to braille during the learning process raises another important fact. Misconceptions about blindness and braille can occasionally lead to uncomfortable or unwanted social interactions for adult braille learners (as described by Kelly who had a book physically removed from her hands). The tendency to view people who use braille in public as exceptional simply because they are reading resonates with what disability scholars have come to call "inspiration porn"[75] and underscores the level of public education that is still required. Previous studies, for instance, illustrate how challenges in the physical environment including attitudinal barriers lead some older adults with acquired low vision to retreat to the private sphere.[76] In this way, clients can be equipped with the tools that they need to manage vision loss (such as braille), but may still encounter barriers outside the training room when using the tools that increase their hypervisibility.[77] These interactions, which may be distressing to adult braille learners who are new to vision loss, raise the need to not merely 'rehabilitate' clients, but also to consider ways to rehabilitate a society that continues to influence the outcomes of the adults who are served.

3.6.3. Institutional Factors

The institutional factors discussed by participants point to the benefit of having access to materials and tools geared towards adults, both to bridge learning between sessions and to maintain braille skills once formal training has concluded. However, a recurring obstacle reiterated by almost all participants was that these practice resources were not consistently available to adult braille learners in Canada, and that the cost of electronic braille devices (upwards of $3,000), which would increase access to braille, remains prohibitive. Currently, governmental funding programs to purchase assistive devices (including braille devices) are not available in all provinces, and typically only support clients who are either studying or working, even when they are available.[78] The problem that arises is that adults with newly acquired vision loss are often temporarily neither working nor studying, but can only return to such forms of social participation once their blindness skills (such as braille) are at an adequate level.[79] Similarly, eligibility criteria based upon these requirements will impede access for older adults with acquired vision loss who are retired but who nonetheless might benefit from braille for home, recreation and personal communication needs. The consequence is that the inability for older adults to develop adequate braille skills during training or the abandonment of braille in the post-training period may wrongly be viewed as a problem with braille as an appropriate tool, rather than due to the insufficient supports provided to adults who genuinely wish to use braille but cannot: “I probably would have used braille more if I actually would have had my own braille display” (Thomas). This points to the need to develop practice materials and tools geared towards the age level and interests of adult learners, and to advocate for the expansion of funding regimes that account for the needs of older adults with acquired vision loss. Though the introduction of lower cost electronic braille devices have gained prominence in recent years,[80] these findings also further the need to reduce the cost of production attributed to these tools.

Finally, several participants described a perceived reluctance on the part of rehabilitation specialists to provide braille training, and the considerable distress that this caused for them during the time when they attempted to access these services. While this certainly does not reflect the response of all professionals, these comments do suggest that unconscious biases about both braille and aging can impact professional judgments and decision-making. Implicit in some comments is that misconceptions about the abilities of older adults in particular may be influencing decisions about whether braille should be considered as a viable option. Prior research has explored the influence of ageism in health care and rehabilitation, illustrating the ways in which implicit views about the elderly may unconsciously determine the amount and quality of care delivered to older adults.[81] Similarly, Wittenstein & Pardee[82] found a direct relationship between the training that blindness professionals receive and their attitudes towards braille, with those who receive more training in braille holding more positive attitudes. These findings bolster the need for rehabilitation specialists to remain self-reflexive and aware of the impact of their unconscious biases, and to ensure that adequate training addresses the misconceptions that rehabilitation specialists may carry with them into the field. Future research should further explore how the often unconscious lens through which both braille and aging are perceived might be informing views on clinical decision-making.

3.7. Limitations and future research priorities

While these results provide vital context about existing barriers, they do not directly probe the experiences of working-age and older adults who tried but ultimately did not prevail with their braille learning goals. This raises a methodological challenge of how to best reach out to clients who abandoned their training or chose not to pursue it in the first place. Often, clients may feel uneasy about sharing these experiences, especially if they view them as personal failures. However, it is this perspective that will provide a more comprehensive picture of why some are able to persist and others encounter obstacles that are ultimately insurmountable. Mixed-method longitudinal studies that follow adult braille clients from referral to the completion (or abandonment) of training could help to address this gap.

A second related limitation stems from the fact that the participants in the present study (save for two) lived in larger Canadian cities during the time of braille training. Despite the differences in residence, participants highlighted recurring themes which suggest that similar facilitators and barriers are experienced by adults who pursue braille rehabilitation training regardless of location. However, those living outside large cities or in smaller provinces encounter additional barriers that must be addressed. Though no research on braille services in rural Canada currently exists, a cursory look at healthcare research generally points to the lack of available services in rural areas, a lack of awareness among prospective clients, and healthcare and rehabilitation models which do not adequately acknowledge cultural context, such as the deep-rooted history between indigenous and non-indigenous peoples.[83] Though invitations to participate were advertised widely and telephone-based interviews were provided as available options for those who could not travel to central locations, no prospective participants from these other geographic areas contacted the research team. Future studies should strive to consider alternative methods of recruitment that better facilitate and encourage participation from adults who live in these regions. The lack of communication from those residing in rural areas or smaller provinces may also suggest that braille training has not routinely been as available to adults in these regions. This raises important concerns that warrant future attention.

Finally, although the current investigation is one of the very few braille studies that incorporates the perspective of older adults, most participants learned braille in middle-age. This may reflect the reality that few older adults above the age of 60 are referred to braille training. This is alluded to in the current findings which point to a possible stigma towards aging and a hesitancy among some (but not all) rehabilitation specialists to view braille as a viable option for older adults. Future research should focus more exclusively on any older adults who have learned braille, to add to the knowledge that this current study provides.

3.8. Conclusion

This study is among the first to explore the experiences of working-age and older adults who pursue braille rehabilitation training. In following the braille learning journey that participants describe, it becomes clear that a variety of personal, social and institutional factors can either facilitate or impede adult braille learning before, during and after training concludes. Findings bring to the forefront barriers that can be addressed through policy and practice changes. Results also complicate the notion that physical factors (such as declines in tactile perception) are solely or primarily responsible for shaping the training outcomes of older braille clients. It can also be seen that many of the variables highlighted by participants reflect existing andragogical learning models. Future research can expand upon these insights to work towards an adult braille learning theory, in order to contemplate how adult braille learning may veer from other forms of adult learning, and the practice implications of these distinctions. Undoubtedly, understanding the enablers and barriers encountered by older adults who pursue braille training will become increasingly important in decades to come.

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3.10. Disclosure statement

The authors report no conflicts of interest.

3.11. Ethics approval

Ethics approval was obtained through the Centre for Interdisciplinary Research in Rehabilitation of Greater-Montreal (CRIR# 1311-0218), a prerequisite for recruiting participants through the Montreal-based network of vision rehabilitation centres. Additional approval was granted by Vision Loss Rehabilitation Canada (formerly the Canadian National Institute for the Blind, the largest Canadian provider of blindness and low vision rehabilitation services outside of Quebec) in order to facilitate the recruitment of participants residing in other provinces.

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3.13. References

1. Ponchillia PE, Ponchillia SV. Foundations of Rehabilitation Teaching with Persons Who Are Blind or Visually Impaired. New York: American Foundation for the Blind; 1996.

2. Knowles MS, Holton EF, Swanson RA. The adult learner : the definitive classic in adult education and human resource development. 2015.

3. Bourne RRA, Flaxman SR, Braithwaite T, Cicinelli MV, Das A, Jonas JB, et al. Magnitude, temporal trends, and projections of the global prevalence of blindness and distance and near

vision impairment: a systematic review and meta-analysis. Lancet Glob Health. 2017; 5(9):e888-e97.

4. Varma R, Vajaranant T, Burkemper B. Visual impairment and blindness in adults in the United States: Demographic and geographic variations from 2015 to 2050. Journal of the American Medical Association: Opthalmology. 2016; 134(7):802-9.

5. Kleege G. Visible Braille/Invisible Blindness. Journal of Visual Culture. 2006; 5(2):209-18.

6. Graves A. Braille literacy statistics research study: History and politics of the "braille reader statistic": A summary of AFB Leadership Conference Session on Education. Journal of Visual Impairment & Blindness. 2018; 112(3):328-31.

7. Dixon J, editor. Braille into the next milennium. Washington, DC: National Library Service for the Blind and Physically Handicapped; 2000.

8. Mick P, Hämäläinen A, Kolisang L, Pichora-Fuller MK, Phillips N, Guthrie D, et al. The prevalence of hearing and vision loss in older Canadians: An analysis of Data from the Canadian Longitudinal Study on Aging. PsyArXiv Preprints; 2019.

9. Holbrook MC, McCarthy T, Kamei-Hannan C. Foundations of Education: Volume I: History and Theory of Teaching Children and Youths with Visual Impairments. 3rd ed: AFB Press; 2017.

10. Wormsley DP, D'Andrea FM. Instructional Strategies for Braille Literacy. New York: American Foundation for the Blind; 1997.

11. Ponchillia PE, Durant PA. Teaching behaviors and attitudes of braille instructors in adult rehabilitation centers. Journal of Visual Impairment & Blindness. 1995.

12. Hannan CK. Review of research: Neuroscience and the impact of brain plasticity on braille reading. Journal of Visual Impairment & Blindness. 2006; 100(7).

13. Sadato N, Okada T, Honda M, Yorekura Y. Critical period for cross-modal plasticity in blind humans: a functional MRI study. Neuroimage. 2002; 16:389-400.

14. Sterr A, Muller M, Elbert T, Rockstroh B, Taub E. Development of cortical reorganization in the somatosensory cortex of adult Braille students. Electroencephalogr Clin Neurophysiol Suppl. 1999; 49:292-8.

15. Stevens JC. Aging and spatial acuity of touch. Journal of Gerontology. 1992; 47(1):35-40.

16. Stevens JC, Foulke E, Patterson MQ. Tactile acuity, aging, and braille reading in long-term blindness. Journal of Experimental Psychology: Applied. 1996; 2(2):91-106.
17. Goldreich D, Kanics IM. Tactile acuity is enhanced in blindness. J Neurosci. 2003; 23(8):3439-45.
18. Goldreich D, Kanics IM. Performance of blind and sighted humans on a tactile grating detection task. Perception & Psychophysics. 2006; 68(8):1363-71.
19. Legge GE, Madison CM, Vaughn BN, Cheong AMY, Miller JC. Retention of high tactile acuity throughout the lifespan in blindness. Perception & Psychophysics. 2008; 70(8):1471-88.
20. Legge GE, Madison CM, Mansfield JS. Measuring braille reading speed with the MNREAD test. Visual Impairment Research. 1999; 1(3):131-45.
21. Schroeder FK. Perceptions of braille usage by legally blind adults. Journal of Visual Impairment & Blindness. 1996; 90(3):210-8.
22. Ryles R. The impact of braille reading skills on employment, income, education, and reading habits. Journal of Visual Impairment & Blindness. 1996; 90(3):219-26.
23. Silverman AM, Bell EC. The Association between Braille Reading History and Well-being for Blind Adults. Journal of Blindness Innovation and Research. 2018; 8(1).
24. Southall K, Wittich W. Barriers to Low Vision Rehabilitation: A Qualitative Approach. Journal of Visual Impairment & Blindness. 2012; 106(5):261-74.
25. Pollard TL, Simpson JA, Lamoureux EL, Keeffe JE. Barriers to accessing low vision services. Ophthalmic and Physiological Optics. 2003; 23(4):321-7.
26. Spafford MM, Laliberte Rudman D, Leipert BD, Klinger L, Huot S. When Self-Presentation Trumps Access: Why Older Adults With Low Vision Go Without Low-Vision Services. Journal of Applied Gerontology. 2010; 29(5):579-602.
27. Fraser SA, Kenyon V, Lagacé M, Wittich W, Southall KE. Stereotypes associated with age-related conditions and assistive device use in Canadian media. The Gerontologist. 2016; 56(6):1023-32.
28. Bolt D. Caught in the chasm: Literary representation and suicide among people with impaired vision. British Journal of Visual Impairment. 2005; 23(3):117-21.

29. Jernigan K. Blindness: Is Literature Against Us? Chicago: National Federation of the Blind; 1974.

30. Rudgard O. Calling people 'blind' is shocking and misleading says charity as it looks to change name. The Telegraph. 2018.

31. Greenland C. Vision Canada: The Unmet Needs of Blind Canadians. Toronto: Canadian National Institute for the Blind; 1976.

32. Martiniello N, Eisenbarth W, Lehane C, Johnson A, Wittich W. Exploring the use of smartphones and tablets among people with visual impairments: Are mainstream devices replacing the use of traditional visual aids? Assistive Technology. 2019:1-12.

33. Hersh M. Cane use and late onset visual impairment. Technology and Disability. 2015; 27(3):103-16.

34. Hogan CL. Stigma, Embarrassment and the Use of Mobility Aids. International Journal of Orientation & Mobility. 2012; 5(1):49-52.

35. Knowles MS. Andragogy: Adult Learning Theory in Perspective. Community College Review. 1978; 5(3):9-20.

36. Tough A. Choosing to Learn. Toronto: Ontario Institute for Studies in Education; 1979.

37. Zhang C, Zheng G, editors. Supporting adult learning: enablers, barriers, and services. SIGITE '13; 2013.

38. Meyer A, Rose DH, Gordon D. Universal design for learning: Theory and Practice. Wakefield, MA: CAST Professional Publishing; 2014.

39. Baumgartner LM. An update on transformational learning. New directions for adult and continuing education. 2001; 2001(89):15-24.

40. Michael J. Where's the evidence that active learning works? Advances in Physiology Education. 2006; 30(4):159-67.

41. Leat SJ. A Proposed Model for Integrated Low-Vision Rehabilitation Services in Canada. Optometry and Vision Science. 2016; 93(1):77-84.

42. Convention on the Rights of Persons with Disabilities (CRPD). United Nations Division for Social Policy and Development - Disability.

43. Creswell JW. Qualitative Inquiry and Research Design: Choosing among Five Approaches. London: Sage Publications; 2007.

44. Corn AL, Lusk KE. Perspectives on Low Vision (Chapter 1). Foundations of Low Vision: Clinical and Functional Perspectives. New York: American Foundation for the Blind; 2010. p. 3-34.

45. Goodman LA. Snowball Sampling. Ann Math Statist. 1961; 32(1):148-70.

46. Smith JA. Semi-structured interviewing and qualitative analysis. In: Smith JA, Harré R, van Langenhove L, editors. Rethinking Methods in Psychology. London: Sage; 1995.

47. Horrigan-Kelly M, Millar M, Dowling M. Understanding the Key Tenets of Heidegger's Philosophy for Interpretive Phenomenological Research. International Journal of Qualitative Methods. 2016; 15(1):1609406916680634.

48. Ninot G, Moullec G, Desplan J, Prefaut C, Varray A. Daily functioning of dyspnea, self-esteem and physical self in patients with moderate COPD before, during and after a first inpatient rehabilitation program. Disability and Rehabilitation. 2007; 29(22):1671-8.

49. Fuhrer MJ. Assistive technology outcomes research: challenges met and yet unmet. Am J Phys Med Rehabil. 2001; 80(7):528-35.

50. Phillips M, Proulx MJ. Social Interaction Without Vision: An Assessment of Assistive Technology for the Visually Impaired. Technology & Innovation. 2018; 20(1-2):85-93.

51. Sugawara AT, Ramos VD, Alfieri FM, Battistella LR. Abandonment of assistive products: assessing abandonment levels and factors that impact on it. Disabil Rehabil Assist Technol. 2018; 13(7):716-23.

52. International Classification of Functioning, Disability and Health (ICF). World Health Organization; 2001.

53. World Medical Association. Declaration of Helsinki: ethical principles for medical research involving human subjects. Journal of the American Medical Association. 2013; 310(20):2191-4.

54. Saleh GM, Patel JI, Sivaprasad S, Tsesmetzoglou E, Fietje N, Saleh NM. Digital Voice Signature: the future of consent? Clin Exp Ophthalmol. 2007; 35(3):297.

55. Knobf M, Juarez G, Lee S-YK, Sun V, Sun Y, Haozous E, editors. Challenges and strategies in recruitment of ethnically diverse populations for cancer nursing research. Oncology Nursing Forum; 2007.

56. Becker H, Roberts G, Morrison J, Silver J. Recruiting people with disabilities as research participants: Challenges and strategies to address them. Intellectual and Developmental Disabilities. 2004; 42(6):471-5.

57. Matua GA, Van Der Wal DM. Differentiating between descriptive and interpretive phenomenological research approaches. Nurse Res. 2015; 22(6):22-7.

58. Hennink MM, Kaiser BN, Marconi VC. Code Saturation Versus Meaning Saturation:How Many Interviews Are Enough? Qualitative Health Research. 2017; 27(4):591-608.

59. Ferguson PM, Nusbaum E. Disability Studies: What is it and what Difference does it Make? Research and Practice for Persons with Severe Disabilities. 2012; 37(2):70-80.

60. Mankoff J, Hayes GR, Kasnitz D. Disability studies as a source of critical inquiry for the field of assistive technology. Proceedings of the 12th international ACM SIGACCESS conference on Computers and accessibility; Orlando, Florida, USA: Association for Computing Machinery; 2010. p. 3–10.

61. Reynolds F, Prior S. 'A lifestyle coat-hanger': a phenomenological study of the meanings of artwork for women coping with chronic illness and disability. Disabil Rehabil. 2003; 25(14):785-94.

62. Braun V, Clarke V. Thematic analysis. APA handbook of research methods in psychology, Vol 2: Research designs: Quantitative, qualitative, neuropsychological, and biological. APA handbooks in psychology®. Washington, DC, US: American Psychological Association; 2012. p. 57-71.

63. InqScribe. 2.2.4 ed: Inquirium; 2018.

64. Finlay L. Unfolding the Phenomenological Research Process:Iterative Stages of “Seeing Afresh”. Journal of Humanistic Psychology. 2013; 53(2):172-201.

65. Smith JA, Flowers P, Larkin M. Interpretative Phenomenological Analysis: Theory, Method and Research. London: Sage Publishing; 2009.

66. Asselin ME. Insider research: issues to consider when doing qualitative research in your own setting. J Nurses Staff Dev. 2003; 19(2):99-103.

67. Mingus M. Leaving Evidence [Internet]2011. [cited 2020]. Available from: https://leavingevidence.wordpress.com/2011/05/05/access-intimacy-the-missing-link/.

68. Levack WMM, Boland P, Taylor WJ, Siegert RJ, Kayes NM, Fadyl JK, et al. Establishing a person-centred framework of self-identity after traumatic brain injury: a grounded theory study to inform measure development. BMJ open. 2014; 4(5):e004630-e.

69. Gorges J, Kandler C. Adults' learning motivation: Expectancy of success, value, and the role of affective memories. Learning and Individual Differences. 2012; 22(5):610-7.

70. Rivers WP. Autonomy at all costs: An ethnography of metacognitive self-assessment and self-management among experienced language learners. The modern language journal. 2001; 85(2):279-90.

71. Gitlin LN. Why older people accept or reject assistive technology. Generations. 1995; 19:41-6.

72. Rogers S. Learning braille and print together — the mainstream issues. British Journal of Visual Impairment. 2007; 25(2):120-32.

73. Bogart KR, Logan SW, Hospodar C, Woekel E. Disability models and attitudes among college students with and without disabilities. Stigma and Health. 2019; 4(3):260-3.

74. Farrow KR. Using a group approach to motivate adults to learn braille. Journal of Visual Impairment & Blindness. 2015; 109(4):318-21.

75. Grue J. The problem with inspiration porn: A tentative definition and a provisional critique. Disability & Society. 2016; 31(6):838-49.

76. Fraser S, Beeman I, Southall K, Wittich W. Stereotyping as a barrier to the social participation of older adults with low vision: a qualitative focus group study. BMJ open. 2019; 9(9):e029940.

77. Hammer G. “If They‘re Going to Stare, at Least I‘ll Give Them a Good Reason To”: Blind Women’s Visibility, Invisibility, and Encounters with the Gaze. Signs: Journal of Women in Culture and Society. 2016; 41(2):409-32.

78. Gordon P, Kerzner L, Sheldon T, Hansen E. Assistive Devices in Canada: Ensuring Inclusion and Independence. Toronto: ARCH Disability Law Centre; 2007.

79. Burmedi D, Becker S, Heyl V, Wahl H-W, Himmelsbach I. Emotional and social consequences of age-related low vision. Visual Impairment Research. 2002; 4(1):47-71.

80. Walker AS, Sangelkar S, editors. Design Exploration of Affordable Refreshable Braille Display Technology for Low-Income Visually Impaired Users. ASME 2017 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference; 2017: American Society of Mechanical Engineers Digital Collection.

81. São José JMS, Amado CAF, Ilinca S, Buttigieg SC, Taghizadeh Larsson A. Ageism in Health Care: A Systematic Review of Operational Definitions and Inductive Conceptualizations. The Gerontologist. 2017; 59(2):e98-e108.

82. Wittenstein SH, Pardee ML. Teachers' Voices: Comments on Braille and Literacy from the Field. Journal of Visual Impairment & Blindness. 1996; 90(3):201-9.

83. Rush KL, Chiasson M, Butterfield M, Straka S, Buckley BJ. Recognition: key to the entrepreneurial strategies of rural coalitions in advancing access to health care. International Journal for Equity in Health. 2019; 18(1):119.

Chapter 4 – Study 3: Exploring correlates of braille reading performance in working-age and older adults with visual impairments

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4.1. Abstract

Tactile, motor and cognitive capacities decline with age, but little is known about how this relates to braille reading outcomes. This study was designed to investigate correlates of braille reading speed among working-age and older adults. Texts were read in two modes: oral/silent, and two media: paper/electronic braille display, by 46 blind adults (age range 23-88) who learned braille between the ages of 5 and 63. (1) Increased age did not correlate with lower reading speeds; (2) active tactile acuity, reading frequency and braille learning age were significantly correlated with reading speed; and (3) reading medium did not have a significant influence, though silent reading was significantly faster than reading aloud. Findings underscore the importance of providing opportunities for older braille learners to practice braille and challenge the suggestion that increased age alone will impede braille learning. Additional research is needed to develop evidence-based strategies to address the needs of older adults.

4.2. Introduction

The prevalence of acquired visual impairment is increasing; yet, research on braille, adulthood and aging remains minimal.[1] While tactile sensitivity, finger and hand dexterity, and cognitive functions are crucial components of efficient braille reading,[2] research is needed to understand the physiological and cognitive characteristics of older braille readers, and to explore the potential role of age-related declines on braille reading outcomes.[3] The goal of this study was therefore to examine the relationship between tactile, motor, and cognitive measures and braille reading performance within a single sample of working-age and older adults.

Braille provides access to vital information including personal communication, leisure reading, and professional correspondence,[4,5] and is read on paper or using electronic displays that instantly convert electronic information into braille.[6] Braille reading requires tactile sensitivity in the fingertips,[7] which has been shown to decline at a rate of approximately 1% per year,[8-10] effectively being more than halved between ages 20 and 80. Notably, braille readers maintain higher tactile acuity thresholds in the braille-reading fingers across all ages by 15% compared to age-matched sighted counterparts.[8,10]

Proficient reading also requires effective finger and hand coordination, to follow a line of text and to transition between lines.[11] Though braille can be read with one hand alone, two-handed reading is associated with higher reading speeds, particularly when the hands are used cooperatively.[12] However, fine-motor dexterity is known to decline with age, with declines of up to 35% reported between those in their early twenties and those in their 80s.[13-15]

Unlike print reading where multiple words are perceived during a single saccadic pause, braille is read sequentially as the fingers fluidly move to perceive each symbol, potentially placing greater demands on working-memory for less proficient readers.[16] Conversely, proficient braille readers draw on contextual cues and are able to predict words based on the first two or three symbols to facilitate reading,[2] contributing to speed increases of 30% or more.[17-20] However, working memory, vital for rapidly recalling text that is read, is shown to decline especially after age 60.[21]

Despite knowledge of these age-related changes, little is known about the extent to which these measures might correlate with braille reading outcomes as individuals age. A recent scoping review (see Chapter 2) revealed that research in this domain is sparse and highly inconsistent.[22] More than 60% of the reviewed studies examined braille reading performance in relation to only *one* physiological or cognitive domain, potentially overlooking the effects of confounding variables. Additionally, the use of a variety of different (and often novel) measures of tactile, motor, and cognitive functioning calls into question the validity, reliability, and comparability of the assessments used. No previous studies have directly explored the relationship between fine-motor or working-memory declines and braille reading outcomes. However, Mousty[19] reported that readers who benefit most from two-handed reading are those whose *slower hand* is not *significantly* inferior to the *faster hand,* suggesting that when both hands are utilized, there is a cooperative element in play. Finally, there is a significant focus in the existing literature on children, with fewer than one-third of prior studies including *any* participants over the age of 60.[22]

In adult braille rehabilitation, two main categories of clients are encountered: those with congenital visual impairments who learned braille early in life but who seek rehabilitation for changing needs as they age, and those who experience vision loss later in life and who require braille training to regain independence.[23] Understanding the characteristics of proficient adult braille readers would provide useful insights to support the unique needs of older braille learners.[3] This study thus explored the relationship between tactile, motor and cognitive capacities and braille reading performance within a single sample of braille readers, with attention devoted to the role of age within this context. Research questions were as follows:

(1) What is the correlation between chronological age and tactile, motor and cognitive capacities among working-age and older adult braille readers?
(2) What variables correlate strongly with their braille reading speed?
(3) What is the influence of reading media (paper vs. braille display) and reading mode (oral vs. silent reading) on braille reading speed?

4.3. Materials and methods

4.3.1. Eligibility and recruitment

Data were collected between May 2019 and January 2020. The protocol was approved by the Centre for Interdisciplinary Research in Rehabilitation of Greater-Montreal (CRIR #1326-0418), and Vision Loss Rehabilitation Canada. Participants were eligible if they were at least 18 years of age, with a visual impairment diagnosed at any age, who self-identified as meeting the legal definition of blindness (a visual acuity of 20/200 with best correction in the better eye or a visual field of less than 20 degrees[24]). They needed to have completed uncontracted or contracted English or French braille training at least one year prior to study participation. Participants were also asked to describe their level of vision, in line with the definitions outlined by the World Health Organization.[25] The invitation to participate was circulated to rehabilitation centres and blindness consumer agencies across Canada, on social media platforms geared towards blind Canadians, and through snowball sampling where participants referred others in their network.[26]

4.3.2. Materials and procedure: Overview

Informed written (large print, electronic, braille) or recorded verbal consent was obtained in accordance with the *Declaration of Helsinki and Public Health*.[27] The battery of tests administered and the approximate length of each test is summarized in Table 11. Tests were presented in a randomized order, except for the cognitive screening test, which was administered first in all cases to minimize the potential influence of cognitive fatigue.[28] Participants had the option of completing all tests at their home or at an approved research site, either within a single session of two hours or over two one-hour sessions.

Test	Time
Demographic Questionnaire	20
Montreal Cognitive Assessment (MoCA)-Blind[29]	10
Tactile Short-Term Memory Test (Tactile VPT)[30]	10
Edinburgh Handedness Inventory[31]	5
Purdue Pegboard Dexterity Test[32]	5
Two-Point Discrimination Test[10,33]	10
Grating Orientation Task[10,34]	10
Legge - Dot Chart[9,10]	8
Legge - Landolt C Chart[9]	8
IReST Reading Speed and Comprehension Test[20,35-38]	15

Table 11. – Assessments included in the correlation study

Appendix D1 provides additional information regarding the assessments and the particular procedures that were utilized for the purpose of this study.

4.3.3. Mild Cognitive Impairment (MCI) screening

Participants were screened for the presence of mild cognitive impairments using the Montreal Cognitive Assessment, adapted for use with blind participants.[29] In this verbal questionnaire, participants were asked a short series of questions to assess factors deemed relevant to reading, including their memory, attention, logical reasoning, language, abstract thought, and orientation. A score of 18 or higher of 22 is considered a 'pass', with lower score indicating a possible risk for a mild cognitive impairment.

4.3.4. Handedness

The Edinburgh Handedness Inventory (EHI) is a short verbal questionnaire to quickly ascertain an individual's handedness.[31] A mathematical formula provides a handedness score (negative = left bias, positive = right bias). While the preferred braille reading hand is not determined by handedness and there is considerable evidence that handedness has no influence on braille reading speed,[20,40-45] this information determined the 'dominant' hand to be used for the Purdue Pegboard Test.

4.3.5. Fine-motor dexterity

The Purdue Pegboard Test is a measure of hand and finger dexterity and coordination.[15,46] A participant's score was determined as the number of metal pegs successfully placed in 30 seconds into vertical rows of holes in a board placed before the subject. The task was repeated three times (and averaged), first with the dominant hand (as determined by the EHI score), then with the non-dominant hand, and then with both hands together. A modification to the assessment procedure when using both hands together was required to accommodate participants, all of whom completed the testing non-visually. Under the standard administration protocol, participants pick up two pegs at a time – one with the left hand from the left cup, and one with the right hand from the right cup – inserting them simultaneously into matching vertical holes on the board, a task that requires independent hand-eye coordination. In our study, pegs were grasped one at a time with alternating hands, with the opposing hand being used to locate the target hole. The sequential (rather than parallel) nature of this approach, and the fact that only complete *pairs* are counted, resulted in significantly lower "hands together" scores than has been reported in past studies.

4.3.6. Tactile working-memory

Participants completed a tactile working-memory test developed by Papagno.[30] This test was selected as an appropriate tactile working-memory assessment because performance was independent of braille competency, unlike conventionally used measures such as "reading span" tasks.[39] Participants first tactually explored (with their preferred braille reading hand) checkerboard matrix patterns of squares, half of which were smooth and half rough, and then re-constructed the pattern from memory. Patterns grew larger until a participant was unable to complete at least two out of three patterns successfully. A "tactile span" score was calculated as the average number of rough blocks in the three largest patterns successfully reconstructed (range 0-15).

4.3.7. Tactile acuity

Tactile acuity may be measured *passively*, where a stimulus is applied to the non-moving finger, or *actively*, where there is movement between the finger and a stimulus.[8,9,47] Four measures of tactile acuity were obtained, two passive (Two-Point Discrimination Test and Grating Orientation Task) and two active (Legge "Dot" and "C" Tactile Acuity Charts), each yielding a tactile acuity threshold (in mm) representing the smallest separation between two stimuli that a participant was able to reliably detect. These tests were selected because they were commonly used in prior research and had potential clinical application in that they could be administered in a field setting by a rehabilitation practitioner.[22] Consistent with prior studies, testing was performed on the index finger of the preferred braille reading hand.[8-10]

4.3.7.1. Two-Point Discrimination

The passive Two-Point Discrimination Test measures the minimum distance at which two points of a caliper can be discerned on the skin.[48] In each trial, using the Touch-Test Discriminator® (Fabricated Enterprises Inc., White Plains, NY), two small (<0.5mm) rounded points were briefly applied to the skin of the test finger with a set distance between them (ranging from 2 to 7mm). Based on the procedure recommended by the device manufacturer and prior studies, 64 presentations were administered in a pseudorandomized sequence: 8 at each of the defined gap sizes, and 8 control 'single point' presentations.[10,33] Correct and incorrect results were plotted and a logistic regression line fitted to the data to ascertain the midpoint, defined as the threshold at which results surpassed chance. Note that as the finest acuity measurable using this instrument was 2mm, and many participants on other measures demonstrated <2mm acuities, a floor effect limited the accuracy of Two-Point Discrimination thresholds.

4.3.7.2. Grating Orientation Task (GOT)

The passive GOT utilizes a set of small, plastic grating domes (JVP Domes, Stoetling Co.) with equidistant groove and ridge widths intended to measure the minimum grating width at which a participant can discern the orientation of the stimulus on the skin.[49,50] The domes were placed on the pad of the immobile index finger in one of two orientations (along or across the finger) for approximately 1 second and participants verbally reported the perceived orientation.[10,34,49] At each groove width, 20 trials were presented, half in each orientation based on pseudorandomized sequences counterbalanced across participants. The smallest grating widths whose orientations were reliably reported (75% correct) represent a threshold estimate of the spatial resolution.

4.3.7.3. Legge "Dot" and "C" Charts

Two charts which measure active tactile acuity, which more closely resembles the process of braille reading than static measurements, were also administered.[9,10,51] The images used to produce the tactile charts were constructed using a custom software tool,[52] printed onto heat-sensitive Swell Touch Paper (American Thermoform: La Verne, CA), and fused with a PIAF Picture in a Flash Tactile Graphic Maker (Piaf Tactile: Poznan, Poland). In each case, participants read through the charts starting at the top, and reported the braille letters read or the position of the gap in the letter "C", as appropriate. The tactile acuity threshold was calculated in logMAR units as the minimum size attainable on each chart plus 0.0125 logMAR for each *incorrect* response. The final scores were converted to millimeters ($mm = 2.28 \times 10^{logMAR}$) for comparison with the other measures.

4.3.8. Reading assessments

Participants read four passages from the International Reading Speed Test (IReST)[53], a standardized multilingual, validated reading assessment which presents the participant with paragraphs of text (approximately 132 words) of an encyclopedic nature:[38,54] two in hard copy braille (one read aloud, one read silently) and two on an electronic braille display (one read aloud, and one read silently). As described in Appendix D2, these passages have similar word-length characteristics as those used in prior braille reading assessments, such as the MNREAD.[20] Participants had the choice of either uncontracted (alphabetic) or contracted (abbreviated) English or French braille, based on their preferred braille reading format. The passages were formatted to be equivalent, with each line consisting of up to 30 cells of braille, whether in hard copy or electronic braille. A BrailleNote Touch Plus 32 (Humanware Technologies, Drummondville, QC, Canada) notetaker was utilized for presenting the electronic braille. The paper reading samples (with up to 12 lines per page, double spaced) were produced using a Juliet Classic braille embosser (Enabling Technologies Inc., Jensen Beach, Florida, USA) on standard 8.5" x 11" 100lb braille paper.

Participants were asked to read as quickly as possible and not to stop to reread or correct errors. Participants were advised that a comprehension question, as devised by Morrice, Hughes, Wittich and Johnson,[54] would be asked when they completed reading the passage. A -minute time limit was imposed for each passage to minimize fatigue and to consider the fact that braille-reading speeds may vary drastically, with some participants requiring more than 3 minutes to read a passage. Reading rate (in characters per minute) and general information about reading behaviour was noted in accordance with the categorization scheme used by Garcia.[55]

4.3.9. Data cleaning

Prior to analysis, the data were cleaned and verified. To remove outliers, all response variables were converted to *z*-scores. A total of 8 raw data points with an associated $|z| > 3$ were then replaced with the most extreme raw value from within the 'normal range' for that variable ($|z| <= 3$). No response variables were severely non-normal by demonstrating a skew greater than 3 or a kurtosis greater than 10.[56] Of note, 9 participants did not complete the full testing protocol, 8 of whom were missing one assessment and one of whom was missing two assessments.

4.4. Results

4.4.1. Demographics

In total, 46 participants between the ages of 23 and 88 (*M* = 52.3, *SD* = 14.9) from British Columbia (*n* = 13), Ontario (*n* = 8), and Québec (*n* = 23) participated, with 31 women (67.4%) and 15 men (32.6%). Table 12 (on the following page) summarizes demographic characteristics.

4.4.1.1. Characteristics of visual diagnoses

Most participants (*n* = 36) self-reported a congenital visual impairment at birth (age of onset of blindness: range 0-23, *M* = 2.6, *SD* = 5.8). The vast majority (*n* = 44, 95.6%) self-reported a profound visual impairment (< 20/400 acuity), while one participant (2.2%) reported a severe loss (< 20/200 but > 20/400) and one other (2.2%) had only a moderate loss (< 20/70 but > 20/200). The most common causes of blindness included retinitis pigmentosa (*n* = 14, 30.4%), glaucoma (*n* = 9, 19.6%), retinitis of prematurity (*n* = 9, 19.6%), and cataracts (*n* = 7, 15.2%).

4.4.1.2. Braille learning and usage

Table 13 (below on p. 140) outlines the braille history and reading frequency for participants and indicates the language and braille code they use. In total, 30 participants learned braille before the age of 12 (range 4-63, *M* = 11.75, *SD* = 9.46). Approximately 78% of participants reported using braille at least weekly. Figure 10 (below on p. 141) provides an overview of the tasks for which braille is used. Reading speeds were highly variable between subjects, ranging from 34 cpm to 600 cpm (approximately 6.4 wpm to 113 wpm), with an average of 245.31 cpm (*SD* = 157.85 cpm), or approximately 46.2 words per minute (*SD* = 29.8 wpm).

Table 12. – Demographic characteristics of participants

Variable	Descriptive Statistics	N	%
Age	Range 23-88, M=52.3, SD=14.9		
18-39		12	26.1%
40-59		20	43.5%
60+		14	30.4%
MoCA-B Score (/22, >18 = 'pass')	Range 15-22, M=19.8, SD=1.9	46	
Level of education			
Less than high school		0	0%
High school		8	17.4%
College		4	8.7%
Bachelor's Degree		16	34.8%
Master's/PhD		18	39.1%
Employment status			
Employed part-time		2	4.4%
Employed full-time		22	47.8%
Self-employed		2	4.4%
Retired		12	26.9%
Student		2	4.4%
Unemployed (but looking)		4	8.7%
Not in labour force		2	4.4%
Age of onset of blindness	Range 0-23, M = 2.6, SD = 5.8		
Visual diagnosis [a]			
Retinitis pigmentosa		14	30.4%
Glaucoma		9	19.6%
Retinitis of prematurity		9	19.6%
Cataracts		7	15.2%
Leber congenital amaurosis		3	6.5%
Nystagmus		3	6.5%
Optic nerve hypoplasia		3	6.5%
Retinal detachment		2	4.3%
Other conditions (each N = 1)		9	19.6%
Handedness (Edinburgh)			
All participants	M = 60.7, SD = 58.8		
Right-handed (EHI > 0)	M = 83.6, SD = 21.4	39	84.8%
Left-handed (EHI < 0)	M = -67.1, SD = 25.6	7	15.2%

[a] Note that each participant could have one or more diagnoses identified, and as such these tallies do not add up to N=46 or 100%

Table 13. – Braille learning and reading characteristics of participants

Variable	N	%
Hand pattern used when reading [(a)]		
One-handed	15	32.6%
Two-handed, conjoint	23	50%
Two-handed, disjointed	4	8.7%
Indeterminate/Unknown	4	8.7%
Where braille learned:		
Mainstream school	12	27.3%
School for the blind	21	47.7%
Rehabilitation centre	8	18.2%
Distance learning/self taught	3	6.7%
Braille codes learned [(b)]		
English (uncontracted *only*)	2	4.4%
English (contracted)	35	76.1%
French (uncontracted *only*)	5	10.9%
French (contracted)	13	28.3%
Braille use frequency		
Daily	23	50%
At least once per week	13	28%
A few times per month	4	9%
Monthly (or less)	6	13%
Braille code used for this study		
English (uncontracted)	9	19.6%
English (contracted)	28	60.1%
French (uncontracted)	1	2.2%
French (contracted)	8	17.4%

[(a)] These hand movement patterns were derived from the categorization employed by Garcia [55].

