

A MULTIMETHOD EXAMINATION OF PSEUDONEGLECT AND AGING

A Thesis Submitted to the College of
Graduate and Postdoctoral Studies
in Partial Fulfillment of the Requirements
for the Degree of Doctor of Philosophy
in the Department of Psychology
University of Saskatchewan
Saskatoon, Saskatchewan

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ABSTRACT

Neurologically healthy adults display a reliable leftward perceptual bias during visuospatial tasks, and this bias appears to change with age. The goal of the current research was to provide an examination of age-related differences in the expression of pseudoneglect and explore whether a shift in the perceptual bias with age was associated with daily activities, such as driving. Chapter 1 provides an overview of hemispatial neglect and pseudoneglect. Chapter 2 reports on results of an Internet-based survey in which the developmental trajectory of pseudoneglect was investigated using the greyscales task, which is known to generate a stronger and more consistent leftward bias among adults than similar tasks. Age was found to be positively correlated with a leftward bias, and the oldest age group exhibited a significantly stronger leftward bias compared to the youngest age group. Chapter 3 outlines the results of a systematic review that was used to synthesize previous literature that has examined the association between age and pseudoneglect. The systematic search revealed that five different tasks have been used to examine pseudoneglect in younger and older adults, and that participants over 60 years of age have demonstrated inconsistent perceptual biases (e.g., enhanced leftward bias, suppressed leftward bias, and rightward bias). The objectives of the quasi-experiment reported in Chapter 4 were to replicate the findings presented in Chapter 2 in a laboratory environment, and further understand influential methodological (e.g., task demands) and individual factors (e.g., normative and non-normative aging) on performance. Again, older adults, whether healthy or displaying symptoms of cognitive impairment, exhibited a leftward bias comparable to younger adults on the greyscales task, but demonstrated a weaker leftward bias on the landmark task. The study presented in Chapter 5 explored the potential association between age-related differences in pseudoneglect and driving by examining location of impact data associated with crashes and near crashes retrieved from a database of real-world driving behaviour. In contrast with results from laboratory environments, age was not associated with location of impact during crashes and near crashes, and overall, crashes were 1.41 times as likely to occur on the left compared to the right side of participants' vehicles. Chapter 6 summarizes the findings presented in prior chapters and notes potential future directions. Together, the results of both laboratory and naturalistic studies outlines the variability in pseudoneglect demonstrated by healthy older adults, informs future research regarding the importance of task demands and non-normative aging, and highlights the potential implications of lateral perceptual biases.

ACKNOWLEDGEMENTS

I would like to thank the many participants who volunteered their time to participate in my studies, particularly those from the community who navigated the university campus to participate in my laboratory experiments. I would also like to thank the Saskatoon Council of Aging for their partnership and instrumental role in assisting in the recruitment of seniors within Saskatoon.

Second, I would like to express gratitude to the Natural Sciences and Engineering Research council (NSERC) for their financial support, which allowed me to concentrate on my research, academic studies, and training.

Third, I would like to convey my appreciation to my supervisors Dr. Lorin Elias and Dr. Paulette Hunter, and thank them for their guidance throughout my graduate career. I am grateful for their collaboration in supervising and supporting both my clinical and neuroscience interests. Both of you have taught me valuable skills that have shaped my development as a scholar and clinician. I would also like to thank my committee members, Dr. Megan O'Connell, Dr. Marla Mickleborough, and Dr. Chelsea Willness, for their respective expertise, insightful ideas, and thoughtful feedback, all of which helped shape my research.

Fourth, on a personal note, I am grateful to my parents, Blair and Lillian Neilly, for valuing education and for supporting me in reaching each goal I set – big or small. Last, I would like to thank my husband, Tyson Friedrich, for his unwavering support and encouragement on my journey through graduate school. Importantly, your patience and composure when I faced new challenges was instrumental in helping me succeed in the clinical psychology program and is greatly appreciated.

TABLE OF CONTENTS

	Page
Permission to Use	i
Abstract	ii
Acknowledgements	iii
Table of Contents	iv
List of Figures	viii
List of Tables	ix
List of Abbreviations	x
List of Appendices	xi
CHAPTER 1	1
GENERAL INTRODUCTION	
1.1 Hemispatial Neglect	1
1.1.1 Tasks Used to Assess Hemispatial Neglect	3
1.2 Brain Regions Associated with Hemispatial Neglect	4
1.3 Pseudoneglect	6
1.3.1 Tasks Used to Assess Pseudoneglect	6
1.4 Brain Regions Associated with Pseudoneglect	8
1.5 Age-related Changes in Pseudoneglect	9
1.6 Models of Neurocognitive Aging	10
1.7 Pseudoneglect in Atypical Populations	14
1.8 Pseudoneglect and Real-World Consequences	15
1.9 Conclusion	17
CHAPTER 2	18
THE DEVELOPMENTAL TRAJECTORY OF PSEUDONEGLECT IN ADULTS USING THE GREYSCALES TASK	
2.1 Methods	22
2.1.1 Participants	22
2.1.2 Survey	22
2.2 Results	24
2.3 Discussion	27

2.3.1 Limitations	29
2.4 Conclusion	30
CHAPTER 3	31
THE TRAJECTORY OF PSEUDONEGLECT IN ADULTS: A SYSTEMATIC REVIEW	
3.1 Methods.....	32
3.1.1 Search Strategy and Information Sources	32
3.1.2 Eligibility Criteria	33
3.2 Results	34
3.2.1 Study Selection	34
3.2.2 Line Bisection Task	36
3.2.3 Landmark Task	43
3.2.4 Greyscales Task	45
3.2.5 Tactile Rod Bisection Task	47
3.2.6 Lateralized Visual Detection Task	48
3.2.7 Summary of Results	49
3.3 Discussion	50
3.3.1 Limitations	56
3.4 Conclusion	57
CHAPTER 4	58
REASSESSING THE SHIFT: AN EXAMINATION OF THE GREYSCALES AND	
LANDMARK TASK IN YOUNGER AND OLDER ADULTS	
4.1 Introduction	58
4.1.1 Age-Related Differences in Pseudoneglect	58
4.1.1.1 Hypothesis 1	59
4.1.2 Pseudoneglect in Atypical Populations	59
4.1.2.1 Hypothesis 2	60
4.1.3 Inter-Task Reliability	61
4.1.3.1 Hypothesis 3	61
4.1.4 Age-Related Differences in Cognitive Strategies	61
4.1.4.1 Hypothesis 4	62
4.2 Methods	62

4.2.1	Participants	62
4.2.2	Procedure and Stimuli	63
4.2.2.1	Greyscales task	63
4.2.2.2	Landmark task	64
4.2.3	Scoring Procedures	65
4.2.4	Analysis	66
4.2.4.1	Preliminary analyses	66
4.2.4.2	Hypotheses 1 and 2	67
4.2.4.3	Hypothesis 3	67
4.2.4.4	Hypothesis 4	67
4.3	Results	68
4.3.1	Comparison of Asymmetry Scores	68
4.3.2	Assessing Inter-Task Reliability	70
4.3.3	Self-Reported Strategies on the Greyscales and Landmark Tasks	71
4.4	Discussion	74
4.4.1	Age-Related Differences in Pseudoneglect	74
4.4.2	Inter-Task Reliability	77
4.4.3	Pseudoneglect in Atypical Populations	77
4.4.4	Age-Related Differences in Cognitive Strategies	78
4.5	Conclusion	80
CHAPTER 5	81
CRASHING LEFT VERSUS RIGHT: EXAMINING NAVIGATION ASYMMETRIES		
USING THE SHRP2 NATURALISTIC DRIVING STUDY DATA		
5.1	Methods.....	85
5.1.1	SHRP2 NDS	85
5.1.2	SHRP2 NDS variables examined	86
5.1.3	Relative Risk Analyses	89
5.2	Results	89
5.2.1	Location of Impact Analyses	89
5.2.2	Characteristics of Crashes	92
5.3	Discussion	95

5.3.1 Limitations	99
5.4 Conclusion	99
CHAPTER 6	101
GENERAL DISCUSSION	
6.1 Directions for Future Research	106
6.2 Conclusion	109
References	111
Appendix A	128
Appendix B	129
Appendix C	130

LIST OF FIGURES

<i>The developmental trajectory of pseudoneglect in adults using the greyscales task</i>	
2-1.	Sample stimulus pairs from the greyscales task23
2-2.	Mean response bias for the greyscales task demonstrated by each age category25
2-3.	Scatter plot illustrating the correlation between mean response bias and age26
<i>The developmental trajectory of pseudoneglect in adults: A systematic review</i>	
3-1.	PRISMA diagram35
<i>Reassessing the shift: An analysis of the greyscales and landmark task in younger and older adults</i>	
4-1.	Sample stimuli used in the landmark task66
4-2.	Mean asymmetry scores for each experimental group demonstrated on the greyscales and landmark task70
<i>Crashing left versus right: Examining navigation asymmetries using the SHRP2 naturalistic driving study data</i>	
5-1.	Position of impact locations on subject vehicle88
5-2.	Frequencies of the most common precipitating events preceding crashes on the left of participants' vehicles94
5-3.	Frequencies of the most common precipitating events preceding crashes on the right of participants' vehicles94

LIST OF TABLES

The developmental trajectory of pseudoneglect in adults using the greyscales task

- 2-1. Response bias scores for each age group24

The developmental trajectory of pseudoneglect in adults: A systematic review

- 3-1. Characteristics of included studies examining the line bisection task41
3-2. Characteristics of included studies examining the landmark task44
3-3. Characteristics of included studies examining the greyscales task46
3-4. Characteristics of included studies examining the tactile rod bisection task48
3-5. Characteristics of included study examining the lateralized visual detection task49
3-6. Summary of the different tasks used and the frequency of results that supported an attenuated leftward bias with age, enhanced leftward bias with age, or comparable performance49

Reassessing the shift: An analysis of the greyscales and landmark task in younger and older adults

- 4-1. One-sample t-tests examining perceptual biases68
4-2. Examples of strategies used to complete the greyscales task72
4-3. Frequency of strategies reported and corresponding asymmetry scores on the greyscales task72
4-4. Examples of strategies used to complete the landmark task73
4-5. Frequency of strategies reported and corresponding asymmetry scores on the landmark task73

Crashing left versus right: Examining navigation asymmetries using the SHRP2 naturalistic driving study data

- 5-1. Characteristics of the SHRP2 NDS sample and participants who were involved in crashes and near crashes87
5-2. Frequency of position of impact in crashes90
5-3. Frequency of position of impact in near crashes90
5-4. Frequency of position of impact during crashes without road departure incidents and relative risk of crashes91
5-5. Frequency of position of impact during near crashes without road departure incidents and relative risk of near crashes92

LIST OF ABBREVIATIONS

Compensation-related utilization of neural circuits hypothesis (CRUNCH)
Electroencephalogram (EEG)
Data acquisition system (DAS)
Hemispheric asymmetry reduction in older adults (HAROLD)
Intra-parietal sulcus (IPS)
Population and situation (PS)
Mild cognitive impairment (MCI)
Montreal Cognitive Assessment (MoCA)
Naturalistic driving study (NDS)
Right hemi-aging model (RHAM)
Strategic Highway Research Program 2 (SHRP2)
Sunnybrook Neglect Assessment Procedure (SNAP)
Superior longitudinal fasciculus (SLF)
Unilateral spatial neglect (USN)
Virginia Tech Transportation Institute (VTTI)

LIST OF APPENDICES

- A. Search terms and search specifications
- B. Description of perceptual tasks
- C. SPSS Analyses

CHAPTER 1

GENERAL INTRODUCTION

Organisms classified in the phylum Bilateria are characterized with bilateral symmetry (Corballis, 2009). Such representative organisms, including humans, have a single median axis that divides the body into equivalent halves that are mirror images. Anatomical bilateral symmetry has been proposed as a natural adaptation, particularly for organisms with locomotion. The symmetrical placement of limbs provides efficient linear movement, and sensory organs with left-right parity allow for equal detection of predators from both directions (Gazzaniga & Hutsler, 2001) to minimize the risk of predation from a weaker side (Corballis, 2009). However, a number of cognitive functions and information processing systems in vertebrate groups, such as chordates, have been found to be predominantly lateralized to one hemisphere, with each hemisphere constituting its own subtle propensities and biases (Hellige, 2008). Such lateralization has often been demonstrated through observation of behaviour changes following unilateral brain damage. For instance, damage to the left hemisphere can result in profound language impairment, whereas injury to the right hemisphere can lead to spatial and attentional biases. A specific lateralized cognitive function of interest in this dissertation is the hemispheric asymmetry of spatial attention. Both cerebral hemispheres are involved in spatial attention; however, the right hemisphere has a more dominant role. In neurologically healthy individuals, the right hemisphere attends to both the left and the right hemifield, albeit more weakly to the right, whereas the left hemisphere attends predominantly to the right hemifield (Mesulam, 2000).

1.1 Hemispatial neglect

The dominance of the right hemisphere in spatial attention and its key role in attentional processes are apparent in the clinical syndrome hemispatial neglect. Hemispatial neglect is a disabling condition that sometimes follows brain injury; most commonly, a cerebral infraction or hemorrhage, and less commonly, pathological processes including neurodegenerative disease, neoplasia, and trauma (Li & Malhotra, 2015). Although hemispatial neglect can arise from lesions located in the left hemisphere, the syndrome occurs most often following lesions to the right hemisphere, and is also characterized by more severe symptoms. In hemispatial neglect, patients most commonly fail to orient, detect, or respond to stimuli located contralaterally to the hemisphere that has been injured, and such behaviour is not attributed to a primary sensory or

motor deficit (Kinsbourne, 1993). For example, symptoms of left hemispacial neglect (injury to right hemisphere) commonly include a marked attentional bias to salient features in the right hemispacial, and difficulty orienting and responding to stimuli presented in the left hemispacial (Corbetta & Shulman, 2011; Karnath & Rorden, 2012; Vallar, 1998). A second hallmark feature is that patients are unaware of their orientation to the ipsilesional side and that their spatial egocenter has shifted (Karnath & Rorden, 2012).