[(b)] These numbers do not add up to 46 because some participants knew both the French and English braille codes, while others may have only known one or the other.

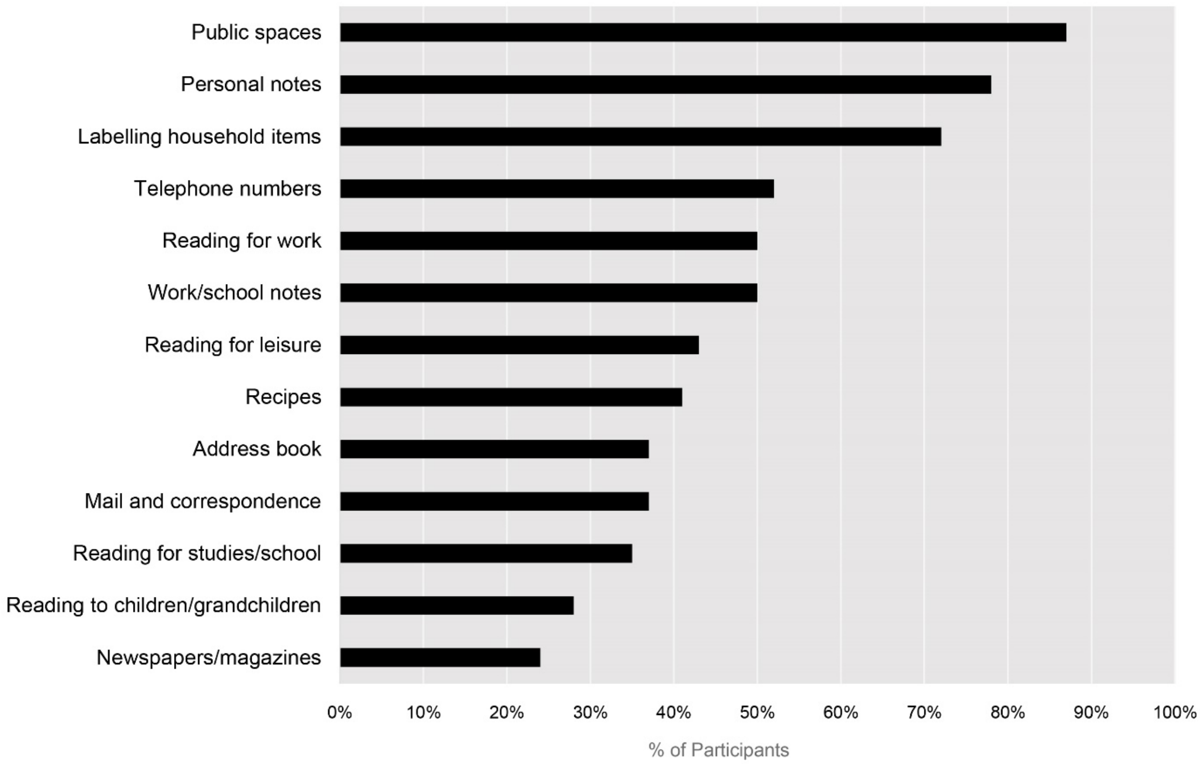

Figure 10. – Percentage of participants who use braille for different daily tasks

4.4.2. Correlation between age and tactile, motor, and cognitive capacities

Means, standard deviations, and Pearson correlations among the measured variables (summarized in Table 14 on page 143) were computed. A review of the Pearson correlations revealed that age was associated with decreased performance on all tactile, motor and cognitive measures, with measures of tactile sensitivity demonstrating the greatest age-related declines.

Figure 11 (on the following page) depicts the four tactile acuity measurements (GOT, 2-Point Discrimination, Legge "Dot" Chart, and Legge "C" Chart) for each of the participants, plotted against their age. This figure demonstrates that, consistent with prior research,[8,9] tactile acuity thresholds rise with age, although only the correlations for GOT (r = .532, p < .001) and Legge "C" Chart (r = .417, p = .004) were found to be statistically significant. Results from the Purdue Pegboard Test for each of the dominant, non-dominant, and bimanual measures indicated a minimal correlation with age (r = -0.045, -0.097, and -0.067 respectively) and were not statistically significant. A decline in working-memory with increasing age was observed; however, the correlation between tactile span and age was minimal (r = -.099) and was not statistically significant.

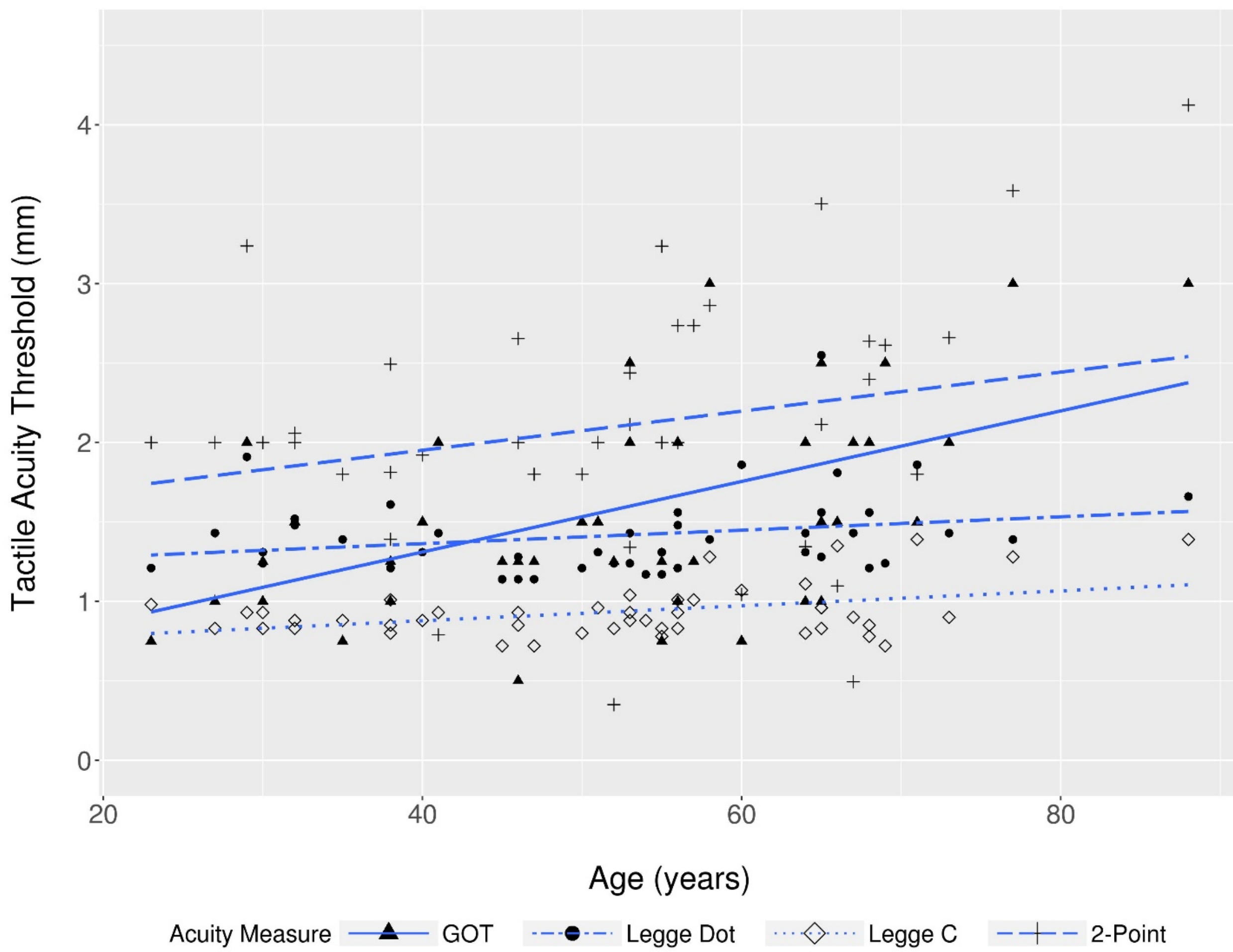

Figure 11. – Tactile acuity thresholds for each participant for each of the four acuity measures

Table 14. – Descriptive statistics and correlations among measure variables

Var [a]	M +/- SD (Min-Max)	Age	ABL	GOT	LD	LC	2PD	PurD	PurND	PurB	TWM	Spd
Age	52.11 +/- 15.06 (23-88)	---										
ABL	11.75 +/- 9.46 (4-36)	.086	---									
GOT	1.58 +/- 0.64 (0.5 – 3.0)	.532*	.307*	---								
LD	1.41 +/- 0.22 (1.14 – 2.55)	.285	.136	.298*	---							
LC	0.93 +/- 0.17 (0.72 – 1.39)	.417*	.135	.456*	.619*	---						
2PD	2.08 +/- 0.79 (0.35 – 4.12)	.231	.208	.390*	.257	.184	---					
PurD	9.63 +/- 2.44 (3.33 – 16.0)	-.045	-.121	-.183	-.503*	-.501*	-.051	---				
PurND	7.44 +/- 2.08 (3.33 – 12.67)	-.097	-.237	-.217	-.314*	-.389*	-.018	.642*	---			
PurB	4.32 +/- 1.95 (0.33 – 10.0)	-.067	-.211	-.138	-.371*	-.370*	-.206	.649*	.757*	---		
TWM	4.2 +/- 1.58 (0.67 – 8.00)	-.099	.195	-.069	-.462*	-.366*	-.113	.471*	.382*	.478*	---	
Spd	245.31 +/- 157.85 (33.75 – 599.98)	-.070	-.623*	-.159	-.349*	-.307*	-.181	.207	.207	.258	.007	---

[a] ABL=age braille learned, GOT=Grating Orientation Task threshold (mm), LD=Legge “Dot” Chart score (mm), LC=Legge “C” Chart score (mm), 2PD: Two-Point Discrimination Test score (mm), PurD/PurND/PurB: Purdue Pegboard score (dominant/non-dominant/both hands), TWM=Tactile Working Memory span score, Spd=IReST passage reading speed (characters/minute), Higher thresholds on the tactile acuity tests (GOT, LC, LD, 2PD) represent poorer acuities. Lower scores on the Purdue Pegboard Test and Tactile Working Memory Test represent poorer performance.

* Correlation is significant at the .05 level

4.4.3. Correlates of braille reading speed

Based on Pearson correlations, active tactile acuity as measured using the Legge "Dot" ($r = -.349$, $p = .022$) and Legge "C" ($r = -.307$, $p = .045$) Charts, frequency of braille usage ($r = .424$, $p = .005$), and the age at which braille was learned ($r = -.623$, $p < .001$) emerged as the most significant predictors of braille reading speed. As Legge "Dot" and Legge "C" measure the same underlying construct and a high correlation among them was observed ($r = .619$, $p < .001$), only Legge "Dot" (which had the highest r value) was retained for further analyses. Although chronological *age* was not correlated in any significant way with braille reading speed ($r = -.07$), the age at which braille was learned significantly correlated with reading speed ($r = -.623$, $p < .001$), as demonstrated by Figure 12.

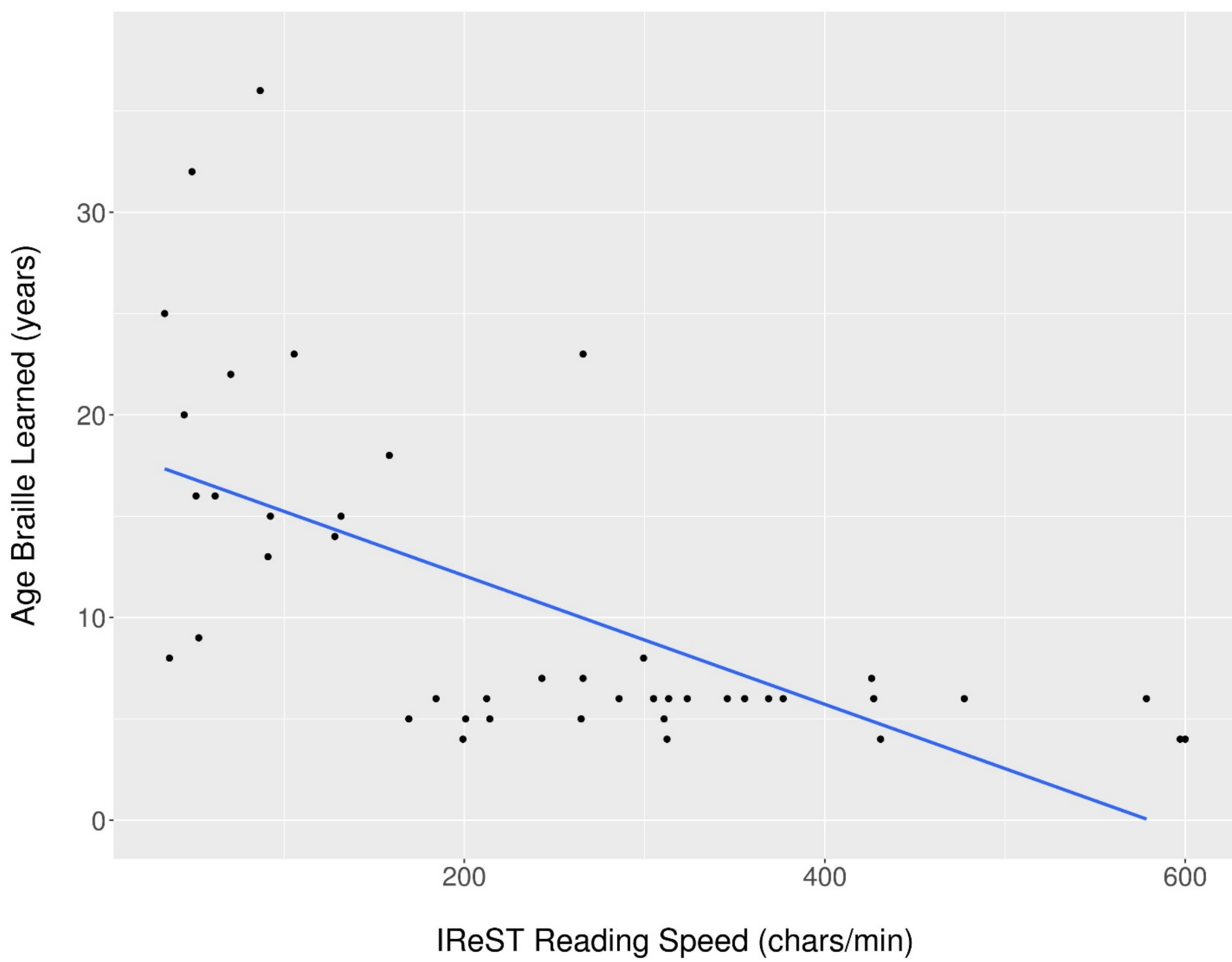

Figure 12. – Depiction of the relationship between IReST reading speed (cpm) and the age at which braille was first learned (years)

As shown in Figure 13, for each of the four measures of tactile acuity, decreased acuity (i.e. an increased tactile sensitivity threshold) was associated with a decline in braille reading speed. These correlations were statistically significant for the Legge "Dot" Chart (r = -.349, p = .022) and Legge "C" Charts (r = -.307, p = .045), but not for the GOT (r = -.159) or 2-point Discrimination Test (r = -.181).

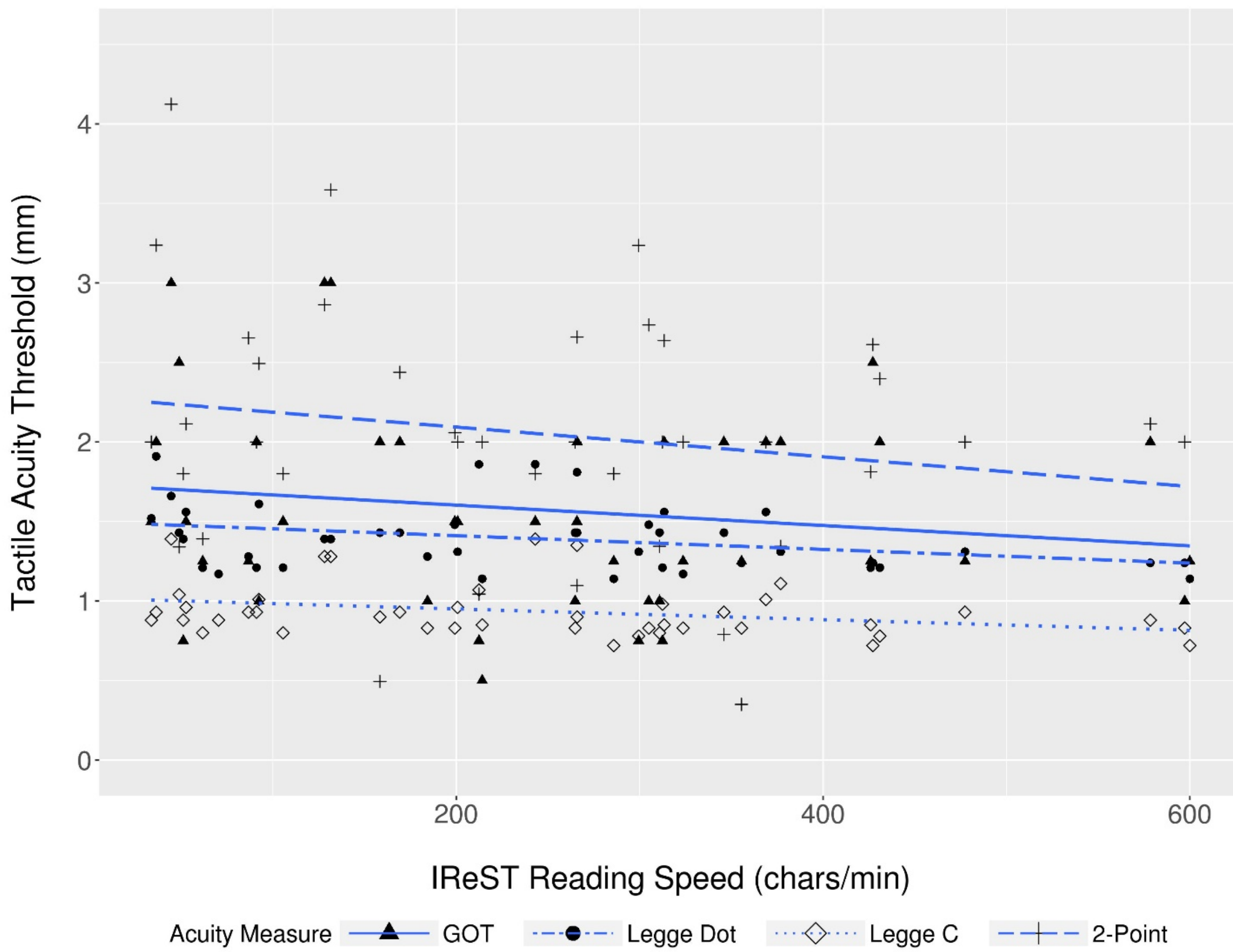

Figure 13. – Depiction of the relationship between each of the tactile acuity measures

Performance on the Purdue Pegboard Test was positively (but not statistically significantly) correlated with IReST reading speed for each of the dominant hand (r = .207), non-dominant hand (r = .207), and both hands together (r = .258). The Tactile Working Memory Test demonstrated no correlation with reading speed (r = .007). Frequency of braille usage was strongly correlated with reading speed (r = .424, p < .01), irrespective of when braille was learned (before age 12: r = .421, p = .023; after age 12: r = .382, p = .041). While there was no statistically significant difference, use of the more advanced disjointed two-handed reading pattern appeared to be fastest (M = 384.13 cpm, SD = 144.24 cpm, n = 4), followed by conjoined two-handed reading (M = 266.67, SD = 149.98, n = 22) and one-handed reading (M = 204.16 cpm, SD = 156.25 cpm, n = 14).

A multiple linear regression was performed to predict braille reading speed based on the age braille was learned, frequency of braille usage, and the Legge "Dot" Chart tactile acuity measure. A significant regression equation was found, $F(3, 41) = 9.589$, $p < .001$, with an adjusted R^2 of .369. The age at which braille was learned, $t(44) = -3.29$, $p = .002$, the frequency of braille us, $t(44) = 2.335$, $p = .025$, and Legge "Dot" Chart for tactile acuity, $t(44) = -2.133$, $p = .039$, were all significant predictors in the model. Specifically: (1) every year older individuals were when they first learned braille was associated with a 6.684 cpm decrease in speed (95% CI [-10.786, -2.582]); (2) increasing frequency of braille use (coded as 0=Never, 1=A few times per month, 2=Once per week, 3=A few times per week, 4=Daily) was associated with a mean increase in reading speed of 30.587 cpm (95% CI [4.134, 57.040]); and (3) every 0.10 mm increase in the Legge Dot tactile acuity threshold was associated with a decrease in reading speed of 18.13 cpm (95% CI [-35.284, -9.681])

4.4.4. Influence of mode and medium

Table 15 (on the following page) presents descriptive statistics regarding speed for reading on paper and for reading on a braille display in both aloud and silent modes. To examine whether reading on paper (versus a braille display) or aloud (versus silently) influenced reading speed, a two-way repeated measures ANOVA was conducted and indicated no significant main effect of medium on reading speed, $F(1,42) = 1.683$, $p > .05$, $\eta_p^2 = .039$. Participants performed similarly whether they were reading on paper (M = 249.43cpm, SD = 164.31cpm) or on a display (M = 241.19cpm, SD = 157.71cpm). There was, however, a significant effect of mode on reading speed, $F(1,42) = 27.10$, $p < .001$, $\eta_p^2 = .392$, with participants reading more quickly in the silent mode (M = 262.21cpm, SD = 175.09) than in the aloud mode (M = 228.41, SD = 143.77).

Table 15. – Descriptive statistics for reading speed by medium and mode

	Speed (cpm)		
Medium / Mode	Range	Mean	SD
Paper	30 – 742.11	249.43	164.31
Display	23.67 – 683.04	241.19	157.71
Aloud	23.67 – 579.76	228.41	143.77
Silent	30.67 – 742.11	262.21	175.09
Paper / Aloud	30 – 579.76	230.44	146.50
Display / Aloud	23.67 – 536.12	226.39	142.69
Paper / Silent	35 – 742.11	268.43	180.10
Display / Silent	30.67 – 683.04	255.99	171.84

To assess the impact of the age at which braille was learned and the Purdue bimanual score, which were identified as potential covariates, additional analyses were conducted. A two-way ANCOVA revealed a significant effect of Purdue "both hands", $F(1,39) = 4.773$, $p = .035$, $\eta_p^2 = .109$, and the age braille was learned, $F(1,41) = 6.716$, $p = .013$, $\eta_p^2 = .141$, on the impact that mode had on reading speed. To explore this further, participants were divided into four groups on two dimensions: whether they learned braille early or late (divided based on the mean age of braille learning: 11.61); and whether they were in the stronger or poorer group for the Purdue Pegboard Test (mean Purdue score for both hands: 4.44). A 2x2 within ANOVA predicted speed by mode and medium separately for each group. The results revealed that reading silently was faster than aloud, a difference that was more pronounced in those that learned earlier ($\eta_p^2 = .490$) versus later ($\eta_p^2 = .381$). The silent advantage was likewise more pronounced in those with high Purdue (Both) scores ($\eta_p^2 = .472$) versus those with low scores ($\eta_p^2 = .342$).

4.5. Discussion

This study explored tactile, motor and cognitive correlates of braille reading speed among working-age and older adults with visual impairments. Given that physiological and cognitive capacities are known to decline with age, previous researchers have questioned whether assessments for these measures could be used to estimate braille reading ability in aging braille readers or serve as remedial activities for older learners of braille.[3] As expected, a steady, linear decline in tactile acuity and fine-motor dexterity with increasing age was observed, though only the tactile sensitivity measures were associated with significant age-related declines. Tactile working memory only marginally decreased with increasing age. This is consistent with research on working-memory in the sighted, where longitudinal evidence indicates that significant declines in working memory are unlikely to be observed until after age 60.[21]

Only the age at which braille was learned, frequency of braille usage, and active tactile acuity (as measured using the Legge dot chart) emerged as significant correlates of braille reading speed. Trent and Truan have previously reported significantly lower reading rates among late-blinded readers as compared with those who learned braille at a very young age.[57] Also consistent with previous findings,[12,41,55,58] advanced two-handed reading corresponded with greater braille reading speeds. Silent reading was associated with greater braille reading rates than reading aloud, though this was especially true for participants who learned braille at an older age and for those with better bimanual fine-motor dexterity scores. Finally, no differences in speed between reading on paper and reading on a braille display were observed.

Although previous studies have explored tactile, motor and cognitive capacities in isolation,[8,39,59,60] this is the first study to explore the role of these measures within a single sample of working-age and older adult braille readers. This is noteworthy given that declines in one age-related capacity could inadvertently effect performance in another.[61] For example, a significant negative correlation between tactile sensitivity and fine-motor dexterity has been reported in numerous studies.[62] Tremblay et al.[63] measured tactile spatial acuity (using the GOT) and fine-motor dexterity (using the Purdue Pegboard Test) in 30 elderly participants between the ages of 60 and 95, and found that impaired tactile spatial acuity at the fingertips was strongly correlated with hand dysfunction in older adults. This close relationship between tactile perception and hand movements is especially relevant to braille reading, where ineffective hand reading patterns can effect tactile perception and poor tactile perception can effect hand reading patterns.[64] In the present sample, moderate negative correlations between active tactile acuity measures and fine-motor dexterity were observed, in that subjects with greater active tactile acuity were more likely to achieve higher scores on the Purdue Pegboard Test. Only tactile acuity was ultimately found to be related to braille reading speed; however, the association between motor function and tactile acuity should serve as a reminder that because of potential confounding variables, clinical decision-making must be based on a comprehensive global evaluation without unduly relying on the outcome of a single assessment. While it may seem appealing to some to seek a single ‘test’ to foresee braille reading potential in older learners, possible overlapping relationships between these underlying capacities highlight the limitations in doing so.[65] While specific correlates emerge as especially important, these findings work to reinforce the multifaceted nature of reading potential.

4.5.1. Relationship between age and tactile, motor and cognitive capacities

Consistent with previous research,[66] age was found to be associated with declines in tactile, motor and cognitive ability. Importantly, however, this study suggests that getting older on its own should not negatively affect braille reading. In the present sample, chronological age did not correlate with braille reading speed. Four previous studies explored the relationship between the age of participants and braille reading speed.[9,39,67,68] However, these investigations resulted in inconsistent findings and not all studies provided ample information about the age distribution of participants. Among those that did, only one[9] included subjects above the age of 60. The present study adds to this body of work, with 46 participants ranging between the ages of 23 and 88, 30% of whom fall above the age of 60. Notably, this study replicates the findings of Legge[9] that also included participants above the age of 60 and did not observe a relationship between age and braille reading speed.

The findings reported herein suggest that, as experienced braille readers age, they do not exhibit significant changes in their braille reading speed due to age alone. This is somewhat inconsistent with research on print reading and aging. The average print reading rate as measured by the IReST is 228 words per minute (wpm) for healthy sighted adults between the ages of 18 – 35, though this is reduced by a factor of 19% (185 wpm) for those within the 65 – 80 age range.[53] Research illustrates that tactile ability is highly experience-dependent.[69] As will be discussed further below, this study suggests that the accumulated tactile experience of participants may play a significant role in both enhancing and maintaining braille reading skills as individuals age.

4.5.2. Correlates of braille reading speed

Among the examined variables, the age at which braille was learned, frequency of braille usage, and active tactile acuity (as measured using the Legge "Dot" chart) emerged as the only significant correlates of braille reading speed. Similarly, and consistent with previous findings,[12,41,55,58] two-handed reading was associated with greater reading speed, with the advanced two-handed technique correlating with the highest reading rates. These findings heighten the importance of having ample opportunities to enhance tactile sensitivity and proper hand reading patterns both between sessions and once formal instruction concludes, especially for those who learn braille later in life. This places an emphasis on developing proper hand movement techniques among older braille learners, rather than focusing on fine-motor declines which do not appear to influence reading outcomes within this sample.

Despite the correlation between active tactile acuity and reading speed, it is worth noting that this correlation was not found in a prior study using the Legge Dot Chart.[9] However, the braille readers in Legge[9] had marginally lower tactile acuity thresholds (by 0.07 logMAR or .18mm) and were significantly faster readers, achieving average speeds of 109.5 wpm compared to 46.2 wpm in this study. Moreover, the *range* of tactile acuity scores in the present study is greater and includes one participant whose acuity was above the standard braille size of 2.28 mm, whereas the worst tactile acuity observed in Legge among blind participants was approximately 1.5 mm (see Figures 3A and 5A in Legge[9]). As Legge[9] and Millar[70] have argued, if acuity is below the braille spacing of 2.28mm, reading speed may become independent of acuity and mediated by other factors, just as with sighted readers.[71] Consequently, it may be that, for the comparatively poorer readers with comparatively poorer acuity measures in the current sample, differences in tactile acuity had a more pronounced effect on reading performance.

Although researchers have explored the correlation between passive and active tactile acuity and braille reading outcomes separately,[8,9,67,72] this is the first study that explores the contribution of both these measures within a single sample. The findings confirm that, while passive tactile acuity tests may be reliable measures of static tactile acuity,[10] these passive measures are not representative of the dynamic process of braille reading. While readers may exhibit low thresholds on a passive tactile acuity test, they may nonetheless struggle with braille reading if they lack proper haptic movements. From a clinical perspective, the use of a measure such as the Legge "Dot" Chart may be helpful as a diagnostic tool to detect potentially undiagnosed neuropathy or tactile acuity limitations. However, as tactile acuities have been shown to improve with practice,[69] and even those with comparatively poorer acuities have demonstrated the ability to read,[73] a reasonable time for familiarization with braille reading must be afforded. Therefore, these evaluations should not be used as a definitive screening tool to determine eligibility for braille instruction, but rather an emphasis on enhancing active tactile acuity through practice should be promoted.

The significance of frequency of braille usage in this study cannot be over-emphasized. Frequency of braille usage is a vital predictor of braille reading outcomes, irrespective of the age at which braille was learned. Participants who learned braille at an older age but who use braille frequently in their daily lives demonstrated greater braille reading performance than those who learn braille at the same age but who use it less frequently. On the surface, this finding is logical. Active tactile perception, also a significant predictor of braille reading speed, is shown to improve with intensive practice.[69] Practitioners have long emphasized the importance of maintaining braille literacy rich environments for blind children, as important determinants of reading achievement.[2] This study underscores that these consistent opportunities to use braille are equally vital for adults, and that it is frequency of braille usage, and not simply age, that influences braille reading outcomes. This is noteworthy given that referral rates for braille instruction in adulthood remain low,[73,74] due in part to beliefs held by some clinicians that older clients will be unable to learn braille.[65] It thus becomes imperative to ensure that adult braille rehabilitation programs incorporate supports to supplement the training provided during sessions.

4.5.3. Differences based on mode and medium

Consistent with prior research,[75-79] a clear and statistically significant difference was found between oral and silent reading, with silent reading being approximately 15% faster. Fertsch[78] hypothesized that the slower reading rates are a consequence of readers feeling self-conscious about mispronouncing a word that, when reading silently, they might predict through context. It has also been suggested that the time and cognitive effort required to decode and work out not only the meaning but also the pronunciation of each word leads to a slowing of reading speed.[77] These findings reinforce the importance of considering both reading task and reading mode when assessing older clients. While performance when reading aloud may be markedly poorer than when reading silently, careful attention should be paid to how braille will be used in daily life when assessing client progress.

The age at which braille was learned and bimanual Purdue performance emerged as especially significant to silent reading speeds. This distinction is likely due to the greater cognitive load associated with reading aloud and the inherent multitasking of such a task, rather than as a direct consequence of the difference in fine motor performance. Proud and Morris, for example, have previously demonstrated decreased performance on the Purdue Pegboard when participants are simultaneously tasked with a verbal serial 7 subtraction exercise.[80]

Finally, no differences in reading speed were observed when comparing reading on paper (M = 249.43cpm, SD = 164.31cpm) and on a braille display (M = 241.19cpm, SD = 157.71cpm). Most participants were already experienced braille readers, and the overwhelming majority (95%) of the subjects had active tactile acuity scores (on the Legge “Dot” Chart) below the 2.28 mm threshold required for braille reading. It is possible, as suggested by Douglas et al.[81], that the increased dot height of a display (.63mm-.8mm for display[82] and .46mm-.48mm for paper braille[81-83]) may be especially beneficial for novice braille learners or for those with reduced tactile sensitivity due to age or age-related conditions. Given the proliferation of lower cost braille displays, future research should examine the influence of reading medium among older learners of braille with reduced tactile sensitivity.

4.5.4. Limitations and future research

This study is the first to explore the role of multiple capacities and age-related factors on the braille reading performance of working-age and older adults; however, several limitations should be noted. First, while speed is generally the focus of attention, even participants with slower reading rates indicated using braille for functional tasks such as identifying elevator buttons. In this way, reading rate may not be the only or best indication of whether a client can successfully use braille to meet specific needs. While data on reading accuracy were collected, the rate of errors, as a percentage of characters read, was exceptionally low (< 0.7%) and thus no meaningful analysis could be conducted. Similarly, the error rate for comprehension questions was less than 10%, and 70% of those errors resulted from a single IReST passage, which at least one author utilizing the IReST in a Canadian sample has previously suggested "reflects the poor quality of content of the question as opposed to participants not understanding the content of the text."[84 (p. 21)] Future research is needed to explore accuracy and comprehension among older braille learners in greater depth.

Second, while some prior studies have observed distinct categories of reading proficiency (e.g. Fig. 3 in Legge[20]), reading speeds were, save for a few of the fastest readers, relatively evenly distributed across the range of observed speeds. As such, dividing the sample to identify differences between "poor" and "good" readers based on mean reading speeds, as has been done in prior studies, was not possible.

Third, this is a cross-sectional study and observed correlations are neither strictly predictive nor evidence of a causal relationship.[85] Longitudinal studies that track these measures over time would help to better understand the impact of *aging* (rather than *age*) on braille reading outcomes.

4.6. Conclusion

This study advances research on braille and aging by clarifying previous work and demonstrating that although tactile, motor and cognitive capacities decline with age, age alone as a variable does not correlate with braille reading speed. Instead, a focus should be placed on introducing braille early in the vision loss process and on providing older braille clients with frequent opportunities to use braille and to enhance their tactile skills. As the population continues to age, further research is needed to develop programs and policies designed to meet the unique needs of older braille learners, including those with reduced tactile sensitivity.

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4.9. Declaration of conflicting interests

The authors declare that there are no conflicts of interest.

4.10. References

1. Varma R, Vajaranant T, Burkemper B. Visual impairment and blindness in adults in the United States: Demographic and geographic variations from 2015 to 2050. Journal of the American Medical Association: Opthalmology. 2016; 134(7):802-9.

2. Wormsley DP, D'Andrea FM. Instructional Strategies for Braille Literacy. New York: American Foundation for the Blind; 1997.

3. Cryer H, Home S. Final report: Feasibility of developing a diagnostic touch test to determine braille reading potential. United Kingdom: RNIB Centre for Accessible Information; 2011.

4. Dixon J, editor. Braille into the next milennium. Washington, DC: National Library Service for the Blind and Physically Handicapped; 2000.

5. Huebner KM. Daily uses of braille as told by 4 adult braille users. Journal of Visual Impairment & Blindness. 1989; 83:308-9.

6. Nadeem M, Aziz N, Sajjad U, Aziz F, Shaikh H, editors. A comparative analysis of Braille generation technologies. 2016 International Conference on Advanced Robotics and Mechatronics (ICARM); 2016 18-20 Aug. 2016.

7. Foulke E. Reading braille. Tactual Perception: A Sourcebook. New York: Cambridge University Press; 1982. p. 168-208.

8. Stevens JC, Foulke E, Patterson MQ. Tactile acuity, aging, and braille reading in long-term blindness. Journal of Experimental Psychology: Applied. 1996; 2(2):91-106.

9. Legge GE, Madison CM, Vaughn BN, Cheong AMY, Miller JC. Retention of high tactile acuity throughout the lifespan in blindness. Perception & Psychophysics. 2008; 70(8):1471-88.

10. Bruns P, Camargo CJ, Campanella H, Esteve J, Dinse HR, Röder B. Tactile acuity charts: a reliable measure of spatial acuity. PloS One. 2014; 9(2):e87384.

11. Kusajima T. Visual reading and braille reading: an experimental investigation of the physiology and psychology of visual and tactual reading. New York: American Foundation of the Blind; 1974.

12. Wright T, Wormsley DP, Kamei-Hannan C. Hand movements and braille reading efficiency: Data from the Alphabetic Braille and Contracted Braille Study. Journal of Visual Impairment & Blindness. 2009; 103(10):649-61.

13. Agnew J, Bolla-Wilson K, Kawas CH, Bleecker ML. Purdue pegboard age and sex norms for people 40 years old and older. Developmental Neuropsychology. 1988; 4(1):29-35.

14. Yeudall LT, Fromm D, Reddon JR, Stefanyk WO. Normative data stratified by age and sex for 12 neuropsychological tests. Journal of Clinical Psychology. 1986; 42(6):918-46.

15. Tiffin J, Asher EJ. The Purdue Pegboard: norms and studies of reliability and validity. Journal of Applied Psychology. 1948; 32(3):234-47.

16. Perea M, Jiménez M, Martín-Suesta M, Gómez P. Letter position coding across modalities: Braille and sighted reading of sentences with jumbled words. Psychonomic Bulletin & Review. 2015; 22(2):531-6.

17. Krueger LE. A word-superiority effect with print and braille characters. Perception & Psychophysics. 1982; 31(4):345-52.

18. Nolan CY, Kederis JC. Perceptual Factors in Braille Word Recognition (Research Series No. 20). New York: American Foundation for the Blind; 1969.

19. Mousty P, Bertelson P. 1. A study of braille reading: Reading speed as a function of hand usage and context. The Quarterly Journal of Experimental Psychology. 1985; 37A:217-33.

20. Legge GE, Madison CM, Mansfield JS. Measuring braille reading speed with the MNREAD test. Visual Impairment Research. 1999; 1(3):131-45.

21. Nyberg L, Lövdén M, Riklund K, Lindenberger U, Bäckman L. Memory aging and brain maintenance. Trends in Cognitive Sciences. 2012; 16(5):292-305.

22. Martiniello N, Wittich W. The association between tactile, motor and cognitive capacities and braille reading performance: a scoping review of primary evidence to advance research on braille and aging. Disability & Rehabilitation. 2020.

23. Ponchillia PE, Ponchillia SV. Foundations of Rehabilitation Teaching with Persons Who Are Blind or Visually Impaired. New York: American Foundation for the Blind; 1996.

24. Corn AL, Lusk KE. Perspectives on Low Vision (Chapter 1). Foundations of Low Vision: Clinical and Functional Perspectives. New York: American Foundation for the Blind; 2010. p. 3-34.

25. World Health Organization. The ICD-10 classification of mental and behavioural disorders: diagnostic criteria for research: World Health Organization; 1993.

26. Goodman LA. Snowball Sampling. Ann Math Statist. 1961; 32(1):148-70.

27. World Medical Association. Declaration of Helsinki: ethical principles for medical research involving human subjects. Journal of the American Medical Association. 2013; 310(20):2191-4.

28. Ackerman PL, Kanfer R. Test length and cognitive fatigue: an empirical examination of effects on performance and test-taker reactions. Journal of Experimental Psychology: Applied. 2009; 15(2):163.

29. Wittich W, Phillips N, Nasreddine ZS, Chertkow H. Sensitivity and specificity of the Montreal Cognitive Assessment modified for individuals who are visually impaired. Journal of Visual Impairment & Blindness. 2010; 104(6):360.

30. Papagno C, Minniti G, Mattavelli GC, Manatovan L, Cecchetto C. Tactile short-term memory in sensory-deprived individuals. Experimental Brain Research. 2017; 235(2):471-80.

31. Oldfield RC. The assessment and analysis of handedness: The Edinburgh inventory. Neuropsychologia. 1971; 9:97-113.

32. Wittich W, Nadon C. The Purdue Pegboard test: Normative data for older adults with low vision. Disability and Rehabilitation: Assistive Technology. 2015; 12(3).

33. Dinse HR, Kleibel N, Kalisch T, Ragert P, Wilimzig C, Tegenthoff M. Tactile coactivation resets age-related decline of human tactile discrimination. Annals of Neurology. 2006; 60(1):88-94.

34. Bleyenheuft Y, Thonnard J-L. Tactile spatial resolution measured manually: a validation study. Somatosensory and Motor Research. 2007; 24(3).

35. Ramalu PY, Swenor BK, Jefferys JL, Rubin GS. Description and validation of a test to evaluate sustained silent reading. Invetigative Ophthalmology & VIsual Science. 2013; 54(1):673-80.

36. Fuchs LS, Fuchs D, Hosp MK, Jenkins JR. Oral reading fluency as an indicator of reading competence: a theoretical, empirical, and historical analysis. Scientific Studies of Reading. 2001; 5(3):239-56.

37. Juel C, Holmes B. Oral and silent reading of sentences. Reading Research Quarterly. 1981; 16(4):545-68.

38. Trauzettel-Klosinski S, Dietz K. Standardized assessment of reading performance: the New International Reading Speed Texts IReST. Investigative Ophthalmology and Visual Science. 2012; 53(9):5452-61.

39. Daneman M. How reading braille is both like and unlike reading print. Memory & Cognition. 1988; 16(6):497-504.

40. Bradshaw JL, Nettleton NC, Speir K. Braille reading and left and right hemispace. Neuropsychologia. 1982; 20(4):493-500.

41. Fertsch P. Hand dominance in reading braille. The American Journal of Psychology. 1947; 60(3):335-49.

42. Millar S. Is there a "best hand" for braille? Cortex. 1984; 20:75-87.

43. Wilkinson JM, Carr TH. Strategic hand use preferences and hemispheric specialization in tactual reading: Impact of the demands of perceptual encoding. Brain and Language. 1987; 32:97-123.

44. Foulke E. Transfer of a complex perceptual skill. Perceptual and Motor Skills. 1964; 18:733-40.

45. Sampaio E, Philip J. Influences of age at onset of blindness on braille reading performances with left and right hands. Perceptual and Motor Skills. 1995; 81\:131-41.

46. Buddenberg LA, Davis C. Test–Retest Reliability of the Purdue Pegboard Test. American Journal of Occupational Therapy. 2000; 54(5):555-8.

47. Goldreich D, Kanics IM. Tactile acuity is enhanced in blindness. J Neurosci. 2003; 23(8):3439-45.

48. Weber EH. E. H. Weber on the tactile senses, 2nd ed. Ross HE, Murray DJ, editors. Oxford, England: Erlbaum (Uk) Taylor & Francis, Publ; 1996. xii, 260-xii, p.

49. Van Boven RW, Johnson KO. The limit of tactile spatial resolution in humans: grating orientation discrimination at the lip, tongue, and finger. Neurology. 1994; 44(12):2361-.

50. Remblay F, Backman A, Cuenco A, Vant K, Wassef MA. Assessment of spatial acuity at the fingertip with grating (JVP) domes: validity for use in an elderly population. Somatosens Mot Res. 2000; 17(1):61-6.

51. Oshima K, Arai T, Ichihara S, Nakano Y. Tactile sensitivity and braille reading in people with early blindness and late blindness. Journal of Visual Impairment & Blindness. 2014; 108(2):122-31.

52. Tibbs A. Tactile Acuity Chart Generators. 2018.

53. Hahn G, Penka D, Gehrlich C, Messias A, Weismann M, Hyvärinen L, et al. New standardised texts for assessing reading performance in four European languages. British Journal of Ophthalmology. 2006; 90(4):480-4.

54. Morrice E, Hughes J, Wittich W, Johnson A. Validation of the international reading speed texts in a Canadian sample. Annals of Eye Science. 2018; 3:AB104.

55. Garcia LG. Assessment of text reading comprehension by Spanish-speaking blind persons. The British Journal of Visual Impairment. 2004; 22(1):4-12.

56. Kline RB. Principles and Practice of Structured Equation Modeling. New York: Guilford; 2011.

57. Trent SD, Truan MB. Speed, accuracy, and comprehension of adolescent braille readers in a specialized school. Journal of Visual Impairment & Blindness. 1997; 91(5):494-500.

58. Davidson PW, Appelle S, Haber RN. Haptic scanning of braille cells by low-and high-proficiency blind readers. Research in Developmental Disabilities. 1992; 13(2):99-111.

59. Holland BF. Speed and Pressure Factors in Braille Reading. Journal of Visual Impairment & Blindness. 1934; 28(1b):13-7.

60. Loomis JM. Tactile recognition of raised characters: A parametric study. Bulletin of the Psychonomic Society. 1985; 23(1):18-20.

61. Heller MA, Gentaz E. Psychology of Touch and Blindness: Psychology Press; 2013.

62. Murata J, Murata S, Hiroshige J, Ohtao H, Horie J, Kai Y. The Influence of Age-related Changes in Tactile Sensibility and Muscular Strength on Hand Function in Older Adult Females. International Journal of Gerontology. 2010; 4(4):180-3.

63. Tremblay F, Wong K, Sanderson R, Coté L. Tactile spatial acuity in elderly persons: assessment with grating domes and relationship with manual dexterity. Somatosens Mot Res. 2003; 20(2):127-32.

64. Wormsley DP. Hand Movement Training in Braille Reading. Journal of Visual Impairment and Blindness. 1981; 75(8):327-31.

65. Martiniello N, Haririsanati L, Wittich W. Enablers and barriers encountered by working-age and older adults who pursue braille training. Disability and Rehabilitation. 2020.

66. Murman DL. The Impact of Age on Cognition. Semin Hear. 2015; 36(3):111-21.

67. Bola L, Siuda-Krzywicka K, Paplinska M, Sumera E, Hanczur P, Szwed M. Braille in the sighted: Teaching tactile reading to sighted adults. PloS One. 2016; 11(5):e0153394.

68. Olson M, Harlow SD, Williams J. Rapid Reading in Braille and Large Print: An Examination of McBride's Procedures. Journal of Visual Impairment & Blindness. 1975; 69(9):392-5.

69. Wong M, Peters RM, Goldreich D. A physical constraint on perceptual learning: tactile spatial acuity improves with training to a limit set by finger size. Journal of Neuroscience. 2013; 33(22):9345-52.

70. Millar S. Reading by touch: Routledge; 2003.

71. Legge GE. Psychophysics of Reading in Normal and Low Vision. Boca Raton: CRC Press; 2007.

72. Nolan CY, Morris JE. Development and validation of the Roughness Discrimination Test. The International Journal for the Education of the Blind. 1965; 15(1):1-6.

73. Bernbaum M, Albert SG, McGarry JD. Diabetic neuropathy and braille ability. Archives of Neruology. 1989; 46:1179-81.

74. Harley RK, Pichert JW, Morrison M. Braille instruction for blind diabetic adults with decreased tactile sensitivity. Journal of Visual Impairment & Blindness. 1985; 79(1):12-7.

75. Knowlton M, Wetzel R. Braille reading rates as a function of reading tasks. Journal of Visual Impairment & Blindness. 1996; 90(3).

76. Wetzel R, Knowlton M. A comparison of print and braille reading rates on three reading tasks. Journal of Visual Impairment & Blindness. 2000; 94(3):146-54.

77. Chen X, Liang L, Lu M, Potměšil M, Zhong J. The effects of reading mode and braille reading patterns on braille reading speed and comprehension: A study of students with visual impairments in China. Research in Developmental Disabilities. 2019; 91:103424.

78. Fertsch P. An analysis of braille reading. Outlook for the blind and the teachers forum1946. p. 128.

79. Laroche L, Boulé J, Wittich W. Reading speed of contracted French braille. Journal of Visual Impairment & Blindness. 2012; 106(1):37-42.

80. Proud EL, Morris ME. Skilled Hand Dexterity in Parkinson's Disease: Effects of Adding a Concurrent Task. Archives of Physical Medicine and Rehabilitation. 2010; 91(5):794-9.

81. Douglas G, Weston A, Whittaker J, Wilkins SM, Robinson D. An investigation of the height of embossed braille dots for labels on pharmaceutical products. Journal of Visual Impairment & Blindness. 2009; 103(10):662-7.

82. Tiresias. Braille cell dimensions 2009 [Available from: http://www.arch.mcgill.ca/prof/klopp/arch678/fall2008/3%20Student%20exchange/Team%20Surface/Connexion%20Surface%20Folder/MA%20files/Braille%20cell%20dimensions.pdf.

83. Gardner JA, editor Braille, innovations, and over-specified standards. Proceedings of GOTHI'05 (Guidelines on Tactile and Haptic Interactions); 2005; Saskatoon, Canada: University of Saskatchewan.

84. Morrice E. Validation of the International Reading Speed Texts in a Canadian Sample. Montreal, Quebec: Concordia University; 2017.

85. Bowen HP, Wiersema MF. Matching method to paradigm in strategy research: limitations of cross-sectional analysis and some methodological alternatives. Strategic management journal. 1999; 20(7):625-36.

Chapter 5 – Study 4: Exploring the influence of reading medium on braille learning outcomes: A case series of 6 working-age and older adults

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5.1. Abstract

Tactile sensitivity is known to decline with age. Braille provides a vital method of reading and writing for working-age and older adults with acquired visual impairment. The proliferation of lower cost braille displays raises new possibilities for adult braille learners, with dots of greater height than standard paper braille, potentially benefiting older adults with reduced tactile sensitivity. This study explored the influence of reading medium (paper versus braille display) on the accuracy and speed of 6 working-age and older adult braille learners, and examined differences when transitioning from one reading medium to another. Findings indicate that (1) learning new letters on a braille display resulted in better speed and accuracy (time: M = 44.2, SD = 37.3, accuracy: M = 83%, SD = 24.8%) than on paper (time: M = 54.3, SD = 40.4, accuracy: M = 80.6%, SD = 28.1%); (2) transitioning from one medium to another generally resulted in the same or better performance (reading times decreased by 11.2% and accuracy improved by 2.4%); and (3) the advantage of the braille display appears to be greatest when reading letters in combination (reading times decreased by 26.8% and accuracy improved by 6.5% for letter-pairs vs a 1.9% reduction in speed and a 2% improvement in accuracy for single letters). The benefit of the braille display condition was most pronounced for participants with reduced tactile sensitivity. Although preliminary, these findings suggest that the use of braille displays in early braille instruction may decrease frustration for those with reduced tactile sensitivity and should not adversely effect the ability for learners to transition to standard paper braille, assuming that both formats are introduced and reinforced throughout training.

Keywords: braille, tactile sensitivity, aging

5.2. Introduction

Tactile acuity, like visual acuity, is known to decline as part of the typical aging process.[1] Braille is a tactile reading and writing system that provides persons with visual impairments (that is, those who are blind or who have low vision) with a method for accessing information needed for both functional tasks and more extensive reading demands.[2,3] Despite these benefits, little research has been devoted to supporting individuals who learn braille later in life. The recent proliferation of lower-cost braille displays raises new questions for the adult braille rehabilitation context.[4] Such devices, which have traditionally been costly, provide greater access to relevant reading materials that increase motivation for adult braille learners,[5] and incorporate braille characters of greater dot height and density that may benefit those with reduced tactile sensitivity.[6] The goal of this study was to explore the influence of reading medium (paper versus electronic braille display) on the accuracy and speed of working-age and older adult braille learners, and to examine differences in accuracy and speed when transitioning from one reading medium to another.

Tactile sensitivity is a vital component of efficient braille reading. For blind children, an emphasis is placed on developing adequate tactile skills and haptic exploration techniques long before formal braille literacy instruction begins.[6] Ample evidence demonstrates that tactile acuity improves with exposure and practice, as indicated by the fact that early learners of braille often maintain higher levels of tactile sensitivity as they age, when compared to sighted controls who lack a similar lifetime of tactile experience.[7] In a study exploring correlates of braille reading performance among working-age and older adults (Chapter 4), frequency of braille usage emerged as a significant correlate of braille reading outcomes, regardless of the age braille is learned.[8] For these reasons, braille learners require ample opportunities to develop tactile sensitivity through the realistic use of braille within daily life.[5,9] The importance of developing tactile skills is especially vital for older adults, who experience age-related declines in tactile sensitivity.[7] Among the sighted, tactile acuity thresholds have been shown to decline at a rate of approximately 1% per year.[7,10,11]

In addition to the importance of tactile experience, several studies have also investigated the influence of adjusting the presentation of braille characters to explore whether such modifications improve learning outcomes for older adults. Current research on the manipulation of braille for persons with reduced tactile sensitivity focuses on the influence of adjusting dot height or size. In a series of studies that investigated the legibility of braille labels on pharmaceutical packages, Douglas et al.[12] compared readability using 6 different braille dot heights. The authors found that a mean dot height of .18 mm was not significantly more difficult to read than standard braille, which ranges from 0.46mm to 1.0mm;[12-14] however, participants above the age of 60 achieved only 83% accuracy at this reduced dot height. Though tactile acuity was not measured, the authors noted that the lower performance of participants above the age of 60 was consistent with the reduced tactile sensitivity expected among older adults.[15] While these results provide evidence that older adults may achieve greater reading accuracy with increased dot height, the dot heights examined by Douglas et al. were lower than that of standard braille. These findings are therefore not directly transferable to braille instruction, given that these heights are not reflective of what braille readers will encounter in everyday use. Moreover, the participants in this study were experienced braille users, and it is possible that variations in dot height may have more of an influence on older learners of braille with reduced tactile sensitivity.

Several authors have also considered the influence of braille cell size and the use of enlarged or “jumbo” braille.[16] Barlow-Brown, Barker and Harris[17] noted that while young print-reading children traditionally learn to read using larger type before transitioning to standard print size, the potential benefits of this approach have received little attention within braille instruction. In a study of very young, sighted prereading children (N = 67, age M = 47.8 months), the authors observed that participants who initially learned braille patterns tactually using an oversized braille cell were, after training, able to accurately read standard-sized braille significantly better than those who learned using standard braille from the start. The authors hypothesized that beginning with enlarged braille enables learners to focus first on the overall shape of braille characters prior to adding the additional complexity of developing the tactile perception needed for standard braille. While there is evidence that manipulating the spacing between standard braille dots (jumbo braille) may improve outcomes for learners with diabetic neuropathy,[18,19] practitioners highlight that the decision to teach jumbo braille should be made with caution, given that most materials are not produced in this format. Millar[20] observed that learners may not always be able to transfer knowledge of braille spatial patterns across different sizes of braille cells. Over-reliance on jumbo braille for older learners by default may decrease motivation for those who are reluctant to transition to standard braille, if that is the ultimate goal.

Although practice is vital for the development of tactile skills, adult braille learners report a lack of resources and opportunities to read braille during and after the learning process.[5] Many practice materials are designed for younger children and may not be as relevant or motivating to older learners of braille.[6] Within this context, electronic braille displays have greatly increased access to information. These devices can be paired to computers and tablets and instantly transform information into braille through a series of pins that rise and fall to form braille characters.[6] The recent proliferation of lower-cost braille devices provides additional options for working-age and older adults who may not have had access to these tools before, due to restrictive funding regimes that prioritize students and those who are employed, where such programs have existed at all.[21] Beyond greater access to information, the dot height of braille characters on electronic braille displays ranges between .63mm and .80mm, compared to a typical dot height of .46 mm (25%-43% lower) on standard paper braille.[14] It is therefore worthwhile to examine whether the use of braille displays during initial braille instruction with working-age and older adults could facilitate the learning of braille symbols as a supplement to traditional paper-based methods. With this objective in mind, the present study addresses the following research questions:

1. Are there differences in the speed and accuracy of participants who learn braille letters on paper compared to those who initially learn on an electronic braille display?
2. Does learning performance (accuracy and speed) change when transitioning from one reading medium (paper or braille display) to the other?
3. Are there observed differences in performance based on tactile acuity?

5.3. Methods

Using a case series approach,[22] the goal of this pilot study was to refine the protocol for a larger study and to describe initial observations, given the exploratory nature of this work. Due to the inherently smaller sample size, the objective of the case series method is to provide a description of cases, rather than to engage in statistical comparisons or to make generalizations among participants.[23] The present case series study was designed in accordance with established guidelines.[24]

5.3.1. Ethics approval

This study was approved by the University of Montreal and the Centre for Interdisciplinary Research in Rehabilitation of Greater Montreal (CRIR #1431-0619).

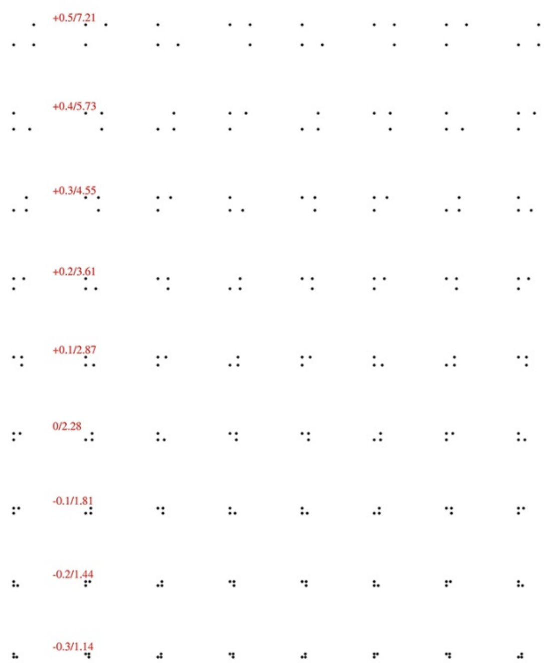
5.3.2. Eligibility and recruitment

Participants who were at least 18 years of age, had no prior experience reading braille visually or tactually, and who were able to communicate orally and in writing in either English or French were eligible to participate. Both those with and without visual impairments could take part. Regardless of vision level, the reading materials were occluded with the use of a cardboard screen. All participants completed two separate sessions of 1.5 hours in length on two consecutive days, either at home or at an approved research site. Informed written or audio-recorded verbal consent was obtained in accordance with the *Declaration of Helsinki and Public Health*.[25]

5.3.3. Materials and procedure

Prior to testing, participants completed a brief verbal demographic questionnaire to gather information about their age, visual diagnosis and age of onset (if applicable), additional diagnoses and language ability. Participants who self-identified as having a visual impairment were asked to self-report as having a mild, moderate, severe or profound visual impairment in accordance with the definitions outlined by the World Health Organization.[26] Additionally, the Montreal Cognitive Assessment, as adapted for blind and visually impaired participants (MoCA-B)[27], was administered to screen for participants at risk to have a mild cognitive impairment that could impact their learning or reading performance.[28]

Finally, active tactile acuity threshold was measured using Legge's "Dot" tactile acuity chart. Developed as a measure of active (hand/finger moving) tactile acuity, Legge's "Dot" Tactile Acuity Chart[7] has been validated as a reliable measure of tactile acuity,[29] and has been applied to both North American and Japanese samples.[30] As shown in Figure 14 (below), the chart contains lines of eight braille-like dot pattern characters (wherein one of four dots in a square pattern has been omitted), scaled upwards or downwards in uniform logMAR steps. The fourth line from the bottom is designated the 0 logMAR line, and on this line, the centers of adjacent dots are spaced 2.28mm apart – the same distance used in standard English braille. Participants read through all of the lines with the index finger of the dominant hand, starting at the top, and reported the location of the missing dot (top-left, top-right, bottom-left, bottom-right). This test was not timed since accuracy was more important than speed. A tactile acuity threshold (in logMAR units) was then calculated based on the number of correct lines and symbols within lines which are read, and converted to millimeters as described by Oshima.[30]



NOTE: The 0/2.28mm line, fourth from the bottom, represents "standard" braille dot spacing

Figure 14. – Image of the Legge "Dot" tactile acuity chart

5.3.4. Experiment

Participants were randomly assigned to one of two groups (as shown in the flowchart in Figure 15 on the following page). In the first training session, group A participants were introduced to letters A to D on paper, while group B was introduced to letters A to D on an electronic braille display. In the second training session, group A was introduced to letters E to H on a braille display, while group B was introduced to letters E to H on paper. In all cases, participants in both groups then switched to reading those same letters in the alternative reading medium (their “second format”), to evaluate whether there was any immediate change in their performance when transitioning from one format to the other. The letters and their composition within a braille cell are shown in Figure 16 (on the following page).

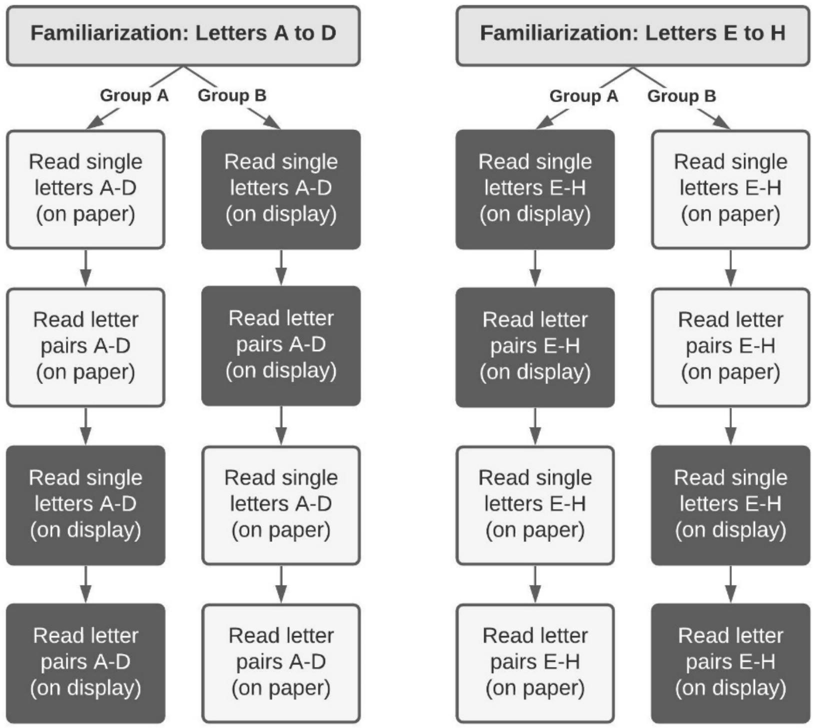


Figure 15. – Flowchart depicting the sequence of reading tasks completed by Group A and Group B participants

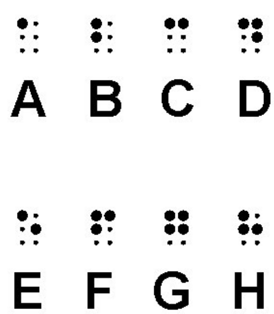


Figure 16. – Image showing the composition of the eight braille letters (A-D, E-H) participants read in Study 4

Each of the two training sessions consisted of two segments:

1. **Familiarization**: At the start of training session 1, participants spent approximately 10 minutes learning the basics of the 3x2 braille cell and the dot configuration for letters A to D. Given standard practice with adult clients [3], participants felt the layout for each of the four braille characters (A to D) using a 6-holed muffin tin and up to 6 large plastic balls. The composition of each of the letters A-D was demonstrated, and participants had an opportunity to re-create the letters from memory several times before beginning the reading exercise. This same familiarization activity was repeated at the start of training session 2 to introduce participants to letters E to H.

2. **Reading letters**: Participants then read each line of letters aloud in their first format (paper or display). There was no time limit, and no feedback was provided to participants as they read. The first five lines for each set of letters contained only single letters (e.g. “D A C B”); the next five lines contained pairs of letters (e.g. “AC BD DB BA”). The time taken to read the four letters or letter pairs (in seconds) and the number of correctly read letters or letter pairs were recorded for each line separately. A letter or letter pair was considered correct if it was read correctly or if the participant corrected an error before moving on. After completing the reading activities in the first format, the participant then completed the same reading activity in the second format (paper or display).

The reading materials consisted of five lines of four single letters (or letter pairs) each in pseudorandomized order, for each of the four reading conditions (A-D/E-H, single letter/letter pairs). The paper versions were produced manually on 3” x 5” standard index cards using a Perkins Braillewriter (Perkins Solutions, Watertown, MA, USA), with one line of letters per index card. Two spaces were left between each letter or letter pair. Fresh copies were provided to each participant to ensure that the quality of the paper format would be maintained. A BrailleNote Touch Plus 32 (Humanware Technologies, Drummondville, QC, Canada) notetaker was utilized for presenting the electronic braille. The ordering of the lines to be read was counterbalanced across participants to minimize fatigue and any learning effects.

5.3.5. Data analysis

Descriptive statistics have been used to summarize the data, with speed reported as the mean time to read a line of letters or letter-pairs (in seconds) and accuracy reported as the overall mean percentage of correctly read letters or letter-pairs. Analysis was performed using R (The R Foundation for Statistical Computing, Vienna, Austria, version 3.4.4). Following standard case series procedures, information for each participant is presented separately.[24]

5.4. Results

Table 16 summarizes the demographic characteristics of the 6 participants, including MoCA-B scores and tactile acuity thresholds. Of note, 3 of the 6 participants were above age 65, and each of them had a tactile acuity threshold at or above the 2.28mm limit that is expected to be required for braille reading. The overall reading speed and accuracy for paper and braille display for each participant is illustrated in Figure 17 (below on p. 175). Table 17 (below on p. 173) outlines participants' reading performance for each reading medium and letter combination. Table 18 (below on p. 174) provides a detailed account of the reading times and accuracy for each participant in each of the reading conditions, as well as the differential in performance observed when transitioning from paper to display or display to paper.

Table 16. – Summary of participant demographics

#	Age	Gender	Education	Employment	MoCA-B (x/22)	Tactile Acuity (mm)
1	66	F	Masters	Retired	17	4.055mm
2	77	M	Bachelors	Retired	20	2.954mm
3	66	M	Bachelors	Retired	20	2.280mm
4	26	F	College	Student	20	1.614mm
5	23	F	College	Student	21	2.870mm
6	52	F	Masters	Employed	18	1.918mm

Table 17. – Descriptive statistics of global reading performance measures for each participant

Participant #		Overall	Display	Paper	A-D Singles	A-D Pairs	E-H Singles	E-H Pairs
1	Time [a]	68.4 (42.8)	42.5 (18.3)	84.5 (46.2)	36.7 (11.9)	28.6 (65.6)	68.7 (25.2)	172.5 (12.3)
	Accuracy [b]	79.7% (30.2%)	87.5% (18.9%)	75.0% (35.4%)	100% (0)	65.6% (35.2%)	95.8% (10.2%)	37.5% (17.7%)
2	Time [a]	87.7 (41.6)	85.3 (40.2)	90.5 (43.9)	49.3 (36.3)	113.3 (17.7)	85.0 (33.7)	114.7 (44.2)
	Accuracy [b]	63.9% (31.9%)	66.7% (32.1%)	61.1% (32.3%)	97.5% (7.9%)	60.0% (31.6%)	57.5% (20.6%)	25.0% (15.8%)
3	Time [a]	62.5 (41.9)	56.1 (41.4)	69.2 (42.3)	22.7 (6.9)	74.0 (45.4)	50.1 (17.8)	103.7 (34.7)
	Accuracy [b]	81.3% (28.2%)	80.0% (27.6%)	82.5% (29.4%)	100% (0)	85.0% (24.2%)	85.0% (17.5%)	55.0% (36.9%)
4	Time [a]	30.8 (17.7)	28.9 (17.1)	32.6 (18.6)	13.7 (3.2)	25.7 (6.7)	26.3 (4.8)	57.2 (11.3)
	Accuracy [b]	98.8% (5.5%)	100.0% (0)	97.5% (7.7%)	100% (0)	100% (0)	97.5% (7.9%)	97.5% (7.9%)
5	Time [a]	21.7 (12.6)	19.8 (9.0)	23.6 (15.4)	11.8 (5.5)	33.2 (15.4)	16.7 (7.3)	25.0 (8.5)
	Accuracy [b]	86.9% (21.2%)	88.8% (17.2%)	85.0% (24.9%)	97.5% (7.9%)	90.0% (17.5%)	82.5% (23.7%)	77.5% (27.5%)
6	Time [a]	37.6 (27.5)	35.5 (36.6)	39.8 (14.1)	19.4 (5.4)	32.6 (7.3)	49.1 (48.4)	49.5 (11.7)
	Accuracy [b]	77.5% (24.6%)	76.3% (25.0%)	78.8% (24.7%)	92.5% (12.1%)	82.5% (16.9%)	77.5% (24.9%)	57.5% (29.0%)
All	Time [a]	49.4 (39.2)	44.2 (37.3)	54.3 (40.4)	24.6 (20.8)	56.7 (38.9)	48.0 (35.4)	70.6 (44.8)
	Accuracy [b]	81.8% (26.5%)	83.0% (24.8%)	80.6% (28.1%)	97.7% (7.3%)	81.0% (26.2%)	81.7% (22.6%)	64.6% (33.8%)

[a] Time: The mean (standard deviation) number of seconds required to read a single line of letters or letter-pairs
[b] Accuracy: The mean (standard deviation) percentage of correct letters or letter-pairs read in each line

Table 18. – Mean reading times and accuracies by participant and reading condition

#	Letters [a]	First Medium			Second Medium			Differential [d]	
		Medium	Time [b]	Accuracy [c]	Medium	Time [b]	Accuracy [c]	Time (%)	Accuracy
1	A-D x1	Paper	37.1	100.0%	Display	36.0	100.0%	-1.1 (-3%)	Nil
	A-D x2	Paper	77.4	60.0%	Display	36.7	75.0%	-40.7 (-53%)	+15%
	E-H x1	Display	52.6	91.7%	Paper	84.8	75.0%	+32.3 (+61%)	-16.7%
	E-H x2	--	--	--	--	--	--	--	--
2	A-D x1	Display	62.6	100%	Paper	36.0	95%	-26.6 (-42%)	-5%
	A-D x2	Display	110.1	60.0%	Paper	116.4	60.0%	+6.3 (+5.7%)	Nil
	E-H x1	Paper	89.6	55.0%	Display	80.3	60.0%	-9.3 (-10%)	+5%
	E-H x2	Paper	139.5	16.7%	Display	89.9	33.3%	-49.6 (-36%)	+16.6%
3	A-D x1	Paper	26.9	100.0%	Display	18.5	100.0%	-8.4 (-31%)	Nil
	A-D x2	Paper	99.0	80.0%	Display	49.0	90.0%	-50.0 (-51%)	+10%
	E-H x1	Display	48.6	85.0%	Paper	51.6	85.0%	3.0 (+6.2%)	Nil
	E-H x2	Display	108.3	45.0%	Paper	99.2	65.0%	-9.1 (-8.4%)	+20%
4	A-D x1	Display	13.3	100.0%	Paper	14.0	100.0%	0.7 (+5.3%)	Nil
	A-D x2	Display	23.1	100.0%	Paper	28.3	100.0%	+5.2 (+22.5%)	Nil
	E-H x1	Paper	27.6	95.0%	Display	25.0	100.0%	-2.6 (-9.4%)	+5%
	E-H x2	Paper	60.2	95.0%	Display	54.2	100.0%	-6 (-11%)	+5%
5	A-D x1	Paper	13.7	95.0%	Display	9.9	100.0%	-3.78 (-38.1%)	+5%
	A-D x2	Paper	41.2	85.0%	Display	25.3	95.0%	-15.9 (-62.8%)	+10%
	E-H x1	Display	21.2	85.0%	Paper	13.7	95.0%	-8.9 (-35%)	+10%
	E-H x2	Display	22.8	75.0%	Paper	27.2	80.0%	4.4 (+19%)	+5%
6	A-D x1	Display	17.5	90.0%	Paper	21.2	95.0%	+3.7 (+21.1%)	+5%
	A-D x2	Display	27.7	90.0%	Paper	37.5	75.0%	+9.8 (+35.4%)	-15%
	E-H x1	Paper	45.0	95.0%	Display	53.2	60.0%	+8.2 (+18.2%)	-35%
	E-H x2	Paper	55.5	50.0%	Display	43.4	65.0%	-12.1 (-21.8%)	+15%

[a] Letters: "x1" indicates reading single letters (A-D or E-H); "x2" indicates reading letter-pairs (A-D or E-H)[a] Time: The mean number of seconds required to read each line of letters or letter-pairs

[b] Accuracy: The mean percentage of letters or letter-pairs correctly read within each line

[c] Differential reports the change in reading time and accuracy in the "second medium" as compared with the "first medium". For reading time, this is reported both as a number (in seconds) and as a percentage of the time taken to read in the first medium.

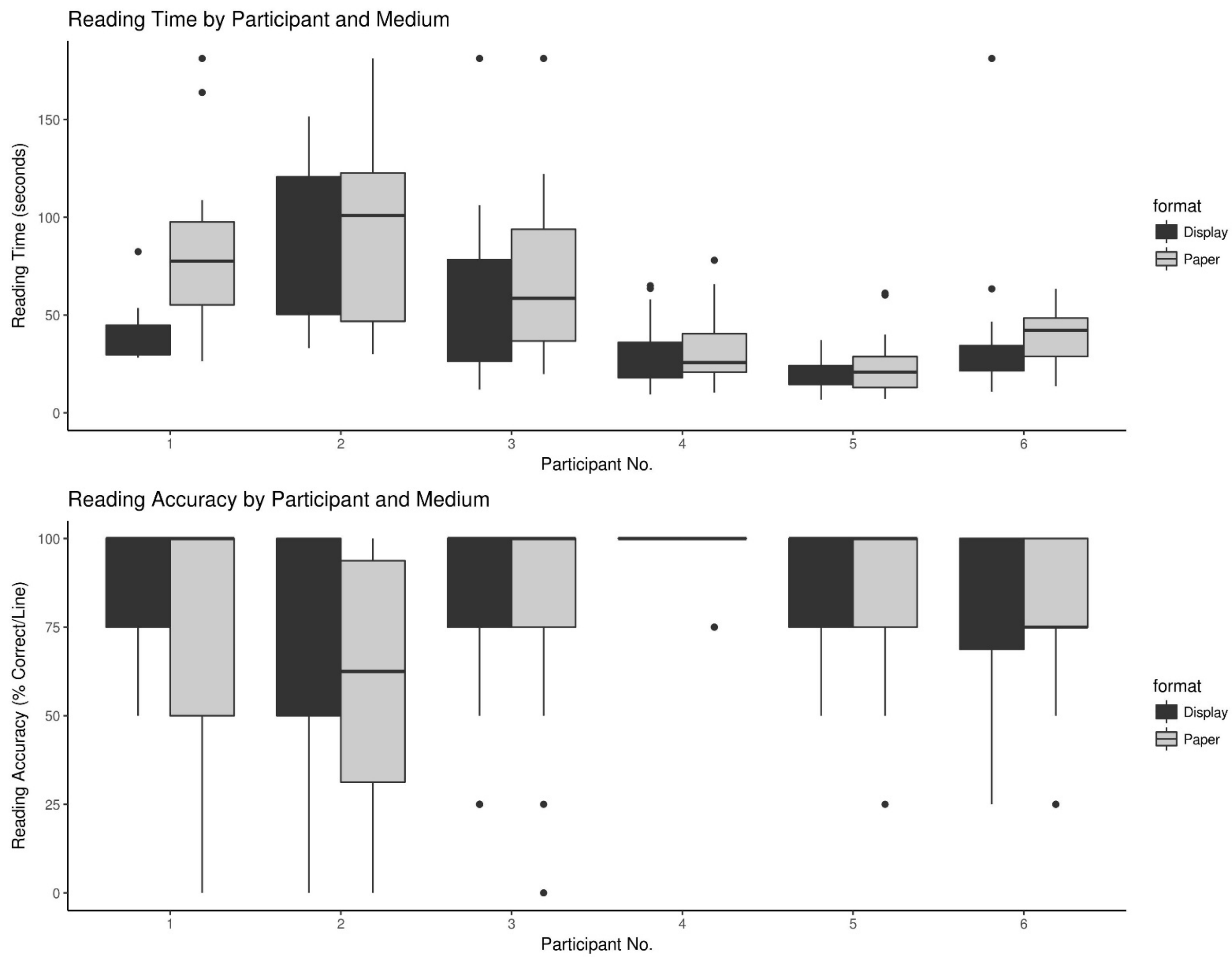


Figure 17. – Boxplot depicting the reading time (mean seconds per line of 4 letters or letter-pairs) and accuracy (mean % of correct letters or letter-pairs per line) using an electronic braille display (black bars) and paper (grey bars) for each of the 6 participants

Overall the results indicate that:

1. Learning new letters on a braille display resulted in better speed and accuracy (time: M = 44.2, SD = 37.3, accuracy: M = 83%, SD = 24.8%) than on paper (time: M = 54.3, SD = 40.4, accuracy: M = 80.6%, SD = 28.1%), especially for those with poorer tactile acuity. However, even those with poor tactile acuity demonstrate the ability to read accurately on both paper and braille display;
2. Transitioning from one medium to another generally resulted in the same or better speed and the same or marginally better accuracy: on average, when the same letters or letter pairs were read in a participant's second format, reading times decreased by 11.2% and accuracy improved by 2.4%;
3. The advantage of the braille display condition appears to be greatest when reading letters in combination. Reading times on the braille display for the letter pairs were, on average, 19.4 seconds faster than on paper (a 26.8% reduction), and accuracy improved, on average, by 6.5%. For single letters, the differences were less acute: reading time on the display was only 0.68 seconds faster (a 1.9% reduction), and accuracy improved by only 2%.