Although hemispacial neglect is characterized by hallmark features, it is also characterized by large heterogeneity in clinical manifestations, with patients demonstrating neglect on some neurological tests, but not others (Verdon, Schwartz, Lovblad, Hauert & Vuilleumier, 2010). The diversity of clinical observations has led to dichotomies in the characterization of different subclasses of hemispacial neglect. For example, neglect has been subdivided by patients who experience personal neglect (e.g., unaware of the contralesional side of the body), extrapersonal neglect (e.g., unaware of the contralesional side of the external environment beyond the body), allocentric neglect (e.g., failure to perceive contralesional side of stimuli regardless of their position relative to the body), and egocentric neglect (e.g., failure to perceive stimuli located on the contralesional side of space relative to the body midline; Molenberghs, Sale, & Mattingley, 2012; Parton, Malhotra, & Husain, 2004). One factor analysis of performance on a series of neuropsychological tests proposed three distinct components of hemispacial neglect, including perceptive visuospatial aspects (e.g., inability to shift attention to contralesional side during the line bisection task), exploratory visuo-motor aspects (e.g., missing targets in the contralesional hemispacial and minimizing interference from distracting stimuli during cancellation tests and landscape copy), and object-based (allocentric) neglect (e.g., impaired perception of or attention for one side of objects and words during word reading and target cancellation; Verdon et al., 2010). Depending on the severity of hemispacial neglect, the symptoms can include behavioural expression of one or multiple combinations of the three components of neglect (Verdon et al., 2010). Hence, researchers and clinicians consider hemispacial neglect a multi-componential syndrome that includes core features, as well as variable manifestations depending on the site and extent of brain damage (Verdon et al., 2010; Vuilleumier, 2013).

1.1.1 Tasks used to assess hemispatial neglect. Hemispatial neglect is characterized by a number of sensory and motor manifestations. To identify the range of clinical manifestations, hemispatial neglect is evaluated through several different tasks rather than a single measure. The various subtypes and different cognitive components of hemispatial neglect have hindered the use of a single “gold standard” test to assess the syndrome (Leibovitch, Vasquez, Ebert, Beresford, & Black, 2012; Verdon et al., 2010). Some of the tests typically administered rely heavily on vision or visuo-motor control; however, others assess personal neglect (e.g., ignoring the contralesional side of the body), motor neglect (e.g., failing to use the contralesional limbs), and even representational neglect (e.g., ignoring the contralesional side of a familiar scene from memory; Parton et al., 2004).

A battery of neuropsychological tests is the most sensitive way to identify the presence of hemispatial neglect, as patients often demonstrate a lateralized bias on one task and normal performance on others (Li & Malhotra, 2015). Diagnosis is often made after identifying impaired performance in one or two tests out of a battery, or when a total score based on multiple tests surpasses a predefined threshold (Karnath, Fruhmann Berger, Kuker, & Rorden, 2004; Vuilleumier, et al., 2013). A well-known comprehensive battery is the Behavioural Inattention Test (Wilson, Cockburn, & Halligan, 1987). The Behavioural Inattention Test consists of six conventional tests (e.g., line crossing, letter and star cancellation, figure and shape copying, line bisection, and representational drawing) and nine behavioural tests (e.g., picture scanning, telephone dialing, menu reading, telling and setting the time, coin sorting, address and sentence copying, map navigation, and card sorting) to assess both visuospatial ability and functionally related activities. Other neuropsychology batteries used in rehabilitation settings have also used functional evaluation in personal (e.g., asymmetry in using a comb and razor) and extrapersonal space (e.g., card dealing, serving tea, and description of objects in a picture; Zoccolotti & Judica, 1991). Other batteries have included line drawing, line bisection, line and letter cancellation, visual picture search, clock drawing, and a tactile maze (Kinsella, Packer, Ng, Olver, & Stark, 1993). In an acute setting, the Sunnybrook Neglect Assessment Procedure (SNAP) has been used to assess hemispatial neglect in patients with left and right hemisphere damage (Leibovitch et al., 2012). SNAP includes spontaneous drawing of a clock and daisy, line cancellation, line bisection, copying of a clock and daisy, and shape cancellation.

Of the tasks typically administered in neuropsychological batteries, line bisection and cancellation tasks are among the most sensitive in identifying hemispatial neglect (Agrell, Dehlin, & Dahlgren, 1997; Bailey, Riddoch, & Crome, 2000; Haligan, Marshall, & Wade, 1989; Molenberghs et al., 2012; Parton et al., 2004). Cancellation tasks require patients to identify targets on a centrally placed sheet of paper. Patients with hemispatial neglect typically begin searching at the ipsilesional edge of the paper and fail to identify targets located contralesionally. The line bisection task is a simple paper-pencil task that involves marking the midpoint of horizontal lines. Patients with hemispatial neglect and a right hemisphere lesion mis-bisect the line to the right of true centre.

Another simple perceptual task used to identify an attentional bias in patients with unilateral hemispheric damage is the greyscales task (Mattingly, Bradshaw, Nettleton, & Bradshaw, 1994). During the greyscales task individuals judge which of two left-right mirror-reversed luminance gradients appears darker overall. Patients with right hemisphere lesions have been found to demonstrate a strong attentional bias to the right (Mattingley et al., 2004; Mattingley, Bradshaw, Nettleton, & Bradshaw, 1994). Mattingley et al. (2004) noted that “the task is highly sensitive to unilateral hemispheric damage and can reveal pathological attentional biases in patients without hemispatial neglect on conventional cancellation or line bisection tasks” (p. 387). Patients with left and right hemisphere lesions who had full visual fields and did not demonstrate hemispatial neglect on the cancellation and line bisection tasks, demonstrated ipsilesional attentional biases on the greyscales task that were more extreme compared to healthy participants. The enhanced sensitivity of the greyscale task compared to commonly used clinical tests, such as line bisection and cancellation tasks, has been proposed to result from the forced-choice decision in which the salience of the right side of the stimuli is directly compared to the salience of the left side (Mattingley et al., 2004).

1.2 Brain Regions Associated with Hemispatial Neglect

Historically, hemispatial neglect was proposed to be associated with damage to the right posterior parietal cortex, specifically the temporo-parietal junction (Heilman, Watson, Bower, & Valenstein, 1983; Vallar & Perani, 1986); however, this view has been challenged and the precise core anatomy of hemispatial neglect is controversial. Given that multiple tests are used to diagnose the presence of hemispatial neglect and that the syndrome is heterogeneous, multiple cortical and subcortical brain regions have been implicated, suggesting that a wider network of

areas may be involved (Husain, 2008). As described above, hemispatial neglect has been proposed to be a multi-componential syndrome (Verdon et al., 2010). Consistent with this hypothesis, through factor analysis, different neural correlates have been identified for various components of the syndrome. Specifically, the right inferior parietal lobule near the supramarginal gyrus, with extension into posterior white matter, has been identified in brain regions underlying perceptive visuospatial components of neglect (Verdon et al., 2010). The object-based component of neglect has been correlated with damage to the right temporal lobe due to strokes in the middle or posterior cerebral artery (Verdon et al., 2010). Exploratory visuo-motor components of neglect have been associated with the dorsolateral prefrontal cortex and frontal-eye-field (Verdon et al., 2010).

Additionally, severe hemispatial neglect has been associated with white matter damage on the frontal-parietal pathway (Verdon et al., 2010). This finding has been supported by Molenberghs, Sale, and Mattingley (2012) who combined 20 lesion mapping studies in a meta-analysis and identified nine significant clusters of lesion sites associated with hemispatial neglect. White matter corresponding to the posterior part of the superior longitudinal fasciculus was an area most consistently associated with hemispatial neglect. All significant clusters were located in the right hemisphere, and other clusters included the angular gyrus, inferior parietal lobule, caudate nucleus, boarder between the anterior hozizontal intraparietal sulcus and postcentral sulcus, precuneus, superior temporal gyrus and sulcus, posterior insula, and middle occipital gyrus (Molenberghs et al., 2012). Impairments on different tasks have also been localized to specific regions. For example, lesions associated with poor performance on the line bisection task, are located more posteriorly than those associated with target cancellation, which are more distributed over dorsolateral prefrontal and parietal areas (Molenberghs et al., 2012). Different brain regions have also been identified as involved in the different subclasses of hemispatial neglect symptoms. For example, personal neglect has been associated with dorsal lesions compared to patients experiencing extrapersonal neglect (Molenberghs et al., 2012). Consistent with the various combinations of deficits in the component involved in the behavioural expression of hemispatial neglect, the syndrome can involve various anatomical correlates (Husain, 2008; Verdon et al., 2010).

1.3 Pseudoneglect

In neurologically healthy individuals, the asymmetry in the involvement of the cerebral hemispheres in spatial attention results in a small but consistent bias towards stimuli in the left hemispace. This attentional bias to the left hemispace is a robust phenomenon known as pseudoneglect (Bowers & Heilman, 1980). Neurologically healthy individuals under the age of 50 years have been found to consistently bias their attention, and err, to the left when asked to complete a range of simple perceptual tasks; tasks that are similar to the tasks administered to diagnose hemispatial neglect. Pseudoneglect reflects a normal, rather than impaired performance on visuospatial tasks, and as the name implies, biases in attention are opposite in direction to those made by patients with hemispatial neglect.

1.3.1 Tasks used to assess pseudoneglect. Researchers who examine pseudoneglect often employ a single task. The task traditionally and most frequently employed to examine pseudoneglect is the line bisection task, which requires participants to bisect the middle of a horizontal line (Karnath & Rorden, 2012). Commonly, in healthy participants, a global leftward bias is observed, and participants systematically misplace the transection to the left of objective centre. Other tasks that have been used to observe a similar global leftward bias include the landmark task, greyscales task, tactile rod bisection task, grating scales task, and lateralized visual detection task (Benwell, Thut, Grant, Harvey, 2014; Brooks, Della Sala, & Logie, 2011; Learmonth, Benwell, Thut, & Harvey, 2017; Learmonth, Thut, Benwell, & Harvey, 2015b; Mattingley et al., 2004; Nicholls, Bradshaw, & Mattingley, 1999; Schmitz & Peigneux, 2011).

Similar to the differences in sensitivity between the tasks administered to diagnose hemispatial neglect, some of the tasks used to examine pseudoneglect have been found to be influenced by extraneous factors. For example, during the line bisection task stimulus factors (e.g., length of the line, and position of the line) and methods (e.g., hand used, and the direction of visual scanning) have been found to influence the magnitude and the direction of the bias observed (reviewed by Jewell & McCourt, 2000). In particular, unilateral motor activity has been found to influence the magnitude of the leftward perceptual bias, as bisection of the line using the left hand often deviates more to the left than when using the right hand (Heilman & Valenstein, 1979), and at times, the use of the right hand results in a rightward bias. To reduce the influence of motor components on bisection performance and dissociate between perceptual

and response biases (Bisiach, Ricci, Lualdi & Colombo, 1998), an alternative version of the task has been used, the landmark task.

The landmark task requires estimating the symmetry of two sections of pre-bisected lines (e.g., Which of the two segments of the transected lines is longer or shorter?), or judgment of the centrality of the transection mark (e.g., Is the vertical bar to the left or right of the perceived midpoint of the line?; Fink, Marshall, Weiss, Toni & Zilles, 2002; Milner, Brechmann, & Pagliarini, 1992; Milner, Harvey, Roberts, & Forster, 1993). During the task, participants perceive equally bisected lines as longer on the left (Milner et al., 1992). Some researchers have argued that the landmark task is superior to the line bisection task, as it minimizes motor cuing that results from bisecting the horizontal line by moving one's hand, and addresses methods (e.g., use of left or right hand) that have been found to influence the magnitude and direction of the bias to the left side of space (Jewell & McCourt, 2000). However, the length of the line examined remains a stimulus factor that influences the magnitude of the bias observed (e.g., leftward bisection errors shift rightward as the length of the line decreases; Benwell, Havey, & Thut, 2014a; Jewell & McCourt, 2000; McCourt & Jewell, 1999).

Similar to the landmark task, the greyscales task has been proposed to reduce motor cuing through a forced choice procedure and limiting response selection to a single button press (McCourt & Olafson, 1997). During the greyscales task participants are asked to make a forced choice judgment on the relative brightness of two simultaneously presented horizontal bars that gradually change from white on one end to black on the other (Mattingley et al., 1994). The two horizontal equiluminant bars are left/right reversals of each other. Neurologically healthy participants typically select the greyscale stimulus that displays the darker end on the left (Nicholls et al., 1999). The magnitude of leftward bias demonstrated by participants on the greyscales task is unaffected when judging stimuli of differing lengths (Nicholls et al., 1999). Thus, the greyscales task does not appear to be influenced by the line length effect (i.e., increases in the leftward bisection bias with increasing stimulus length) that is present during the line bisection and landmark task (McCourt & Jewell, 1999). Accordingly, the greyscales task addresses some of the stimulus factors that are known to influence the magnitude of pseudoneglect.

1.4 Brain Regions Associated with Pseudoneglect

A bilateral parieto-frontal network with right hemisphere dominance has been implicated in visuospatial attention processing, both in monkeys and humans (Heilman & Van Den Abell, 1980; Buschman & Miller, 2007). Leftward attention biases found in pseudoneglect have been proposed to result from right posterior parietal dominance for visuospatial processing that results in asymmetry of activity between the right and left parietal cortices when performing spatial judgments. Functional magnetic resonance imaging studies have reported right superior posterior and inferior parietal cortex (or intra-parietal sulcus; IPS) activation during the landmark task (Fink et al., 2000; Fink, Marshall, Weiss, & Zilles, 2001). Other researchers have examined the neural mechanisms of both the line bisection and landmark task. Using positron emission tomography, Weiss, Marshall, Zilles, and Fink (2003) reported bilateral activation of the superior and inferior parietal areas along the intraparietal sulcus and premotor cortex during the manual line bisection task, and activation of the right inferior parietal cortex, anterior cingulate and dorsolateral prefrontal cortex, and bilateral activation of the superior temporal cortex during the landmark task. In contrast, Cicek, Deouell, and Knight (2009) reported that both the line bisection and landmark tasks activated the dorsal fronto-parietal network in the right hemisphere. Specifically, Cicek et al., (2009) reported activation of the right IPS and lateral peristriate cortex in both the landmark and line bisection task, and activation of the frontal eye field in the line bisection task. Activation of the right dorsal attention network was proposed to result from the role of sustained attention rather than reorienting responses during the tasks (Cicek et al., 2009; Fink et al., 2002).