5.4.1. Case 1

This 66-year-old sighted female scored the highest tactile acuity threshold (4.055mm) among the 6 participants, and was the only participant who did not achieve the 18 required to "pass" the MoCA. Despite these apparent disadvantages, she was neither the slowest (overall reading time M = 68.5, SD = 42.8) nor the least accurate (overall accuracy M = 79.7%, SD = 30.2%). She read much more quickly on a braille display (overall reading time M = 42.5, SD = 18.3) than on paper (M = 84.5, SD = 46.2), and had better accuracy with a display (overall accuracy M = 87.5%, SD = 18.9) than on paper (M = 75%, SD = 35.4).

As shown in Table 18, when transitioning from paper to display, this individual's speed and accuracy either improved or remained approximately the same. Transitioning from a display to paper (for single letters E-H) resulted in a noticeable increase in the time taken to read (by more than 32%), and decreased accuracy by more than 16%. Note that due to fatigue, this participant was unable to complete the paired-letter E-H evaluation.

5.4.2. Case 2

This 77-year-old male scored a tactile threshold of 2.954mm, approximately 30% above the 2.28mm braille spacing. He was visually impaired due to glaucoma diagnosed at age 49, with no light perception in his left eye and 20/200 acuity (with less than 100 degrees of peripheral vision) in his right. He demonstrated the longest overall reading times (M = 87.8, SD = 41.5) and the poorest overall accuracy (M = 63.9%, SD = 31.9%). Performance on a display (time: M = 85.3, SD = 40.2, accuracy: M = 66.7%, SD = 32.1%) was generally not very different from paper (time: M = 90.5, SD = 43.9, accuracy: M = 61.1%, SD = 32.3%), and transitions to the second format were associated with similar or better performance. Noteworthy is that when reading the E-H double letter pairs, a significant improvement was observed when transitioning from paper to display, with a 36% decrease in time and a 16% increase in accuracy (see Table 18).

5.4.3. Case 3

This 66-year-old male demonstrated a tactile acuity threshold of *exactly* 2.28mm, and presented roughly in the middle of the group in terms of both overall reading time (M = 62.6, SD = 41.9) and accuracy (M = 81.3%, SD = 28.2%). He had, at age 56, been diagnosed with macular dystrophy and had a mild vision impairment (between 20/30 and 20/70). He read more quickly on a display (as his second format) for the letters A-D (by a margin of 31% for single letters and 50% for letter pairs). Interestingly, when going the other direction with the letter pairs for E-H (that is, initially reading E-H on a display and then transitioning to paper), there was a small (8.4%) decrease in the time required but accuracy improved by 20%.

5.4.4. Case 4

At age 26, this female college student (with no visual impairment) demonstrated the lowest tactile acuity threshold among the 6 participants (1.614mm), achieving the highest accuracies (overall accuracy M = 98.8%, SD = 5.5%) and the second-quickest times (overall time

M = 30.8, *SD* = 17.7). This pattern held for both reading on paper (time: *M* = 32.6, *SD* = 18.6; accuracy: *M* = 97.5%, *SD* = 7.7%) and on a braille display (time: *M* = 28.9, *SD* = 17.1; accuracy: *M* = 100%, SD = 0%). Transitions for this participant from paper to display and from display to paper for single letters did not result in any substantial change in performance; however, for letter pairs, the transition to the second format was accompanied by an 22.5% increase in speed for A-D and an 11% increase in speed (along with a 5% increase in accuracy) for E-H.

5.4.5. Case 5

The youngest participant, a sighted 23 year old female college student, presented with an estimated tactile acuity on the Legge "Dot" Chart of 2.870mm. (This tactile acuity threshold is above what prior research suggests would be expected from a 23-year-old sighted individual, which is in the range of 1.3-1.6mm[29,31] but this did not appear to affect her performance.) She was the fastest reader overall (*M* = 21.7, *SD* = 12.6), on paper (*M* = 23.6, *SD* = 15.4), and on a braille display (*M* = 19.8, *SD* = 9.0), and had the second highest accuracy in each modality (overall: *M* = 86.9%, *SD* = 21.2%; paper: *M* = 85%, *SD* = 24.7%; display: *M* = 88.8%; *SD* = 17.2%). As shown in Table 18, transitioning from paper to a display for the letters A-D significantly reduced her reading times and improved her accuracy, but less consistent results were observed for the letters E-H. She first read E-H as single letters on a display, gaining a 35% speed advantage and a 10% accuracy improvement when transitioning to paper; however, for E-H letter pairs, transitioning from a display to paper took 19% longer (but was 5% more accurate).

5.4.6. Case 6

This 52-year-old female had a severe visual impairment (with a self-reported acuity of approximately 20/400), and had additional diagnoses including diabetes, mild multiple sclerosis, and neuropathy. Notwithstanding these diagnoses, her tactile acuity measured 1.918mm, which is not inconsistent with what prior research suggests would be expected for a sighted individual in their 50s.[7,31] Her overall reading times were commensurate with her tactile acuity, being faster than the participants over age 65, all of whose tactile acuity thresholds were higher. As indicated in Table 18, transitioning from one medium to the other had an inconsistent impact on her performance. For the single and double letters A-D, switching from a display to paper resulted in longer reading times and, for letter pairs, a 15% decrease in accuracy. For the single letters E-H, switching from paper to a display resulted in not only an 18.2% increase in reading times, but also a 35% decrease in accuracy. Interestingly, for the E-H letter pairs, the transition from paper to a display resulted in both a 21.8% decrease in reading time and a 15% improvement in accuracy.

5.5. Discussion

This study explored the influence of reading medium (paper and electronic braille display) on reading accuracy and speed when participants were presented with single and double-letter pairs, and examined the observed performance differences when transitioning from one medium to another.

5.5.1. Learning new letters on paper vs. display

For these 6 participants, learning new letters on a braille display resulted in better accuracy and speed than learning on paper, though this is especially true for speed. Though accuracy for new letters was overall better on a braille display, the difference was minimal (just over a 2% difference). The advantage of the braille display condition appears to be greatest when reading paired double letters. Douglas et al.[12] found that experienced braille users achieved similar accuracy when comparing standard braille dot height and a lower dot height of M = .18 mm; however, lowering the dot height in that study resulted in slightly less accuracy for those above the age of 60. In the present study, the speed and accuracy advantage when learning new letters on a braille display was especially true for participants with poorer tactile acuity. The greater dot height afforded by a braille display may thus be especially beneficial for older adults who are new to braille. However, despite the apparent advantage of the braille display, even participants with poorer tactile acuity read with relative accuracy on both conditions. The older adults demonstrated an ability to read new letters both on paper and display (countering the misconception that older adults will be unable to perceive standard paper braille[5,32]), but a braille display could ease learning frustration that might be encountered if tactile perception is impaired.

5.5.2. Transitioning from one medium to another

Transitioning from one medium to another generally resulted in the same or better speed. The improvement in performance when transitioning from display to paper (which was expected to result in less accuracy and speed) is likely due in part to practice or learning effects.[33] However, this finding lends support to the notion that learning to read using a braille display should not disadvantage the client who subsequently transitions to reading on paper. Consistent with the observations made by Millar,[20] practitioners should provide ongoing exposure to both paper and braille to ensure that perception on both formats is maintained and developed. Moreover, the advantage of the braille display when reading paired double letters is consistent with previous work confirming that novice braille learners may initially struggle most with letters that contain a greater number of dots.[34,35] In this way, a braille display can supplement paper braille when progressing to words and sentences, to increase motivation and solidify learning.

5.5.3. Limitations

Mean reading times and accuracy appeared to differ substantially between letters A-D and letters E-H (see Table 17), potentially confounding comparisons among participants. While previous studies have suggested that braille characters in the upper portion of the cell are easier for novice learners to perceive,[34,35] the letters E to H mostly consist of 3 or 4 dots respectively (with the exception of E) compared to letters A to D (where only D contains 3 dots). The decision to use the letters A to D and E to H was made because the most common adult braille curriculum in Canada introduces letters in alphabetical order;[36] however, counter-balancing the letters should be done in future work. Second, while this experiment provides useful insights, it does not mimic adult braille training which takes place over a longer period of time, and, as with any learning situation, may involve periods of both regression and progress. Longitudinal studies on the use of braille displays within training paradigms would add to the findings presented here. Finally, the circumstances surrounding COVID-19 disrupted recruitment, preventing the ability to obtain a larger sample size. Nonetheless, the included case studies are presented as these preliminary findings raise the need for future research on braille learning methods within the adult rehabilitation context, and highlight important observations for clinical practice.

5.4. Conclusion

Although preliminary, these findings provide evidence that older adults are able to read single and double letters on both paper and braille display. However, the braille display condition may serve as an advantage to solidify learning and decrease frustration. This coincides with adult learning paradigms which accentuate the importance of ensuring success early in the learning process, and in providing learners with real-life applications of what is being taught.[37] There are evident advantages to incorporating braille displays early in the learning process, given the greater amount of relevant reading materials that such devices afford. However, practitioners must ensure that older learners have ample opportunities to encounter and practice braille on paper as well, given the importance of paper braille for specific daily tasks (such as labels and lists).[38] These preliminary findings suggest that the use of a braille display early in the braille learning process should not adversely effect the ability for learners to transition to standard paper braille, assuming that both formats are introduced and reinforced throughout training.

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5.6. Declaration of conflicting interests

The authors declare that there are no conflicts of interest.

5.7. References

1. Stevens JC, Foulke E, Patterson MQ. Tactile acuity, aging, and braille reading in long-term blindness. Journal of Experimental Psychology: Applied. 1996; 2(2):91-106.

2. Convention on the Rights of Persons with Disabilities (CRPD). United Nations Division for Social Policy and Development - Disability.

3. Ponchillia PE, Ponchillia SV. Foundations of Rehabilitation Teaching with Persons Who Are Blind or Visually Impaired. New York: American Foundation for the Blind; 1996.

4. Nadeem M, Aziz N, Sajjad U, Aziz F, Shaikh H, editors. A comparative analysis of Braille generation technologies. 2016 International Conference on Advanced Robotics and Mechatronics (ICARM); 2016 18-20 Aug. 2016.

5. Martiniello N, Haririsanati L, Wittich W. Enablers and barriers encountered by working-age and older adults who pursue braille training. Disability and Rehabilitation. 2020.

6. Wormsley DP, D'Andrea FM. Instructional Strategies for Braille Literacy. New York: American Foundation for the Blind; 1997.

7. Legge GE, Madison CM, Vaughn BN, Cheong AMY, Miller JC. Retention of high tactile acuity throughout the lifespan in blindness. Perception & Psychophysics. 2008; 70(8):1471-88.

8. Martiniello N, Wittich W. Exploring predictors of braille reading performance among aging adults with visual impairment. Investigative Ophthalmology & Visual Science. 2020; 61(7):1563-.

9. Wong M, Peters RM, Goldreich D. A physical constraint on perceptual learning: tactile spatial acuity improves with training to a limit set by finger size. Journal of Neuroscience. 2013; 33(22):9345-52.

10. Bola L, Siuda-Krzywicka K, Paplinska M, Sumera E, Hanczur P, Szwed M. Braille in the sighted: Teaching tactile reading to sighted adults. PloS One. 2016; 11(5):e0153394.

11. Olson M, Harlow SD, Williams J. Rapid Reading in Braille and Large Print: An Examination of McBride's Procedures. Journal of Visual Impairment & Blindness. 1975; 69(9):392-5.

12. Douglas G, Weston A, Whittaker J, Wilkins SM, Robinson D. An investigation of the height of embossed braille dots for labels on pharmaceutical products. Journal of Visual Impairment & Blindness. 2009; 103(10):662-7.

13. Gardner JA, editor Braille, innovations, and over-specified standards. Proceedings of GOTHI'05 (Guidelines on Tactile and Haptic Interactions); 2005; Saskatoon, Canada: University of Saskatchewan.

14. Tiresias. Braille cell dimensions 2009 [Available from: http://www.arch.mcgill.ca/prof/klopp/arch678/fall2008/3%20Student%20exchange/Team%20Surface/Connexion%20Surface%20Folder/MA%20files/Braille%20cell%20dimensions.pdf.

15. Stevens JC. Aging and spatial acuity of touch. Journal of Gerontology. 1992; 47(1):35-40.

16. Tobin MJ, Burton P, Davies BT, Guggenheim J. An experimental investigation of the effects of cell size and spacing in braille: with some possible implications for the newly-blind adult learner. The New Beacon. 1986; 829:133-5.

17. Barlow-Brown F, Barker C, Harris M. Size and modality effects in Braille learning: Implications for the blind child from pre-reading sighted children. British Journal of Educational Psychology. 2019; 89(1):165-76.

18. Bernbaum M, Albert SG, McGarry JD. Diabetic neuropathy and braille ability. Archives of Neruology. 1989; 46:1179-81.

19. Harley RK, Pichert JW, Morrison M. Braille instruction for blind diabetic adults with decreased tactile sensitivity. Journal of Visual Impairment & Blindness. 1985; 79(1):12-7.

20. Millar S. Perceptual and task factors in fluent braille. Perception. 1987; 16:521-36.

21. Martiniello N, Wittich W. The perception and use of technology within braille instruction: A preliminary study of braille teaching professionals. British Journal of Visual Impairment. 2018; 36(3):195-206.

22. Vandenbroucke JP. In defense of case reports and case series. Annals of Internal Medicine. 2001; 134(4):330-4.

23. Creswell JW. Qualitative Inquiry and Research Design: Choosing among Five Approaches. London: Sage Publications; 2007.

24. Carey TS, Boden SD. A Critical Guide to Case Series Reports. Spine. 2003; 28(15):1631-4.

25. World Medical Association. Declaration of Helsinki: ethical principles for medical research involving human subjects. Journal of the American Medical Association. 2013; 310(20):2191-4.

26. World Health Organization. The ICD-10 classification of mental and behavioural disorders: diagnostic criteria for research: World Health Organization; 1993.

27. Wittich W, Phillips N, Nasreddine ZS, Chertkow H. Sensitivity and specificity of the Montreal Cognitive Assessment modified for individuals who are visually impaired. Journal of Visual Impairment & Blindness. 2010; 104(6):360.

28. Julayanont P, Nasreddine ZS. Montreal Cognitive Assessment (MoCA): concept and clinical review. Cognitive screening instruments: Springer; 2017. p. 139-95.

29. Bruns P, Camargo CJ, Campanella H, Esteve J, Dinse HR, Röder B. Tactile acuity charts: a reliable measure of spatial acuity. PloS One. 2014; 9(2):e87384.

30. Oshima K, Arai T, Ichihara S, Nakano Y. Tactile sensitivity and braille reading in people with early blindness and late blindness. Journal of Visual Impairment & Blindness. 2014; 108(2):122-31.

31. Legge GE, Granquist C, Lubet A, Gage R, Xiong YZ. Preserved tactile acuity in older pianists. Atten Percept Psychophys. 2019; 81(8):2619-25.

32. Cryer H, Home S. Final report: Feasibility of developing a diagnostic touch test to determine braille reading potential. United Kingdom: RNIB Centre for Accessible Information; 2011.

33. Greenwald AG. Within-subjects designs: To use or not to use? Psychological Bulletin. 1976; 83(2):314.

34. Hall AD, Newman SE. Braille learning: Relative importance of seven variables. Applied Cognitive Psychology. 1987; 1:133-41.

35. Nolan CY, Kederis JC. Perceptual Factors in Braille Word Recognition (Research Series No. 20). New York: American Foundation for the Blind; 1969.

36. Rodrigues M, Carter F. Celebrating Braille - UEB - A Canadian Approach. Toronto: CNIB; 2013.

37. Knowles MS, Holton EF, Swanson RA. The adult learner : the definitive classic in adult education and human resource development. 2015.

38. Huebner KM. Daily uses of braille as told by 4 adult braille users. Journal of Visual Impairment & Blindness. 1989; 83:308-9.

Chapter 6 – Global discussion and conclusion

6.1. A portrait of the adult braille learner: interlinking elements

This thesis presents the first comprehensive portrait of the adult braille learning process, the multifaceted and overlapping factors which bare upon this process, and outlines a roadmap to guide future priorities in this domain. Each study explored fundamental questions on braille, adulthood and aging that had not yet been examined, while also serving to inform the methodological and thematic focus of subsequent studies. The scoping review in Chapter 2 provides evidence that, although the field of adult braille rehabilitation has been in existence since the early 20th century,[1] very little empirical research on the factors which influence braille reading performance across the adult age spectrum has been conducted. The question of whether aging might influence braille reading outcomes stems from the print reading domain, where a vast body of research has delineated the ways in which sensory and cognitive declines, owing in part to the intertwined nature of these processes, may impede print reading rate and comprehension.[2] While tactile, motor and cognitive capacities are known to decline with age,[3] prior research on the relationship between these measures and braille reading performance is scant and marred with inconsistencies. The scoping review revealed that the passive two-point test,[4] grating orientation test,[5] and active acuity Legge charts[6] emerged as the most commonly used instruments to measure tactile acuity; however, these were each only employed in a maximum of three studies respectively, with some, but not all, finding a relationship to braille reading performance. Similarly, while a vast body of work has confirmed the advantage of two-handed reading,[7-16] the scoping review also revealed a lack of emphasis on the potential role of fine-motor and working-memory declines. Finally, these capacities have for the most part been examined within the context of young readers, rather than explicitly probing the influence of chronological age or braille learning age beyond childhood. Learning braille at the age of 16 is both practically and physiologically distinct from learning braille at the age of 40 or 60, owing to the added component of age-related degeneration and lived experience (as illustrated in the chapters of this thesis). This is not taken into account in studies which examine braille readers who are still benefiting from the cross-modal plasticity characteristic of childhood development.[17]

The cross-sectional correlation study in Chapter 4 thus added to this previous body of research by replicating the use of the identified instruments and incorporating measures of fine-motor dexterity and working-memory.[18,19] Addressing the limitations identified in the scoping review, the cross-sectional correlation study also directly explored the effect of age-related declines on the underlying capacities recruited during braille reading, widened the scope of participants (23 to 88 years of age) and considered the contribution of braille learning and reading history which had often been previously overlooked.

The 36 articles in the scoping review had focused entirely on hard copy, embossed braille-reading performance. The proliferation of lower cost braille displays in recent years[20] introduces new possibilities for older braille learners, both because they significantly widen the scope of motivating reading materials available to adults and because they incorporate dots of slightly greater density and height than that of traditional paper braille.[21-24] There existed some evidence that younger, experienced braille readers can perceive braille dots of differing heights without significant difficulty,[25] but the influence of dot height variability had not been explored within the context of older adult braille learners with reduced tactile sensitivity. The cross-sectional correlation study addressed this gap by considering the additional influence of reading medium, but the findings from the qualitative study in Chapter 3 also contributed to this decision. The adult braille learners interviewed in the qualitative study placed great emphasis on the lack of funding regimes for working-age and older adult braille clients and the cost of braille devices which many of them felt would have been helpful in the context of learning. Several also touched on the perceived benefit of crisper dot height and expanded practice reading materials.

The cross-sectional correlation study found that active tactile acuity, frequency of braille usage and braille learning age emerged as significant correlates of braille reading speed, but no difference in reading speed based on reading medium was observed. Of note, tactile sensitivity, the capacity that appears to decline most with age among all those measured, was also the only underlying capacity to be significantly related to braille reading performance. Importantly, frequency of braille usage influenced braille reading speed irrespective of the age at which braille was learned. Thus, older adults who used braille more often achieved greater reading rates than age-matched participants who used it less often. Psychophysical studies have illuminated the ways in which intensive tactile exposure improves cortical magnification and thus enhances tactile acuity. For example, intensive trials of passive tactile acuity using the Grating Orientation Task have been shown to improve thresholds by approximately 20% (see Figure 2 in Wong[26]). Pascual et al.[27] likewise found that cortical magnification of the reading fingers decreased in experienced braille readers after several days of rest, but expanded after a full day of intensive braille reading. This heightens the cortical implications of frequent braille usage, which, as the studies in this thesis suggest, is of even greater importance for older braille learners who begin with diminished tactile acuity. The importance of frequent braille usage in the cross-sectional correlation study is especially telling, given that the adult braille learners from the qualitative study in Chapter 3 overwhelmingly indicated that there were few opportunities to practice braille between sessions and once training concluded.

The relevance of tactile acuity (as emphasized in the cross-sectional correlation study) along with the potential benefit of braille displays (as described in the qualitative study) thus led to the question of whether the increased dot height of braille displays could enhance performance for older adults with reduced tactile acuity. Though no differences based on reading medium emerged among the mostly experienced braille users in the correlation study, the final case series study in Chapter 5 found that the use of braille displays contributed to increased accuracy and speed among older adult learners who were previously naive to braille, and thus might function as an effective supplement to traditional paper based methods.

Finally, while most of the studies in this thesis explored the role of physiological and cognitive capacities and the influence of reading medium, the qualitative study in Chapter 3 underscores that there are a variety of personal, social and institutional factors that may influence training outcomes far more than the capacities that older clients possess. This contradicts the misconception that age will primarily impede learning outcomes among older populations, a misconception that the adult braille learners from the qualitative study felt that even some clinicians advanced.

6.2. Reading is a complex, dynamic process

At the broadest level, the interlinked studies of this thesis paint a portrait of adulthood braille reading as a complex and dynamic process. It is complex in that, like print reading, it draws on many underlying capacities that cannot be neatly separated or examined in isolation, despite the tendency for researchers to do this in previous investigations on braille and aging. While measured tactile acuity emerged as especially important, the hand reading patterns used were also critical. Even lifelong braille readers with low tactile acuity thresholds exhibited reduced reading rates if they were taught to engage in one-handed reading, especially when compared to those who used the more advanced two-handed scissors technique. However, as evidenced by the participants in both the qualitative and correlation studies, adult braille readers also bring with them a life time of perceptions, prior learning experiences, diverse reading habits, internalized feelings about themselves, their blindness and their ability to learn, and a host of external and often invisible influential forces, including the perceptions of those around them. In essence, adult braille learners are more than the hands, sensory receptors and brains they bring with them or their measured capacities on these underlying functions, and studies which reduce braille reading to any one of these variables alone will necessarily remain incomplete. While it is clear that tactile sensitivity is key and must be better supported, it is of note that even those with poor tactile acuity and reading speeds still reported using braille for functional tasks (such as the reading of elevator buttons). This accents the role of motivation and the integration of practical applications for what is learned.

Moreover, braille reading is dynamic because learning ability may fluctuate and depend upon the interaction of all these overlapping components. If an adult client exhibits good tactile acuity thresholds but is reluctant to use braille in public due to deep-rooted stigma that they or those around them possess, or if they experience significant drops in motivation during training or after it concludes due to unaddressed difficulties or the lack of practice opportunities, they may nonetheless exhibit impaired performance or abandon braille altogether, despite its potential to address their expressed needs. The outcomes of adult braille learners thus depend heavily on the amount and quality of services provided, and on a host of factors that are neither visible nor present within the training room. While both the age of prospective braille learners and the physical attributes of the braille code itself have led some clinicians, prospective clients, and members of the general public to conclude that braille might be too difficult for older individuals to learn,[28] these findings support the argument that this is often too simplistic a view. Examining the individual pieces that contribute to the overall portrait of the adult braille learner in this thesis thus raises a vital question that warrants further attention in future research: Are current adult braille rehabilitation services adequate to support adult braille learners and the components which this thesis highlights as critical to successful braille use later in life? Given the need to work towards evidence-based recommendations in braille, adulthood and aging, the following sections will discuss the implications of several key themes for future practice, policy and research.

6.3. Implications for practice

There are a number of implications for practice that immediately emerge from the findings and which have already been discussed in separate chapters. To expand on their practical significance, key statements about factors which facilitate adult braille learning are summarized in Appendix E, along with a reference to the chapters that provide evidence for each statement, and a resulting practice recommendation for each finding. The following sections will expand upon how findings related to tactile acuity can be used to inform both assessment and training interventions, and the clinical implications of the interaction between sensory and cognitive processes when intervening with older braille clients.

6.3.1. Objective measures of tactile acuity as a predictor of current or future braille reading ability

The introductory chapter of this thesis indicated that researchers and practitioners have questioned whether tests which measure capacities vital for braille reading could be used to predict current or future braille reading ability, or as part of remedial activities to enhance the underlying skills needed for efficient braille reading.[29,30] This is of particular interest for those who intervene with older adult braille clients, given that these individuals will exhibit different degrees of age-related declines that should be understood within the context of the initial braille assessment.[3,31]

In both the correlation and case series studies, active tactile acuity was found to be related to braille reading performance, suggesting that such measures might be partially useful for clinical purposes within the adult braille context. In the seminal study on the Dot Chart by Legge,[6] all participants had an active tactile acuity of 1.5mm or better. The range of active tactile acuities in the correlation study (Chapter 4) was 1.14 to 2.55 mm, with one participant having a threshold above 2.28mm (the centre-to-centre dot spacing in a braille cell), and 10 having thresholds above the *worst* acuity reported in Legge. This may explain why a statistically significant relationship between Legge Dot Acuity and reading speed was found in the correlation study but not by Legge in his examination, as a similar pattern emerges in print readers. As explained by Bailey et al.[32], for sighted or low vision readers, the "critical print size" is the font size that marks the demarcation point between easy and effortful reading, and is the smallest print size that allows for the fastest reading. For a given reader, smaller fonts (that approach the individual's limit of resolution) will be read more slowly and with less accuracy, but increasing the size of the text beyond the "critical print size" will not result in any further gains in speed (and at very large font sizes, speed may actually decrease). Thus, for readers whose tactile acuity measures below 2.28mm, the standard dot spacing in a braille cell, variability in reading performance may be attributable to factors other than tactile acuity. It is therefore possible that the Legge Dot Chart may be informative regarding potential reading performance only when acuities approach or exceed the 2.28mm threshold.

The studies in this thesis do not provide an indication of the minimum acuity threshold that is needed to read standard braille. Future research with participants that exhibit a wider range of acuities is needed to explore this question in greater depth. However, it is clear that a significant difference in reading speed is observable between the participants with the best and worst acuity in the correlation sample. It can thus be argued that objective measures of tactile acuity should be interpreted as similar to those of visual acuity which are collected as part of the standard provision of low vision reading rehabilitation services.[33] It is of note that low vision rehabilitation begins by collecting objective data about residual vision (near and distance acuity, visual fields, contrast sensitivity) to be considered alongside information gathered through intake interviews and other assessments, for the planning of targeted services and the provision of optical devices.[34] There are, on the other hand, no objective measures of tactile acuity routinely collected as part of the initial adult braille assessment process (although the most recent revision of *Foundations of Vision Rehabilitation Therapy* does reference the need to explore the use of tactile acuity charts as potential clinical diagnostic tools[30]).

The greater emphasis afforded to objective acuity measures within low vision can be understood as primarily resulting from the practical distinction between low vision and braille reading rehabilitation, in that information about acuity is arguably only of limited use in the provision of adult braille rehabilitation services. Unlike vision, there are no immediate methods for improving the performance of tactile receptors.[35] There is no equivalent to the eye glass, magnifier or binocular to immediately enhance the level of tactile perception that a client initially exhibits. As illustrated in the studies of this thesis, the sole method for enhancing tactile sensitivity is through frequent usage and practice, with the potential additional benefit of braille display usage to supplement embossed standard braille.

Given the evident importance of tactile sensitivity, collecting objective measures of tactile acuity as part of the initial braille assessment would nonetheless strengthen clinical decision making in several key ways, if interpreted within a broader context. The use of the Legge Dot Chart may provide a baseline for understanding where a prospective learner's tactile acuity initially falls prior to braille training, and whether difficulties with tactile perception may be expected if the threshold is far above the 2.28 mm line. These contextual data can provide rehabilitation practitioners with an objective reference point to justify (to management and funding agencies) the provision of a more extensive prebraille program to target the development of tactile perceptual efficiency prior to formal braille instruction and the need for more concentrated practice (more time) to supplement the interventions incorporated within a standard adult braille curriculum. Indeed, in a context where contemporary vision rehabilitation services are often restricted by heavy caseloads, bureaucracy and limited funding, objective data to bolster the need for additional time and resources is often vital, but historically not always available within adult braille instruction.[36] Second, the case series study raises the potential benefit of braille devices for clients with reduced tactile sensitivity. Objective data about tactile acuity may thus also serve to justify the purchase of braille devices early in the training process, as a supplement to traditional methods, to alleviate reading difficulties owing to impaired perception even when such devices may not otherwise be attributable.[37]

Third, for older adults of more advanced age, such objective measures might help to determine whether a transition to jumbo braille might be more appropriate, if progress is not ultimately observable during standard braille training. However, Given the perceived stigma towards braille and aging described in this thesis, there is a risk that baseline tactile acuity measures might be used as a justification to avoid standard braille instruction without consideration, or to abandon the decision to recommend braille training at all. There is evidence that even adults with poor tactile acuity are able to successfully learn and use the braille alphabet for functional literacy purposes, both in this thesis and based on prior practitioner observations.[30] Moreover, for adults with vision loss who were previously sighted, tactile skills will be latent and under-developed.[38] It is thus reasonable to expect that most older learners with acquired vision loss will initially struggle and exhibit poorer tactile perception until adequate practice and skill is acquired.[39] Initial measures of tactile acuity would therefore not take into account the later effects of such sensory-perceptual learning. Caution is therefore needed to ensure that such decisions are not made prematurely.

Finally, though performance on the cognitive measure examined in this thesis (tactile working-memory) did not correlate with braille reading outcomes, practitioners should bear in mind that this does not imply that working-memory is not important to braille reading or that cognitive functions do not play a vital role during the adult braille learning process.[40] As will be elaborated on below, the reduced tactile sensitivity exhibited by some older adults may increase cognitive load during braille reading and place greater stress on working-memory even if, when isolated, working-memory is not abnormally impaired. Given the association between sensory and mild cognitive impairment[41], objective measures of tactile acuity can thus serve to help tease out whether difficulties encountered during braille learning, particularly for older adults, are due simply to abnormally high tactile thresholds or whether other cognitive factors may be at play. Objective tactile acuity thus can enable the practitioner to compare a client's individual threshold to what is typically expected for someone within that age range, and such data can be used to individualize a targeted braille training program.

6.3.2 Clinical implications of the distinction between objective and functional touch

Beyond providing objective measures as a baseline for the reasons outlined above, the findings of this thesis suggest that tactile acuity charts should be used with caution, and that over-reliance on the scores from such charts can lead to misinterpretation. While the correlation study suggests a relationship between objective tactile acuity and braille reading ability, the case series study nuances this by suggesting that objective tactile acuity measures are only partially informative. Three of the participants in the case series study, all older adults in the 6th and 7th decade of life, had active tactile acuity thresholds at or beyond the 2.28 mm threshold (2.280mm, 2.2954mm, and 4.055mm). These individuals were substantially slower readers than those who had a threshold below 2.28mm (by a factor of almost one-half), although these differences were generally less pronounced in the braille display condition. All of the participants in the case series, even those with acuities of over 4mm, demonstrated reasonable accuracy on both the paper and braille display conditions. Likewise, even the vast majority of participants in the correlation study who achieved a reading rate of 50 WPM or less reported that they used braille effectively for functional tasks, such as reading phone numbers (72%), household labels (82%), and elevator buttons (96%). In a study by Harley,[42] blind diabetics with high thresholds likewise exhibited the ability to read braille, though the authors did not define reading ability beyond a dichotomous can/cannot read categorization. Consequently, while clients with poorer tactile acuity thresholds will achieve slower reading rates on standardized reading passages and will benefit most from specific provisions (such as braille display usage or targeted training strategies), this does not imply that they will be unable to read braille to meet their individualized needs.

For these reasons, this thesis demonstrates that a future distinction must be made between objective and functional definitions of touch, much like that which exists between objective and functional vision in the context of low vision reading rehabilitation.[43] The low vision assessment consists of an evaluation of visual function (the performance of the ocular system, obtained through tests of acuity, fields, contrast, etc.) and functional vision (visual-task performance, obtained by evaluating the ability to visually function while completing activities of daily living).[43] Central to the distinction between objective and functional vision is that two clients with an identical objective visual profile (the same visual diagnosis, acuities and fields) may in actuality display very different functional capacities.[44] For example, while central scotomas will distort fine vision and impair visual reading ability, some clients will unconsciously find their preferred retinal locus even though eccentric training has not been provided,[45] and exhibit apparently better functional performance than others with a similar clinical presentation. Similarly, some clients with peripheral vision loss naturally compensate by turning the head while navigating and may experience fewer falls or collisions than those who do not.[33,46]

Beyond these compensatory strategies, low vision therapists underscore the need to measure visual ability under real-world scenarios to determine the extent to which clients are able to functionally use their vision for ecologically valid tasks.[47,48] Collectively, objective information about vision obtained through eye exams alongside functional visual assessments provide a more comprehensive portrait of visual ability, drawing a distinction between diagnosed impairment and functional ability as advanced by the International Classification of Functioning.[49] This distinction acknowledges that visual performance may depend upon intrinsic factors (e.g. fatigue) and extrinsic factors (environmental conditions, time of day) as well as task (identifying the correct can in the kitchen is not akin to reading a continuous narrative passage). The predictive validity of objective measures of vision in real-world scenarios is thus limited.[50] In sum, while objective visual measures are necessary for confirming eligibility for various supports and for providing a baseline, they do not necessarily provide a comprehensive description of functional vision.

It is arguable that a similar phenomenon exists for active touch acuity, in that while a relationship between objective tactile acuity and braille reading appears to exist, practitioners must understand this within a broader context of function. Aging is associated with a significant decrease in the concentration of Meissner corpuscles.[51] These peripheral touch receptors are critical for active touch activities such as reading braille, given that they are explicitly stimulated through motion vibration.[35] Older adults with reduced tactile perception due to the deterioration of these transducers may perform poorly on baseline measures of active tactile acuity, especially if they additionally employ inefficient movements. The properties of active touch are such that greater control is afforded to the individual to employ compensatory strategies and to effectively interact with a stimulus, behaviours which become more sophisticated through experience (trial and error) and sensory-perceptual learning.[52] The adoption of compensatory strategies may significantly improve performance. For example, studies on haptic touch describe the ways in which individuals may unconsciously learn to use different parts of the finger to maximize tactile ability, not altogether unlike the compensatory strategy of eccentric viewing.[53] In the context of braille, practitioners have noted that older clients may adopt similar strategies to facilitate perception, such as directing touch to more sensitive parts of the finger, exploring the use of multiple fingers, and learning to perceive braille through the coordinated use of fingers and hands.[30,54] Similarly, individuals with no prior braille training may exhibit a tendency to use forceful touch to facilitate perception when, in actuality, more experienced braille users come to recognize that a light touch is most effective.[55] Moreover, touch performance is especially vulnerable to factors such as cold temperature, particularly for those who are not already proficient touch users.[56]

The importance afforded to frequent braille usage in this thesis should serve as a reminder that objective measures of tactile acuity will only provide a clinical data point for current tactile ability in the prospective adult braille user, when tactile perception (and braille reading ability generally) will necessarily improve with practice. While it is important to collect data on objective measures of tactile accuracy and speed, and to maximize the enhancement of these skills throughout training, such measures may not always reflect the efficacy of braille usage in functional daily activities.

This distinction between objective and functional touch has not been acknowledged in previous studies which have explored the relationship between tactile perception and adult braille reading performance. For example, Stevens measured passive acuity in a sample of braille readers and found a relationship between two-point threshold and braille reading speed.[4] This relationship is likely due to the fact that braille readers, and the blind in general, have better tactile perception skills flowing from their increased tactile experience.[57] Such measures do not describe the added influence of factors such as learned haptic strategies and motivation, nor does it consider that reading rate may not always function as the most pertinent operational definition of efficient braille reading performance for all clients. While reading rate is an important metric, studies from print reading also illustrate that drastically increasing reading speed through targeted training may inadvertently lead to reduced retention and comprehension.[58] Ultimately, the functional role of touch and of braille more generally must be considered within assessment.

6.3.3. Sensory-cognitive interactions: isolating the role of touch

One of the significant limitations of previous research on braille and aging is that capacities have been examined in isolation. Thus, while passive acuity may emerge as a correlate of braille reading performance in one study, it is impossible to know what other factors may influence performance on this specific tactile measure, or on braille reading outcomes more generally. There is thus the potential of wrongly assuming from isolated studies that performance in a single domain can be used to predict current or future braille reading ability. In the introductory chapter of this thesis, two hypotheses were presented to explain the interwoven nature of sensory-cognitive processes, and while both are accurate descriptions of sensory-cognitive degeneration, they arguably carry different implications for the design of interventions.

The *scarce resource allocation* hypothesis[59] suggests that the degradation of sensory perception (such as declines in vision or touch) will impede the ability to perceive a stimulus. If, for instance, an older adult with reduced vision has more difficulty seeing what they are reading, they must allocate greater cognitive resources to perceiving what is being read, thereby limiting the cognitive resources available for information processing. As a result, retention and comprehension measures may be compromised not because of any active *cognitive* impairment, but because so much effort has instead been devoted to perceiving the sensory input. This may be even more true for older adults who engage in unfamiliar activities that require the coordination of multiple sensorimotor-cognitive domains that decline with age.[60] For these reasons, clinicians underscore the importance of adapting reading and more global cognitive assessments to accommodate for sensory impairment (for example, providing large print or reading the questions aloud, as in the Montreal Cognitive Assessment (Blind).[41]

Alternatively, the *common cause* hypothesis suggests that changes in sensory abilities (the ability to acquire and perceive information from the five senses) and cognitive functioning (the ability to *process this sensory input)* are two symptoms of a more global deterioration in gray and white matter integrity, caused by cognitive aging which slows both perceptual and processing abilities.[59,61] Given that age-related changes operate across functional boundaries (sensory, motor, cognitive), they inherently impact more than one domain,[62] and may properly be termed a common cause. However, studies which have attempted to examine this question regarding the link between visual and cognitive impairments have been unable to provide strong evidence for the operation of this common cause phenomenon,[60] in part because they have been largely correlational examinations.[63]

While neither theory is likely all-encompassing, the results from the present thesis are especially illustrative of the scarce resource allocation hypothesis. In Chapter 4, decreased tactile acuity was the only variable significantly associated with increasing age, and tactile acuity also emerged as the only capacity significantly correlated with braille reading speed. The slight decreases in performance in other measures (including cognitive and motor measures) were not significantly correlated with braille reading performance. This does not mean that significant cognitive declines would not influence braille reading performance among older adults; however, when examined separately, it is tactile perception that deteriorates more significantly and rapidly with normal aging. This is consistent with studies that have explored tactile perception in both the blind and sighted, and that have demonstrated gradual declines in tactile sensitivity throughout the life span,[64-66] while more significant cognitive declines appear at advanced age.[67]

There is empirical evidence that, in print readers, poorer visual perception requires the reader to devote greater attention to perceiving what is being read, which results in a decrease in processing capabilities. For example, Bertone and colleagues[68] demonstrated that even a slight simulated visual impairment (blurring of vision to the 20/40 level) has been found to reduce performance on nonverbal cognitive tests even among young, healthy, highly educated individuals. Dickinson and Rabbit[69] likewise found that while younger adults could read passages aloud as well under simulated visual impairment conditions as when not impaired, their ability to recall details from the passages was significantly degraded under the visual impairment condition. For older adult braille learners, the combined variables of reduced tactile perception, the need to immediately recall newly learned symbols and the sequential nature of braille reading may likewise increase cognitive load. In the correlation study, neither measures of cognitive capacity nor motor function were found to be significantly related to braille reading speed (see Table 14). The decreased performance among participants therefore appears to be primarily attributable to decreased sensory input and not cognitive ability alone.

From a clinical perspective, the practice implication of this is that improving sensory input (tactile perception) should reduce cognitive load and in turn improve braille reading performance. The studies in this thesis hone in on two methods for enhancing tactile sensory input, and by extension, braille reading outcomes: frequent usage (practice) and the use of compensatory tools (such as braille devices which may enhance readability for some individuals). A failure to address the role of sensory input may wrongly lead to the assumption that cognitive impairments are mediating performance outcomes, or that aging overall is of primary concern.

While this provides some initial direction for where practitioners should concentrate their efforts, it is important to note that the participants in Chapter 4 ranged between the ages of 23 and 88, with only 14 above the age of 60 (see Table 12). None of the participants failed the MOCA-B test (they were unlikely to be at risk for mild cognitive impairment[41]), thus it remains unknown how mild cognitive impairment might influence the braille reading outcomes of older adults who pursue braille training. The *common cause* hypothesis may have more validity with older individuals in the 8th and 9th decade of life, who exhibit more significant simultaneous declines in tactile, motor, and cognitive functioning. However, it seems reasonable to assume that the degree to which cognitive impairment will affect braille reading will depend on the severity of cognitive impairment, and the reasons for which braille is being used (e.g. functional vs more complex reading tasks). Even many children with combined visual and cognitive impairments (such as those with cortical visual impairment) demonstrate the use of print or braille for functional literacy tasks.[70] Given the possible interplay between diminished sensory input and cognitive load, it is clear that enhancing tactile perception through frequent braille instruction is key. However, consideration of the sensory-cognitive interaction also raises the value of incorporating evidence-based strategies which reduce cognitive load for older adult braille learners who exhibit diminished tactile sensitivity. The practical implications of this will be discussed next.

6.3.4. Training tactile perception

Tactile sensitivity, frequency of braille usage and braille learning age were significant correlates of braille reading speed in the correlation study. Additionally, these variables were highlighted as barriers to learning and as weaknesses of current adult braille training paradigms by the adult braille learners in the qualitative study. Participants spoke of delays to the start of braille training due in part to the lack of access to services, and many expressed a lack of resources to develop and maintain braille skills once training commenced. An evident clinical implication is therefore the need for greater support and practice throughout training and once formal instruction concludes.

The question of how to increase support is one that partially requires broader policy change (as will be discussed in later sections). However, at the practitioner level, the knowledge gained from andragogical learning theory serves as a vital guide.[71] Adult learning is shown to be more conducive when the learner is mutually responsible for defining goals, planning activities and evaluating their progress.[72] This is of even greater importance in the context of rehabilitation after vision loss, where clients (as expressed by the adult learners from the qualitative study) are experiencing significant life changes which can feel disorienting and disempowering.[73] Careful attention at the initial assessment stage should be afforded to discussing with adult clients how braille can be immediately applied to improve independence and to gather information about interests to incorporate throughout sessions. For example, though discussed in the context of children, Wormsley[74] suggests completion of a reading inventory assessment to collect information about motivating reading topics. As part of the planning process, resources to supplement and support training, such as access to peer-support groups, accessible libraries and information about where and how to purchase braille household items should be provided.[75]

A shortcoming of vision rehabilitation generally is that, unlike blind children who ideally have more structured opportunities to apply braille skills throughout the school day, adult rehabilitation training customarily occurs during a single weekly session, if not less.[76] This time constraint is partially a symptom of a persistent resource problem at the organizational level (few qualified professionals with heavy case loads[77]), but is also emblematic of the adult learning context generally.[78] For example, Walsh[79] highlighted the challenges in scheduling a 22-month teacher preparation course for a group of adult learners who had to balance work, childcare and other responsibilities, often needing to prioritize these obligations above the course. The adult braille learners in the qualitative study of Chapter 3 noted similar restrictions, which in the case of vision rehabilitation, are often compounded by transportation and other barriers which limit the quantity and duration of in-person sessions.[80] These time constraints and external obligations may also pose additional stress during the adult learning process which may adversely effect the ability to learn.[81] It is therefore incumbent upon the practitioner to incorporate strategies and resources to supplement traditional sessions.

While the lack of recurrent training sessions may be less problematic for specific domains of adult learning, and even some spheres of vision rehabilitation, this poses a significant barrier for advancing in adult braille rehabilitation. This is because braille learning consists of more than merely skill-based learning (how to do something). It is at its core the learning of a new code, and like other examples of perceptual learning, requires repetition and active engagement to exercise the tactile sense and to build rapid recall of symbols. Braille is not a language, though much like learning a language, it requires immersion to achieve fluency.[82] Clients who do not use an assistive device (such as a book reader) between weekly sessions may need to review specific functions. Clients who routinely do not practice braille between sessions, particularly those of more advanced age who do not have a lifetime of tactile experience to draw upon, will likely regress on gains made in tactile perception.

Research on childhood braille literacy instruction highlights the role of early opportunities to develop tactile skills as a predictor of later braille reading ability.[83] It should logically follow that a similar level of pre-braille exposure is crucial to braille learning in adulthood, particularly when age-related declines may pose an additional disadvantage. Yet, despite the relationship between measured tactile sensitivity and braille reading in the correlation study, several of the adult braille learners from the qualitative study (Chapter 3) noted that this prebraille training was not provided. One approach that may be considered is Mangold's *Basic Braille* Program, an evidence-based program regularly used with children to train tactile perception and basic braille letter recognition through carefully sequenced activities designed to teach proper hand movements and tactile recognition.[84] In her seminal study, Mangold found that 90% of the beginning and remedial readers benefited from this hierarchical approach to developing tactile perception prior to the commencement of formal braille reading instruction.[85] Alternatively, the *Individualized Meaning-centered Approach to Braille Literacy Education* (I-M-ABLE) has been shown to effectively facilitate tactile development and braille learning for children who do not benefit from traditional approaches.[86] The program hones in on words that are immediately meaningful to the learner, to increase motivation and recognition.[87] Studies on the I-M-ABLE method provide evidence that careful consideration of key words and phrases used during training can contribute to more rapid progression in braille recognition skills for learners who struggle due to cognitive impairment or diminished perception.[88] Although both programs have traditionally been discussed in the context of childhood learning, it is evident that these approaches would carry similar benefits for the development of tactile perception among adult braille clients.

Research on sensory-perceptual training demonstrates that learning stimulates cortical plasticity and performance gains even among older adults;[89] however, consideration of how to reduce cognitive load by maximizing domains that are known to remain intact with aging will often facilitate training outcomes. For example, drawing on crystallized intelligence which remains intact into old age is shown to often bolster learning, by connecting new information to already-learned information.[90] in the case of braille, this may involve drawing on visual memory where braille symbols resemble print letters or using other deep-rooted memories and associations to facilitate the learning of symbols. Indeed, such tactics were highlighted as beneficial by several of the participants in Chapter 3. Moreover, both Anderson[91] and Beauchamp[92] found that repetition alone does not lead to improvements in perceptual-cognitive task performance among older individuals. Quite apart from other limitations, this is one reason why intense trials of passive acuity would arguably not facilitate adult braille learning. Even if passive acuity thresholds were found to be related to braille reading performance (which they were not in the present thesis), improving the ability to accurately identify a stimulus that is applied to the stationary finger will not instill in older learners the appropriate hand movements or resemble real-world applications of braille, thus reducing motivation and transferability. Likewise, the inefficiency of repetitive learning, especially as delineated in most andragogical theories, likely explains why many adult braille learners (as evidenced in Chapter 3) prefer the use of varied hands-on training activities rather than longer sessions of sustained reading.

Finally, Faubert and Overbury[93] have previously demonstrated the benefits of active perceptual learning and breaking sensorimotor task into its component parts. They proposed a CCTV training regime whereby participants would first learn the motor skills to manipulate the X/Y table by actively tracking and tracing figures on the screen without initially being required to read or comprehend textual material. Such examples support the benefits of prebraille instruction to develop tactile perception while incorporating activities which stimulate active perceptual engagement (such as differentiating among different braille symbols) prior to formal braille reading instruction. If the task is initially too difficult for a particular learner, or involves multi-tasking and therefore an increased cognitive load, a graduated approach to training wherein certain skills are taught individually before being combined is shown to be beneficial in other domains.[94,95] Such examples support the preliminary findings of the case series in Chapter 5 and the use of braille displays (with their more pronounced dots) to supplement paper braille, which enables the older learner to focus on the overall shape of the letter while reducing initial difficulties in tactile perception.

6.4 Policy implications

There are evident benefits to earlier braille learning age, more frequent braille usage and access to braille devices to both expand reading materials and support those with reduced tactile sensitivity, as demonstrated across the studies in this thesis. Despite the importance of these factors, three common refrains emanating from the qualitative study were that adult braille clients experienced significant difficulties securing access to services, electronic braille displays and relevant reading materials. At least three policy-induced barriers exist that limit access to all three of these resources. At the broadest level, access to training and assistive device funding is severely limited by current resource constraints and inadequate professional capacities. Second, even where training is available, conditions for entitlement to services or to funding for assistive technologies do not appropriately account for the unique needs of those with a progressive or fluctuating condition. Finally, program-level directives as to what tools are available fail to recognize the continuum of varying needs that an individual adult client may have.

A component of the challenge for funders and policymakers is that technology is evolving at an ever-increasing pace and rapid change inherently challenges regulatory institutions.[96] Ten years ago, there were no low cost braille displays on the market, nor were consumer devices such as smartphones and tablets (that can provide access through a braille display) so commonplace. New and experienced braille users alike are now using electronic braille for tasks that, only a few years ago, were not possible. Repositories such as the Centre for Equitable Library Access (CELA) and Bookshare now make eBraille books available for direct download, in place of producing and shipping paper braille volumes.[75,97] However, for adult braille clients to take advantage of these advances in access to information, they must have access to training and the technology needed to benefit from it. It is evident from the barriers raised among the findings in this thesis that regulations are still often structured around young braille students and must evolve to account for an aging demographic.

6.4.1. Adequacy and availability of braille rehabilitation services and funding programs

Given the central role afforded to frequency of braille usage, failure to progress in adult braille rehabilitation may in actuality result from a lack of adequate services or a restriction in the amount of services that are provided. Indeed, although focused on children, Peanava[98] reported a statistically significant relationship between the length of a braille program and the degree to which braille is used within activities of daily living. Canada's universal health care system is limited in its coverage of vision-related rehabilitation care. The provision of braille rehabilitation and associated funding of assistive technologies does not squarely fall within the mandate of either the federal or provincial health care systems. With health care falling under the responsibility of individual provinces, there are significant inequalities across jurisdictions with respect to the provision of vision rehabilitation services.[99] Even where programs exist that may be of benefit to prospective clients, there is evidence that navigating the tangled web of governmental, not-for-profit, and charitable organizations can be time-consuming, require a significant amount of self-advocacy and a level of persistence that an individual new to vision loss is unlikely to have.[100]

Only in the very recent past have governments (outside of Québec) intervened to provide any funding toward vision rehabilitation services beyond low vision assessments and certain services provided by optometrists.[101] Traditionally, the majority of the low vision and blindness rehabilitation delivered in Canada has been the result of efforts by the charitable sector, most notably the Canadian National Institute for the Blind (CNIB).[1] As a result, services are very limited outside of major urban centers,[99] and annual or bi-annual itinerant visits from a rehabilitation professional prove to be highly ineffectual for braille training. Moreover, as Leat[102] reports, the availability of funding programs to acquire assistive devices such as electronic braille displays is only currently available on a limited basis to qualified individuals in Ontario, Alberta, Saskatchewan and Québec (4 of the 10 provinces), subject to varying eligibility requirements, a limited selection of 'approved' aids, income testing, and substantial co-pays that function as barriers to access. A 2017 cross-jurisdictional review enumerating virtually all funding and access programs for assistive technology in Canada affirms the limited supports for blindness or braille-related technologies (see the appendices in Schreiber et al.[103]). Mattison, Wilson, Wong, and Waddell[104] highlight the need for the development of a pan-Canadian approach to coordinating assistive device provisioning, achievable in much the same way as *The pan-Canadian Pharmaceutical Alliance* negotiates jointly across provinces and territories to ensure core pharmaceuticals are equitably available across the country.

From a policy standpoint, this patchy approach to rehabilitation services is untenable. It is clear from the institutional barriers raised in this thesis that services and access to devices must be made available on an equitable basis to all who require them, whether through loan programs (as in Québec) or funding support for purchases (as in Ontario). Significant additional funding will be required to hire and support an increasing number of vision rehabilitation therapists to serve the growing needs of the aging population. Other healthcare professionals such as occupational therapists (of whom there are a greater number) may be able to detect the presence of vision impairment, but their education and training does not provide the foundation or skill set required to provide extensive rehabilitation services such as braille training.[105,106]

6.4.2. Ensuring that eligibility criteria are not restricted to students and those who are employed

Where access to training is assured and funding or technology loan programs have been established, further barriers often flow from the eligibility criteria that apply to receive braille rehabilitation training or access to braille technologies. Eligibility is often tied either to employment or education status, or to the specific purposes for which the technology will be used. For example, in Québec, while any person who is functionally blind can access screen reading technologies, access to braille displays is limited to those who are full-time students or who are employed/entering employment, and those who are deafblind.[107] An individual who is not in the labour force, who is not attending full-time post-secondary education, but who could benefit from access to information in braille to improve quality of life unrelated to paid employment or education, is excluded.[108,109] Likewise, Ontario's Assistive Devices Program (which for applicants not receiving social assistance will pay only 75% of the associated costs) limits eligibility for braille displays to those who "have the tactile ability to read braille" and who can demonstrate that they are "an avid braille user who uses braille for his/her every day writing needs."[110 (p. 33)] These definitions exclude those learning braille who may require the display in order to successfully complete their training, such as those who are akin to the participants in the case series study. Eligibility criteria must therefore be reviewed to ensure that they are not limited to those who have an employment or educational imperative, and that they reflect the needs of working-age and older adults who are adjusting to progressive vision loss.

6.4.3. Ensuring that eligibility criteria enable planning for future needs

In many cases, eligibility for various categories of rehabilitation services or devices is determined based on ostensibly objective clinical criteria such as visual acuity. In Ontario, for example, "Sight Substitution Devices" (including a refreshable braille display) are "devices which substitute for one's vision (for persons with no functional vision or with total blindness),"[110 (p. 9)] thereby precluding attribution to a person with low (but some functional) vision even if the condition is progressive and braille will, in time, become a necessity. Québec, on the other hand, recognizes that a transition to braille is possible and permits, at least for a limited time, attribution of braille aids secondarily to others.[107]

Eligibility for braille rehabilitation training and for the attribution of braille devices should not be strictly tied to objective measures of current performance on specific assessments. As evidenced in the findings of this thesis, benefits appear to accrue to those who are introduced to braille earlier in the vision loss process. As such, evaluations which represent the current circumstance but do not take into account expected future declines may take from adult clients a valuable opportunity to develop basic braille competencies before other age-related declines may make the task of learning braille more difficult.

6.4.4. Confronting stigma through policy review and change

Setting aside the physiological and cognitive factors which may bear upon the outcomes of adult braille clients, this thesis also draws attention to the often invisible and pervasive role of stigma. Despite the importance of other variables highlighted in subsequent chapters, the qualitative study illustrated the ways in which stigma can function as a barrier that impedes the decision to engage in the very activities that would enhance braille skills. Stigma in the context of braille appears to manifest in at least three ways, as expressed by the adult braille learners in Chapter 3. Stigma may consist of the *unconscious biases* about braille and aging that practitioners may hold, as suggested by participants who were initially dissuaded by professionals from pursuing braille training after vision loss. *Self-stigma* consists of the feelings towards braille, blindness and aging that adult braille clients carry with them, and which may deter them from pursuing braille or from adequately committing to the learning process. Finally, *public stigma* consists of the often deep-rooted perceptions that family, friends and members of the general public may hold about blindness and those symbols that are outwardly associated with blindness, and which often shape social interactions. In each case, stigma refers to the perceptions that are (sometimes consciously, but often unconsciously) attached to entire groups of individuals, including people with disabilities and older adults.[111] In most cases, stigma is perpetuated by outward signs that an individual identifies with a specific group, and as evidenced in Chapter 3, braille can function as such an outward sign. Thus feelings that practitioners, clients or the public may inadvertently associate with blindness may become superimposed onto symbols of blindness, such as braille.[73]

There is evidence that each of these categories of stigma can be at least partially addressed through some form of targeted education, given that stigma, often perpetuated through stereotypes, is shown to diminish through the acquisition of knowledge.[112] At the level of self-stigma, Chapter 3 touched on the importance of incorporating peer-support and providing adult braille clients with opportunities to interact with other adult braille users. At the public level, governmental policies that increase the visibility and availability of braille in public spaces assist in normalizing braille and by extension, blindness.[113] Policies that increase accessibility also serve to increase the visibility of people with disabilities in public spaces, providing the public with reference points for how braille may be used to perform a wide range of tasks.[114] Research on stigma affirms that lack of contact often fosters discomfort, distrust, and fear, and that contact-based interventions are among the most effective anti-stigma strategies to change public attitudes.[115] While there is undoubtedly a need to review targeted policies (such as the ways in which blindness, and more general disability stereotypes, are addressed through mainstream educational policy), such broader accessibility policies are also shown to be effective.

While broader governmental accessibility policies might at first appear to be outside the scope of direct rehabilitation practice, the evident impact of such efforts carries implications that can inform policy at the organizational level. Disability scholars question whether healthcare institutions (including rehabilitation centres) may work to unconsciously reinforce inaccurate or ableist portrayals of people with disabilities and older adults.[116] For example, fundraising efforts at the organizational level may play on common tropes to elicit pity in order to secure donations.[117] Given the increased attention devoted to accountability and allyship,[118] this raises the value for rehabilitation agencies to review their own policies, including the extent to which their messaging may work to either reinforce or dismantle perceptions about braille and blindness. Moreover, several agencies have employed specialists who focus exclusively on public education and advocacy, recognizing that this plays an important role in the experiences of the clients who are served.[119]

At the practitioner level, there is a growing body of research which explores the factors that either support or inhibit the implementation of evidence-based practices within healthcare domains, where uptake is often limited.[120] Discomfort or a reluctance to employ a specific clinical tool or recommendation is often partially associated with a clinician's perceived level of competency. For example, Bussier[121] found that clinicians' self-efficacy, self-confidence, past experience, and clinical uncertainty all influenced whether they would use an X-ray for diagnostic purposes, even though concrete guidelines exist. Ponchilia[122] likewise found that vision rehabilitation practitioners who felt more confident about their braille competencies were more likely to recommend it to adult clients. In essence, those who feel more confident about their braille skills should be less intimidated by it, less likely to believe that it will be difficult for older clients to learn, and more likely to recommend it as a tool.

While the association between perceived self-competence and clinical decision-making seems logical, ensuring that such braille competencies are maintained remains a persistent problem amidst a shortage of practitioners who face mounting caseloads.[30] However, the emphasis on stigma in Chapter 3 raises at least three policy implications that warrant future consideration. First, there is a need to review policies around professional certification and the braille competencies that vision rehabilitation therapists acquire through approved university programs.[123] This thesis points to the potential benefit of applying andragogical theory, the need to understand the implications of aging, and the use of effective strategies to support the unique profiles of older braille clients. As the knowledge-base on braille, adulthood and aging continues to expand, it will become imperative to ensure that approved university programs and professional certification standards are reviewed and revised accordingly to reflect these priorities. Rosenblum[124] conducted a survey of university braille courses in 2010, but did not explore the extent to which such courses incorporated themes that our research would suggest are vital for those intervening with working-age and older adults. Similarly, as of 2020, the core body of knowledge that vision rehabilitation therapists must possess does not include direct mention of andragogy or age-related factors within the context of braille training.[123]

Moreover, if perceived stigma is partially attributable to degree of competency, policies pertaining to re-certification and continuing education for vision rehabilitation therapists should be examined with consideration afforded to employing mechanisms to support the maintenance of braille competencies among in-service practitioners.[123] Given the existing distinction between the low vision therapist and the certified vision rehabilitation therapist/CVRT (where the latter specializes in sight substitution), and that braille skills will be diminished if not maintained,[125] it may be worthwhile to consider allocating a certain proportion of CVRT renewal credits to braille-related content. Finally, there is evidence that, although centres may hire vision rehabilitation therapists who possess the full range of certification-level competencies, organizational policies may result in specializations, such that some VRTs focus on braille and technology, while others focus more heavily on activities of daily living.[30] While this may not be feasible where resources are limited, such measures alongside these other policy considerations may serve to partially address issues related to adequate competency.

6.5. Implications for research

The scoping review in Chapter 2 highlighted that braille, adulthood and aging are themes that have received little attention in prior research. While some of the knowledge gained from research on braille-reading children is transferable to the adulthood context, there are clearly unique aspects of adulthood and aging that require further investigation. While the studies in this thesis have identified factors that appear to correlate with positive adult braille learning and reading outcomes, they also illuminate continuing pervasive gaps in knowledge.

6.5.1. The need for a comprehensive scan of current adult braille rehabilitation services

To date, little is known about the current state of adult braille rehabilitation programs; however, the barriers underscored in Chapter 3 indicate significant service gaps. With a greater understanding of the factors which correlate with braille reading outcomes throughout adulthood, a subsequent question thus relates to the extent to which such variables are embedded within current standardized practices. It remains unclear as to how clinical decisions about referrals to adult braille training are made, though under-identification and lower referral rates for working-age and older adults to braille rehabilitation services have been previously reported.[42,126] The lack of clarity about the factors which guide practice decisions is especially concerning given that the findings of this thesis emphasize that working-age and older adults exhibit age-related declines which must be considered within intervention design.[65,127] Moreover, our findings suggest that there is an evident level of perceived stigma towards braille and aging which may serve to influence the decisions of adult braille rehabilitation clinicians.

As a vital next step for advancing practice on braille and aging, an environmental scan of the current state of adult braille rehabilitation is needed to clarify current practices and to identify precisely where service gaps exist, as a precursor to the development, implementation and evaluation of evidence-based targeted solutions. Among the indicators that require further analysis in adult braille rehabilitation are the percentage of current practitioners that exist across distinct geographic locations and the extent to which this is meeting current needs; data on referral rates and procedures, average wait list times and length of service; information about current assessment, training and post-rehabilitation services provided to adult braille clients, including the use of specific instruments and protocols, and data related to success rate. It is also evident that there is a need to more closely probe the influence of practitioner perceptions and behaviours related to braille, adulthood and aging, and to illuminate the individual and organizational factors that bear upon these practice behaviours. Implementation science provides a useful reference point, demonstrating that a complex association between the knowledge, attitudes and practices of healthcare clinicians often exists, and may be further mediated by their skills in a specific domain.[120] Environmental scans have been effectively employed in other healthcare domains to objectively assess quality of care with the aim of improving practice.[128] One approach that has been successfully used in other healthcare domains is the theoretical domains framework (TDF),[129] which maps 33 psychological theories to 14 theoretical domains (e.g. knowledge, skills, social influences and beliefs about capabilities), and can guide new interventions by interpreting and predicting the clinical behaviours and causal mechanisms that are most likely to contribute to successful change.[130] Collectively, knowledge on the current state of adult braille rehabilitation practices and the factors which shape clinical beliefs and behaviours would provide a critical foundation for the development, implementation and evaluation of evidence-based interventions designed to address gaps and to meet the needs of a quickly aging demographic.

6.5.2. Further probing the development of adult braille learning paradigms

The facilitators and barriers highlighted by adult braille learners in this thesis give rise to relevant questions about the applicability of adult learning theory and praxis within the adult braille rehabilitation context. Indeed, many of the factors highlighted by participants in Chapter 3 map onto existing adult learning principles and paradigms.[72] It is noteworthy that pedagogical theory and knowledge gained from childhood development continues to empirically inform braille literacy instruction with children. For example, Steinmann[131] outlines how braille literacy instruction can be theorized, organized and understood through consideration of childhood developmental theory. No similar research currently contemplates the mapping of braille training methods alongside andragogical theory or aging and learning.

Given the growing prevalence of acquired vision loss, there have been recent calls for research on evidence-based adult braille learning strategies, and appropriate applications of adult learning theory within braille instruction.[30] For example, Colton and Hatcher[132] developed the Online Adult Learning Inventory, an instrument for measuring the degree to which adult learning principles have been applied to web-based (online learning) courses. Using a Delphi study, the authors collected information from experts in andragogy, instructional design, and web design to advise on the content and structure of the instrument, and used two rounds of refinement to link each of these practices to defined principles of andragogy. Similar research exploring the development of adult braille learning frameworks and the application of existing andragogical models would provide vital direction for practitioners. From an aging perspective, such theorizing can extend to existing frameworks of perceptual-cognitive learning and aging which can guide the structure of evidence-based braille training strategies that strive to maximize intact domains among older adults, thereby providing a stronger empirical basis for the use of specified methods.[133]

Given the need to merge expertise from both the educational and rehabilitation/healthcare (and even gerontological) domains, a collaborative, transdisciplinary approach to advancing such research would arguably be ideal.[134] Moreover, building towards such evidence-based frameworks of andragogical and aging learning paradigms would necessarily benefit from the involvement of working-age and older adult braille clients, policymakers, practitioners, managers and other stakeholders who carry valuable insights about current practices. As Walsh observed, adult learners are experts on their own learning, and their perspective is of critical importance.[79] Stakeholder engagement assists in ensuring that the ultimate findings are responsive to actual needs, increasing uptake of research findings and enhancing clinical awareness of the evidence, potential resources, and their role in the evaluation.[135] In this way, the quality of the ultimate implementation is improved because it adds knowledge on clinical applications, behaviours of stakeholders, and considers the impact of institutional mechanisms.[136]

6.5.3. Usability and design of braille display devices for aging clients

As outlined among the findings of this thesis, braille devices carry potential benefits for older adults, including those with reduced tactile sensitivity. Future research is needed to more directly explore the usability of such braille displays among older adults, to ensure that their benefits are maximized and to minimize the potential for device abandonment.[137] Current braille displays are available in a variety of dimensions (ranging between 12 to 80 cells). Some models incorporate input keys to type braille characters while others do not. Similarly, some have "cursor keys" to move the editing cursor or activate commands without having to move the hands from the display while others do not, and some incorporate additional function buttons.[138] While all of these characteristics increase user functionality, each also increases the potential complexity associated with device operation. Moreover, performance on the Purdue Pegboard has, for example, been associated with slower interactions and increased error rates when using assistive technologies.[139] Renaud and van Biljon[140] proposed a theoretical approach to modeling the acceptance of mobile phone technologies among older users that could have equal application to braille displays, as it takes the physical context (design of the device in light of age-related declines in motor dexterity and precision), social context (including the interactions or information involved or enabled by using the device), and mental context (the time required for older adults to learn the steps to using a device) into account. A clearer picture of the impact that all of this potential complexity has on reading performance would be important in aiding vision rehabilitation therapists in selecting appropriate tools for a given client, taking into account their unique physical/motor/cognitive profile. Such information would also provide vital direction for designers.

Determining which of the many available braille devices would be most appropriate for a given older adult requires consideration of the entire utilization context, accounting for factors related to the user (user satisfaction, physiological and cognitive capabilities), the environment (where and how the technology will be used), and the functioning of the device (what it will be used for and how intuitive it is to use). Frameworks exist which could be applied to aid in the process of evaluating device usability and satisfaction.[141] For example, these elements are encapsulated by Arthanat et al.'s Usability Scale for Assistive Technology – Computer Access (USAT-CA) model,[142,143] which has demonstrated good reliability in other domains. However, more research is needed to understand how the ergonomics of braille displays impact on reading performance, as these were not questions that were considered in the studies of this thesis.

6.5.4. The reading implications of braille displays

Significantly more research is required to determine the differential impact of reading on a braille display (vs paper braille) by naïve (and to a lesser extent experienced) braille readers. In Chapter 4, the mostly experienced braille readers demonstrated very similar speeds when reading either by paper or on a braille display; however, the pilot results in Chapter 5 suggest that, for individuals with reduced tactile acuities or those with less tactile experience, the more pronounced dots on a braille display may in fact aid in learning and reading speeds. However, the purpose of reading ultimately extends to processes of retention and comprehension, and these are questions that were not directly explored in the context of this thesis.

There is mounting evidence from the print reading domain that significant differences in comprehension and retention of information may exist between reading from traditional paper sources and reading on electronic devices, such as tablets. In a 2018 meta-analysis of 38 studies (representing the examination of 169,524 readers), Delgado, Vargas, Ackerman, and Salmerón[144] reported that the mean effect size (Hedges' *g*) from between-subjects designs of comprehension when reading from an electronic source (rather than a paper source) was -0.21 (95% CI: [-.28, .14]). A similar trend was observed for within-subject studies (d_c = -0.21, 95% CI: [-.37, -.06]).

Several hypotheses exist that may explain the apparent superiority of paper-based texts. Among these, the fact that users must continually interact with a device when reading on a digital display has been suggested as a source of interference in the reading comprehension task. The need to "scroll" the text, particularly if that occurs very often, may add a cognitive load to the reading task that infringes upon the cognitive capacities that would otherwise be used for reading comprehension.[145,146] This may be an especially significant factor when reading on shorter braille displays (i.e. those with 20 or fewer cells), where scrolling may be required every two or three words depending on the text being read.

A second hypothesis is that the use of an electronic display concerns what Mangen and Kuiken[147] term the "spatio-temporal intangibility of digitized texts" (p. 152). In the digital mode, physical and tactile cues are often lacking. Even if there is a concept of 'pages', they rarely align to the physical pages of an equivalent book, and readers often do not have the benefit of being able to glance at the entirety of a page in order to ascertain its overall layout. Moreover, there is considerable evidence that readers' mental reconstruction of read texts is aided by recall of the spatial orientation of particular passages or phrases: in other words, people recall information because they can recall where, approximately, on the page it appeared.[148] Most widely available braille displays are limited to a single segment of text (very often not even representing a complete line in a document). This arguably eviscerates any tactile sense of the layout of a page, and thus readers using an electronic display do not have the benefit of this spatial information. The one study that examined this question specifically in the context of braille did not find a statistically significant difference between reading comprehension using a display vs paper, but further research is needed (with a wider range of reading tasks) to validate those findings.[149]

Whether these factors operate as an impediment to braille reading performance among experienced or new readers of braille has not been explored. Certainly, any interference effects will be moderated by the nature of the task at hand. Reading a narrative (story) and answering a comprehension question is inherently distinct, for instance, from studying a passage containing statistical information that may later need to be referenced. Future research should therefore investigate whether any of the differences observed in print readers have application to experienced (and less experienced) braille readers.

6.5.5. Feasibility of remote learning in adult braille rehabilitation

As indicated by the participants in the qualitative study (Chapter 3), adult learners who wish to pursue braille rehabilitation may have few training options. The number of vision rehabilitation professionals who are available and qualified to provide braille instruction to adult learners is limited, and these services are generally only available in major centers. Self-paced correspondence courses *are* available (e.g. through the Hadley School for the Blind in the United States), but such self-directed learning is limiting for older adults who require greater support and remaining motivated may be a challenge.[150]

Given these realities, research into potential remote training options would be of great assistance to the field. Telerehabilitation efforts have been successful in other fields (with one systematic review reporting a 71% success rate[151]), but only limited evidence exists for the use of this model in low vision and blindness rehabilitation.[152] The ability to deliver braille training remotely could help to overcome many of the barriers to attending rehabilitation services that clients often face, including the limited time available, transportation difficulties, and challenges surrounding the COVID-19 pandemic.[80] Use of a braille display would enable the vision rehabilitation therapist to generate and display meaningful and task-appropriate braille dynamically, to respond to specific learning needs. Deficiencies in tactile perception and instruction on appropriate hand movement techniques may be more difficult to diagnose and correct. Moreover, video and audio links in telerehabilitation settings are prone to distortion and interruption, potentially complicating the delivery of instruction.[153]

Nonetheless, it would appear to be technologically *feasible* for an instructor to control a braille display from a remote location (as demonstrated by Freedom Scientific's JAWS Tandem service or the NVDARemote project[154]) and utilize the camera on a tablet or smartphone to observe a braille reader and provide instructional assistance. The feasibility, effectiveness, and outcomes of this training model have not yet been evaluated. Given the proliferation of lower cost braille displays, these questions will become increasingly relevant in the years ahead.

6.6. Limitations

6.6.1. General limitations applicable across studies

Although accumulated literacy experience and instruction, phonological awareness, and orthography are undoubtedly important contributors to reading outcomes,[155] neither the scoping review nor the correlation or pilot studies explored, in any great detail, the impact of literacy competencies on braille reading performance. The focus of these investigations was limited to domain-specific physiological and cognitive factors that were known to decline with age. Nonetheless, for adult learners, the overall literacy skills that they possess prior to learning braille will undoubtedly shape their braille learning outcomes.[30] As evidenced from the qualitative study (Chapter 3), prior learning experiences are often not adequately accounted for in designing braille training interventions. An adult's ability to learn generally and the behaviours they engage in when reading or learning to read a new code must be understood in the context of their current reading abilities. Future research which considers such literacy competencies would help to contextualize progress made in adult braille rehabilitation and help determine whether difficulties that arise are specific to the braille code or due to more global literacy deficiencies.[156]

Objective measures of visual functioning (such as acuity and fields) were not obtained as a part of any of the study protocols, which instead relied on self-identification of age of onset, degree of vision loss (per the WHO classifications) and visual acuity and fields. While there had been some hope of reviewing client files to gather this information, most of the participants across the studies were not actively receiving vision rehabilitation services and up-to-date objective measures were not available. There is a body of research on the impact of visual deprivation suggesting that tactile performance may improve in the absence of visual input (whether from vision loss or occlusion);[157-160] however, more recent evidence lends greater support to the hypothesis that the improved tactile performance observed in blind persons stems from the more extensive tactile experience gained over months and years.[5,57,161-163] In the correlation sample (Study 3), the age of onset and the age at which braille generally coincided ($r = .83$), such that the age at which braille was learned could be relied upon as a measure of tactile experience. There is additionally some evidence from the psychophysical field that vision can interfere with or moderate performance on tactile tests, particularly when the part of the body receiving the tactile stimulation can be seen.[164-166] In light of these potential confounders, all assessments in these studies were conducted with full occlusion (using a cardboard screen), regardless of self-identified level of vision.

6.6.2. Limitations of the qualitative study (Study 2/Chapter 3)

This study examined the braille learning experiences of those who had learned braille as adults, but from a purely retrospective perspective. Given the limited time available to complete this research, a longitudinal investigation was not possible. Following adult learners of braille before, during, and after braille rehabilitation would provide a more comprehensive understanding of what leads some to succeed and others to fail. Finally, the identification of participants and the inclusion criteria meant that all of the participants in this study had succeeded in completing their braille training. Future research should strive to encompass the experiences of those who could not achieve their braille goals, and the factors that bear upon these circumstances.