The fronto-parietal connections involved in visuospatial attention have been found to be separated into three dorsal superior longitudinal fasciculus (SLF) tracts: SLF I, SLF II, and SLF III. In their seminal study, Thiebaut de Schotten et al. (2011) reported that of the three tracts, the SLF II (middle) and SLF III (ventral) are right lateralized and the degree of hemispheric lateralization was found to predict the degree of specialization of the right hemisphere for visuospatial processing. Correlational analysis revealed that larger SLF II volume in the right hemisphere corresponded to larger deviations to the left on the line bisection task (Thiebaut de Schotten et al., 2011). The SLF II has been proposed to facilitate direct communication between the dorsal and ventral attention networks, as the track overlaps with the parietal component of the

ventral network and the prefrontal component of the dorsal network (Thiebaut de Schotten et al., 2011).

Electroencephalographic studies have also investigated the neural bases of the landmark task. Foxe, McCourt, and Javitt (2003) identified a line-bisection effect - a distinct negative ERP component 170 to 400 milliseconds post-stimulus presentation that consists of three phases. The component begins 170 to 190 milliseconds after stimulus presentation over the right parieto-occipital and lateral occipital regions of the scalp, shifting to a right central parietal distribution during the second phase (190-240 milliseconds), and becoming dominant in the right central parietal region in the third phase (240-400 milliseconds). A right lateralized negativity over the occipital-parietal scalp regions has also been confirmed by Longo, Tripper, Vagnoni, and Lourenco (2015). More recently, Benwell et al. (2014a) argued that the temporal locus of the bias is earlier after identifying an event related potential 100-200 milliseconds post-stimulus onset in the right ventral attention network (i.e., temporal-parietal junction) during the landmark task (Benwell et al., 2014a). The N1 (i.e., ERP 100-200 milliseconds post stimulus onset) component positively correlated with strength of the leftward bias, providing evidence for engagement of the right ventral attention network contributing to the early information processing stages and the left perceptual bias (Benwell et al., 2014a).

Overall, the pattern of results supports the dominant role of the right hemisphere in voluntary spatial attention (Benwell et al., 2014; Cicek et al., 2009; Fink et al., 2000; Foxe et al., 2003; Thiebaut de Schotten et al., 2011; Weiss et al., 2000). These findings suggest that completion of both the line bisection and landmark task involve both the right ventral and dorsal attention systems (Cicek et al., 2009), with some researchers suggesting a relay between object processing in the ventral stream and space processing in the dorsal stream (Foxe et al., 2003). However, there are also discrepancies in the neural regions activated by the line bisection and landmark task (Cicek et al., 2009; Weiss et al., 2003).

1.5 Age-related changes in pseudoneglect

In addition to stimulus factors and methods employed, demographic difference among research participants, such as age, have been observed to influence the direction and magnitude of lateral perceptual biases in neurologically healthy adults (Jewell & McCourt, 2000). Over the past two decades, a small number of researchers have begun to examine pseudoneglect in the context of aging. Although pseudoneglect is widely considered to be a systematic bias to the left

side of space (Jewell & McCourt, 2000), findings from research on the phenomenon of pseudoneglect among older adults is inconsistent. The majority of researchers have identified an attenuation of the leftward bias with age, some have identified a rightward bias, and still others have found that older adults demonstrate a stronger leftward bias than younger adults. For example, a shift from a leftward bias to a rightward bias with age has been demonstrated using the line bisection task (Barrett & Craver-Lemley, 2008; Chen, Goedert, Murray, Kelly, Ahmeti, & Barrett, 2011; Failla, Sheppard, & Bradshaw, 2003; Fujii, Fukatsu, Yamadori & Kimura, 1995; Fukatsu, Fujii, Kimura, Saso & Kogure, 1990; Goedert, LeBlanc, Tsai, & Barrett, 2010) and landmark task (Benwell et al., 2014b; Schmitz & Peigneux, 2011). In contrast, the reverse pattern, a stronger leftward bias with age, has been demonstrated using the line bisection task (Varnava & Halligan, 2007), landmark task (Harvey, Pool, Robertson, & Olk, 2000), tactile rod bisection task (Brooks et al., 2011), and greyscales task (Friedrich, Hunter, & Elias, 2016; Mattingley et al., 2004). A detailed synthesis of published research on pseudoneglect in the context of aging is presented in Chapter 3.

One finding from this synthesis is that additional research will be needed to further clarify age-related changes in pseudoneglect. In particular, additional experimental controls will be needed to account for various factors that may be influencing inconsistent results (e.g., task demands, age, size of age ranges, presence of clinical diagnoses). The experiments presented in Chapter 2 and 4 provide further examination of age-related differences in pseudoneglect. In these experiments, prior research was extended by improving research design and methodology. Specifically, the aim of the experiment presented in Chapter 2 was to investigate previous inconsistencies in research on age-related differences and understand the stability of pseudoneglect across adulthood. To build upon previous research, pseudoneglect was examined using the greyscales task - a task that addresses stimulus factors that are known to influence the magnitude of pseudoneglect, and, by increasing the sample size relative to previous studies, to observe pseudoneglect in each decade of life. Moreover, the aim of the study presented in Chapter 4 was to replicate the results presented in Chapter 2, and, using a within-person design, account for task demands and the presence of clinical diagnoses.

1.6 Models of Neurocognitive Aging

A number of models and hypothesis have been proposed to account for age-related changes in pseudoneglect. The primary models that have been used were originally developed to

describe cognitive aging and outline proposed reorganization of brain functions with age. These models have been extrapolated to describe changes in spatial attention and predict behavioural changes that broadly fall into three categories: those that propose a rightward perceptual bias with age, those that propose an elimination of a perceptual bias with age, and those that propose a leftward bias similar in magnitude to younger adults.

The right hemi-aging model (RHAM) proposes that the right-hemisphere demonstrates greater age-related decline compared to the left hemisphere resulting in greater cognitive decline in functions attributed to the right hemisphere compared to functions attributed to the left hemisphere (Goldstein & Shelly, 1981). Increased involvement of the left hemisphere has been proposed to result from reduced attentional inhibitory influence of the left hemisphere, (Fujii et al., 1995; Chieffi et al., 2014), or a combination of reduced inhibitory influence and functional decline (Failla et al., 2003). The model has been supported by evidence from functional domains that are lateralized in young adults, such as verbal, spatial, affective and sensorimotor domains (Dolcos, Rice & Cabeza, 2002). Initial evidence for the model was identified when comparing age-related effects on verbal and spatial tasks, that predominately involve the left and right hemisphere in the processing of information, respectively. Using the Wechsler Adult Intelligence Scale elderly participants demonstrated greater impairment on spatial tasks compared to verbal tasks (Goldstein & Shelly, 1981). The model has also been supported in the affective domain and in sensorimotor processing. For example, research investigating hemispheric asymmetries in emotional processing have found that older participants exhibit deficits in the perception of unpleasant emotions, a proposed right hemisphere dominant function, compared to younger participants (McDowell, Harrison & Demaree, 1994). Similarly, using a sensorimotor task, manipulative abilities associated with the right hemisphere were found to be more affected by aging compared to abilities associated with the left hemisphere (Weller & Latimer-Sayer, 1985).

Depending on the extent of right hemisphere deterioration, the model proposes reversed hemispheric asymmetry (i.e., greater left hemispheric activation). The changes in the dominance of the right hemisphere are hypothesized to influence behavioural biases on visuospatial tasks. As a result, RHAM has been commonly used to explain the elimination of attentional biases with aging, and observed rightward attentional biases. Researchers have also suggested that the rightward shift in lateralized biases may be a subtle sign of unilateral neglect (Fujii et al., 1995).

Relatedly, the hemispheric asymmetry reduction in older adults (HAROLD) model hypothesizes that activity in the prefrontal cortex during cognitive tasks becomes less lateralized with age resulting in bilateral recruitment of cerebral hemispheres to maintain cognitive performance (Cabeza, 2002). The model has been supported by evidence from functional neuroimaging, electrophysiological and behavioural measures (Dolcos et al., 2002). Research examining the HAROLD model has found that older adults display increasing bilateral activation of the prefrontal cortex following tasks that involve memory (e.g., episodic retrieval, semantic retrieval, and working memory), face recognition, and inhibitory control, compared to younger adults who display lateralized activation in the right prefrontal cortex (Cabeza, Anderson, Locantore, & McIntosh, 2002). For example, during episodic retrieval, activity in the prefrontal cortex is typically lateralized to the right hemisphere in younger adults. When older adults have completed the same task, bilateral activation of the prefrontal cortex has been found (Cabeza, Grady, Nyberg, McIntosh, Tulving, & Kapur, 1997).

Neuroimaging research examining episodic, semantic and working memory has provided evidence for the HAROLD model. Although the model has not been supported by evidence from other cognitive domains, it has been extrapolated and used to explain the age-related reduction in the lateralization of various other lateralized cognitive processes. With regards to pseudoneglect, attenuation of leftward biases with age, or lack of a bias, has been most commonly explained by the HAROLD model. The elimination of hemispheric asymmetry and attentional bias is a pattern that is distinct from younger adults and has not shifted to a rightward bias, as proposed by RHAM. Consistent with the HAROLD model, this behavioural finding has been hypothesized to result from loss of hemispheric asymmetry through increased involvement of the left hemisphere and loss of right hemisphere dominance in spatial tasks leading to bihemispheric recruitment (Barrett & Craver-Lemley, 2008; De Agostini, Curt, Tzortzis & Dellatolas, 1999; Learmonth, Benwell, Thut & Harvey, 2017; Learmonth, Thut, Benwell & Harvey, 2015, August; Learmonth, Thut, Benwell & Harvey, 2015b; Milano, Douyon, Falchook, & Heilman, 2014; Schmitz & Peigneux, 2011).

The function of reduced hemispheric asymmetry with age is debated, but has been proposed as a compensation strategy, either through bihemispheric recruitment of both hemispheres or reduced interhemispheric inhibition due to callosal deterioration (Cabeza, 2002; Dolcos et al., 2002). As such, increased left hemisphere involvement with age has been proposed

to result from decline in the integrity of the corpus callosum (Benwell et al., 2014b; Beste, Hamm, & Hausmann, 2006; Failla et al., 2003; Schmitz & Peigneux, 2011). For example, Failla and colleagues (2003) proposed that performance on the line bisection task with the right hand is consistent with the development of the corpus callosum, as midpoint estimations become leftward until the callosal structure matures. Behavioural findings of a symmetrical and rightward bias demonstrated by older adults has been proposed to indicate degeneration of the myelinated corpus callosal fibers or decrease in the size of the callosum with older age (Failla et al., 2003).

Other researchers have failed to find a difference in lateral biases across adulthood with both younger and older adults demonstrating a leftward bias. Such findings are inconsistent with the above models of cognitive aging (e.g., HAROLD, RHAM), and researchers have suggested that the models of cognitive aging do not generalize to spatial attention processing (Brooks et al., 2011; McPherron, 2015). The HAROLD model was developed specifically for tasks requiring involvement of the prefrontal cortex, such as inhibitory control, and episodic, semantic, and working memory. The model may not be generalizable to age-related changes in spatial attention that activate temporal-parietal areas (Brignani, Bagattini, & Mazza, 2018). Researchers that have identified the presence of pseudoneglect in older adults have proposed that the process of dedifferentiation - the reliance on a range of cognitive resources - may be selective and modality-specific (Brooks et al., 2011). Different cognitive processes, such as higher-level representations, may be subject to aging, while pure visual perceptual processing may not (Brooks, Darling, Malvaso & Della Sala, 2016).

Researchers who have found that older adults demonstrate leftward bias similar in magnitude to younger adults, or a stronger bias to the left hemispace, have explored the compensation-related utilization of neural circuits hypothesis (CRUNCH). CRUNCH proposes that older adults achieve performance equivalent to younger adults at low levels of task demand and compensate for age-related processing inefficiencies through recruitment of additional neural resources (Reuter-Lorenz & Cappell, 2008). Functional reorganization and redistribution of neural regions in response to aging is not limited to the contralateral hemisphere and age-related overactivation does not necessarily lead to hemispheric asymmetry reduction, as suggested by the HAROLD mode (Learmonth et al., 2017). Rather, compensation can occur at any location in the cortex, including the ipsilateral hemisphere, which could lead to increased activity.

Researchers who have found that older adults demonstrate leftward bias similar in magnitude to younger adults, or a stronger bias to the left hemispace, have explored CRUNCH as a possible explanation (Brooks, Della Sala, & Darling, 2014; Brooks et al., 2016; Hatin, Tottenham & Oriet, 2012; Learmonth et al., 2017). Consistent with the activation-orientation hypothesis, asymmetrical activation of the right hemisphere orientates attention to the contralateral left hemispace, which increases the salience of the left portion of the stimulus, resulting in the left portion being perceived as longer, brighter, darker, or more numerous (Reuter-Lorenz et al., 1990). Tasks that are used to examine pseudoneglect engage attentional orienting mechanisms in the right parietal cortex, and with age, additional neural regions may be recruited in the right hemisphere in response to maintain attention and leftward bias.