6.6.3. Limitations of the correlation study (Study 3/Chapter 4)

The participants in the correlation study included more older adults (i.e. above age 60) than 64% (n = 25) of the prior research identified in the scoping review, and represented a broad range of ages (23-88). However, the vast majority of participants had learned braille at a much younger age (with only 1 person having learned above age 30), making it impossible to analyze aspects that are specifically relevant to the performance of those who learned as working-age and older adults. Moreover, if the retention or improvement of these capacities is impacted by the fact of braille reading itself, the results of this study may not directly inform us about older adults who have had no prior braille exposure. Further research will be required to examine the performance of those learning much later in adulthood. The participants in Study 2 all consented to be contacted for future research studies, and so an initial sample for such investigations is readily available.

Similarly, in several past studies, clear delineations have been found between groups of poor, moderate, and very good braille readers,[10,167,168] allowing for some meaningful exploration of the characteristics that define each of these groups. Our sample included a wide range of reading speeds (from 34 to 600 characters/minute), but these were distributed fairly evenly across the range. Delineating "good" from "poor" based on the mean (245.31 cpm) or median (243.05 cpm) did not appear practical, given that this equates to an approximate reading speed of only 47 wpm. A larger sample may have permitted for analyses of subgroups but, with no clear dividing point, such analysis was not possible. Nonetheless, this remains the only study that has considered motor, cognitive, and tactile indicators within a single sample and has provided a useful starting point for future research.

The Purdue Pegboard was selected because it is generally regarded as a reliable and valid measure of fine motor performance. However, the motions involved (grasping and placing pegs in a particular location) are significantly different from those required for effective braille reading, notwithstanding the moderate correlation between Purdue scores and reading speed. Moreover, the Purdue Pegboard demands a degree of spatial orientation to locate the pegs and the holes that undoubtedly impacts on performance as compared with sighted participants.[169,170]

Finally, while the correlation study has provided valuable information on the impact of age and age-related declines after the fact, it tells less about the causal impact of *aging* on reading performance for a given reader. To address the latter point, longitudinal investigations tracking tactile, motor, cognitive, and braille reading performance declines over a longer period of time are required.

6.6.4. Limitations of the experimental study (Study 4/Chapter 5)

Study 4 (Chapter 5) was presented as a pilot study/case series owing to the fact that the COVID-19 pandemic interfered with the recruitment and testing of participants. The original protocol called for a larger sample with representative age distributions, thereby permitting group comparisons between younger and older adults. With only six participants, statistical analyses were not possible. However, the initial results signal the potential speed and accuracy benefits associated with use of a braille display. These initial participants also highlighted a potential confounding variable (letter choice), which would have modified the letters used within the larger study. As noted in the chapter, the letters A-D and E-H (the first eight letters in the alphabet) were used for consistency with a commonly used Canadian adult braille learning curriculum; however, other programs advocate for different letter sequences, such as the Mangold program where the first eight letters introduced are *g*, *c*, *l*, *d*, *y*, *a*, *b*, and *s*.[171] When COVID-19 conditions permit, this study will be revisited and revised in accordance with these initial findings.

6.6.5. Limitations as to the clinical application of these assessments

In reporting that no significant correlation was found between, for example, tactile working memory and braille reading speed, the intention is not to imply that these capacities are not important for braille reading. It is possible that other assessments or tests could have resulted in different correlations being found. There is significant prior research with both children and adults underscoring the role that each of these factors may play in either print or braille reading. That no correlation was found with a particular measure may suggest that (1) the assessments used simply were not sensitive enough to the particular interaction that exists between these capacities and braille reading performance, or (2) the evaluation was confounded by an external factor not considered in our protocol (such as the impact that spatial orientation skills may have had on both the Purdue Pegboard and the Tactile Working Memory test). As such, these findings should not be utilized as justification for employing any one assessment as a definitive screening or threshold eligibility tool. However, the results provide strong support for the particular importance of tactile sensitivity within the aging braille context.

6.7. Conclusion

Although braille has been in existence for 200 years, much of the empirical research conducted has centered on children and on the use of braille to acquire initial literacy skills. For working-age and older adults who experience vision loss, braille affords a means to access information and replaces the prior use of print. Both the nature and emphasis of training at the adult level is therefore necessarily distinct from childhood braille instruction. Among these distinctions, practitioners must possess a comprehensive understanding of how age-related declines may influence braille learning and reading outcomes. It is evident that working-age and older adults exhibit the ability to learn and use braille, but to date, the field has had little evidence to guide assessment and training decisions. For these reasons, clinicians may feel ill-equipped to determine who, from an older adult perspective, may benefit from braille, or whether certain age-related considerations may pose a significant barrier. Beyond these considerations, barriers faced at the personal, social and institutional level may uniquely shape the experiences of adult braille clients. Understanding the facilitators and barriers encountered by older braille clients will provide vital direction for addressing future service gaps. As the population continues to age, these questions will become increasingly imperative.

Collectively, the studies in this thesis address fundamental questions about braille, adulthood and aging. Taken together, they provide a more comprehensive portrait of the adult braille client, and demonstrate how a variety of overlapping factors work to shape the adulthood braille rehabilitation context. This research suggests that although tactile, motor and cognitive factors are shown to decline with age, most of these age-related variables should not adversely affect the ability to pursue braille training until older adulthood. Among the examined variables, the importance of active tactile acuity, frequency of braille usage and earlier braille learning age emerged as especially significant. Moreover, these findings provide evidence for the efficacy of incorporating electronic braille displays, particularly for those who exhibit reduced tactile sensitivity. Despite the relevance of these factors, it is nonetheless evident that access to adequate support, opportunities for frequent braille usage, and funding to purchase braille devices represent significant barriers for working-age and older adult braille clients. This foundation provides a vital starting point to inform future research, policy and practice on braille, adulthood and aging.

6.8. References

1. Herie E. Journey to Independence: Blindness - The Canadian Story: Dundurn Publishing; 2005.

2. Van der Linden M, Hupet M, Feyereisen P, Schelstraete M-A, Bestgen Y, Bruyer R, et al. Cognitive Mediators of Age-Related Differences in Language Comprehension and Verbal Memory Performance. Aging, Neuropsychology, and Cognition. 1999; 6(1):32-55.

3. Kandel ER, Schwartz JH, Jessell TM, Siegelbaum SA, Hudspeth AJ. Principles of Neural Science: McGraw-Hill Companies Inc.; 2013.

4. Stevens JC, Foulke E, Patterson MQ. Tactile acuity, aging, and braille reading in long-term blindness. Journal of Experimental Psychology: Applied. 1996; 2(2):91-106.

5. Goldreich D, Kanics IM. Tactile acuity is enhanced in blindness. J Neurosci. 2003; 23(8):3439-45.

6. Legge GE, Madison CM, Vaughn BN, Cheong AMY, Miller JC. Retention of high tactile acuity throughout the lifespan in blindness. Perception & Psychophysics. 2008; 70(8):1471-88.

7. Laroche L, Boulé J, Wittich W. Reading speed of contracted French braille. Journal of Visual Impairment & Blindness. 2012; 106(1):37-42.

8. Chen X, Liang L, Lu M, Potměšil M, Zhong J. The effects of reading mode and braille reading patterns on braille reading speed and comprehension: A study of students with visual impairments in China. Research in Developmental Disabilities. 2019; 91:103424.

9. Davidson PW, Appelle S, Haber RN. Haptic scanning of braille cells by low-and high-proficiency blind readers. Research in Developmental Disabilities. 1992; 13(2):99-111.

10. Fertsch P. An analysis of braille reading. Outlook for the blind and the teachers forum1946. p. 128.

11. Garcia LG. Assessment of text reading comprehension by Spanish-speaking blind persons. The British Journal of Visual Impairment. 2004; 22(1):4-12.

12. Millar S. Is there a "best hand" for braille? Cortex. 1984; 20:75-87.

13. Mousty P, Bertelson P. 1. A study of braille reading: Reading speed as a function of hand usage and context. The Quarterly Journal of Experimental Psychology. 1985; 37A:217-33.

14. Wormsley DP. Reading rates of young braille-reading children. Journal of Visual Impairment & Blindness. 1996; 90(3).

15. Wright T, Wormsley DP, Kamei-Hannan C. Hand movements and braille reading efficiency: Data from the Alphabetic Braille and Contracted Braille Study. Journal of Visual Impairment & Blindness. 2009; 103(10):649-61.

16. Bertelson P. Language by touch: the case of braille reading. Speech and Reading: A Comparative Approach. East Sussex: Erlbaum (UK) Taylor & Francis; 1995. p. 91-108.

17. Sadato N, Okada T, Honda M, Yorekura Y. Critical period for cross-modal plasticity in blind humans: a functional MRI study. Neuroimage. 2002; 16:389-400.

18. Papagno C, Minniti G, Mattavelli GC, Manatovan L, Cecchetto C. Tactile short-term memory in sensory-deprived individuals. Experimental Brain Research. 2017; 235(2):471-80.

19. Wittich W, Nadon C. The Purdue Pegboard test: Normative data for older adults with low vision. Disability and Rehabilitation: Assistive Technology. 2015; 12(3).

20. Dixon J. Refreshable braille displays: Their origins and evolution. In: Dixon J, editor. Braille into the next milennium. Washington, DC: National Library Service for the Blind and Physically Handicapped; 2000. p. 348-73.

21. Nadeem M, Aziz N, Sajjad U, Aziz F, Shaikh H, editors. A comparative analysis of Braille generation technologies. 2016 International Conference on Advanced Robotics and Mechatronics (ICARM); 2016 18-20 Aug. 2016.

22. Bickford JO, Falco RA. Technology for early braille literacy: Comparison of traditional braille instruction and instruction with an electronic notetaker. Journal of Visual Impairment & Blindness. 2012; 106(10):679-93.

23. Cooper HL, Nichols SK. Technology and early braille literacy: Using the Mountbatten Pro Brailler in primary-grade classrooms. Journal of Visual Impairment & Blindness. 2007; 101(1):22-31.

24. Runyan NH, Carpi F. Seeking the 'holy Braille' display: might electromechanically active polymers be the solution? Expert Review of Medical Devices. 2011; 8(5):529-32.

25. Douglas G, Weston A, Whittaker J, Wilkins SM, Robinson D. An investigation of the height of embossed braille dots for labels on pharmaceutical products. Journal of Visual Impairment & Blindness. 2009; 103(10):662-7.

26. Wong M, Peters RM, Goldreich D. A physical constraint on perceptual learning: tactile spatial acuity improves with training to a limit set by finger size. Journal of Neuroscience. 2013; 33(22):9345-52.

27. Pascual A, Wassermann EM, Sadato N, Hallett M. The role of reading activity on the modulation of motor cortical outputs to the reading hand in Braille readers. Annals of Neurology. 1995; 38(6):910-5.

28. Franks J. To braille, or not to braille? That is the question. British Journal of Visual Impairment. 1998; 16(2):57-60.

29. Cryer H, Home S. Final report: Feasibility of developing a diagnostic touch test to determine braille reading potential. United Kingdom: RNIB Centre for Accessible Information; 2011.

30. Abbott P, Connors E. Braille and other tactile forms of communication. In: Lee H, Ottowitz J, editors. Foundations of Vision Rehabilitation Therapy. 4th ed. Louisville, KY: APH Press; 2020. p. 199-243.

31. Murman DL. The Impact of Age on Cognition. Semin Hear. 2015; 36(3):111-21.

32. Bailey IL, Lueck AH, Greer RB, Tuan KM, Bailey VM, Dornbusch HG. Understanding the relationships between print size and reading in low vision. Journal of Visual Impairment & Blindness. 2003; 97(6):325-34.

33. Corn AL, Lusk KE. Perspectives on Low Vision (Chapter 1). Foundations of Low Vision: Clinical and Functional Perspectives. New York: American Foundation for the Blind; 2010. p. 3-34.

34. Şahlı E, İdil A. A Common Approach to Low Vision: Examination and Rehabilitation of the Patient with Low Vision. Turkish journal of ophthalmology. 2019; 49(2):89-98.

35. Heller MA, Gentaz E. Psychology of Touch and Blindness: Psychology Press; 2013.

36. Greenland C. Vision Canada: The Unmet Needs of Blind Canadians. Toronto: Canadian National Institute for the Blind; 1976.

37. Tariff for insured visual aids and related services, CQLR c A-29, r 8.1 (Health Insurance Act), (2018).

38. Bach-y-Rita P. Brain plasticity as a basis of sensory substitution. Journal of Neurological Rehabilitation. 1987; 1(2):67-71.

39. D'Andrea FM. Making the transition from print to braille. In: Wormsley DP, D'Andrea FM, editors. Instructional strategies for braille literacy. New York, NY: AFB Press; 1997. p. 111-44.

40. Daneman M. How reading braille is both like and unlike reading print. Memory & Cognition. 1988; 16(6):497-504.

41. Wittich W, Phillips N, Nasreddine ZS, Chertkow H. Sensitivity and specificity of the Montreal Cognitive Assessment modified for individuals who are visually impaired. Journal of Visual Impairment & Blindness. 2010; 104(6):360.

42. Harley RK, Pichert JW, Morrison M. Braille instruction for blind diabetic adults with decreased tactile sensitivity. Journal of Visual Impairment & Blindness. 1985; 79(1):12-7.

43. Bennett CR, Bex PJ, Bauer CM, Merabet LB. The Assessment of Visual Function and Functional Vision. Seminars in Pediatric Neurology. 2019; 31:30-40.

44. Colenbrander A. Aspects of vision loss – visual functions and functional vision. Visual Impairment Research. 2003; 5(3):115-36.

45. Jeong JH, Moon NJ. A study of eccentric viewing training for low vision rehabilitation. Korean Journal of Ophthalmology. 2011; 25(6):409-16.

46. Saftari LN, Kwon OS. Ageing vision and falls: a review. Journal of Physiological Anthropology. 2018; 37(1):11.

47. Petty LS, Foster JE, Rigby P. Identifying community-dwelling older adults' vision loss during mobility assessments: A scoping review. Canadian Journal of Occupational Therapy. 2019; 86(2):95-105.

48. Koenig AJ, Holbrook MC. Learning media assessment of students with visual impairments: A resource guide for teachers: ERIC; 1995.

49. Barrow FH. The International Classification of Functioning, Disability, and Health (ICF), A New Tool for Social Workers. Journal of Social Work in Disability & Rehabilitation. 2006; 5(1):65-73.

50. National Research Council. Visual impairments: Determining eligibility for social security benefits: National Academies Press; 2002.

51. Abdouni A, Djaghloul M, Thieulin C, Vargiolu R, Pailler-Mattei C, Zahouani H. Biophysical properties of the human finger for touch comprehension: influences of ageing and gender. R Soc Open Sci. 2017; 4(8):170321.

52. Heller MA, Wilson K, Steffen H, Yoneyama K, Brackett DD. Superior haptic perceptual selectivity in late-blind and very-low-vision subjects. Perception. 2003; 32:499-511.

53. Alary F, Goldstein R, Duquette M, Chapman CE, Voss P, Lepore F. Tactile acuity in the blind: a psychophysical study using a two-dimensional angle discrimination task. Experimental Brain Research. 2008; 187(4):587-94.

54. Foulke E. Reading braille. Tactual Perception: A Sourcebook. New York: Cambridge University Press; 1982. p. 168-208.

55. Yamashita E, Matsumoto H. The dependence of finger tip touch-pressure upon the condition of Braille reading. The Tohoku Journal of Experimental Medicine. 1977; 123(3):221-5.

56. Stevens JC. Temperature can sharpen tactile acuity. Perception and Psychophysics. 1982; 31(6):577-80.

57. Wong M, Gnanakumaran V, Goldreich D. Tactile Spatial Acuity Enhancement in Blindness: Evidence for Experience-Dependent Mechanisms. Journal of Neuroscience. 2011; 31(19):7028-37.

58. McBride VG. Explorations in Rapid Reading in Braille. Journal of Visual Impairment & Blindness. 1974; 68(1):8-12.

59. Valentijn SAM, von Boxtel MPJ, von Hooren SAH, Bosma H, Beckers HJM, Ponds RWHM, et al. Change in sensory functioning predicts change in cognitive functioning: results from a 6-year follow up in the Maastricht Aging Study. Journal of the American Geriatric Society. 2005; 53:374-80.

60. Lindenberger U, Ghisletta P. Cognitive and sensory declines in old age: gauging the evidence for a common cause. Psychology and Aging. 2009; 24(1):1.

61. Lindenberger U, Baltes PB. Sensory functioning and intelligence in old age: a strong connection. Psychology and Aging. 1994; 9(3):339-55.

62. McIntosh AR. Towards a network theory of cognition. Neural Networks. 2000; 13(8-9):861-70.

63. Monge ZA, Madden DJ. Linking cognitive and visual perceptual decline in healthy aging: The information degradation hypothesis. Neuroscience and biobehavioral reviews. 2016; 69:166-73.

64. Bruns P, Camargo CJ, Campanella H, Esteve J, Dinse HR, Röder B. Tactile acuity charts: a reliable measure of spatial acuity. PloS One. 2014; 9(2):e87384.

65. Stevens JC. Aging and spatial acuity of touch. Journal of Gerontology. 1992; 47(1):35-40.

66. Stevens JC, Alvarez-Reeves M, Dipietro L, Mack GW, Green BG. Decline of tactile acuity in aging: a study of body site, blood flow, and lifetime habits of smoking and physical activity. Somatosensory and Motor Research. 2003; 20(3-4):271-9.

67. Nyberg L, Lövdén M, Riklund K, Lindenberger U, Bäckman L. Memory aging and brain maintenance. Trends in Cognitive Sciences. 2012; 16(5):292-305.

68. Bertone A, Bettinelli L, Faubert J. The impact of blurred vision on cognitive assessment. Journal of Clinical and Experimental Neuropsychology. 2007; 29(5):467-76.

69. Dickinson C, Rabbitt PA. Simulated visual impairment: Effects on text comprehension and reading speed. Clinical vision sciences. 1991; 6(4):301-8.

70. Roman-Lantzy C. Cortical visual impairment: An approach to assessment and intervention: American Foundation for the Blind; 2007.

71. Taylor DCM, Hamdy H. Adult learning theories: Implications for learning and teaching in medical education: AMEE Guide No. 83. Medical Teacher. 2013; 35(11):e1561-e72.

72. Knowles MS, Holton EF, Swanson RA. The adult learner : the definitive classic in adult education and human resource development. 2015.

73. Tuttle DW, Tuttle NR. Self-esteem and adjusting with blindness: The process of responding to life's demands. Springfield, IL: Charles C. Thomas Publisher Ltd.; 2004.

74. Wormsley DP, D'Andrea FM. Instructional Strategies for Braille Literacy. New York: American Foundation for the Blind; 1997.

75. Ciccone M. Equitable public library services for Canadians with print disabilities. Reference Services Review. 2018.

76. Douglas G, Franks J, Weston A, Clements B. Braille in the 21 st Century: opportunities, benefits, and challenges for adults with acquired sight loss Research report for RNIB. Birmingham, UK: Visual Impairment Centre for Teaching and Research. 2009.

77. Hunt B. Managing a caseload. In: Lee H, Ottowitz J, editors. Foundations of vision rehabilitation therapy. Louisville, KY: APH Press; 2020. p. 494-520.

78. Zhang C, Zheng G, editors. Supporting adult learning: enablers, barriers, and services. SIGITE '13; 2013.

79. Walsh F, Abi-Nader J, Poutiatine MI. What Do Adult Learners Experience in a Teacher Certification Program? Journal of Adult Education. 2005; 34(1):6-21.

80. Southall K, Wittich W. Barriers to Low Vision Rehabilitation: A Qualitative Approach. Journal of Visual Impairment & Blindness. 2012; 106(5):261-74.

81. Polk TA. The Aging Brain. Chantilly, VA: The Great Courses; 2016.

82. Gardner RC. Second-language learning in adults: Correlates of proficiency. Applied Language Learning. 1991; 2(1):1-28.

83. Emerson RW, Holbrook MC, D'Andrea FM. Acquisition of literacy skills by young children who are blind: Results from the ABC Braille Study. Journal of Visual Impairment & Blindness. 2009; 103(10):610-24.

84. Holbrook MC, Koenig AJ. Teaching Braille Reading to Students with Low Vision. Journal of Visual Impairment & Blindness. 1992; 86(1):44-8.

85. D'Andrea FM. A History of Instructional Methods in Uncontracted and Contracted Braille. Journal of Visual Impairment & Blindness. 2009; 103(10):585-94.

86. D'Aurizio VR. IM-ABLE: A pathway to literacy. Journal of Visual Impairment & Blindness. 2011; 105(3):141-4.

87. Siu Y-T. Book Review: IM-ABLE: Individualized Meaning-Centered Approach to Braille Literacy Education. SAGE Publications Sage CA: Los Angeles, CA; 2016.

88. McMillan J. A student success story through the use of an Individualized Meaning-centered Approach to Braille Literacy (IM-ABLE). Journal of Visual Impairment & Blindness. 2015; 109(1):56-60.

89. Kelly C, Foxe JJ, Garavan H. Patterns of normal human brain plasticity after practice and their implications for neurorehabilitation. Archives of Physical Medicine and Rehabilitation. 2006; 87(2):S20-S8.

90. Wolfson NE, Cavanagh TM, Kraiger K. Older adults and technology-based instruction: Optimizing learning outcomes and transfer. Academy of Management Learning & Education. 2014; 13(1):26-44.

91. Andersen GJ, Ni R, Bower JD, Watanabe T. Perceptual learning, aging, and improved visual performance in early stages of visual processing. Journal of Vision. 2010; 10(13):1-13.

92. Beauchamp P, Faubert J. Visual perception training: Cutting edge psychophysics and 3D technology applied to sport science. High Performance CIRCuit e-Journal. 2011.

93. Faubert J, Overbury O. Active-passigm paradigm in assessing CCTV-aided reading. American Journal of Optometry and Psychological Optics. 1987; 64:23-8.

94. Bower JD, Andersen GJ. Aging, perceptual learning, and changes in efficiency of motion processing. Vision Research. 2012; 61:144-56.

95. Lustig C, Shah P, Seidler R, Reuter-Lorenz PA. Aging, training, and the brain: A review and future directions. Neuropsychology Review. 2009; 19(4):504-22.

96. Holloway C, Dawes H. Disrupting the world of disability: The next generation of assistive technologies and rehabilitation practices. Healthcare technology letters. 2016; 3(4):254-6.

97. DiGiovanni AM. Electronic Library Collections and Users with Visual Impairments: Challenges, Developments, and the State of Collections Policies in Academic and Public Libraries. School of Information Student Research Journal. 2020; 10(1):5.

98. Penava V, Bilić Prcić A, Iličić L. The influence of braille literacy programme length on frequency of braille usage. Hrvatska revija za rehabilitacijska istraživanja. 2017; 53(Supplement):152-62.

99. Lavis J, Hammill A, editors. Care by sector. Ontario’s health system: Key insights for engaged citizens, professionals and policymakers Hamilton: McMaster Health Forum; 2016.

100. McColl MA, Jaiswal A, Jones S, Roberts L, Murphy C. A review of disability policy in Canada. Kingston, Ontario: Canadian Disability Policy Alliance. 2017.

101. Harper K, McFee C, MacDonald I, Jones M. Low vision service models in Alberta: innovation, collaboration, and future opportunities. Canadian journal of ophthalmology. 2006; 41(3):373-7.

102. Leat SJ. A proposed model for integrated low-vision rehabilitation services in Canada. Optometry and Vision Science. 2016; 93(1):77-84.

103. Schreiber D, Wang RH, Durocher E, Wilson MG, Chalghoumi H, Gauthier-Beaupré A, et al. Access to Assistive Technology in Canada: A Jurisdictional Scan of Programs: AGE-WELL NCE; 2017.

104. Mattison CA, Wilson MG, Wang RH, Waddell K. Enhancing equitable access to assistive technologies in Canada: Insights from citizens and stakeholders. Canadian Journal on Aging/La Revue canadienne du vieillissement. 2020; 39(1):69-88.

105. Wittich W, Jarry J, Barstow E, Thomas A. Vision and hearing impairment and occupational therapy education: Needs and current practice. British Journal of Occupational Therapy. 2017; 80(6):384-91.

106. Wittich W, Barstow EA, Jarry J, Thomas A. Screening for sensory impairment in older adults: Training and practice of occupational therapists in Quebec: Formation et pratique des ergothérapeutes du Québec dans le dépistage des troubles sensoriels chez les personnes âgées. Canadian Journal of Occupational Therapy. 2015; 82(5):283-93.

107. Regulation respecting insured visual aids and related services, CQLR c A-29, r 3 (Health Insurance Act). Sect. 26, 29, 31.6 (2017).

108. Schreiber D, Wang R, Durocher E, Wilson M, editors. Access to assistive technology in Canada: A jurisdictional scan of programs. Toronto, Canada: AGE-WELL NCE, University of Toronto, McMaster Health Forum, March of Dimes Canada; 2017.

109. Durocher E, Wang RH, Bickenbach J, Schreiber D, Wilson MG. “Just access”? Questions of equity in access and funding for assistive technology. Ethics & Behavior. 2019; 29(3):172-91.

110. Ontario Ministry of Health & Long-Term Care. Visual Aids Policy and Administration Manual: Government of Ontario; 2016 [updated February 2016. Available from: http://www.health.gov.on.ca/en/pro/programs/adp/policies_procedures_manuals/docs/visual_aids_manual.pdf.

111. Barnes C, Mercer G, Shakespeare T. Exploring Disability: A Sociological Introduction. Cambridge: Polity Press; 1999.

112. Corrigan PW, Watson AC. Understanding the impact of stigma on people with mental illness. World psychiatry : official journal of the World Psychiatric Association (WPA). 2002; 1(1):16-20.

113. May C, Finch T. Implementing, embedding, and integrating practices: an outline of normalization process theory. Sociology. 2009; 43(3):535-54.

114. Johnson J, Kennedy K. Introduction: Disability, In/Visibility, and Risk. Rhetoric Society Quarterly. 2020; 50(3):161-5.

115. Committee on the Science of Changing Behavioral Health Social Norms, Board on Behavioral C, and Sensory Sciences,, Division of Behavioral and Social Sciences and Education, National Academies of Sciences E, and Medicine,. Chapter 4: Approaches to Reducing Stigma Washington, DC: National Academies Press; 2016 [Available from: https://www.ncbi.nlm.nih.gov/books/NBK384914/?report=classic.

116. Hubbard S. Disability studies and health care curriculum: The great divide. Journal of Allied Health. 2004; 33(3):184-8.

117. Barnes C. Disabling imagery and the media. An Exploration of the Principles for Media Representations of Disabled People The First in a Series of Reports Halifax. 1992.

118. Forber-Pratt AJ, Mueller CO, Andrews EE. Disability identity and allyship in rehabilitation psychology: Sit, stand, sign, and show up. Rehabilitation Psychology. 2019; 64(2):119.

119. Pearson V, editor Engaging blind and partially sighted stakeholders in transformational change. Healthcare Management Forum; 2016: SAGE Publications Sage CA: Los Angeles, CA.

120. Nilsen P. Making sense of implementation theories, models and frameworks. Implementation Science. 2015; 10(1):53.

121. Bussières AE, Patey AM, Francis JJ, Sales AE, Grimshaw JM, the Canada PPT. Identifying factors likely to influence compliance with diagnostic imaging guideline recommendations for spine disorders among chiropractors in North America: a focus group study using the Theoretical Domains Framework. Implementation Science. 2012; 7(1):82.

122. Ponchillia PE, Durant PA. Teaching behaviors and attitudes of braille instructors in adult rehabilitation centers. Journal of Visual Impairment & Blindness. 1995.

123. Academy for Certification of Vision Rehabilitation & Educational Professionals. Vision Rehabilitation Therapist Certification (CVRT) Handbook, Section 4, History of Vision Rehabilitation Therapy Certification Tucson, AZ: Academy for Certification of Vision Rehabilitation & Educadtional Professionals (ACVREP); n.d. [Available from: https://www.acvrep.org/certifications/cvrt-history.

124. Rosenblum LP, Lewis S, D'Andrea FM. Current practices in instruction in the literary braille code university personnel preparation programs. Journal of Visual Impairment & Blindness. 2010; 104(9):523-32.

125. Wittenstein SH, Pardee ML. Teachers' Voices: Comments on Braille and Literacy from the Field. Journal of Visual Impairment & Blindness. 1996; 90(3):201-9.

126. Bernbaum M, Albert SG, McGarry JD. Diabetic neuropathy and braille ability. Archives of Neruology. 1989; 46:1179-81.

127. Martiniello N, Wittich W. The relationship between tactile, motor and cognitive factors in braille reading performance: A scoping review. Disability & Rehabilitation. 2020 - submitted.

128. Rowel R, Moore ND, Nowrojee S, Memiah P, Bronner Y. The utility of the environmental scan for public health practice: lessons from an urban program to increase cancer screening. Journal of the National Medical Association. 2005; 97(4):527.

129. Cane J, O'Connor D, Michie S. Validation of the theoretical domains framework for use in behaviour change and implementation research. Implementation Science. 2012; 7(1):37.

130. Atkins L, Francis J, Islam R, O'Connor D, Patey A, Ivers N, et al. A guide to using the Theoretical Domains Framework of behaviour change to investigate implementation problems. Implementation Science. 2017; 12(1):77.

131. Steinman BA, LeJeune B, Kimbrough B. Developmental stages of reading processes in children who are blind and sighted. Journal of Visual Impairment & Blindness. 2006; 100(1):36-46.

132. Colton S, Hatcher T, editors. The Development of a Research Instrument to Analyze the Application of Adult Learning Principles to Online Learning. cademy of Human Resource Development International Conference (AHRD); 2004 March 3-7, 2004; Ausin, TX.

133. Park DC. The aging mind: neuroplasticity in response to cognitive training. Dialogues in Clinical Neuroscience. 2013; 15(1):109-19.

134. Wada M, Grigorovich A, Fang ML, Sixsmith J, Kontos P. An Exploration of Experiences of Transdisciplinary Research in Aging and Technology. 2020. 2020; 21(1).

135. Camden C, Shikako-Thomas K, Nguyen T, Graham E, Thomas A, Sprung J, et al. Engaging stakeholders in rehabilitation research: a scoping review of strategies used in partnerships and evaluation of impacts. Disability and Rehabilitation. 2015; 37(15):1390-400.

136. van Rooijen M, Lenzen S, Dalemans R, Beurskens A, Moser A. Stakeholder engagement from problem analysis to implementation strategies for a patient-reported experience measure in disability care: A qualitative study on the process and experiences. Health Expectations. 2020.

137. Fuhrer MJ. Assistive technology outcomes research: challenges met and yet unmet. Am J Phys Med Rehabil. 2001; 80(7):528-35.

138. Walker AS, Sangelkar S, editors. Design Exploration of Affordable Refreshable Braille Display Technology for Low-Income Visually Impaired Users. ASME 2017 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference; 2017. V02BT03A012.

139. Wittich W, Southall K, Johnson A. Usability of assistive listening devices by older adults with low vision. Disability and Rehabilitation: Assistive Technology. 2016; 11(7):564-71.

140. Renaud K, Van Biljon J, editors. Predicting technology acceptance and adoption by the elderly: a qualitative study. Proceedings of the 2008 annual research conference of the South African Institute of Computer Scientists and Information Technologists on IT research in developing countries: riding the wave of technology; 2008.

141. Demers L, Weiss-Lambrou R, Ska B. The Quebec User Evaluation of Satisfaction with Assistive Technology (QUEST 2.0): an overview and recent progress. Technology and Disability. 2002; 14(3):101-5.

142. Arthanat S, Bauer S, Lenker J, Nochajski S, Wu Y. Conceptualization and measurement of assistive technology usability. Disability and rehabilitation Assistive technology. 2007; 2:235-48.

143. Gosselin LR, Arthanat S. Reliability and validity of the usability scale for assistive technology for computer access: a preliminary study using video-based evaluation. Assistive Technology. 2019:1-7.

144. Delgado P, Vargas C, Ackerman R, Salmerón L. Don't throw away your printed books: A meta-analysis on the effects of reading media on reading comprehension. Educational Research Review. 2018; 25:23-38.

145. Pommerich M. Developing computerized versions of paper-and-pencil tests: Mode effects for passage-based tests. The Journal of Technology, Learning and Assessment. 2004; 2(6).

146. Jennifer H, Michael R, Thomas H. Examining the Effect of Computer-Based Passage Presentation of Reading Test Performance. The Journal of Technology, Learning and Assessment. 2005; 3(4).

147. Mangen A, Kuiken D. Lost in an iPad: Narrative engagement on paper and tablet. Scientific Study of Literature. 2014; 4(2):150-77.

148. Mangen A, Walgermo BR, Brønnick K. Reading linear texts on paper versus computer screen: Effects on reading comprehension. International Journal of Educational Research. 2013; 58:61-8.

149. Stepien-Bernabe NN, Lei D, McKerracher A, Orel-Bixler D. The Impact of Presentation Mode and Technology on Reading Comprehension among Blind and Sighted Individuals. Optometry and Vision Science. 2019; 96(5):354-61.

150. Farrow KR. Using a group approach to motivate adults to learn braille. Journal of Visual Impairment & Blindness. 2015; 109(4):318-21.

151. Hailey D, Roine R, Ohinmaa A, Dennett L. Evidence of benefit from telerehabilitation in routine care: a systematic review. Journal of Telemedicine and Telecare. 2011; 17(6):281-7.

152. Lorenzini M-C, Wittich W. Measuring changes in device use of a head-mounted low vision aid after personalised telerehabilitation: protocol for a feasibility study. BMJ open. 2019; 9(9):e030149.

153. Bittner AK, Yoshinaga P, Bowers A, Shepherd JD, Succar T, Ross NC. Feasibility of telerehabilitation for low vision: satisfaction ratings by providers and patients. Optometry and Vision Science. 2018; 95(9):865-72.

154. Billah SM, Ashok V, Porter DE, Ramakrishnan IV. A Platform Agnostic Remote Desktop System for Screen Reading. Assets. 2016; 2016:283-4.

155. Boets B, Wouters J, Van Wieringen A, De Smedt B, Ghesquiere P. Modelling relations between sensory processing, speech perception, orthographic and phonological ability, and literacy achievement. Brain and language. 2008; 106(1):29-40.

156. Dahlen SPC. Seeing college students as adults: Learner-centered strategies for information literacy instruction. Endnotes: The Journal of the New Members Round Table. 2012; 3(1):1-18.

157. Facchini S, Aglioti SM. Short term light deprivation increases tactile spatial acuity in humans. Neurology. 2003; 60(12):1998-9.

158. Zubek JP, Flye J, Willows D. Changes in cutaneous sensitivity after prolonged exposure to unpatterned light. Psychonomic Science. 1964; 1(1-12):283-4.

159. Kauffman T, Théoret H, Pascual-Leone A. Braille character discrimination in blindfolded human subjects. Neuroreport. 2002; 13(5):571-4.

160. Merabet LB, Hamilton R, Schlaug G, Swisher JD, Kiriakopoulos ET, Pitskel NB, et al. Rapid and reversible recruitment of early visual cortex for touch. PloS One. 2008; 3(8):e3046.

161. Wong M, Hackeman E, Hurd C, Goldreich D. Short-term visual deprivation does not enhance passive tactile spatial acuity. PloS One. 2011; 6(9):e25277.

162. Goldreich D, Kanics IM. Performance of blind and sighted humans on a tactile grating detection task. Perception & Psychophysics. 2006; 68(8):1363-71.

163. Crabtree CE, Norman JF. Short-term visual deprivation, tactile acuity, and haptic solid shape discrimination. PloS One. 2014; 9(11):e112828.

164. Tipper SP, Lloyd D, Shorland B, Dancer C, Howard LA, McGlone F. Vision influences tactile perception without proprioceptive orienting. Neuroreport. 1998; 9(8):1741-4.

165. Tipper SP, Phillips N, Dancer C, Lloyd D, Howard LA, McGlone F. Vision influences tactile perception at body sites that cannot be viewed directly. Experimental Brain Research. 2001; 139(2):160-7.

166. Wesslein A-K, Spence C, Frings C. When vision influences the invisible distractor: Tactile response compatibility effects require vision. Journal of Experimental Psychology: Human Perception and Performance. 2014; 40(2):763.

167. Legge GE, Madison CM, Mansfield JS. Measuring braille reading speed with the MNREAD test. Visual Impairment Research. 1999; 1(3):131-45.

168. Holland BF. Speed and Pressure Factors in Braille Reading. Journal of Visual Impairment & Blindness. 1934; 28(1b):13-7.

169. Maxfield KE, Perry JD. Performance of blind vocational rehabilitation clients on the purdue pegboard. Perceptual and Motor Skills. 1960; 11(2):139-46.

170. Bauman MK. Studies in the application of motor skills techniques to the vocational adjustment of the blind. Journal of Applied Psychology. 1946; 30(2):144.

171. Herlich SA. The Mangold Basic Braille Program, from tactual perception to learning the Unified English Braille Code: International Council on English Braille; 2016 [Available from: http://www.iceb.org/2016-p03-Herlich--Mangold_Basic_Braille_Program.docx.

Appendix A: Resolution 2020-3 of the International Council on English Braille affirming the importance of braille for adults and older adults with acquired visual impairment

Whereas, there is a growing prevalence of adults and older adults with acquired visual impairment due to both population growth and aging;

Whereas, the most common reason for referral to vision rehabilitation services today are difficulties related to reading and access to information;

Whereas, access to information is critical to regaining or maintaining independence after acquired visual impairment;

Whereas, braille is an important method of reading and writing that is used with and without technology for both basic and more advanced communication needs;

Whereas, braille may also be the primary, if not the only, mode of communication available for persons who are deaf-blind;

Whereas, braille has been empirically demonstrated as being correlated with higher levels of education, stronger employment outcomes, and higher incomes among blind adults; and

Whereas, there is a long tradition of braille research and services for children, but not necessarily for adults or older adults.

This Seventh General Assembly of ICEB therefore resolves that ICEB:

- Prepare a position statement affirming:
  - The importance of braille for adults and older adults with acquired visual impairment;
  - The need for member countries to support adult and older adult braille learners through research, training, and access to braille resources, and
  - The importance of ensuring that all adults and older adults who may benefit from braille have access to it in ICEB member countries; and that
- ICEB establishes a working group to catalog a list of the available learning resources for adult and older adult braille learners in English-speaking countries, with the goal of making this list available within a centralized, public online platform.

Appendix B: Supplementary Material for Chapter 2 (Scoping Review)

Appendix B1: PRISMA-ScR Checklist

This space intentionally left blank: Supplementary File 1 (PRISMA-ScR Checklist), as published, appears on the following two pages.

Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) Checklist

SECTION	ITEM	PRISMA-ScR CHECKLIST ITEM	REPORTED ON PAGE #
TITLE			
Title	1	Identify the report as a scoping review.	1
ABSTRACT			
Structured summary	2	Provide a structured summary that includes (as applicable): background, objectives, eligibility criteria, sources of evidence, charting methods, results, and conclusions that relate to the review questions and objectives.	2
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of what is already known. Explain why the review questions/objectives lend themselves to a scoping review approach.	3-7, 8-9
Objectives	4	Provide an explicit statement of the questions and objectives being addressed with reference to their key elements (e.g., population or participants, concepts, and context) or other relevant key elements used to conceptualize the review questions and/or objectives.	9-12
METHODS			
Protocol and registration	5	Indicate whether a review protocol exists; state if and where it can be accessed (e.g., a Web address); and if available, provide registration information, including the registration number.	N/A
Eligibility criteria	6	Specify characteristics of the sources of evidence used as eligibility criteria (e.g., years considered, language, and publication status), and provide a rationale.	12-13, Table 1
Information sources*	7	Describe all information sources in the search (e.g., databases with dates of coverage and contact with authors to identify additional sources), as well as the date the most recent search was executed.	12-13
Search	8	Present the full electronic search strategy for at least 1 database, including any limits used, such that it could be repeated.	12-13
Selection of sources of evidence†	9	State the process for selecting sources of evidence (i.e., screening and eligibility) included in the scoping review.	13-14
Data charting process‡	10	Describe the methods of charting data from the included sources of evidence (e.g., calibrated forms or forms that have been tested by the team before their use, and whether data charting was done independently or in duplicate) and any processes for obtaining and confirming data from investigators.	15-16
Data items	11	List and define all variables for which data were sought and any assumptions and simplifications made.	15, Appendix A
Critical appraisal of individual sources of evidence§	12	If done, provide a rationale for conducting a critical appraisal of included sources of evidence; describe the methods used and how this information was used in any data synthesis (if appropriate).	N/A
Synthesis of results	13	Describe the methods of handling and summarizing the data that were charted.	15-16

SECTION	ITEM	PRISMA-ScR CHECKLIST ITEM	REPORTED ON PAGE #
RESULTS			
Selection of sources of evidence	14	Give numbers of sources of evidence screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally using a flow diagram.	13-14, 17, Figure 1
Characteristics of sources of evidence	15	For each source of evidence, present characteristics for which data were charted and provide the citations.	Appendix A
Critical appraisal within sources of evidence	16	If done, present data on critical appraisal of included sources of evidence (see item 12).	N/A
Results of individual sources of evidence	17	For each included source of evidence, present the relevant data that were charted that relate to the review questions and objectives.	Appendix A
Synthesis of results	18	Summarize and/or present the charting results as they relate to the review questions and objectives.	17-21
DISCUSSION			
Summary of evidence	19	Summarize the main results (including an overview of concepts, themes, and types of evidence available), link to the review questions and objectives, and consider the relevance to key groups.	21-30
Limitations	20	Discuss the limitations of the scoping review process.	30-32
Conclusions	21	Provide a general interpretation of the results with respect to the review questions and objectives, as well as potential implications and/or next steps.	32
FUNDING			
Funding	22	Describe sources of funding for the included sources of evidence, as well as sources of funding for the scoping review. Describe the role of the funders of the scoping review.	33

JBI = Joanna Briggs Institute; PRISMA-ScR = Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews.
* Where *sources of evidence* (see second footnote) are compiled from, such as bibliographic databases, social media platforms, and Web sites.
† A more inclusive/heterogeneous term used to account for the different types of evidence or data sources (e.g., quantitative and/or qualitative research, expert opinion, and policy documents) that may be eligible in a scoping review as opposed to only studies. This is not to be confused with *information sources* (see first footnote).
‡ The frameworks by Arksey and O'Malley (6) and Levac and colleagues (7) and the JBI guidance (4, 5) refer to the process of data extraction in a scoping review as data charting.
§ The process of systematically examining research evidence to assess its validity, results, and relevance before using it to inform a decision. This term is used for items 12 and 19 instead of "risk of bias" (which is more applicable to systematic reviews of interventions) to include and acknowledge the various sources of evidence that may be used in a scoping review (e.g., quantitative and/or qualitative research, expert opinion, and policy document).

From: Tricco AC, Lillie E, Zarin W, O'Brien KK, Colquhoun H, Levac D, et al. PRISMA Extension for Scoping Reviews (PRISMAScR): Checklist and Explanation. Ann Intern Med. 2018;169:467–473. doi: 10.7326/M18-0850.

Appendix B2: Table of publications summarizing each study's sample characteristics, task and assessment characteristics, factors considered, and most relevant findings

This space intentionally left blank: Table begins on the following page. Citation numbers are referenced to the list at *§2.11. References*.

Study	Journal / Pub Year	Country / Lang.	Study Design and Objective	Sample Size / Characteristics	Measured Capacities / Instruments	Measured Reading Outcomes / Instruments	Modality and Nature of Reading Task	Relevant Findings
Bernbaum et al.[27]	Archives of Neurology / 1989	USA / English	Design: Prospective trial; Aim: to evaluate braille reading to understand neurologic and tactile limitations in diabetic patients	n = 35 Diabetes Type I (n = 22, M = 33 +/- 2) - Male: n = 9 - Female: n = 13 Diabetes Type II (n = 13, M = 56 +/- 1) - Male: n = 4 - Female: n = 9	Perceptual: Tactile acuity (static two-point discrimination threshold + nerve conduction study)	Gross determination of "reading capable," "reading incapable," or "reading Jumbo braille only"	N.R.	Two-point discrimination associated with braille reading ability, but not nerve conduction study results, among patients with known diabetic neuropathies (no statistical analyses reported)
Bertelson et al.[57]	The Quarterly Journal of Experimental Psychology / 1985	USA / English	Design: Cross-sectional systematic analysis; Aim: Examine hand movements used when reading	n = 24 Age range 18-64 - 5 female - 19 male	Motor: Hands utilized for reading and reading patterns (video examination)	Speed (reading time)	Aloud; Prose, statistical approximations, and scrambled words (with one hand, and with two hands simultaneously) – uncontracted braille	Reading patterns (one hand vs two hands) are strongly correlated with speed of reading (*r* with two hands separately vs together = -0.72, p = .001)
Bola et al.[11]	PLoS ONE / 2016	Poland / Polish	Design: Prospective trial; Aim: Evaluate success of	n = 29 Age range 22-49, Mdn = 27, Male: n = 3 Female: n = 26	Perceptual: Tactile acuity (GOT)	Speed (wpm)	Aloud; Character / word recognition –	No correlation between GOT tactile acuity threshold and reading speed: *r*(26) = -0.25, p = 0.206.

Study	Journal / Pub Year	Country / Lang.	Study Design and Objective	Sample Size / Characteristics	Measured Capacities / Instruments	Measured Reading Outcomes / Instruments	Modality and Nature of Reading Task	Relevant Findings
			braille reading course for sighted adults				uncontracted braille	No correlation between age of participant and reading speed: $r(27) = 0.11$, $p > .25$
Bradshaw et al. [58]	Neuropsychologia / 1982	USA / English	Design: Cross-sectional study; Aims: Test left-hand superiority of blind subjects in braille reading; Assess phonological and semantic processing mechanisms	n = 12 Age range 28-57 Male: n = 6 Female: n = 6	Motor: Hands utilized for reading (in front of and across the body)	Speed (reading time)	Silent; Scanning (lists of boy/girl names, words/non-words, vowels/ consonants) – uncontracted braille	No effect of hand used or hand position (cross body or not): $F(1, 11) = 1.2$, $p > .05$.
Chen et al. [59]	Research in Developmental Disabilities / 2019	China / Chinese (Common Chinese Braille)	Design: Cross-sectional study; Aim: Examine impact of hand patterns and reading	n = 73 Age range 11.42-22.08 (M = 14.89, SD = 2.17) Male: 49 Female: 24 48 congenital; 25 adventitious	Motor: Hands utilized for reading and reading patterns (video examination)	Speed (wpm); Comprehension (% of correct questions)	Silent and Aloud; Studying	Speed: Significant main effect for reading mode, with silent reading being faster ($F(1, 65) = 15.656$, $p < .001$, $\eta^2 = .194$); "Marginally significant" main effect for hand patterns ($F(3, 65) = 2.602$, $p = .059$, $\eta^2 = .107$). Comprehension: Significant main effect for reading

Study	Journal / Pub Year	Countr y / Lang.	Study Design and Objective	Sample Size / Characteristics	Measured Capacities / Instruments	Measured Reading Outcomes / Instruments	Modality and Nature of Reading Task	Relevant Findings
			mode on reading speed and comprehe nsion					mode, with oral reading leading to better comprehension ($F(1, 65) = 4.303$, $p < .05$, $\eta^2 = .062$). No main effect of reading pattern ($p > .05$). Adventitious vs congenital blindness not related to reading speed ($p > .10$) or reading comprehension ($p > .10$)
Clegg [60]	AFB Research Bulletin / 1973	USA / English	Design: Cross-sectional study; Aim: Evaluate whether the Tactile Discrimina tion Test predicts ability to discriminat e among braille characters	n = 52, all "legally blind"	Perceptual: Tactile acuity (Tactile Discrimination Test)	Accuracy (ability to recognize letters)	Modality N.R.; Discriminati on of braille letters (ranked and judged by two independent certified braille instructors)	Speed: Time to complete TDT associated with braille proficiency ranking ($r = .62$, $p = .01$); Accuracy: Correct response to TDT associated with braille proficiency ranking ($r = .55$, $p = .01$)
Danema n [61]	Memory & Cognition / 1988	Canada / English	Design: Cross-sectional study; Aim: to evaluate	n = 31 Age range: 23-59 (M = 37)	Cognitive: Listening comprehensio n; Braille span; Listening span	Accuracy (# of questions correct or errors detected); Speed (wpm)	Modality N.R.; Prose (reading for comprehens ion, and to identify out-	Reading comprehension significantly associated with listening comprehension ($r = .49$, $p < .01$), braille span ($r = .64$, $p < .001$), and listening span ($r = .66$, $p < .001$), but

Study	Journal / Pub Year	Countr y / Lang.	Study Design and Objective	Sample Size / Characteristics	Measured Capacities / Instruments	Measured Reading Outcomes / Instruments	Modality and Nature of Reading Task	Relevant Findings
			relationship between braille, listening comprehension, and working memory				of-context words) – contracted braille	not reading rate (*r* = .32, .18, .16 respectively, p > .05) Adventitious vs congenital blindness correlated with speed (r = -.55, p < .01) but not comprehension (r = .06). Age correlated with speed (r = .38, p < .05) but not comprehension (r = .09)
Davidson et al. [62]	Neurophysiologia / 1980	USA / English	Design: Cross-sectional study; Aim: examine whether haptic scanning variables impact braille proficiency	n = 18 Age M = 16.38, range 13-21 IQ M = 92.2, SD 14.58	Motor: Reading patterns and finger(s) used to read (video examination)	Accuracy (# of oral reading errors made); Comprehension (# of correct answers)	Aloud; Prose (reading for recall and comprehension) – contracted braille	"There was … no relationship between the use of any particular style and either the S's predetermined reading ability or the frequency of oral reading errors or retention errors." (No specific data or statistical analyses presented)
Davidson et al. [63]	Research in Developmental Disabilities / 1992	USA / English	Design: Cross-sectional study; Aim: Describe scanning movements (pauses,	n = 16, Age M = 16.5 (range 13-21), IQ M = 92.2 (SD = 14.6), divided into low- and high-proficiency groups based on Wide Range	Motor: Reading patterns – forward scanning, pausing, regressing (video examination)	Speed: Measured in cells per second	Aloud; Prose passages (source and content unspecified) – contracted braille	High proficiency readers used two handed methods on 75% of the cells read; Low-proficiency readers used two-handed methods only on 41% of cells read (chi-sq (1) = 22.35, p < .01);

Study	Journal / Pub Year	Country / Lang.	Study Design and Objective	Sample Size / Characteristics	Measured Capacities / Instruments	Measured Reading Outcomes / Instruments	Modality and Nature of Reading Task	Relevant Findings
			regressions, forward movements) of braille readers	Achievement Test (WRAT)				
Fertsch [64]	Outlook for the Blind *aka* Journal of Visual Impairment & Blindness / 1946	USA / English	Design: Cross-sectional study; Aim: Examine whether hand/finger use and movements during reading predict proficiency	N.R.	Motor: Reading patterns – forward regressing (video examination)	Speed: measure N.R.	Aloud and Silent; Prose passages – contracted vs uncontracted not reported	"Using both hands together to make regressive movements is a distinguishing characteristic of poor readers" (No specific data or statistical analyses presented)
Fertsch [65]	American Journal of Psychology / 1947	USA / English	Design: Cross-sectional study; Aim: determine which hand plays a greater role in reading and assess right/left hand superiority	n = 63 - 33 male - 30 female	Motor: Handedness (preference for throwing a ball); Hands utilized for reading (video examination)	Speed (reading time)	Silent and Aloud; Prose (reading for comprehension) – contracted vs uncontracted not reported	Handedness did not correlate with hand reading preferences or dominance; Readers whose hands were equal or who dependant mainly on their right hand read faster than readers dependant upon their left hand ($p < .05$); Individuals with significant hand dominance (i.e. % of cells read with the right or left hand being much greater than the opposing hand) read more slowly when

Study	Journal / Pub Year	Country / Lang.	Study Design and Objective	Sample Size / Characteristics	Measured Capacities / Instruments	Measured Reading Outcomes / Instruments	Modality and Nature of Reading Task	Relevant Findings
								forced to read with only one hand ($p < .05$)
Foulke [66]	Perceptual and Motor Skills / 1964	USA / English	Design: Prospective study; Aim: to evaluate transfer of braille reading ability from the index finger to others	n = 12 Age range 29-62 ($M = 47.08$, $SD = 9.53$) - 3 male - 9 female	Motor: Finger used to read	Speed of reading (wpm), Speed of letter identification (reading time), Accuracy of letter identification (# of errors)	Silent (for speed) + Aloud (for experimental condition); Prose (reading for comprehension, to determine reading speed); Random letter identification with various fingers (experimental task) - contracted vs uncontracte	No relationship between hand used and reading speed ($F(1) = 3.79$, $p > .05$) or accuracy ($F(1) = 2.97$, $p > .05$); As one moves away from the index finger for reading, degradations in speed ($F(3) = 103.92$, $p < .01$) and accuracy ($F(3) = 112.43$, $p < .01$) are observed

Study	Journal / Pub Year	Country / Lang.	Study Design and Objective	Sample Size / Characteristics	Measured Capacities / Instruments	Measured Reading Outcomes / Instruments	Modality and Nature of Reading Task	Relevant Findings
							d not reported	
Garcia [67]	British Journal of Visual Impairment / 2004	Spain / Spanish	Design: Prospective study; Aim: examine whether cloze or formal passage reading tests are equal for assessing braille reading comprehension	n = 13 Age: M = 44 11 male, 2 female	Motor: Reading patterns (one handed vs conjoined two-handed vs disjoint two-handed)	Speed (wpm), Comprehension (# correct answers)	Modality N.R.; Prose (reading for comprehension) – uncontracted braille	No significant difference in comprehension across reading pattern groups (*F*=0.64); Statistically significant difference between one-handed readers and two-handed disjoint readers (*t*=3.15, p < .05) Years of braille reading experience / age when braille learned was correlated with reading speed (C=.518, p = .037) but not reading comprehension (C=.250, p = .549)

Study	Journal / Pub Year	Country / Lang.	Study Design and Objective	Sample Size / Characteristics	Measured Capacities / Instruments	Measured Reading Outcomes / Instruments	Modality and Nature of Reading Task	Relevant Findings
Heinrichs [68]	New England Journal of Medicine / 1969	Canada / English	Design: Cross-sectional study; Aim: explore the impact of diabetic neuropathy on touch perception	Non-diabetic: N = 10 (6 male, 4 female, age M = 30, SD = 9); Diabetic: N = 10 (6 male, 4 female, M = 31, SD = 9)	Perceptual: Sensitivity to vibration with light touch ('touch perception') and heavy contact ('proprioception') Perceptual: Tactile acuity (Semmes-Weinstein nylon filament test) Perceptual: Tactile acuity (Two-Point discrimination (static))	Capacity (measured subjectively as "learned readily", "moderate difficulty", "great difficulty", "couldn't learn", "didn't try")	N.R.	"Subjects with marked elevation of touch-perception thresholds at their fingertips were scarcely able to feel the type at all" (Conclusory statement only; Raw data but no statistical analyses presented) NOTE: Nakada [78] subsequently describes this as a statistically significant difference ($p < .02$).
Hermelin et al. [69]	Neuropsychologia / 1971	England / English	Study #1: Design: Cross-sectional study; Aim: examine transfers of braille reading ability to	N = 16, age range 8-10	Motor: Reading hand and finger used	Speed (time taken); Accuracy (error count)	Modality N.R. but assumed to be aloud; Reading individual words and sentences – contracted braille	Speed: Index fingers were superior to other fingers ($p = .001$); Left hands were significantly faster than right ($F=12.99$, $p < .001$); Left index was significantly faster than right index ($t = 2.18$, $p < .05$); Left middle was significantly faster than right middle ($t = 2.90$, $p < .02$)

Study	Journal / Pub Year	Country / Lang.	Study Design and Objective	Sample Size / Characteristics	Measured Capacities / Instruments	Measured Reading Outcomes / Instruments	Modality and Nature of Reading Task	Relevant Findings
			non-preferred fingers/hand					Accuracy: No significant difference between index fingers; Significant difference between left and right middle fingers ($t = 2.45$, $p < .05$)
			Study #2: Design: Cross-sectional study; Aim: examine speed and accuracy of reading with non-preferred fingers	N = 15, age range 25-65, 7 male, 8 female	Motor: Reading hand and finger used	Speed (number of characters read in allotted time); Accuracy (error count)	Modality N.R. but assumed to be aloud; Reading randomized permutations of the alphabet – uncontracted braille	Speed: No significant difference (data and analyses N.R.) Accuracy: Significantly fewer errors were made with the left than the right hand (partial $F = 6.98$, $p = .02$)
Hislop et al. [70]	Journal of Rehabilitation Research and Development / 1985	USA / English	Design: Cross-sectional; Aim: to explore hand usage/reading patterns	N = 20 ('early 20's – 1 subject in her 60's, and a number of participants over 30)	Motor: Reading patterns (one vs two handed) (horizontal/vertical position measured with a position sensing system and finger-	Speed (wpm)	Silent; Prose (reading for comprehension) – contracted braille	Reading with two hands was marginally faster than with one (no statistical analysis reported)

Study	Journal / Pub Year	Countr y / Lang.	Study Design and Objective	Sample Size / Characteristics	Measured Capacities / Instruments	Measured Reading Outcomes / Instruments	Modality and Nature of Reading Task	Relevant Findings
					mounted LEDs)			
Holland [71]	Journal of Visual Impairment & Blindness / 1934	USA / English	Design: Prospective study; Aim: explore relation of pressure to speed	N = 17, pupils in grades 4-10 (estimated 9-15 years old)	Motor: Pressure/contact force of finger on reading material at start/mid/end of line)	Speed (time to read)	Modality N.R.; Prose (7-line passages from the Stanford Achievement Reading Test) – uncontracted vs contracted braille not reported	Positive correlation observed between pressure and reading speed (*r* = .27), but non-significant (and questionable given that overall, better/faster readers tended to use less and more consistent force)
Laroche et al. [72]	Journal of Visual Impairment & Blindness / 2012	Canada / French	Design: Cross-sectional study; Aim: assess impact of reading modality, age of learning braille, and hand	n = 30 Age range: 18-67 (M = 40.9, SD = 3.1) 15 male, 15 female	Motor: Reading hand used/hand patterns (one vs two handed)	Speed (wpm)	Silent and Aloud; Prose (newspaper article, novel passage) – contracted braille	Two-handed readers were faster, especially if they used the "scissors" pattern ($F(1, 10) = 12.91$, $p = .005$) Age of first learning braille correlated with reading speed ($F(1, 28) = 8.07$, $p = .008$, $\eta^2 = .40$). Those who learned braille before age 10 made significantly more errors when reading aloud ($t(20) = 2.08$, $p = .05$, $\eta^2 = .18$), but

Study	Journal / Pub Year	Country / Lang.	Study Design and Objective	Sample Size / Characteristics	Measured Capacities / Instruments	Measured Reading Outcomes / Instruments	Modality and Nature of Reading Task	Relevant Findings
			movements on speed					comprehension was unimpacted (no statistics reported).
Legge et al. [9]	Perception & Psychophysics / 2008	USA / English	Study #1: Design: Prospective study; Aim: explore correlation between a novel measure of tactile acuity and age in braille readers	n = 49 Age range: 18-74, M = 44.3, SD = 15.2	Motor: Hand used; Perceptual: Tactile acuity (Legge Dot Chart)	Speed (wpm)	Aloud; Sentence reading (MNREAD) – contracted braille	Neither "hand used" nor Legge Dot Chart acuity was associated with reading speed (p > .06)
			Study #2: Prospective study; Aim: explore correlation between a novel measure of tactile acuity and age in braille readers	"Younger" group: n = 10 age 23-39, M = 31.2 "Older" group: n = 12, age 56-81, M = 67.4, SD = 8.7	Perceptual: Tactile acuity (Legge Dot Chart and Legge Ring Chart)	Speed (wpm)	Aloud; Sentence reading (MNREAD) – contracted braille	No significant correlation between braille reading speed and tactile acuity (p > .70)

Study	Journal / Pub Year	Country / Lang.	Study Design and Objective	Sample Size / Characteristics	Measured Capacities / Instruments	Measured Reading Outcomes / Instruments	Modality and Nature of Reading Task	Relevant Findings
Loomis [73]	Bulletin of the Psychonomic Society / 1985	USA / English	Design: Prospective study; Aim: evaluate legibility of braille mediated by dot height, mode of touch (static or moving), character size, and contact force	n = 6 Age: 21-27 All female	Motor: Contact force	Accuracy (% correct)	Aloud; Discrimination of individual braille letters – uncontracted braille	Contact force/pressure (16-28g or 75-125g) was not associated with reading accuracy (48.5% vs 48.9% accuracy – no statistical analysis presented)
Millar [74]	Cortex / 1984	USA / English	Study #1: Design: Cross-sectional; Aim: examine impact of laterality on braille reading	n = 20 Age: M = 9.54 (range 6.0 - 11.83)	Motor: Hand used	Speed: Reading time (response latency); Accuracy (% correct)	Aloud; Same/different matching; Discrimination of individual braille letters – uncontracted braille	No significant effect of Hand on accuracy/errors, but task type (matching vs letter discrimination) showed an interaction with hand used ($F(1, 12) = 32.32$, $p < .001$). For speed, better readers showed a right-hand advantage for letter naming ($p < .025$) and discrimination tasks ($F(1, 12) = 5.55$, $p < .05$); poor readers showed a left-hand superiority for

Study	Journal / Pub Year	Countr y / Lang.	Study Design and Objective	Sample Size / Characteristics	Measured Capacities / Instruments	Measured Reading Outcomes / Instruments	Modality and Nature of Reading Task	Relevant Findings
								discrimination tasks ($p < .025$).
			Study #2: Design: Cross-sectional stud; Aim: compare two-handed reading and reading with either hand alone	n = 15 Age: M = 10.28 (range 6.58 - 11.83)	Motor: Hand (or hands) used	Speed (wpm)	Aloud; Reading lists of single words – uncontracted braille	No significant effect of Hand on speed ($F(1, 12) = 3.74$, $p > .05$ but $< .10$), but pre-planned t-tests suggested that one-handed reading was inferior to reading with either hand alone ($p < .025$)
Mommers (1976) [75]	Journal of Visual Impairment & Blindness / 1976	Holland / Dutch	Design: Cross-sectional study; Aim: validating correlates	N = 120, age 6-14	Perceptual: Tactile acuity (Roughness Discrimination Test (RDT); Tactile Kinesthetic	Speed (measure N.R.)	Aloud; Reading lists of words, sentences, and short stories –	No significance testing reported. For speed, correlations (for reading words/sentences) reported as follows: RDT = .24/.20

Study	Journal / Pub Year	Countr y / Lang.	Study Design and Objective	Sample Size / Characteristics	Measured Capacities / Instruments	Measured Reading Outcomes / Instruments	Modality and Nature of Reading Task	Relevant Findings
			to standardized braille reading tests in Holland		Form Discrimination Test (TKFDT); Haptic Size Discrimination Test (HSDT); Haptic Figure Orientation Test (HFOT); Haptic Object Discrimination Test (HODT)		uncontracted braille	TKFDT = .43/.42 HSDT = .30/.26 HFOT = .49/.47 HODT = .51/.49
Mommers (1980) [76]	Journal of Visual Impairment & Blindness / 1980	Holland / Dutch	Design: Cross-sectional; Aim: evaluate division of labour between both hands (replication of [69])	N = 25, age range 7.5-12	Motor: Hand and finger used	Speed (# words read, correctly or incorrectly, in 2 minutes + # of numerals read, correctly or incorrectly, in 1 minute); Accuracy (# of errors in first 50 words or numerals);	Aloud; Reading lists of words and numerals – uncontracted braille	Two hands together were “clearly faster than even the fastest index finger” alone for words and numerals: t(24) = 7.02 for words, t(24) = 4.35 for numerals, p = .005. No statistically significant difference for accuracy. No significant difference between right index finger and left index finger or right middle finger and left middle finger alone (for speed or accuracy). However, the data presented supports a “trend for left-handed reading of words to be faster and more accurate.”

Study	Journal / Pub Year	Country / Lang.	Study Design and Objective	Sample Size / Characteristics	Measured Capacities / Instruments	Measured Reading Outcomes / Instruments	Modality and Nature of Reading Task	Relevant Findings
Mousty & Bertelson [77]	The Quarterly Journal of Experimental Psychology / 1985	Belgium / French	Design: Cross-sectional study; Aim: consider how reading speed is affected by hand usage and reading context	n = 24 5 male, 19 male Age range: 18-64	Motor: Hand (or hands) used	Speed (wpm)	Aloud; Prose (novel passages); Approximations to French; Scrambled words – uncontracted braille	Use of two hands is faster than one (but not statistically significant: $F(2, 21) = 1.47, p > .10$)); otherwise, there was no effect of hand(s) Mean reading speed is higher for congenitally blind when reading with left hand ($t(22) = 1.79, p < .05$) and both hands together ($t(22) = 1.19, p < .1$).
Nakada & Dellon [78]	Microsurgery / 1989	Japan / Japanese	Design: Cross-sectional; Aim: evaluation tactile acuity and reading performance after 2 years of training	n = 25 Age: range 18-58, M=42.6, SD=10.2	Perceptual: Tactile acuity (Semmes-Weinstein nylon filament test, in both static/passive and moving/active modes); Static two-point discrimination; Two-point discrimination (moving)	Capacity (measured subjectively as "good" (sentence reading), "fair" (word reading), or "unable")	N.R.	No difference between good/fair readers across all tactile acuity tests; Significant difference ($p < .001$) in acuity levels between "unable" and "good/fair" groups on both moving and static two-point discrimination. Age/age braille learned significantly related to capacity for reading ($F(2, 22) = 3.956, p = .341$) *(**NOTE**: Japanese braille dot spacing is more compact than US/European braille and these results may not carry over to standard*

Study	Journal / Pub Year	Countr y / Lang.	Study Design and Objective	Sample Size / Characteristics	Measured Capacities / Instruments	Measured Reading Outcomes / Instruments	Modality and Nature of Reading Task	Relevant Findings
								US/European braille formats.)
Nolan & Morris [8]	The International Journal for the Education of the Blind / 1965	USA / English	Design: Prospective study; Aim: determine whether results from Roughness Discrimination Test predict reading readiness	n = 256, 133 male, 123 female, age range 6-12.3	Cognitive: IQ; Perceptual: Tactile acuity (Roughness Discrimination Test)	Speed (reading time), Accuracy (# of errors)	N.R.	Correlations reported between RDT scores and reading speed (-.42) and error performance (-.42) ($p < .05$) For students in grade two, multiple correlation including RDT performance *and* IQ yielded a stronger relationship to speed ($r = .48$) and accuracy ($r = .51$).

Study	Journal / Pub Year	Country / Lang.	Study Design and Objective	Sample Size / Characteristics	Measured Capacities / Instruments	Measured Reading Outcomes / Instruments	Modality and Nature of Reading Task	Relevant Findings
Olson et al. [79]	Journal of Visual Impairment & Blindness / 1975	USA / English	Design: Prospective study; Aim: explore impact of structured rapid reading training on speed and comprehension	Missouri group: n = 15, 11 female, 4 male, age 19-62 (M = 38.6) North Dakota group: n = 12, 8 female, 4 male, age 10-65 (M = 34.2)	Motor: Hand movements (number of fingers used)	Speed (reading rate)	Aloud; Reading prose selections from the Diagnostic Reading Scales test – contracted vs uncontracted braille not reported	The use of more than one finger in the braille reading process was positively correlated with an increase in reading rate (p < .05). No significant differences in speed found based on age. Age was significantly positively correlated with comprehension. (No statistics reported.)
Oshima et al. [80]	Journal of Visual Impairment & Blindness / 2014	Japan / Japanese	Design: Cross-sectional study; Aim: examine relationship between braille reading and tactile sensitivity	n = 19 Early blind (n = 9): - 5 male, 4 female - Age: Range 23-59, M = 41.3 (SD = 10.5) Late blind (n = 10): - 3 male, 7 female - Age: Range 20-65, M = 45.1 (SD = 16.4)	Perceptual: Tactile acuity (Legge "Dot" Chart, adapted for Japanese braille spacing)	Speed (reaction time), Accuracy (% correct answers),	Aloud; Word reading (2-cell words); Prose reading; Scrambled word reading; Numerical passage reading – uncontracted braille	No relationship found between tactile acuity and braille reading speed (when controlling for number of years reading braille ($r = -0.46$, $p < .05$), age of onset of blindness ($r = -0.08$, ns), or both ($r = 0.04$, ns). Age of learning braille significantly influenced speed ($F(1, 17) = 7.648$, $p < .05$, $\eta^2 = .24$) but not accuracy. *(**NOTE**: Japanese braille dot spacing is more compact than US/European braille and these results may not carry over to standard*

Study	Journal / Pub Year	Countr y / Lang.	Study Design and Objective	Sample Size / Characteristics	Measured Capacities / Instruments	Measured Reading Outcomes / Instruments	Modality and Nature of Reading Task	Relevant Findings
								US/European braille formats.)
Papadimitriou & Argyropoulos [81]	International Journal of Educational Research / 2017	Greece / Greek	Design: Cross-sectional study; Aim: explore relationship between hand movements and accuracy	n = 32, 18 female, 14 male, age M = 14.2 (SD = 3.3), range 8-21	Motor: Hand movements used	Accuracy: Number of errors in reading	Aloud; Reading prose – uncontracted braille	Braille reading patterns affected the number of errors (chi-sq (12) = 95.7, p < .001)
Sampaiao & Philip [82]	Perceptual and Motor Skills / 1995	France / French	Design: Cross-sectional study; Aims: To explore whether prior visual experience influenced laterality advantages; and to verify	n = 38 All right-handed participants Congenitally blind: - Age 19-62, M = 33.9 - 12 female, 9 male Early childhood blindness: - Age 20-50 (M = 34.4)	Motor: Use of non-preferred reading hand	Speed (reading time)	Aloud; Scanning (lists of 5-letter words, matched for braille legibility) – uncontracted braille	Among those blind at birth, those who preferred to read with the right hand performed better with this hand than with the left (when forced to read with one hand); those who preferred to read with the left hand performed better with this hand than with the right. This was not observed among those who lost their vision in early childhood.

Study	Journal / Pub Year	Country / Lang.	Study Design and Objective	Sample Size / Characteristics	Measured Capacities / Instruments	Measured Reading Outcomes / Instruments	Modality and Nature of Reading Task	Relevant Findings
			impact of hand preference in one-handed reading	- 10 female, 7 male				Congenital group: left preference, $F(1,10) = 6.97$, $p < .03$; right preference: $F(1,8) = 7.09$, $p < .03$. Early childhood group: left preference: $F(1,4) = 3.16$, ns; right preference: $F(1,7) = 3.51$, ns] A difference in speed was observed between the congenital and early childhood groups: $F(1, 34) = 6.89$, $p < .01$
Stevens et al. [10]	Journal of Experimental Psychology: Applied / 1996	USA / English	Design: Cross-sectional study; Aim: to explore tactile acuity, the effects of aging, and the impact on reading	Study #1: n = 33 - Age 18-81 ($M = 48.6$, $SD = 16.2$)	Perceptual: Tactile acuity (Gap Detection, Two-point Discrimination (static), Two-point Orientation)	Speed (wpm)	Silent; Sentences and words (Tinker-Carver Basic Reading Rate Scale) – uncontracted vs contracted braille not specific	Reading rate significantly correlated with gap detection ($r = -.54$, $p = .002$) and two-point orientation ($r = -.36$, $p < .05$); Two-point discrimination threshold was not ($r = -.16$, $p = .41$)

Study	Journal / Pub Year	Country / Lang.	Study Design and Objective	Sample Size / Characteristics	Measured Capacities / Instruments	Measured Reading Outcomes / Instruments	Modality and Nature of Reading Task	Relevant Findings
			performance	Study #2: n = 36 Younger Group (n = 15) - Age 19-34 Older Group (n = 21) - Age 60-82	Perceptual: Tactile acuity (Two-Point Gap Discrimination, Line Orientation, Length Discrimination)	Speed (wpm)	Silent; Sentences and words (Tinker-Carver Basic Reading Rate Scale) -- uncontracted vs contracted braille not specific	Two-point Gap Discrimination significantly inversely related to reading rate among older participants ($r = -.48$, $p < .04$); Line Orientation and Line Discrimination were not (statistics not reported).

Study	Journal / Pub Year	Country / Lang.	Study Design and Objective	Sample Size / Characteristics	Measured Capacities / Instruments	Measured Reading Outcomes / Instruments	Modality and Nature of Reading Task	Relevant Findings
Veispak et al. [83]	Research in Developmental Disabilities / 2012	Estonia / Estonian	Design: Cross-sectional study; Aim: to investigate associations between auditory, speech, phonological and tactile spatial processing, and reading performance	n = 12 Age Range 9-19.5, M = 14.25, SD = 3.25	Perceptual: Tactile acuity (Grating Orientation Test, GOT); Cognitive: Phonological awareness (phoneme deletion and spoonerism task); Cognitive: Verbal short-term memory (Digit span; Non-word repetition) Cognitive: Rapid Automatic naming; Cognitive: Speech perception (Word-in-Noise test)	Speed (measure not specified)	Aloud; Word and pseudoword reading – uncontracted braille	- Word-reading speed significantly correlated with phonological awareness (speed) ($r = .74, p < .05$), rapid automatic naming ($r = .81, p < .01$), and tactile acuity (GOT) ($r = .70, p < .05$) - Pseudoword-reading speed significantly correlated with phonological awareness (speed) ($r = .80, p < .01$) and rapid automatic naming ($r = .70, p < .05$) - Word-reading accuracy not significantly correlated with phonological awareness (speed or accuracy: $r = .33$ and $.45$), verbal short term memory ($r = .17$), rapid automatic naming ($r = .12$), speech-in-noise ($r = .01$), or tactile acuity ($r = .50$) - Pseudoword-reading accuracy correlated with phonological awareness (accuracy) ($r = .66, p < .05$), verbal short-term memory ($r = .64, p < .05$), rapid automatic naming ($r = .64, p < .05$), speech-in-noise ($r = .75, p < .05$), and tactile acuity (GOT) ($r = .66, p < .1$)

Study	Journal / Pub Year	Country / Lang.	Study Design and Objective	Sample Size / Characteristics	Measured Capacities / Instruments	Measured Reading Outcomes / Instruments	Modality and Nature of Reading Task	Relevant Findings
Veispak et al. [12]	Research in Developmental Disabilities / 2013	Holland / Dutch	Design: Cross-sectional study; Aim: to investdigate associations between auditory, speech, phonological and tactile spatial processing, and reading performance	n = 28 Age: M = 15.5 (SD = 3.5), 7 female, 7 male	Perceptual: Tactile acuity (Grating Orientation Test); Cognitive: Verbal Intelligence, Phonological Processing (phoneme deletion), Verbal Short-term Memory, Speech Perception	Speed (reading time); Accuracy (number of errors)	Aloud; Word, pseudoword, and story reading	- Phonological awareness accuracy correlated with word reading accuracy (r = .47, p < .05), pseudoword reading accuracy (r = .55, p < .01), story reading accuracy (r = .53, p < .01), and marginally with story reading speed (r = .34, p < .10) - Phonological processing speed was not correlated with reading performance on any measure (r <= .27) - Verbal short-term memory significantly correlated with word reading accuracy (r = .41, p < .05), pseudoword reading accuracy (r = .52, p < .01), story reading accuracy (r = .40, p < .05) - Tactile acuity (GOT) was significantly correlated with word reading speed (r = .45, p < .05) and marginally with story reading speed (r = .38, p < .10)

Study	Journal / Pub Year	Country / Lang.	Study Design and Objective	Sample Size / Characteristics	Measured Capacities / Instruments	Measured Reading Outcomes / Instruments	Modality and Nature of Reading Task	Relevant Findings
Wilkinson & Carr [84]	Brain and Language / 1987	USA / English	Design: Cross-sectional; Aim: examine impact of using non-preferred hand for reading	n = 63 (34 male, 29 female) - Congenitally blind or lost vision <= 2 years old - 41 were students in residential schools for the blind (age 11-18); - 22 were adult volunteers (age 19-70)	Motor: Handedness (Edinburgh) and hand preference; Hand and fingers used and hemispheric position relative to body; Cognitive: Short-term memory test (oral repetition of words); Comprehension test with concurrent memory load	Speed (reading time); Accuracy (number of errors)	Aloud; Word reading; Letter identification; Same/different matching; Passage reading (24 2-3 sentence paragraphs)	- Letter identification: hand use / hand preference impacted speed ($F(1,55) = 14.56$, $p < .001$) and accuracy ($F(1, 55) = 13.53$, $p < .001$) -- but a four-factor interaction between hand use, hand preference, sex, and order of hand use was also found, $F(1, 55) = 7.31$, $p < .05$. - Same/different matching: For 'easy' lists, hand use and hand preference impacted speed ($F(1, 55) = 5.66$, $p < .05$), but not accuracy. For 'hard' lists, hand use/hand preference were significant for both speed ($F(1, 55) = 9.59$, $p < .01$) and accuracy ($F(1, 55) = 6.32$, $p < .05$). - Recall lists: Phonological similarity of lists increased reading speed ($F(2, 118) = 7.15$, $p < .01$) - Comprehension under concurrent memory load: Hand use and hand preference demonstrated a robust relationship with reading times ($F(1, 55) = 34.49$, $p < .001$), but no significant results for accuracy

Study	Journal / Pub Year	Country / Lang.	Study Design and Objective	Sample Size / Characteristics	Measured Capacities / Instruments	Measured Reading Outcomes / Instruments	Modality and Nature of Reading Task	Relevant Findings
Wormsley [85]	Journal of Visual Impairment & Blindness / 1996	USA / English	Design: Cross-sectional study; Aim: to determine whether a hand-movement training program increased reading rates	n = 22 Age 6-12	Cognitive: IQ; Motor: Hand movement patterns	Speed (wpm)	Aloud; Passage reading – contracted vs uncontracted braille not specified	- Category 6 (both hands reading, the left for the first half of the line and the right for the second half of the line) "is associated with fastest reading rates" (raw data but no statistical analyses presented)
Wright et al. [86]	Journal of Visual Impairment & Blindness / 2009	USA and Canada / English	Design: Normalized five-year longitudinal; Aim: examine impact of hand movement patterns on reading speed	n = 38 15 male, 23 female Age (first year) M=5.33, range 3-7 Age (final year) M=8.51, range 7-11	Motor: Hand(s) used for reading; Movement patterns; Movement characteristics (regressions, scrubbing, etc.)	Speed (wpm)	Aloud; Passage reading; Reading included uncontracted, partially contracted, and fully contracted materials	- Reading rate was significantly impacted by hand pattern use ($F(12, 27) = 3.99$, $p < .01$, $r^2 = .76$) - Reading speed of two-handed readers increased significantly more quickly than for one-handed readers over time (i.e. starting with a two-handed method lead to greater gains in the long run): $B = 7.21$, $p < .05$

Appendix C: Interview guide for Chapter 3 (Qualitative)

Before learning braille

We are interested to know more about the factors that contributed to your decision to learn braille. Can you tell us a bit about the time before you started learning braille, what that time was like, and what factors led to you learning braille? Were there things that you found helpful or unhelpful to you at that time?