As outlined above, each model predicts distinct biases observed in samples of older adults. Specifically, cortical changes predicted by RHAM support reduced or reversed hemispheric asymmetry and an eliminated bias or distinct rightward bias with age, whereas the HAROLD model predicts older adults exhibit hemispheric symmetry and no associated behavioural bias, and yet the CRUNCH predicts increased neural recruitment that maintains attention and older adults demonstrate a leftward bias similar in magnitude to younger adults. However, as discussed in Chapter 4, the current models of cognitive aging are underspecified and unable to account for the divergent results demonstrated on different visuospatial tasks.

1.7 Pseudoneglect in Atypical Populations

Understanding the sources of heterogeneity in the literature examining age-related changes in pseudoneglect is a central issue, yet, as the systematic review reported in Chapter 3 suggests, it has received limited attention in research to date. A common approach to understanding the variability of performance in older adult populations is to differentiate persons who have a clinical diagnosis (i.e., persons who have brain injury or disease) from those who are pathology free (Hofer & Sliwinski, 2006). Clinical diagnoses typically differentiate individuals who are considered to have normal cognitive function from individuals who have been diagnosed with mild cognitive impairment and from individuals who have been diagnosed with dementia (Mungas et al., 2010). The diagnosis of dementia presumes that an individual has a high probability of neuropathology, whereas the diagnoses of normal cognitive function presumes that an individual has a low probability of neuropathology, and a diagnosis of mild cognitive impairment (MCI) presumes an intermediate likelihood (Mungas et al., 2010). By

definition, MCI falls between normal cognitive function and dementia, and the diagnosis aims to identify individuals with increased risk for future neuropathology and consequently cognitive decline (Mungas et al., 2010).

As outlined in Chapter 3, a consistent categorization of older adults and specification of whether participants are neurologically healthy in the studies reviewed was limited. Of the studies included in the review, six screened participants for neuropathology when examining pseudoneglect in the context of aging, and two compared the performance of older adults with and without clinical diagnoses. Without screening for cognitive impairment, it is difficult to determine the presence of neuropathology and whether age-related changes are related to *healthy* aging. Further, large individual difference in cognitive performance may be contributing to the variability in age-related changes in research examining pseudoneglect.

The study presented in Chapter 4 examines age-related differences in pseudoneglect in younger and older adults. As recommended in the systematic review presented in Chapter 3, older adults were screened for cognitive impairment and presumably the presence of age-related neuropathology. Specifically, pseudoneglect was examined in groups defined by age (i.e., younger versus older adults), and by clinical diagnosis (e.g., no symptoms of cognitive impairment versus symptoms of MCI) to examine the association between healthy aging and differences in pseudoneglect. Older adults with different levels of cognitive functioning were examined in an attempt to minimize the variability in the range of perceptual biases, and to allow for examination of the association between presumed neuropathology and pseudoneglect to understand the continuum of normal and pathological aging.

1.8 Pseudoneglect and Real-World Consequences

These findings are timely given the increasing proportion of older persons in Canadian society (Statistics Canada, 2011) and the potential implications of spatial attention on independent living and quality of life in older age. Continued research is needed to improve the construct validity of pseudoneglect and develop models of cognitive aging that are able to account for divergent results between different visuospatial tasks, but it is also important to identify the predictive validity and real-world consequences of age-related changes in pseudoneglect. An important question that remains to be answered is whether age-related changes in pseudoneglect are present in real-world settings.

A prominent practical application of perceptual attention is driving behaviour. Collision data indicates that in countries with right-sided traffic directionality, where driving occurs on the right side of the road, left turns are problematic for older adults (Foerch & Steinmetz, 2009). This has been proposed to result from age-related changes in attention to the left side of space (Foerch & Steinmetz, 2009). Older drivers are twice as likely to be involved in a crash at an intersection and three times more likely to be at fault in left-turn crashes compared to younger drivers (Mayhew, Simpson, & Ferguson, 2006). Failure to yield the right of way has been identified as the most critical error that results in left-turn crashes, as older adults report misjudging or failing to detect the oncoming vehicle (McGwin & Brown, 1999; Braitman, Kirley, Ferguson, & Chaudhary, 2007). Research has also identified an over representation of turning collisions striking older adult pedestrians on their left side (Roudsari, Kaufman, & Koepsell, 2006). Furthermore, difficulty attending to visual stimuli on the left is consistent with stronger associations between visual attention deficits and crash risk compared to the association between primary measures of vision and crash risk (Clay et al. 2005). Foerch and Steinmetz (2009) suggest that left attentional deficits may impair recognition of oncoming hazardous vehicles. In contrast, countries that have left-sided traffic directionality (e.g., Australia, New Zealand, United Kingdom) require less observation of the left hemifield (Foerch & Steinmetz, 2009). In Australia, seniors only have slightly higher crash rates than younger cohorts, and are not over-involved in right-turn crashes, with right-turn crashes accounting for less than 10% of accidents involving older adults (Baldock, Mathias, Kloeden, & McLean, 2002). Together, changes in lateralization of attention may have a negative impact on older adults, particularly those who live in countries with right-sided traffic directionality, which requires extensive attention to the left side of space. In younger populations, pseudoneglect has been associated with tasks that involve extrapersonal space, such as navigating through one's environment. Previous research has reported right-sided veering and collisions when walking (Nicholls, Loftus, Mayer, & Mattingley, 2007; Turnbull & McGeorge, 1998), navigating an electric wheelchair or scooter (Nicholls et al., 2010; Robertson, Forte, & Nicholls, 2015), and driving a car in a simulator (Jang, Ku, Na, & Lee, 2009), as well as correlations between collisions and line bisection performance (Nicholls, Loftus, Orr & Barre, 2008).

The final experiment, presented in Chapter 5, examines the association between pseudoneglect and driving in a real-world environment. The location of the position of another

vehicle, pedestrian, animal, or object (i.e., position of impact) involved in near crashes and crashes in a large sample of drivers across adulthood from the Strategic Highway Research Program 2 (SHRP 2) naturalistic driving study is examined.

1.9 Conclusion

Together, the experiments presented in this dissertation: (1) explore the presence of pseudoneglect in each decade of adulthood (Chapter 2), (2) address modulating factors that have been identified as influencing the magnitude of the leftward bias observed, including task demands and non-normative aging (Chapter 4), and (3) extend research on age-related differences in pseudoneglect to a naturalistic setting (Chapter 5).

CHAPTER 2

THE DEVELOPMENTAL TRAJECTORY OF PSEUDONEGLECT IN ADULTS USING THE GREYSCALES TASK

This chapter has been previously published:

Friedrich, T. E., Hunter, P. V., & Elias, L. J. (2016). Developmental trajectory of pseudoneglect in adults using the greyscales task. *Developmental psychology*, 52, 1937-1943. doi:10.1037/dev0000202

Patients suffering from left hemispatial neglect typically exhibit perceptual deficits in the left hemifield. These deficits often result from lesions to the right temporal-parietal junction and inferior temporal gyrus (for review see, Karnath & Rorden, 2012). Symptoms of left hemispatial neglect commonly include difficulty orienting and responding to stimuli presented in the left hemispace, as well as demonstrating an attentional bias to salient features in the right hemispace (Corbetta & Shulman, 2011; Karnath & Rorden, 2012; Vallar, 1998). Perceptual asymmetries are also observed, to a lesser extent, in neurologically healthy individuals when completing midpoint estimations (Bowers & Heilman, 1980), and judgments of luminosity, numerosity and size (Nicholls et al., 1999), a robust phenomenon called pseudoneglect. However, in contrast to the marked rightward bias demonstrated by patients experiencing left neglect, neurologically healthy individuals bias their attention and response slightly towards the left hemispace.

The task traditionally and most frequently employed to examine neglect in clinical populations, and pseudoneglect in non-clinical populations, is the line bisection task (Karnath & Rorden, 2012). Commonly, a global leftward bias is observed, however, several stimulus factors (e.g., size, and position of the line) and methods (e.g., hand used, and the direction of visual scanning) have been found to influence the magnitude and the direction of the bias observed (Jewell & McCourt, 2000; Nicholls & Roberts, 2002). In particular, unilateral motor activity has been found to influence the magnitude of the leftward perceptual bias, as bisection of the line using the left hand often deviates more to the left than when using the right hand (Heilman & Valenstein, 1979), and at times, the use of the right hand has resulted in rightward biases. To reduce the influence of motor components on bisection performance and dissociate between perceptual and response biases (Bisiach et al., 1998), an alternative version of the task has been

used, the landmark task. The landmark task requires estimating the symmetry of two sections of pre-bisected lines (e.g., Which of the two segments of the transected lines is longer or shorter?), or judgment of the centrality of the transection mark (e.g., Is the vertical bar to the left or right of the perceived midpoint of the line?) (Fink et al., 2002; Milner et al., 1992; Milner et al., 1993). However, the length of the line examined remains a stimulus factor that influences the magnitude of the bias observed (e.g., leftward bisection errors shift rightward as the length of the line decreases; Benwell et al., 2014b; Jewell & McCourt, 2000; McCourt & Jewell, 1999).

Pseudoneglect has also been observed in tasks that require judgments in left/right mirror-reversed stimuli, such as the greyscales task (Mattingley et al., 1994). During the greyscales task participants are asked to make a forced choice judgment on the relative brightness of two simultaneously presented horizontal bars that gradually change from white on one end to black on the other. The two horizontal equiluminant bars are left/right reversals of each other. Similar to the landmark task, the greyscales task has been proposed to reduce motor cuing through a forced choice procedure and limiting response selection to a single button press (McCourt & Olafson, 1997). Further, in contrast to increases in the leftward bisection bias with increasing stimulus length (i.e., line length effect) on the line bisection and landmark task (McCourt & Jewell, 1999), the magnitude of leftward response bias demonstrated by participants on the greyscales task is unaffected when judging stimuli of differing lengths (Nicholls et al., 1999). On the basis of available research, the greyscales task addresses some of the modulating stimulus factors that are known to influence the magnitude of pseudoneglect.

In addition to modulating stimulus factors, individual variation, including sex and age, influence the direction and magnitude of lateral visuospatial biases in neurologically healthy adults (Jewell & McCourt, 2000). Sex is a biological factor that contributes to the magnitude of pseudoneglect demonstrated; however, the literature is limited and equivocal. Developmental research examining pseudoneglect has indicated that the leftward line bisection bias demonstrated by males becomes rightward with age, whereas females continuously demonstrate leftward biases throughout the lifespan, particularly during bisection of the longest line (Chen et al., 2011; Varnava & Halligan, 2007). Others have indicated that younger participants and older male participants demonstrate a larger leftward line bisection bias compared to older female participants (Barrett & Craver-Lemley, 2008; Beste et al., 2006). Researchers have proposed that sex differences between older male and female participants may result from differing patterns of

aging in the dorsal visual system (Chen et al., 2011), as well as differing hormone levels, specifically during menopause, which may influence age-related changes in the morphology of the corpus callosum, a integral structure in the line bisection task (Dubb, Gur, Avants, & Gee, 2003; Hausmann, Waldie, & Corballis, 2003). However, sex differences were not found when examining age-related changes in adults during the landmark task or tactile rod bisection (Benwell et al., 2014b; Brooks et al., 2011; Schmitz & Peigneux, 2011).

Likewise, the investigation of pseudoneglect in the context of aging is limited and available research findings are inconsistent. These inconsistencies may appear as previous research has typically focused on a limited number of participants that are commonly separated in two age groups, younger (19-39 years) and older (60+ years) adults (Barrett & Craver-Lemley, 2008; Goedert et al., 2010; Hatin et al., 2012; Schmitz & Peigneux, 2011; Benwell et al., 2014b). Examining a small sample of older adults who differ in age by 30 years may lead to the reliance on a small number of outliers for the results observed (De Agostini et al., 1999), and may mask changes in lateralized biases or only reveal changes that may occur in a particular decade of life rather than changes that occur across the lifespan. Using the line bisection task, some researchers investigating the developmental progression of pseudoneglect have identified an attenuation of the leftward bias, or even a rightward bias with age (Barrett & Craver-Lemley, 2008; Chen et al., 2011; Failla et al., 2003; Fujii et al., 1995; Fukatsu et al., 1990). A similar attenuation of the leftward bias has also been observed during the landmark task (Benwell, et al., 2014b; Schmitz & Peigneux, 2011). Other researchers have failed to find a difference or have identified the reverse pattern, a stronger leftward bias with age, in both line bisection and tactile rod bisection tasks (Beste et al., 2006; Brooks et al., 2011; De Agostini et al., 1999; Hatin et al., 2012; Varnava & Halligan, 2007).

To account for leftward attentional asymmetries observed in healthy adults, a number of models have been proposed. Recently, Duecker and Sack (2015) proposed a hybrid model of attentional control in healthy adults that applies to distinct parts within the dorsal fronto-parietal attention network by combining Kinsbourne's opponent processor model (Kinsbourne, 1977) and Heilman's hemispacial theory (Heilman & Valenstein, 1979). Duecker & Sack (2015) propose that visuospatial attentional asymmetries are characterized by inter-hemispheric competition in the parietal regions and by the right hemisphere mediating attentional shifts to both hemifields in the frontal region, compared to the left hemisphere mediating an attentional

shift to the right hemifield, resulting in lateralization of attention to the right hemisphere.

Various models have been proposed to account for age-related changes in lateralization. The hemispheric asymmetry reduction in older adults (HAROLD) model proposes that aging is associated with a decrease in lateralized activity in frontal regions that results from recruitment or reduced inhibition of the left (non-dominant) hemisphere to compensate for impairment in the right hemisphere (Cabeza, 2002). During visuospatial tasks, activation of the left hemisphere results in lateralization of pertinent features to the right and an absence or reversal of pseudoneglect. Another model, the right hemi-aging model (RHAM), suggests that the right hemisphere is more sensitive to aging, resulting in a reduction of attentional inhibitory mechanisms (Chieffi, et al., 2014), and a more pronounced decline in right hemisphere dominant cognitive functions including spatial processing (Dolcos et al., 2002). Additionally, enhanced aging of the right hemisphere may be associated with reduced arousal and down-regulation of the attention network, which may contribute to the attenuation of pseudoneglect in older adults (Benwell, et al., 2014b; Benwell, Harvey, Gardener, & Thut, 2013). The change in orientation asymmetry and arousal may be related to change in dopamine neurotransmission, particularly in the striatum (Ebersbach, et al., 1996; Greene, Robertson, Gill, & Bellgrove, 2010; Midgley & Tees, 1986), as orientation of attention direction has been found to be contralateral to the hemisphere with higher dopamine receptor binding (Tomer et al., 2013). Dopamine transporter density has been shown to decrease with age (Lavalaye, Booij, Reneman, Habraken, & Van Royen, 2000), which may account for the rightward shift in attentional biases across the lifespan.