- Had you ever known a braille user or seen someone using braille before you began learning it yourself? How would you describe these interactions?
- How would you describe your feelings about learning braille when it was first considered as an option for you?
- How would you describe your feelings about vision loss before you began learning braille?
- How would you describe the response from family members once you decided to learn braille? How do you think they felt about you learning braille?

During Braille Training

We are also interested to learn more about your experience of learning braille as an adult, and whether there are certain things that you found helpful (facilitators) during this time, or things that you found unhelpful (barriers). Overall, how would you describe your experience of learning braille? Tell me what it was like to learn braille for you.

- How would you describe the response from your family members while you were learning braille?
- How did your point of view towards braille change, if at all, once you began learning it?
- Looking back on your braille training, is there one memory you have that still sticks with you today? For example, a positive or negative memory from your braille training?

After learning braille

Overall, what role does braille play in your life today, and how has this changed since your braille training ended, if at all?

- Now that you’ve learned braille, how would you describe your feelings about it?
- What would you tell an adult who is considering braille training?
- What are your feelings towards your vision loss today? How did learning braille influence these feelings, if at all?
- If you could change any aspect of your braille training to improve it, what would it be? Are there any features you would add/remove?

- What advice would you give family members related to someone who is going to be learning braille?
- Do you have any final thoughts you'd like to share about your experiences related to learning braille?

Background – Demographic Questions

Note: These questions will only be asked at the end of the interview if the information is not already available in the participant's rehabilitation file.

- Age
- Sex
- Visual diagnosis
- What is your level of education? (e.g. Some high school, High school, CEGEP/college diploma, Undergraduate, Masters, Ph.D, Graduate diploma or certificate)
- What is your employment status? (e.g. employed full-time, employed part-time, unemployed, retired, self-employed, student)
- What methods had you been using to read before you began learning braille? (e.g. print, audio)
- What methods do you currently use for reading now? (e.g. braille, audio, print)
- Where are you currently living (e.g. city)?
- What were your living arrangements during the time when you were learning braille (e.g. location, with whom)?
- Do you have any other diagnoses or health conditions?
    - e.g. diabetes mellitus, arthritis, hypertension, stroke, vascular problems, hearing impairment, reading disabilities
- Were there any medical procedures or other events that interrupted your braille training?
- At what age did you start learning braille?
- What braille codes did you learn?
- For how many years did you pursue braille training?
- How often were your braille lessons? (e.g. once a week for two hours)
- Would you consider yourself to be a poor, average or very good reader while growing up?
- How would you rate your current knowledge of braille? (poor, average, very good)
- How often do you currently use braille? (e.g. everyday, several times a week, once a week, never)
- For what tasks do you use braille? (address book, phone numbers, labelling household items, recipe book, personal notes, course/work notes, novels, reading related to studies, reading related to work, newspapers/magazines, letters/mail, reading to children/grandchildren, other)
- What do you consider to be your first learned language?
- What do you consider to be your second learned language (if applicable)?
- What language would you consider your dominant language (the language you're most comfortable in)?

- What was the language of instruction while you attended school?
- Please rate your level of ability using this scheme for each of the below tasks (for the language in which braille was learned)
    - 1 = no ability at all 2 = elementary 3 = moderate 4 = very good 5 = fluent ability
    - (speaking, reading, writing, listening)

Appendix D: Supplementary information for Chapter 4 (Correlation)

Appendix D1: Supplementary methodological information

This Supplementary Appendix provides additional information and details regarding the administration of certain assessments used in the study (not submitted for publication).

Motor: Purdue Pegboard Test

The Purdue Pegboard Test is a rectangular board with two sets of 25 holes running vertically, and four cups along the top edge. The full test battery includes four subtests, but for our purpose only the three peg placement tests (using the dominant hand, non-dominant hand, and both hands together) were utilized.

In this assessment, participants take small metal pegs from the cups at the top of the board and place them into the vertically aligned holes as rapidly as possible. The task was completed first with their dominant hand (taking from the cup on the right), then with the non-dominant hand (taking from the cup on the left), and then with both hands together. This process was repeated three times and the number of pegs successfully inserted averaged to arrive at a score for the dominant, non-dominant, and hands together modalities. In the “hands together” condition, the score is determined as the number of matching *pairs* of pins inserted into the board.

Cognitive: Tactile Working Memory Test

In our study, a silicone ice cube tray (Mity Rain B07FZ5FWZ1 40-Cavity Square Mold) was used as a holder or frame for the pattern, which was constructed using a combination of cotton balls (jumbo size) and 1” wood cubes (Nicedmm PY00407N-LFT-1CM) covered in coarse-grit sandpaper (Austor AMA-17-520, silicon carbide, 60 grit).

Beginning with the smallest possible pattern (2x2), participants were given a 10 second exploration period in which to memorize the pattern, after which time it was cleared from the board and the participant was asked to reconstruct it from memory. Figure 18 illustrates a few examples of the patterns used at different difficulty levels, where the shaded squares represent "rough" sections of the pattern. Consistent with Papagno,[1] the patterns were explored only with the preferred braille reading hand. This process was repeated twice, and each correct pattern scored. If at any given pattern size the participant achieved two or three correct patterns, the process was repeated with the next largest size. If the participant achieved only 1 or 0 correct patterns, testing was terminated.

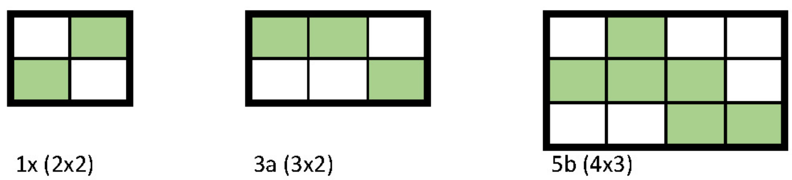
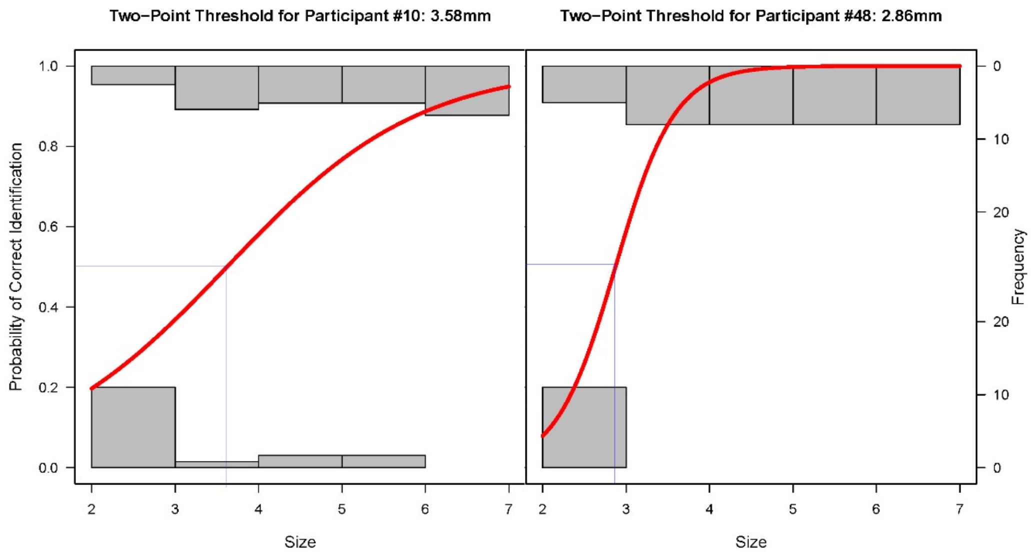


Figure 18. – Example patterns from the Tactile Working Memory test (shaded cells indicate "rough" portions of the pattern)

Following Papagno's methodology, the tactile span score was calculated as the average count of the number of rough blocks in the three largest patterns successfully reconstructed, with possible values ranging from 0 (if fewer than 2 matrices were successfully completed) to 15 (for the largest 6x5 matrix).

Tactile: Two-Point Discrimination Test

The passive two-point discrimination test measures the minimum distance at which two points of a caliper can be discerned on the skin. In our study, the points of the caliper were applied to the pad of the index finger on the preferred braille-reading hand for 3 seconds, with just enough force to blanch the skin, and the participant indicated verbally whether they perceived one or two points. Correct and incorrect results were plotted and a logistic regression line fitted to the data to ascertain the midpoint, defined as the threshold at which results surpassed chance, as shown in the subset of examples in Figure 19.



The grey bars represent the number of correct (top) and incorrect (bottom) trials at each distance; the red line represents the fitted logistic regression; the horizontal blue line represents the 50% correct threshold; and the intersecting vertical line is utilized to determine the two-point discrimination threshold.

Figure 19. – Example Two-Point Discrimination Plots

Tactile: Grating Orientation Task (GOT)

The JVP domes (Stoetling Co.) used for this test included groove widths of 3.5, 3, 2.5, 2, 1.5, 1.25, 1, 0.75, 0.5, and 0.35-mm, consistent with Bruns.[2] Participants were instructed to rest their hand on a table and the domes were manually applied to the tip of the index finger for approximately 1 second. Each stimulus was presented only once and participants were instructed to provide their 'best guess' where unsure.

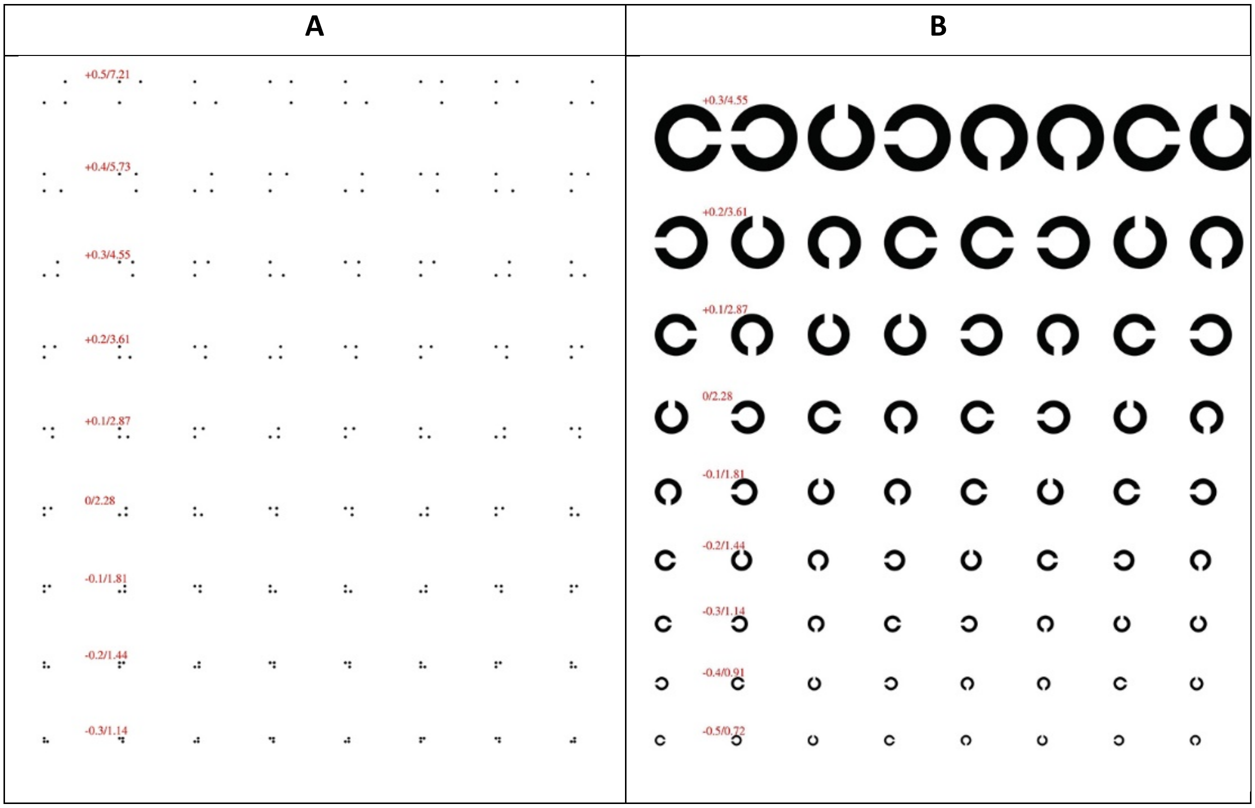
At each groove width, 20 trials were presented, half in each the horizontal (transverse) orientation, and half in the vertical (longitudinal) orientation, based on a predetermined pseudorandomized sequencing (of which four variations were used to counterbalance across all participants). As suggested in previous studies (see, for example, Bruns[2]), the 2mm groove width was selected as a starting point for those under age 55, while the 3mm groove width was selected as a starting point for those 55 and older.

At the end of each set of trials, the percentage correct was calculated and a decision was made on whether to repeat the current block (50-75% correct), increase the difficulty of the task by moving to a smaller gap size (if the participant achieved >75% correct), or accept that the perception threshold has been reached (< 50% correct or 50-75% correct on two consecutive blocks). If, at the very start of testing, a participant scored less than 50%, a larger groove width was selected until either the largest width had been tested (3.5mm) or they achieved more than 75% correct.

Tactile: Legge "Dot" and "C" Charts

The "Dot" chart (Figure 20A) consists of symbols containing four dots in a square configuration, one of which is omitted in each character, roughly equivalent to the braille characters *d*, *f*, *h*, and *j*. Each line of the chart contains eight characters, including all four character orientations. Standard braille dot spacing (2.28mm) is designated as the "0 log" line, and the lines above and below are scaled in uniform logMAR steps (from -0.3 to +0.5) so that distance between the center of each dot to the adjacent dots changes accordingly, with the size of the dots themselves kept constant at 1mm.

The "Landolt-C" chart (Figure 20B) consists of repeated occurrences of the letter "C" (represented by the Sloan TrueType font) in one of four orientations (0°, 90°, 180°, 270°). Each line of the chart contains eight characters, including all four character orientations. Standard braille spacing (2.28mm), measured by the width of the gap in the letter "C", is designated as the "0 log" line, and scaled in uniform logMAR steps (from -0. to +0.3) so that distance between the edges of the gap in the letter "C" changes accordingly, in proportion to the size of the "C" itself.



NOTE: logMAR and mm gap size values are depicted in red text. The “0/2.28” lines on each chart represent standard braille spacing.

Figure 20. – Images of the (A) Legge “Dot” and (B) Legge “C” Charts

The Legge “Dot” and “C” Charts used in this study were produced on heat-sensitive Swell Touch Paper Touch Paper (American Thermoform: La Verne, CA), and fused with a PIAF Picture in a Flash Tactile Graphic Maker (Piaf Tactile: Poznan, Poland). While this material differed from Legge et al.’s original charts, Bruns et al.[2] demonstrated that variations in the materials utilized were immaterial to the acuity measurements. For each batch of charts produced, the size and spacing of two randomly selected symbols from each line were manually verified using a Mastercraft 6-inch Digital Caliper (P/N 058-6800-4) and slight scaling adjustments made (<2% in each case) to account for paper swell and variations in printer precision. Replacement charts were used with each participant to avoid quality deterioration.

Consistent with the Legge and Bruns procedures, this test was not timed since accuracy was more important than speed.

Tactile Acuity Norms

Table 19 (on the following page) presents a summary of the tactile acuity thresholds that have been reported in prior research involving blind and sighted participants, as well as the thresholds found in the studies reported in Chapters 4 and 5 (for comparative purposes).

Table 19. – Tactile acuities reported in selected prior research and the current studies

Measure/Subject Group [a]	M ± SD (mm)
Two-point Discrimination	
Sighted (age 19-30, M=23.4)[2]	1.37 ± 0.32
Sighted (age M=24 ± 3.0)[3]	1.58 ± 0.17
Sighted pianists (age 21-27)[4]	1.14 ± 0.35
Sighted non-pianists (age M=25)[4]	1.59 ± 0.20
Sighted (age 18-33)[5]	1.95 ± 0.69
Blind (age 18-39, M = 32.67 ± 5.21)[6]	2.06 ± 0.45
Sighted (age 41-63)[5]	2.68 ± 0.44
Blind (age 18-81, M = 48.6 ± 16.2)[7]	1.01
Sighted (age 18-81, M= 48.7 ± 16.1)[7]	1.21
Sighted (age 47-51)[3]	2.61 ± 0.48
Blind (age 41-60, M = 52.2 ± 4.97)[6]	1.95 ± 0.75
Blind (age 64-88, M = 69.29 ± 6.54)[6]	2.29 ± 1.06
Sighted (age M=74.9 ± 5.4)[3]	3.42 ± 0.5
Sighted (age 66-91)[5]	5.03 ± 1.88
Grating Orientation Test	
Sighted (age 19-30, M=23.4)[2]	1.35 ± .51 [b]
Blind – at age 25[8]	1.49 [c]
Sighted – at age 25[8]	1.65 [c]
Blind (age 18-39, M = 32.67 ± 5.21)[6]	1.22 ± 0.36
Sighted (age 19-75, M=40)[4]	1.28 ± 0.11
Blind (age 18-70, M=41)[4]	1.35 ± 0.13
Blind (age 25-55)[9]	1.04 ± 0.19
Sighted (age 25-55)[9]	1.46 ± 0.46
Blind (age 41-60, M = 52.2 ± 4.97)[6]	1.56 ± 0.66
Blind (age 64-88, M = 69.29 ± 6.54)[6]	2.04 ± 0.59
Blind – at age 75[8]	2.01 [c]
Sighted – at age 75[8]	2.62 [c]

Measure/Subject Group [a]	M ± SD (mm)
Legge "Dot" Chart	
Sighted (age 19-30, M=23.4)[2]	1.32 ± 0.27 [b]
Sighted pianists (age M=24.5)[10]	1.60
Sighted (age 22-35, M=29.3 ± 4.8)[11]	1.45 [d]
Blind (age 23-39, M=31.2 ± 5.8)[11]	1.21 [d]
Blind (age 18-39, M = 32.67 ± 5.21)[6]	1.40 ± 0.21
Sighted (age 12-82, M=40.1 ± 21.2)[11]	1.21 [d]
Blind (age 23-59, M=41.3 ± 10.5)[12]	1.16 ± 0.10
Blind (age 18-74, M=44.3 ± 15.2)[11]	1.61 [d]
Blind (age 20-65, M=45.1 ± 16.4)[12]	1.31 ± 0.18
Blind (age 41-60, M = 52.2 ± 4.97)[6]	1.34 ± 0.18
Sighted pianists (age M=64.7)[10]	1.95
Blind (age 52-77, M=65.3 ± 10.24)[13]	2.80 ± 0.94
Blind (age 56-81, M=67.4 ± 8.7)[11]	1.24 [d]
Blind (age 64-88, M = 69.29 ± 6.54)[6]	1.57 ± 0.35
Sighted (age 57-85, M=70.3 ±9.5)[11]	2.26 [d]
Legge "C" Chart	
Sighted (age 19-30, M=23.4)[2]	0.82 ± 0.13 [b]
Sighted pianists (age M=24.5)[10]	0.90
Sighted (age 22-35, M=29.3 ± 4.8)[11]	0.94 [d]
Blind (age 23-39, M=31.2 ± 5.8)[11]	0.83 [d]
Blind (age 18-39, M = 32.67 ± 5.21)[6]	0.89 ± 0.06
Blind (age 41-60, M = 52.2 ± 4.97)[6]	0.91 ± 0.13
Sighted pianists (age M=64.7)[10]	1.10
Blind (age 56-81, M=67.4 ± 8.7)[11]	0.77 [d]
Blind (age 64-88, M = 69.29 ± 6.54)[6]	1.03 ± 0.25
Sighted (age 57-85, M=70.3 ±9.5)[11]	1.25 [d]

[a] Results (age reported as mean ± standard deviation where available) are presented approximately in order by the median/mean age of each subject group. Results from the present studies are shaded in gray.
[b] Calculated based on the overall average threshold scores reported in Table S1
[c] As reported by Legge[11] with the aid of additional information from the authors
[d] Reported as the median (not the mean)

References

1. Papagno C, Minniti G, Mattavelli GC, Manatovan L, Cecchetto C. Tactile short-term memory in sensory-deprived individuals. Experimental Brain Research. 2017; 235(2):471-80.
2. Bruns P, Camargo CJ, Campanella H, Esteve J, Dinse HR, Röder B. Tactile acuity charts: a reliable measure of spatial acuity. PloS One. 2014; 9(2):e87384.
3. Dinse HR, Kleibel N, Kalisch T, Ragert P, Wilimzig C, Tegenthoff M. Tactile coactivation resets age-related decline of human tactile discrimination. Annals of Neurology. 2006; 60(1):88-94.
4. Grant AC, Thiagarajah MC, Sathian K. Tactile perception in blind braille readers: A psychophysical study of acuity and hyperacuity using gratings and dot patterns. Perception & Psychophysics. 2000; 62(2):301-12.
5. Stevens JC. Aging and spatial acuity of touch. Journal of Gerontology. 1992; 47(1):35-40.
6. Martiniello N, Barlow M, Wittich W. Exploring correlates of braille reading performance in adults and older adults with visual impairment: a retrospective study. Scientific Studies of Reading. 2020 – submitted.
7. Stevens JC, Foulke E, Patterson MQ. Tactile acuity, aging, and braille reading in long-term blindness. Journal of Experimental Psychology: Applied. 1996; 2(2):91-106.
8. Goldreich D, Kanics IM. Tactile acuity is enhanced in blindness. J Neurosci. 2003; 23(8):3439-45.
9. van Boven RW, Hamilton RH, Kauffman T, Keenan JP, Pascual-Leone A. Tactile spatial resolution in blind Braille readers. Neurologist. 2000; 54:2230-6.
10. Legge GE, Granquist C, Lubet A, Gage R, Xiong YZ. Preserved tactile acuity in older pianists. Atten Percept Psychophys. 2019; 81(8):2619-25.
11. Legge GE, Madison CM, Vaughn BN, Cheong AMY, Miller JC. Retention of high tactile acuity throughout the lifespan in blindness. Perception & Psychophysics. 2008; 70(8):1471-88.
12. Oshima K, Arai T, Ichihara S, Nakano Y. Tactile sensitivity and braille reading in people with early blindness and late blindness. Journal of Visual Impairment & Blindness. 2014; 108(2):122-31.

13. Martiniello N, Wittich W. Exploring the influence of reading medium on braille learning outcomes: A case series of 6 working-age and older adults. British Journal of Visual Impairment. 2020 - submitted.

Appendix D2: Textual equivalence of IReST passages to prior assessments of braille reading performance (submitted for publication as Supplementary Appendix A)

The use of standardized texts for reading performance evaluations is important to enable comparisons to be made across studies.[1] While well-developed tests (utilizing single sentences) exist for measuring basic reading performance, including in braille readers with Legge's MNREAD,[2] reading longer *paragraphs* is more akin to daily reading demands, allows for less error in timing measurements, and affords readers the benefit of context while reading.[1,3] As few studies have utilized the IReST with braille readers, it was considered prudent to assess its equivalence to other braille performance reading measures.

The four IReST passages,[3] as a group, have similar word-length characteristics as those used in prior braille reading assessments such as Legge's MNREAD.[2] Table 20 describes the characteristics of these four IReST passages individually and as a group and compares those characteristics with MNREAD and the five comparative texts that Legge et al. analyzed when developing the MNREAD assessment. Table 21 describes the relationships (character count ratios) between print and braille as well as between contracted and uncontracted braille.

No material differences emerged from the comparison. The uncontracted braille passages contained only a few more characters than the original print texts, accounted for entirely by the presence of capital sign indicators at the beginning of each sentence in each of the passages. The contracted braille passages are 23% shorter than their uncontracted and print counterparts. While the MNREAD passages were more contracted (with a reduction of 28%), the IReST passages are written at a higher vocabulary level making them slightly less contractable, consistent with Legge et al.'s prior findings.

Table 20. – Word and character counts of IReST passages utilized in this study and Legge et al. comparative passages

Source	Print Text		Uncontracted Braille		Contracted Braille	
	Words[b]	Chars[c]	Words[b]	Chars[c]	Words[b,d]	Chars[c,d]
IReST Passages						
#1 “Mice”	156	831	156	837	156	642
#3 “Trees”	157	835	157	.846	157	627
#4 “Prey”	165	830	165	838	165	674
#10 “Colours”	141	833	141	842	141	658
IReST Overall (Total)	**619**	**3,329**	**619**	**2,518**	**619**	**2,601**
Legge Comparators[a]						
MNREAD	597	3,000	597	3,050	561	2,200
DNR	5,123	30,757	5,177	32,159	4,912	25,975
Norman	6,870	41,511	6,915	42,379	6,569	32,248
Alice	26,458	142,508	26,660	149,416	25,443	112,254
Starr	65,090	382,926	65,566	411,496	62,912	337,608
Grimm	281,047	1,442,477	282,871	1,469,443	269,681	1,061,193
Legge Overall (Total)	**385,185**	**2,043,179**	**387,786**	**2,107,943**	**370,078**	**1,571,478**

[a] The Legge et al.[2] comparator sources included a corpus of 50 MNREAD sentences and copies of texts attained from publicly available internet sites, including boating regulations extracted from the Wisconsin Department of Natural Resources Bureau of Law Enforcement web site (DNR); *Alice’s Adventures in Wonderland* by Lewis Caroll (Alice); the *Referral from Independent Counsel Kenneth W. Starr in Conformity with the Requirement of Title 28, United States Code, Section 595, is a United States federal government report by Independent Counsel Ken Starr concerning his investigation of President Bill Clinton* (Starr); Chapter 1 from *The Invisible Computer* by D.A. Norman, MIT: Bradford Books, 1998 (Norman); and *Grimm’s Fairy Tales* from Project Gutenberg (Grimm)

[b] Words were counted as any string of letters, numbers, or punctuation separated by spaces or new lines

[c] All characters were counted, including punctuation, spaces, and new line symbols. (In Legge’s materials, multiple spaces were counted as a single space, but this was not an issue with the IReST passages.)

[d] Certain changes occurred in the rules for contracted braille ca. 2010 that would impact on these word and character counts. For example, in 1999, certain words such as “to” could be contracted to a single symbol, and certain symbols could be run together or abutted without a space between them. The adoption of the new Unified English Braille Code rules in Canada in 2010[4] and the United States in 2016[5] removed certain of these contractions, and as such these word and character counts may have been slightly greater had the Legge comparator passages been prepared today.

Table 21. – Word and character ratios comparing among print, uncontracted braille, and contracted braille

Source	Print chars[c] / Print words[b]	Uncontracted chars[c] / Print chars[c]	Contracted chars[c,d] / Print chars[c]	Contracted chars[c,d] / Uncontracted chars[c]
IReST Passages				
#1 “Mice”	5.33	1.01	0.77	0.77
#3 “Trees”	5.32	1.01	0.77	0.74
#4 “Prey”	5.03	1.01	0.81	0.80
#10 “Colours”	5.91	1.01	0.79	0.78
IReST Mean	**5.38**	**1.01**	**0.78**	**0.77**
Legge Comparators [a]				
MNREAD	5.02	1.02	0.73	0.72
DNR	6.00	1.05	0.84	0.81
Norman	6.04	1.02	0.78	0.76
Alice	5.39	1.05	0.79	0.75
Starr	5.88	1.07	0.88	0.82
Grimm	5.13	1.02	0.76	0.72
Legge Mean	**5.30**	**1.03**	**0.77**	**0.76**

[a] The Legge et al.[2] comparator sources included a corpus of 50 MNREAD sentences and copies of texts attained from publicly available internet sites, including boating regulations extracted from the Wisconsin Department of Natural Resources Bureau of Law Enforcement web site (DNR); *Alice’s Adventures in Wonderland* by Lewis Caroll (Alice); the *Referral from Independent Counsel Kenneth W. Starr in Conformity with the Requirement of Title 28, United States Code, Section 595, is a United States federal government report by Independent Counsel Ken Starr concerning his investigation of President Bill Clinton* (Starr); Chapter 1 from *The Invisible Computer* by D.A. Norman, MIT: Bradford Books, 1998 (Norman); and *Grimm’s Fairy Tales* from Project Gutenberg (Grimm)

[c] All characters were counted, including punctuation, spaces, and new line symbols. (In Legge’s materials, multiple spaces were counted as a single space, but this was not an issue with the IReST passages.)

[d] Certain changes occurred in the rules for contracted braille ca. 2010 that would impact on these word and character counts. For example, in 1999, certain words such as “to” could be contracted to a single symbol, and certain symbols could be run together or abutted without a space between them. The adoption of the new Unified English Braille Code rules in Canada in 2010[4] and the United States in 2016[5] removed certain of these contractions, and as such these word and character counts may have been slightly greater had the Legge comparator passages been prepared today.

References

1. Trauzettel-Klosinski S, Dietz K. Standardized assessment of reading performance: the New International Reading Speed Texts IReST. Investigative Ophthalmology and Visual Science. 2012; 53(9):5452-61.
2. Legge GE, Madison CM, Mansfield JS. Measuring braille reading speed with the MNREAD test. Visual Impairment Research. 1999; 1(3):131-45.
3. Hahn G, Penka D, Gehrlich C, Messias A, Weismann M, Hyvärinen L, et al. New standardised texts for assessing reading performance in four European languages. British Journal of Ophthalmology. 2006; 90(4):480-4.
4. Marshall C, Holbrook MC. Description of Unified English Braille Implementation in Canada. Journal of Visual Impairment & Blindness. 2015; 109(6):518-20.
5. D'Andrea FM. Unified English Braille: The future of braille in the United States. Journal of Visual Impairment & Blindness. 2013; 107(3):243-6.

Appendix E: Supplementary information for Chapter 6: Table of Recommendations

Statement	Chapter	Recommendation(s)
The motivation to learn braille is instigated by a perceived “need to know” but prospective learners may be operating upon misconceptions about what braille is and who it can serve (e.g. only for extensive reading, only for the totally blind, too difficult to learn)	3 (Qualitative)	Provide early and ongoing practical applications of braille based on personal goals
		Address misconceptions about braille with prospective clients to ensure that it is not overlooked merely based on lack of awareness
Clients who identified strongly as readers and with the physicality of reading prior to vision loss may use other methods (such as audio) but this may not address the loss of identity they feel	3 (Qualitative)	Consider not only what tools may be best to complete a specific task, but also the holistic experiences attached to literacy that adults carry with them as important sources of motivation
Clients with positive previous learning experiences may both consciously and unconsciously draw on these examples as reference points and sources of information. Negative learning experiences from the past may also serve as invisible barriers, especially if clients do not feel confident in their identity as learners generally	3 (Qualitative)	As part of the initial information gathering process of assessment, inquire about past learning experiences, study tactics which have been most effective, level of education, previous literacy experiences
Adult learners may benefit from past tactics which have served them well, such as drawing on visual imagery or the use of self-checking study tools	3 (Qualitative)	Include adult learners in the assessment process, by discussing which methods work well and which do not. Recognize adult learners as experts in the learning process
Family members may carry misconceptions and stigma about braille, may not understand its utility, and may either motivate or discourage the learning of braille based on their reactions.	3 (Qualitative)	As part of the initial information gathering assessment process, ask adult braille learners about their support system and about any perceived or expressed feelings towards braille that family members may have.

Statement	Chapter	Recommendation(s)
		Provide resources (information about the utility of braille; information to address misconceptions; basic resources to learn the braille alphabet) as needed. Consider compiling a package of resources for family members that is provided to all new adult braille clients, as part of the process.
		Provide the option for family member or spouse to attend an initial session to learn more about the use of specific braille tools (such as braille labelling devices) and how they can support braille learning. Check in to see if additional resources or concerns arise among family members as the client's learning progresses learning
		Investigate community resources, both within and outside of the organization, where sighted family members and friends can be directed, should they want to learn braille as well. Consider possible grass-root efforts if there is enough interest
Reactions from the general public may lead adult braille learners to feel reluctant about braille due to stigma and hypervisibility of braille as a symbol of blindness. Adult braille learners may also carry stigma towards braille and blindness that influences the learning process	3 (Qualitative)	Provide adult braille learners with opportunities to meet other braille users as positive examples of braille to counter feelings of stigma. Consider group-based options for learning braille, to provide adult braille learners with others as reference points
		Talk about braille as a tool that will ultimately minimize impairment by enabling independence rather than heightening it. Discuss the impact of social interactions as part of the adult braille learning process, and possible ways of responding to these interactions
		Consider organization-wide strategies for community-based public education, alongside braille users, to address public misconceptions

Statement	Chapter	Recommendation(s)
Reading performance can be enhanced both through ongoing practice and the use of tools that mitigate the impact of reduced tactile acuity	3 (Qualitative) 4 (Correlation) 5 (Case Series)	Collect information about topics of interest (reading inventory) to use when designing reading activities as part of the initial information gathering assessment process
		Ensure that adult braille learners are connected to libraries for the blind and other organizations that can immediately start providing practice materials, as part of the initial braille learning process
		Investigate funding options for braille display devices or the purchase of lower cost braille devices, as appropriate. Liaise with technology specialists on team to consider ways of incorporating braille within assistive technology training
		Consider incorporating braille displays early in the learning process to supplement paper-based methods. Can be used to initially introduce symbols and to decrease frustration if tactile sensitivity is impaired
		Have a plan to support adult braille learners as they transition away from training. Consider peer-support groups or other resources to help them maintain their skills once training concludes. Consider keeping file open for a duration for follow-up to facilitate responsive remedial training if required
Passive acuity measures provide information about tactile perception, but active tactile perception and hand movements are vital to efficient braille reading	2 (Scoping) 4 (Correlation)	If measuring tactile acuity to provide a baseline as part of initial assessment, or to objectively measure changes throughout training, use measures of *active* tactile acuity, such as the Legge Dot chart. However, recognize that tactile acuity is only one component of efficient braille reading and this information alone will not determine reading potential in most cases
		Ensure that clients, unless physically unable due to other impairments, are taught to use bimanual reading techniques

Statement	Chapter	Recommendation(s)
		from the start, beginning with cooperative two-handed reading and possibly advancing to scissors technique if appropriate
		Consider tactics to facilitate tactile perception, such as explaining the logic of the braille system to assist in recognizing letter configurations; using braille displays of greater height and density to supplement traditional methods
Clients who learn braille at younger ages will achieve better braille reading performance, if well supported	3 (Qualitative) 4 (Correlation)	Consider incorporating braille instruction early in the vision loss process, even if sight enhancement is still being primarily used, assuming practical applications for braille outside of sessions can be found
The reduced tactile sensitivity that older learners exhibit may increase cognitive load and slow reading speed even in the absence of observable age-related cognitive declines	4 (Correlation)	Evaluate both cognitive and tactile functioning to help isolate the source of reading challenges and provide appropriate rehabilitation supports, including the use of strategies that build upon intact domains
Objective measures of tactile acuity will provide information about threshold and might be useful for determining whether a prospective client will benefit from increased support	4 (Correlation)	Active tactile acuity measures may help from a diagnostic perspective; however, as with measures of visual acuity, these measures do not necessarily inform about functional capacities. A functional assessment of demonstrated ability should also be undertaken, and it must be remembered that tactile acuity can, in many cases, be improved with practice