Further investigation of how age influences pseudoneglect is needed to understand and refine models accounting for developmental changes in lateralized visuospatial attention. Understanding the stability of pseudoneglect across the lifespan is of clinical relevance as age is a risk factor for neglect following a right hemispheric stroke, with the likelihood of neglect increasing 1.83 times for every additional 10 years of age (Gottesman et al., 2008; Ringman, Saver, Woolson, Clarke, & Adams, 2004). A limited volume of research illustrates age effects on visual pseudoneglect in line bisection and landmark task, but the effect has not been examined using the greyscales task. To examine pseudoneglect using the greyscales task in a large sample of adults across the lifespan, the task was completed through an online survey. In line with research investigating the influence of age on line bisection and the landmark task, a systematic leftward response bias in younger adults and a gradual attenuation and rightward shift of the bias

with age was predicted. An effect of sex on the response bias was not predicted, since this effect has previously only been observed in the context of visuospatial tasks influenced by unilateral motor cuing.

2.1 Methods

2.1.1 Participants

Seven hundred and seventy-six individuals accessed the Internet link for this study, which was hosted on Qualtrics and distributed by two survey panels: Probit, and the undergraduate participant pool at the University of Saskatchewan (SONA). A total of 503 participants ranging from 18 to 88 years of age who were living in Canada completed the survey. Ten participants indicated their native language read from right-to-left (e.g., Arabic and Urdu), which has been shown to influence the magnitude of the bias on the greyscales task (Friedrich & Elias, 2014). To minimize the influence of reading direction on the attentional bias, these participants were excluded from analysis. As a result, a total of 493 participants ($M = 43.49$, $SD = 24.04$, $range = 18-88$, 61.1% female) were included in the sample. Handedness was assessed by asking participants which hand they would throw a ball with and which hand they used for writing on a 5 point scale, providing a laterality quotient from -4 (exclusive left-handers) to +4 (exclusive right-handers). Four hundred forty-six participants had laterality quotients larger than 0 and were considered right-handed (90.5%). The survey was available from February 2nd to February 10th 2015 with the survey closing when a minimum of 40 participants in each of seven age categories¹ had completed the survey. All procedures received ethical approval from the university's Behavioural Research Ethics Board.

2.1.2 Survey

To provide an illustration of perceptual biases across the adult lifespan an Internet-based survey was used. The survey was administered through Qualtrics, an Internet-based survey software, with the link distributed by Probit and SONA. Upon visiting the study link, participants completed a series of demographic questions, which were followed by the greyscales task. During the task, participants simultaneously viewed two rectangle-shaped greyscale stimulus that were presented horizontally on top of each other. The horizontal midlines of the stimuli were aligned with the middle of the screen with a vertical distance of 100 pixels between the upper

¹ The seven age categories that the participants were separated into are 18-29, 30-39, 40-49, 50-59, 60-69, 70-79, and 80-89.

and lower stimulus. The stimuli were constructed using instructions from Nicholls, Bradshaw, and Mattingley (1999). Two reverse luminance gradients that changed in brightness from one end to the other were outlined by a thin black outline and shown against a white background (see Figure 2-1). The stimuli measured 49 pixels high and changed in brightness over 50 increments, creating stimuli changing from black at one end to white at the other. The vertical position of the pixels within each increment was randomized to create a smooth change in brightness and create slight differences in the stimuli. The rectangles were presented as mirror reversals one on top of the other, but were equiluminant at a global level. The stimuli were presented in two different lengths, long (720 pixels) and short (400 pixels), and in two different orientations (upper stimulus dark on the left and lower stimulus dark on the right and vice versa).

The task consisted of 40 trials that were presented in a pseudo-randomized order. Each stimulus pair appeared on the screen for a maximum 3000 msec. On the same webpage, below the stimuli, participants were subsequently asked to determine which stimulus appeared darker overall, and responses were made by clicking the response icon “top” or “bottom”. The participants’ responses were categorized based on which greyscale stimulus they selected as appearing darker. A leftward response was indicated when the participant chose the stimulus with the darker feature on the left, whereas a rightward response was indicated when the participant chose the stimulus with the darker feature on the right, irrespective of whether the stimulus was on the top or bottom. Response bias, the dependent measure, was calculated by subtracting the number of leftward responses from the number of rightward responses and could range from -40 to +40; hence a negative score indicated a leftward bias.

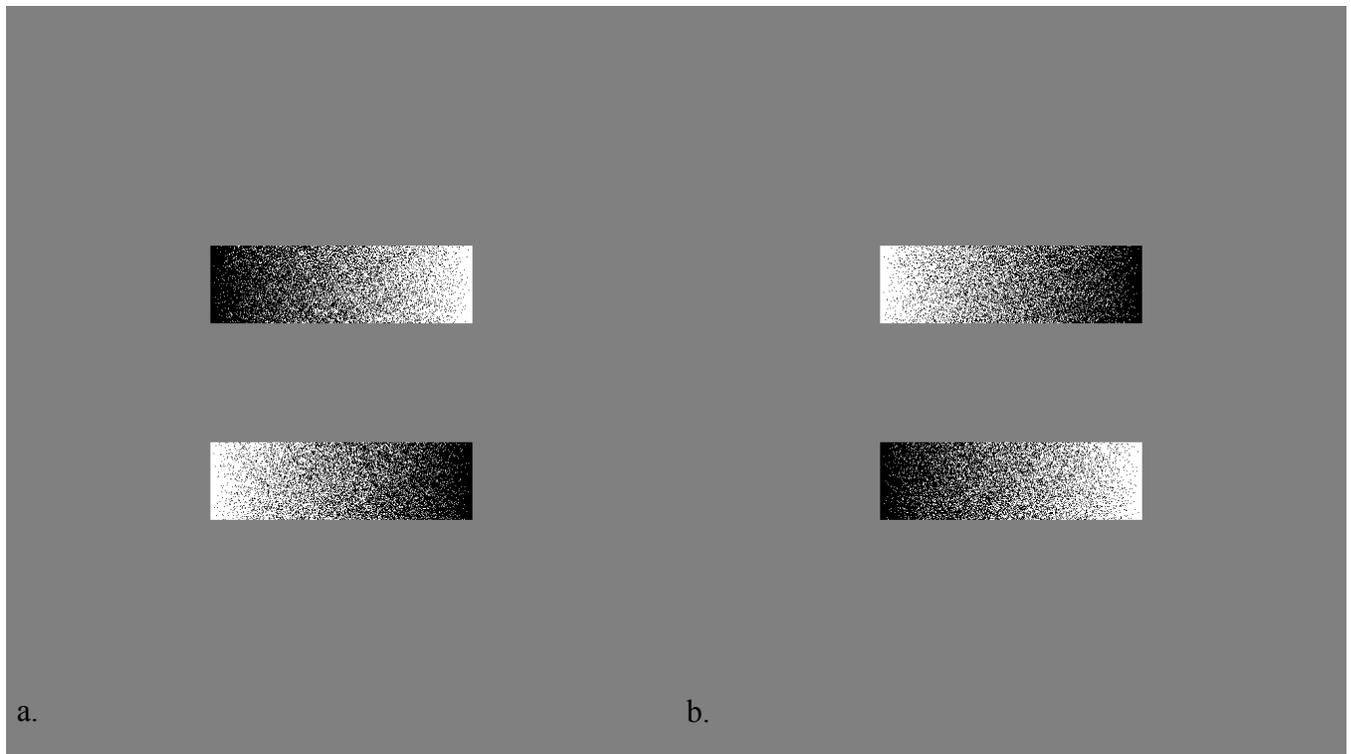


Figure 2-1. Sample stimulus pairs from the greyscales task. The stimulus pairs are each identical (i.e., equiluminant), although the luminance gradient extends in opposite orientations. A left response results from the participant choosing the stimulus with the darker feature on the left, irrespective of whether the stimulus is on the top or bottom.

2.2 Results

The participants were split into seven different age groups [18-29, 30-39, 40-49, 50-59, 60-69, 70-79, 80-89] and one-sample *t*-tests with significance levels of 5% (two-tailed) were conducted to determine if the response bias demonstrated by each age group was different than 0. Each age group judged the mirrored equiluminant stimulus as darker when the stimulus displayed the darker feature on the left (see Table 2-1 for mean response bias scores and *t*-test for each age group). Participants also chose the stimulus on top more often than the stimulus on the bottom, $t(493) = 3.66, p < .001$.

Table 2-1

Response bias scores for each age group

Age	<i>M</i>	<i>SD</i>	<i>n</i>	<i>t</i>	<i>p</i>	Cohen's <i>d</i>
18-29	-7.62	16.38	221	-6.19	.000	-.93
30-39	-10.84	15.264	38	-4.38	.000	-1.42
40-49	-7.97	14.98	34	-3.10	.004	-1.06
50-59	-12.50	15.54	36	-4.83	.000	-1.61
60-69	-9.11	21.73	54	-3.08	.003	-.83
70-79	-15.38	16.65	56	-6.85	.000	-1.83
80-89	-16.39	17.90	54	-6.73	.000	-1.83

Note. A negative score corresponds with a leftward response bias.

To compare the magnitude of the leftward response bias between the age groups, an ANOVA with between factors Age (18-29, 30-39, 40-49, 50-59, 60-69, 70-79, 80-89) and Sex (Male, Female) was conducted. A significant main effect was indicated for age group, $F(6, 478) = 2.53, p = .020, \eta_p^2 = .031$ (see Figure 2-2). However, Sex, $F(1, 478) = .13, p = .716$, and Age by Sex interaction effects were not significant, $F(6, 478) = 1.08, p = .372$. In accordance with previous research, it was hypothesized that the leftward response bias often demonstrated in the greyscales task would attenuate over the adult lifespan. However, a (Bonferroni corrected; $p < .05$) pairwise comparison analyzing the response bias between the different age groups revealed a significant difference in response bias between 18-29 year olds and 80-89 year olds ($p = .016$), which indicated that the youngest age group ($M = -7.62; SD = 16.38$) demonstrated a significantly weaker leftward bias than the oldest age group ($M = -16.39; SD = 17.90$). The pairwise comparison between 18-29 year olds and 70-79 year olds ($M = -15.25; SD = 16.65$) was trending towards significance using the Bonferroni correction ($p = .060$). No other comparisons were significant.

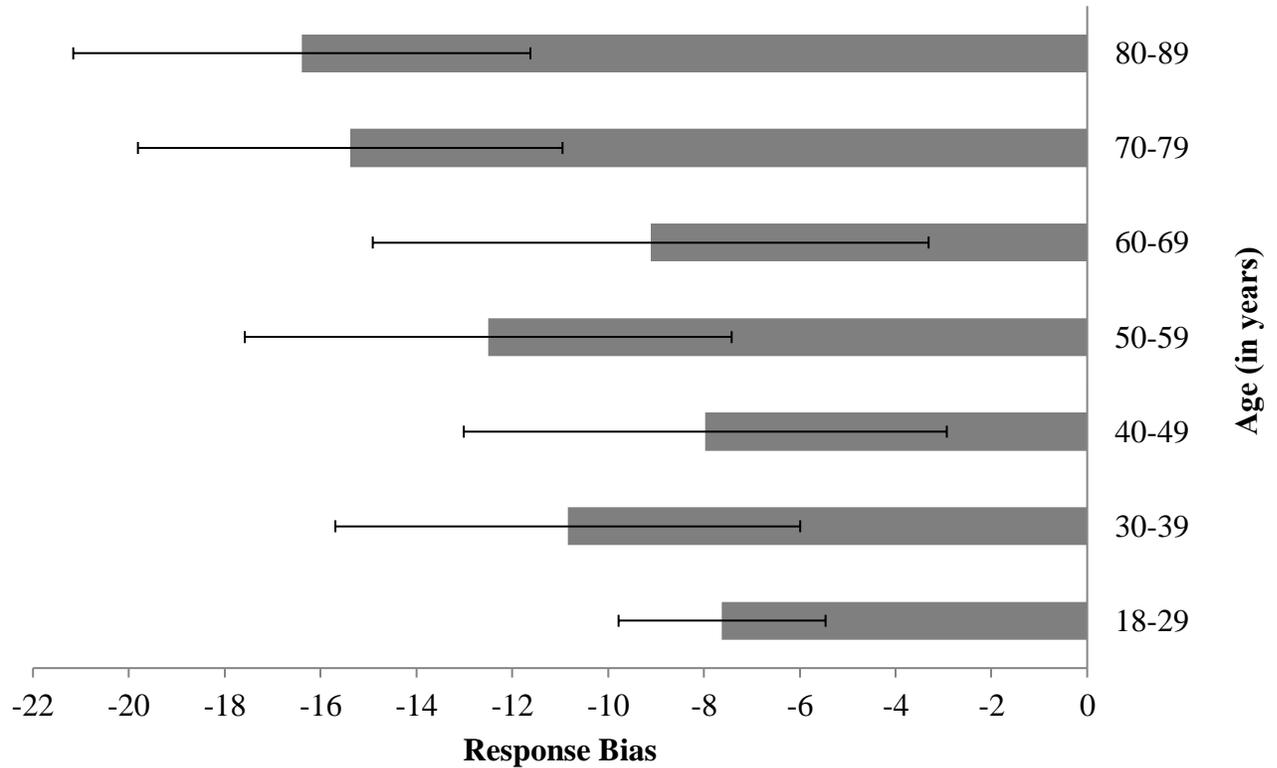


Figure 2-2. The mean response bias for the greyscales task demonstrated by each age category. A negative score indicates a preference for the darkest edge of the equiluminant gradient stimulus pair to be located on the left. Error bars represent the 95% confidence intervals.

To examine the relationship between age and the magnitude of the response bias demonstrated during the greyscales task a Pearson’s correlation analysis was used. A negative relationship between the magnitude of the leftward bias and age, $r(492) = -.154, p = .001$, was observed (see Figure 2-3). This negative relationship indicates that leftward response biases became larger with age, as negative numbers indicated leftward responses.

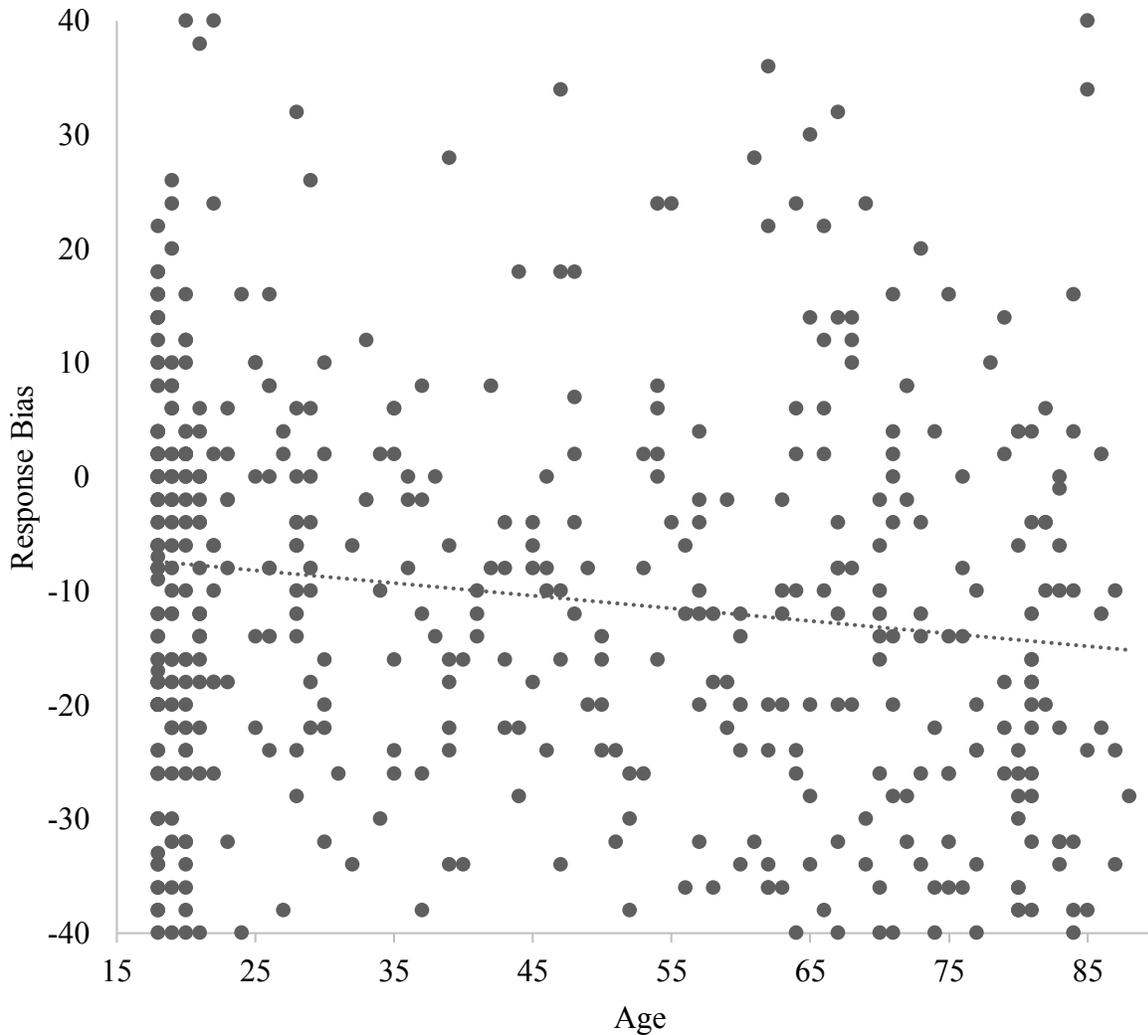


Figure 2-3. Scatter plot illustrating the correlation between the mean response bias demonstrated by each participant and his or her age.

2.3 Discussion

In the present study, the greyscales task was used to examine lateralized perceptual biases across the adult lifespan in a large and diverse sample. Unlike previous research using the line bisection task and landmark task, the performance on the greyscales task indicated that lateralized biases become stronger with age. Both older adults (80-89 year olds) and younger adults (18-29 year olds) demonstrated a leftward bias (i.e., identified the equiluminant stimulus that had the darker feature located on the left more frequently) and this leftward bias became demonstrably stronger with age. Specifically, changes in lateralized biases began occurring in the

seventh decade of life with strongest lateralized biases observed in the eighth decade of life. Younger participants demonstrated a leftward response biases consistent with previous research examining lateral biases of neurologically healthy adults on the line bisection, landmark and greyscales task (Jewell & McCourt, 2000; Nicholls et al., 1999). Although the stronger lateral biases demonstrated by older adults is inconsistent with the majority of previous research examining the effect of age on pseudoneglect (Barrett & Craver-Lemley, 2008; Chen et al., 2011; Failla et al., 2003; Fujii et al., 1995; Fukatsu et al., 1990; Goedert et al., 2010), these results are consistent with a small number of studies (Beste et al., 2006; De Agostini et al., 1999; Varnava & Halligan, 2007).

Further, the lateral bias demonstrated by each age group was similar between males and females. Although researchers have identified differences in lateral biases between males and females on the line bisection task (Barrett & Craver-Lemley, 2008; Beste et al., 2006; Chen et al., 2011; Varnava & Halligan, 2006), the results are consistent with research examining the effects of sex on pseudoneglect using the landmark and tactile rod bisection tasks, which also failed to identify a sex difference (Benwell et al., 2014b; Brooks et al., 2011; Schmitz & Peigneux, 2011). Previous research has proposed that the effect of sex on line bisection performance may result from fluctuations across the menstrual cycle (Cicinelli et al., 2011; Hausmann, 2005), as well as sex-differences in the structure of the corpus callosum (Beste et al., 2006). Investigations of pseudoneglect in patients with callosal infarction (Corballis, 1995), split brains (Heilman, Bowers, & Watson, 1984), and neurologically normal children with callosal immaturity (Bradshaw, Nettleton, Wilson, & Bradshaw, 1987) have identified the importance of the corpus callosum in line bisection. Further, the size and degree of interhemispheric connectivity of the corpus callosum has been found to differ between sexes, with females having a larger corpus callosum greater and interhemispheric connectivity (for review see, Driesen & Raz, 1995), which may influence sex-differences in line bisection. However, in contrast to the sex differences demonstrated using the line bisection task, the negligible sex differences in the current experiment are consistent with previous research examining pseudoneglect using other tasks including the landmark and tactile rod bisection tasks.

The hypothesis primarily proposed to account for age-related changes in pseudoneglect has commonly involved the HAROLD model and describes impairment of the right hemisphere leading to greater involvement of the left hemisphere, due to compensation or reduced inhibition,

that results in increased symmetrical activation (Benwell et al., 2014b; Failla et al., 2003; Schmitz & Peigneux, 2011). However, limited neuroimaging and electrophysiological evidence has used visuospatial tasks to support the HAROLD model (Cabeza et al., 2002). The HAROLD effect may be task specific, as the model proposes decreased lateralization and reduced inhibitory control in the prefrontal cortex. Further, Cabeza (2002) warns of specificity and reduced generalizability of the HAROLD model when considering reduced lateralization as a neural network phenomenon. The network view of the HAROLD model suggests that age-related changes in activity are task specific, as different tasks involve different networks (Cabeza, 2002). Bilateral recruitment of the prefrontal cortex to compensate for age-related neural decline, as proposed by the HAROLD model, may not be as dominant in visuospatial tasks compared to more complex tasks, such as memory.

The results from the current study suggest that compensation may result in increased lateralization for specific tasks, such as visuospatial tasks. The larger response bias demonstrated with aging could represent functional reorganization or redistribution in response to neural anatomical degeneration and neurotransmitter reduction (e.g., dopamine) that occurs with aging (De Agostini et al., 1999; Varnava & Halligan, 2007). Consistent with a recently proposed hybrid model of attention (Duecker & Sack, 2015), reorganization and redistribution of attentional mechanisms through recruitment of adjacent neural regions in the partial node within the right dorsal fronto-parietal network may enhance right hemisphere activation (Varnava & Halligan, 2007). Hence, greater activation of the right hemisphere increases the magnitude of attention applied to the left hemisphere, and consequently enhances the strength of the leftward response bias observed during the task.

2.3.1 Limitations

To examine the developmental trajectory of pseudoneglect in a large and diverse sample across the adult lifespan, the greyscales task was administered through an online survey that used stimuli identical to other modalities used. To our knowledge the greyscales task has not been administered through an online survey, as it is typically administered through a computer or paper version. It is unclear if participants respond in a similar manner across modalities. Older adults demonstrated a greater leftward response bias compared to prior research, which may have been influenced by the method of administration, however, the performance of younger adults was consistent with previous findings (Nicholls et al., 1999). When examining the

generalizability of lateralization tasks to the Internet, Rueckert (2005) found a greater leftward bias on the computerized chimeric faces task compared to the paper version conducted by Levy and colleagues (1983). She proposed her results were affected by the lack of symmetry on some browser screens (e.g., Internet Explorer for Windows). Unfortunately, this hypothesis cannot be tested, as we did not inquire about the browser or operating system the participants used.

Secondly, the viewing time of the stimuli was 3000ms, which is consistent with the instructions for the paper version; however, viewing time longer than 150ms may have influenced a perceptual bias shift. Longer viewing time allows participants to disengage from the stimulus, which facilitates perception of the stimuli as a whole, thus the observed leftward shift could have occurred as a result of a failure of inhibition of return (Posner & Cohen, 1984). Shorter viewing times (150 ms), which have been proposed to measure perceptual bias shifts, have been associated with rightward shifts in attention with healthy aging observed following the landmark task (Benwell et al., 2014b). As a result, the stronger leftward bias may have resulted from the longer viewing time and perception of the stimuli in its entirety.

2.4 Conclusion

In conclusion, the results highlight the importance of assessing lateral biases across the lifespan, particularly following the seventh decade of life. However, further investigation is needed to address inconsistent findings across studies of pseudoneglect in order to refine models of cognitive aging.

CHAPTER 3

THE TRAJECTORY OF PSEUDONEGLECT IN ADULTS: A SYSTEMATIC REVIEW

This chapter has been previously published:

Friedrich, T. E., Hunter, P. V., & Elias, L. J. (2018). The trajectory of pseudoneglect in adults: A systematic review. *Neuropsychology Review*. doi:10.1007/s11065-018-9392-6

Pseudoneglect, a phenomenon first identified by Bowers and Heilman (1980), initially referred to a directional error to the left when neurologically healthy individuals attempted to locate the midpoint of a tactile stimulus – a balsa stick. Since 1980, young neurologically healthy individuals have also been found to err to the left when asked to complete other simple perceptual tasks using different modalities. These tasks have included the line bisection, tactile rod bisection, landmark, greyscales, and lateralized visual detection tasks. For example, during such tasks, participants typically systematically misplace the transection to the left of the objective centre, perceive equally bisected lines as longer on the left, or select the greyscale stimulus that displayed the darker end on the left. Although these findings are robust and have been supported by research using animals (Diekamp, Regolin, Güntürkün, & Vallortigara, 2005; Regolin, 2006), the magnitude of the bias is small, particularly in comparison to larger errors made by patients experiencing hemispatial neglect.

The modesty of the phenomenon led researchers to question whether leftward errors and biases were an artifact related to random sampling errors in small sample sizes. However, the most recent meta-analysis that integrated peer-reviewed literature examining pseudoneglect and moderating variables in line bisection performance supported the notion that the phenomenon exists (Jewell & McCourt, 2000). The meta-analysis consisted of 73 studies and 2119 participants. Jewell and McCourt (2000) reported a leftward bisection bias with effect sizes (d) ranging from $-.37$ to $-.44$, which was modulated by both task and participant variables. Task variables consisted of modality specific effects (e.g., visual, pointing, tactile, kinesthetic), line length, line position, cueing, direction of scanning, and hand used to complete the task (e.g., left, right, or both hands). Participant variables included age, sex, and handedness.

Of the participant variables examined in this meta-analysis, age is of particular interest. The meta-analysis conducted included a limited number of studies that had examined age-related

changes in pseudoneglect, and the conclusion reported may have been premature (Jewell & McCourt, 2000). Jewell and McCourt (2000) concluded that younger subjects (less than 40 years-of-age) typically err to the left of centre on the line bisection task, whereas older adults (greater than 50 years-of-age) err to the right of centre. This conclusion was formulated based on two experiments that specifically focused on age-related changes of pseudoneglect in adults. Since Jewell and McCourt's (2000) meta-analysis and over the past two decades, researchers have begun investigating the effects of age-related differences in pseudoneglect using a variety of tasks. However, the phenomenon in older adults is not well understood and a synthesis of research that has examined pseudoneglect using the line bisection task, as well as other tasks, in the context of aging is lacking.

Tasks that are used to examine pseudoneglect are also used to assess hemispatial neglect in clinical populations, and research examining populations with neglect often used control subjects who are matched in age to patients who are typically in or beyond their fifth decade of life. Understanding the normal variability demonstrated on visuospatial tasks by older adults can assist researchers and clinicians in interpreting the findings observed in clinical populations (e.g., patients with hemispatial neglect). The aim of the current systematic review is to integrate the available research on pseudoneglect in late adulthood to discuss the association between age and a bias to the left hemispace. Synthesizing the literature on age effects will contribute to an understanding of the normal variability in pseudoneglect demonstrated by neurologically healthy older adults.

3.1 Methods

The systematic review has been conducted in accordance with the PRISMA guidelines (Moher et al., 2015). A university librarian provided general training on search methods, including: (1) review frameworks, (2) choosing databases, and (3) identifying relevant search terms. A review protocol was written but not registered. A second university librarian (1) reviewed the search methods, (2) provided feedback, and (3) assisted in identifying electronic programs to organize the retrieved the articles (e.g., reference management software).

3.1.1 Search Strategy and Information Sources

To identify relevant literature, DiCenso, Guyatt, and Ciliska's (2005) "population and situation" (PS) framework was used. The PS framework allows the research question to be separated into two key elements: 1) concern for the population ("P") of interest, in this case,

older adults, and 2) the situation (“S”), also called the condition, in this case, pseudoneglect. Synonyms of “older adult” and “pseudoneglect” were used as key words and subject headings to guide a systematic search for relevant literature (see Appendix A for full search specifications, including other search terms). The following databases were searched most recently on 5 July 2017: PsychInfo (1806 to June week 2 2017), Medline (1946 to June week 2 2017), Embase (1947 to June 19, 2017), Web of Science (1900 to July 4, 2017), Scopus (without time restrictions), OpenGrey (1997 to July 5, 2017), and Open Science Framework (January 2013 to July 2017). A search was specifically conducted in the OpenGrey database and Open Science Framework repository, and grey literature was included in the review to minimize publication bias. In addition to systematic electronic searches in the above databases, reference lists of reviews and retrieved articles were searched for additional studies (i.e., searching backwards), and citation searches on key articles were performed (i.e., searching forwards).

3.1.2 Eligibility Criteria

The review focused on integrating literature that examined pseudoneglect in relation to aging using a variety of tasks. An inclusive inclusion criterion was used to screen for articles to allow for a broader overview of the literature. Studies were eligible if they included one of the following tasks to examine pseudoneglect: line bisection task, landmark task, greyscales task, grating scales task, tactile rod bisection task, or lateralized visual detection task, and if they included participants who were 60 years of age or older and identified as neurologically healthy (i.e., not having a diagnosis of a neurological condition). Results were not restricted by study type, date of publication, or gender, but were limited to original research articles written in English.

After each database search was conducted, results were compiled using EndNote X8 and screened using the reference manager Rayyan. Duplicate records of identical studies were initially removed using EndNote and subsequently (i.e., if any were missed) using Rayyan. Titles and abstracts were screened by TF in Rayyan and records not fulfilling the inclusion criteria were excluded. Subsequently, the articles that were marked as potentially relevant were examined for eligibility by reviewing the full-text. Descriptive information from each study, including the aim of the study and the study population (e.g., sample size, age, gender), was extracted into Tables 1 to 5 (as suggested by Green, Johnson, & Adams, 2006).

Previous research has reported low inter-task reliability and correlations between visuospatial tasks that examine pseudoneglect (Learmonth, Gallagher, Gibson, Thut, & Harvey, 2015a; Rueckert, Deravanesian, Baboorian, Lacalamita, & Repplinger, 2002). This suggests that pseudoneglect may be multi-component phenomenon and subject to variations based on task demands (Learmonth et al., 2015a). If this is the case, it raises the possibility that the tasks are also subject to different patterns of age-related changes (Benwell, Thut, Grant, & Harvey, 2014; Brooks, Della Sala, & Logie, 2011; Friedrich, Hunter, & Elias, 2016; Fujii, Fukatsu, Yamadori, & Kimura, 1995; Fukatsu, Fujii, Kimura, Saso, & Korgure, 1990; Schmitz & Peigneux, 2011; Varnava & Halligan, 2007). As a result, the tasks used to examine pseudoneglect in this systematic review were categorized and examined independently in an attempt to minimize variability and inconsistency in the results.

3.2 Results

3.2.1 Study Selection

The database search generated 5196 titles, of which 1616 were duplicates, resulting in a total of 3657 unique articles (see Figure 1). After title and abstract screening, 3598 articles did not meet eligibility criteria and were therefore excluded. Of the excluded articles, the majority failed to meet inclusion criteria either because the task under study was not relevant (e.g., assessed memory or language) or because the study population did not include older adults. Using the same criteria, the full-text of the remaining 41 titles were assessed for eligibility. At this point, four additional articles were excluded as they employed neuropsychological test batteries designed to assess hemispatial neglect but did not include tasks specifically designed to assess pseudoneglect (e.g., cancellation, copying, and personal neglect tasks). Although such tasks are commonly used to identify hemispatial neglect, healthy participants often display ceiling effects on the tasks (Schindler, Clavagnier, Karnath, Derex & Perenin, 2006); thus, they are not typically used to examine pseudoneglect and the results were not considered for the review. Another eight articles employed the chimeric faces task, a task that requires judgment of similarity, gender, age, attractiveness, or emotional expression of a constructed image where the left and right sides differ, were excluded. During the chimeric faces task, participants typically demonstrate a left perceptual bias (i.e., a predisposition to base decisions on the left side) for chimeric images; however, the bias has been proposed to result from right hemisphere dominance for face processing rather than right hemisphere dominance for visuospatial attention

processing; thus, results are not considered relevant to this review. A further four articles were excluded because they examined adults younger than 60 years of age. This reduced the pool of articles to 25. However, seven additional articles were identified through backwards searching, and one dissertation was identified through forward searching. Thus, in total, 33 titles qualified for inclusion.

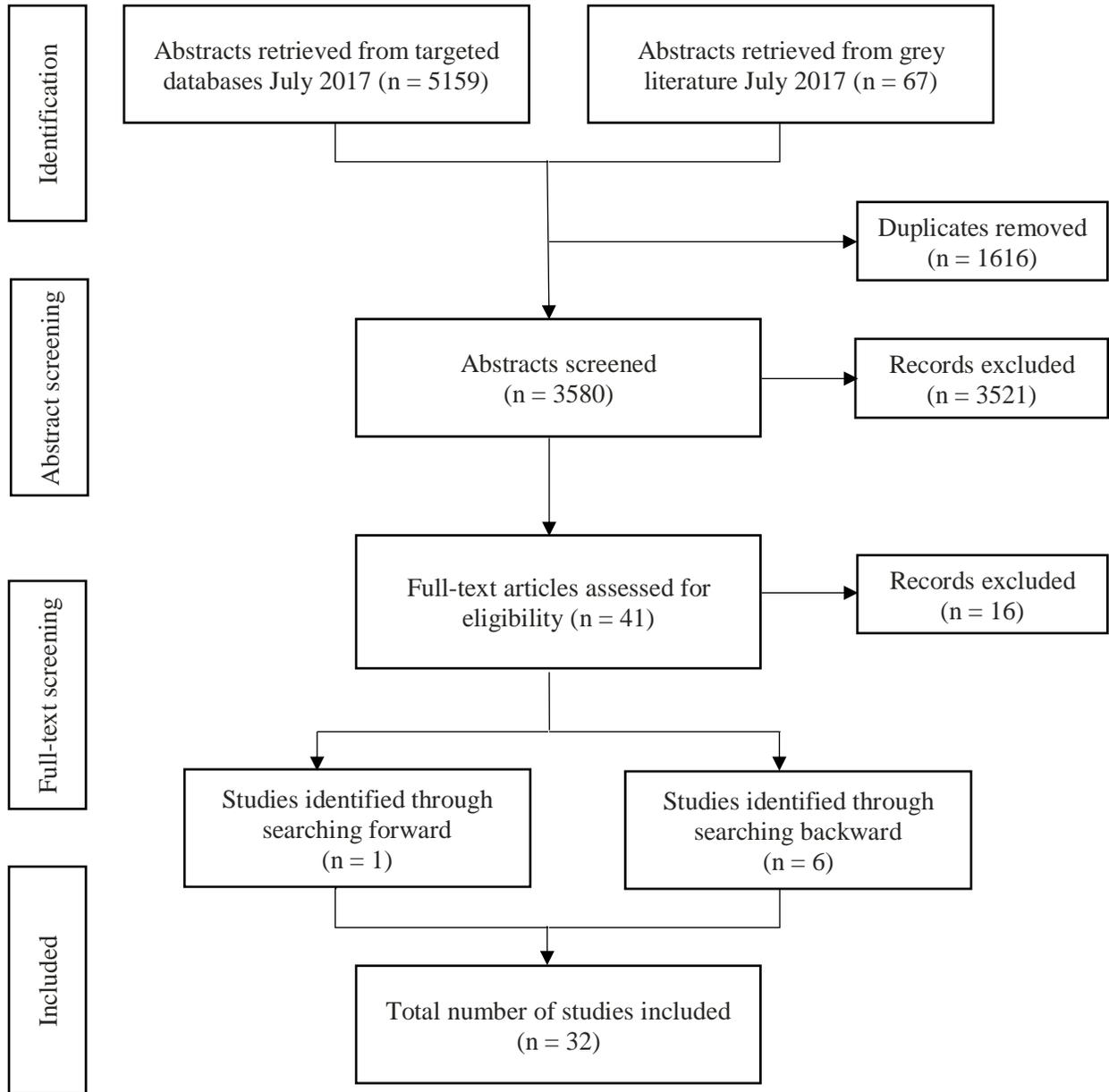


Figure 3-1. An outline of the search process using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) diagram (Moher et al., 2015).

The 33 titles were published between 1989 and 2017 and consisted of journal articles, theses, and conference presentations. Five tasks were used to examine pseudoneglect: the line bisection task, landmark task, greyscales task, tactile rod bisection task, and lateralized visual detection task. Specifically, the line bisection task requires participants to place a mark with a pencil or cursor through the centre of a horizontal line to divide the line in equal halves (Albert, 1973). Similarly, the tactile rod bisection task requires participants, with their eyes closed, to place their index finger at the perceived middle of a wooden doweling rod after exploring the entire length of the rod (Brooks et al., 2011). A non-manual variant of the line bisection task is the landmark task, which requires the participant to make a two-alternative forced choice decision regarding the length of the two halves of a line that is pre-bisected in the centre (Milner, Brechmann & Pagliarini, 1992). In contrast to judgments in size required by the line bisection and landmark task, the greyscales task requires judgments in luminance. The task requires participants to judge which of two horizontal mirror-imaged equiluminant gradients (i.e., one shaded from black to white and the other shaded from white to black) appears darker (Nicholls, Bradshaw, & Mattingley, 1999). Last, the lateralized visual detection task requires participants to detect small dots that briefly appear at the individual's peri-threshold in the left or right side of space and detection accuracy is calculated (Hilgetag, Théoret, & Pascual-Leone, 2001). In total, 21 titles employed the line bisection task, six employed the landmark task, one employed the line bisection and landmark task, two employed the greyscales task, two employed the tactile rod bisection task, one employed the lateralized visual detection task, and one employed five perceptual tasks (line bisection task, landmark task, grating scale task, greyscales task, and lateralized visual detection).

3.2.2 Line Bisection Task

Of the studies included in the systematic review, 23 examined how performance on the line bisection task varied with age. There was considerable variability in the results, with 14 studies pointing to an attenuated leftward bias with age, one study pointing to a leftward bias, two studies pointing to enhanced bias, and six studies not finding any significant age-dependent effects (see Table 1). For example, with respect to attenuated leftward biases, Fujii, Fukatsu, Yamadori, and Kimura (1995) compared three groups of 36 participants to investigate the effect of age on the line bisection task. The oldest age group (61-82 years of age) bisected lines to the right of centre, and their bisections were also significantly more rightward than the middle (42-

60 years of age) and young (21-30 years of age) groups, who were accurate in their bisections and did not deviate from centre. Similarly, Barrett and Craver-Lemley (2008) reported younger adults demonstrated a leftward line bisection bias that was significantly larger than the accurate bisection demonstrated by the older participants. Others have found similar results (Barrett & Craver-Lemley, 2008; Chen et al., 2011; Failla, Sheppard, & Bradshaw, 2003; Goedert, LeBlanc, Tsai, & Barrett, 2010).

In contrast, a single published study reported evidence of an enhanced leftward bias with age, particularly for participants who were women. Varnava and Halligan (2007) examined the effects of age and sex on line bisection by examining seven even age cohorts using three different line lengths. Age and sex-related differences were found in bisecting different line lengths with women over 30 demonstrated larger leftward deviations as line length increased, whereas women under 30 had similar leftward deviations on all line lengths. In contrast, men, as a group, did not demonstrate a trend and deviated to the left on short lines and either to the left or right on longer lines. Furthermore, DeAgostini, Curt, Tzortzis, and Dellatolas (1999) failed to find significant difference in the magnitude and direction of the bisection deviation between children, adults, and older adults, and a similar finding of insignificant differences between age groups have also been observed by others (Andrews, d'Avossa, & Sapir, 2017; Beste, Hamm, & Hausmann, 2006; Brooks, Darling, Malvaso, & Della Sala., 2016; Chieffi et al., 2014; Hatin, Tottenham, & Oriet, 2012).

When such variability in results exists, it becomes important to more precisely examine research questions and methods for indications of the potential causes of these discrepancies, beyond age and task. For example, one important observation from this review is that researchers have used different comparison groups to assess age-related effects on line bisection. Some have compared the performance of healthy older adults to patients with hemispatial neglect (Choi et al., 2007; Mennemeier, Vezey, Chatterjee, Rapcsak, & Heilman, 1997; Nichelli, Rinaldi, & Cubelli, 1989) or Alzheimer's Disease (Mendez, Cherrier, & Cymerman, 1997), whereas others have compared the performance of participants in various age groups. Further, researchers who have compared performance of participants in various age groups have used different age categories and have varied in the number of age categories examined. For example, some researchers limited comparisons between a single younger and older age group (Andrews et al., 2017; Barrett & Craver-Lemley, 2008; Brooks et al., 2016; Chieffi et al., 2014; Goedert et al.,

2010; Hatin et al., 2012; Milano, Douyon, Falchook, & Heilman, 2014; Pierce, 2000), whereas others compared multiple age groups (DeAgostini et al., 1999; Failla et al., 2003; Fujii et al., 1995), some of which were evenly divided across the adult lifespan (Beste et al., 2006; Varnava & Halligan, 2007). Furthermore, other researchers did not use a comparison group and limited the population examined in their research to older adults who had comparable age to patients with neglect (Fukatsu et al., 1990; Halligan, Manning, & Marshall, 1990; Maerker, Learmonth, Thut, & Harvey, 2016, August).

In addition to comparing older adults to various age groups, studies also differed in their approach to defining healthy older adults and accounting for cognitive impairment.

Differentiating between neurologically healthy participants and participants who have symptoms of cognitive impairment assists in establishing whether age-related differences in perceptual biases are due to neuropathology (Learmonth et al., 2017). Of the 23 studies, five studies used the Mini Mental State Exam to screen for symptoms of mild cognitive impairment in older participants. When cognitive performance was assessed, older adults who were identified as neurologically healthy demonstrated accurate bisections (Barrett & Craver-Lemley, 2008; Chieffi et al., 2014; Mendez et al. 1997) or demonstrated a leftward bias that did not differ from younger adults (Brooks et al., 2016; Chen et al., 2011 (female participants)), except in the case of a study by Chen and colleagues (2011), who identified an interaction between sex and age with only male participants demonstrating a rightward bisection bias with age.

Another observation is that studies did not universally examine gender differences in age-related differences on bisection performance. More specifically, some researchers did not specify the gender of participants (Andrews et al., 2017; Choi et al., 2007; Hatin et al., 2012; Mendez et al., 1997; Mennemeier et al., 1997; Milano et al., 2014; Nichelli et al., 1989), whereas others specified and examined gender-related effects on line bisection performance (Barrett & Craver-Lemley, 2008; Beste et al., 2006; Chen et al., 2011; Pierce, 2000; Varnava & Halligan, 2007). In these studies, an interaction between sex and age was common, with men demonstrating an attenuated leftward bias or rightward bias with age, and women demonstrating a leftward bias that was either comparable to that shown by younger adults (Barrett & Craver-Lemley, 2008; Chen et al., 2011; Pierce, 2000), or larger than that of younger adults (Varnava & Halligan, 2007).

In addition to variation in the participant variables examined, it was observed that researchers also used different methods to bisect lines, including variations in the hand used to make bisections. Five researchers specifically investigated age-related differences in line bisection as a function of hand use (Beste et al., 2006; DeAgostini et al., 1999; Failla et al., 2003; Fukatsu et al., 1990; Hatin et al., 2012). The results were largely inconsistent. For example, Fukatsu, Fujii, Kimura, Saso, and Kogure (1990) found that participants in their fifties and sixties demonstrated deviations significantly to the right of centre when bisections were conducted with the right hand and accurate bisections (i.e., not significantly different from zero) when using the left hand, whereas Hatin, Tottenham, and Oriet (2012) found that older adults were accurate when using their right hand and that bisections were significantly to the left of true centre when completing the task with their left hand. Further, Failla, Sheppard, and Bradshaw (2003) and DeAgostini, Curt, Tzortzis, and Dellatolas (1999) both identified a significant interaction between hand used and age group. Failla et al. (2003) reported that the interaction was driven by a stronger and consistent leftward bias with left hand across age groups than when using the right hand and both hands (i.e., bimanual). Specifically, the oldest age group demonstrated a significant deviation to the right of true centre when using the right hand and demonstrated accurate bisections when using both hands. Whereas DeAgostini et al. (1999) reported that all age groups demonstrated a significant constant bias to the left of centre when using the left and right hand, except for male children and male older adults when using the right hand who demonstrated accurate bisections. An interaction between hand use, age, and sex was also reported by Beste, Hamm, and Hausmann (2006), as the findings in their study revealed hand-use differences in women for the first three decades of life (i.e., a leftward bias when using the left hand and a rightward bias when using the right hand), which disappeared in 50 and 60-year-olds and re-emerged in their 70-year-olds. This was in contrast to men, who, in all age groups, demonstrated leftward bisections when using the left hand and accurate bisections when using the right hand (Beste et al., 2006).

In reviewing the studies retrieved it was also observed that the line bisection task differed with regards to stimulus properties, such as line length. Of the studies reviewed, stimulus line length varied from 20 to 400 mm in length and the number of different lengths presented to participants varied from two to 13. Of the studies reviewed, only two explicitly examined the effects of age on line bisection using different line lengths. Both studies reported an interaction

between age and line length, but the findings were contradictory (Pierce, 2000; Varnava & Halligan, 2007). Pierce (2000) reported that younger adults bisected to the left of true centre on short lines and to the right of true centre on longer lines (i.e., the crossover effect), whereas older adults bisected to the right of true centre on short lines and became more accurate as line length increased. In contrast, Varnava and Halligan (2007) reported that four older age cohorts (31 - 80 years) deviated to the left of true centre with greater magnitude on the longest line compared to the two shorter lines, whereas the two youngest cohorts (14 - 30 years) deviated to a similar magnitude across all three line lengths.

Together, the variation in methods (e.g., hand used) and stimulus properties (e.g., line length) employed within these studies, as well as the use of different comparison groups and variability in accounting for gender and cognitive impairment, makes it difficult to assess the degree to which differences in performance on the line bisection task is influenced by age. Nevertheless, some general patterns in the relationship between bisection performance and aging were apparent. For instance, researchers using the line bisection task commonly reported an attenuation of the leftward bias with age, with older adults demonstrating bisections further to the right than younger adults (Barrett & Craver-Lemley, 2008; Chen et al., 2011; Failla et al., 2003; Fujii et al., 1995; Goedert et al., 2010; Harvey et al., 2000; Milano et al., 2014; Pierce, 2000). Similarly, researchers also reported that older adults, as a control group, demonstrated accurate bisections (Choi et al., 2007; Harvey, Poll, Roberson, & Olk, 2000; Halligan et al., 1990; Mendez et al., 1997; Nichelli et al., 1989) or bisections to the right of true centre (Fukatsu et al., 1990; Mennemeier et al., 1997). However, these results were not universal. In a number of studies, there were no differences between older and younger age groups with all age groups either bisecting lines to the left of true centre (Andrews et al., 2017; Beste et al., 2006; Brooks et al., 2016; DeAgostini et al., 1999; Hatin et al., 2012) or demonstrating accurate bisections (Chieffi et al., 2014). Further, a limited number of studies reported older adults demonstrating a stronger leftward bias compared to younger adults (Varnava & Halligan, 2007), or a bias to the left of true centre without comparing performance to another age group (Choi et al., 2007; Harvey, Milner & Roberts, 1995; Maerker et al., 2016, August).

Table 3-1

Characteristics of included studies examining the line bisection task

Author, date of publication	Study Aim	Number of Comparison Groups	Sample Size	Gender (Male%/Female%)	Age (years)
Attenuated leftward bias with age					
Nichelli et al., 1989	Discern whether displacement in line bisection by USN patients could be traced back to the same mechanisms that may affect a normal population through randomizing hemispace presentations within cue and no-cue conditions.	Normal subjects USN patients	10 10	Unspecified	47-73 ($M = 64.3$) 56-77 ($M = 69.1$)
Fukatsu et al., 1990	Investigate the effects of spatial conditions and hand use on a visual line bisection task in normal subjects having an age comparable to patients with neglect.	General medical in-patients	24	50%/50%	50-60 ($M = 61.6$)
Halligan et al., 1990	Using mixed methods, determine whether patterns of transection displacement seen in young normal subjects can be replicated with an older sample.	Hospital volunteers	20	50%/50%	57-85 ($M = 69.3$)
Fujii et al., 1995	Investigate effects of age on the line bisection test.	Young age Middle age Old age	36 36 36	50%/50% 50%/50% 50%/50%	21-30 ($M = 30.4$) 42-60 ($M = 50.0$) 61-82 ($M = 70.1$)
Mendez et al., 1997	Evaluate the presence of neglect on visual search and line bisection tasks in patients with mild to moderate AD as compared with healthy elderly controls.	Patients with AD Healthy controls matched to age, sex, and education, and MMSE scores >28	15 15	Unspecified	> 65 years of age
Mennemeier et al., 1997	Examine the effect of hemispatial placement and cuing on line bisection performance in subjects with LHL and RHL.	Patients with RHL Patients with LHL Normal controls	31 11 10	Unspecified	$M = 66.9$ $M = 66.4$ $M = 71.9$
Harvey et al., 2000	Investigate whether invisible cues (e.g., drawing a vertical mark with a leadless pencil to either or both ends of the line) produced different bisection and landmark performance than visible cues.	Healthy volunteers	18	50%/50%	64-82 ($M = 71$)
Pierce, 2000	Use the crossover effect as a tool to test the effects of age and gender on magnitude estimation and attentional bias.	Undergraduate students Elderly subjects	30 30	50%/50%	18-30 60-85
Failla et al., 2003	Investigate age-related changes as a function of hand-response method in the line bisection and chimeric faces tasks.	Younger group Young group Middle group Older group	25 28 24 30	48%/52% 43%/57% 37.5%/62.5% 47%/53%	5-7 ($M = 6.1$) 10-12 ($M = 11.1$) 20-30 ($M = 22.9$) 60-70 ($M = 66.1$)

Choi et al., 2007	Investigate whether the influence of induced motion on the attentional biases of healthy individuals is different from the attentional biases of patients with hemispatial neglect, and, if so, what mechanisms might account for these differences.	Healthy volunteers Outpatients with left hemispatial neglect from RH cerebral infarctions	22 9	Unspecified 78%/22%	$M = 66.4$ 46-70 ($M = 63.7$)
Barrett & Craver-Lemley, 2008	Examine horizontal and radial visual-spatial bias explicitly and implicitly in aged and young subjects.	Young adults Aged adults	60 60	50%/50% 50%/50%	$M = 20.4$ $M = 73.7$
Goedert et al., 2010	Investigate whether the asymmetric effect of left versus right prism training is consistent with baseline asymmetric spatial biases.	Young adults Aged adults	12 12	50%/50% 50%/50%	21-33 ($M = 25.3$) 61-85 years ($M = 72.8$)
Chen et al., 2011	Assess how perceptual-attentional and motor-intentional biases contribute to line bisection performance as a function of age and sex.	Healthy community-dwelling adults	44	50%/50%	22-93 ($M = 58.8$)
Milano et al., 2014	Examine whether there is a relative change between the magnitude of vertical and horizontal pseudoneglect with aging.	Healthy younger adults Healthy older adults	9 9	Unspecified	$M = 24.89$ $M = 72.3$
Leftward bias					
Harvey et al., 1995	Examine whether determinants of neglect phenomena were perceptual or action related, and inspecting the location of lesion to determine whether it was related to the extent of perceptual effects found.	Patients with RCVA	12	50%/50%	$M = 65.8$
		Patients with LCVA	12	50%/50%	$M = 58.4$
		Healthy subjects	12	34%/66%	$M = 66.2$
Enhanced leftward bias with age					
Varnava & Halligan, 2007	Examine the effects of biological factors (age and sex) on normal line bisection using different line lengths.	14-20 years	20	50%/50%	$M = 18.5$
		21-30 years	20	50%/50%	$M = 25.5$
		31-40 years	20	50%/50%	$M = 35.5$
		41-50 years	20	50%/50%	$M = 46$
		51-60 years	20	50%/50%	$M = 56$
		61-70 years	20	50%/50%	$M = 67$
		71-80 years	20	50%/50%	$M = 74$
Maerker et al., 2016	Investigate the test-retest reliability of five tasks of spatial attention in older adults	Cognitively healthy older adults	38	50%/50%	60-86 ($M = 69.7$)

Comparable performance between age groups

DeAgostini et al., 1999	Examine the effect of age and hand use on line bisection.	Children	60	52%/48%	5-6 ($M = 5.5$)
		Young adults	60	50%/50%	21-45 ($M = 34.6$)
		Older adults	66	35%/65%	60-94 ($M = 74.6$)
Beste et al., 2006	Examine age and sex-related changes in line bisection as a function of hand use.	20-29 years	45	49%/51%	$M = 24.1$
		30-39 years	49	49%/51%	$M = 34.7$
		40-49 years	47	38%/62%	$M = 44.4$
		50-59 years	73	49%/51%	$M = 53.9$
		60-69 years	38	45%/55%	$M = 63.2$
		70-79 years	29	45%/55%	$M = 73.5$

Hatin et al., 2012	Examine the effect of age and hand use on line bisection and whether line bisection scores correlate with collision scores.	Undergraduate students Community-dwelling seniors	16 12	Unspecified	$M = 21.4$ $M = 72.7$
Chieffi et al., 2014	Explore whether there are age-related differences in susceptibility to distractor interference when asked to bisect horizontal lines.	Younger adults Older adults	20 20	35%/65% 40%/60%	25-33 ($M = 27.2$) 65-78 ($M = 69.0$)
Brooks et al., 2016	Investigate pseudoneglect in older adults across three different bisection tasks: visuo-spatial line bisection, tactile rod bisection and mental number line bisection.	Younger adults (from Scotland) Older adults (from S. Australia)	60 60	20%/80% 38%/62%	18-40 ($M = 24.0$) 55-90 ($M = 69.8$)
Andrews et al., 2017	Test the hypothesis that diminished light source bias in older adults reflects reduced hemispheric lateralization by correlating assumed light source direction with line bisection performance.	Young adults Healthy older adults	20 14	Unspecified	19-30 ($M = 21.9$) 63-79 ($M = 69.3$)

Note. The studies highlighted are considered grey literature (e.g., theses and poster presentations) and were not retrieved from peer-reviewed journals. Terms used to describe age groups are as reported in the original studies. USN = Unilateral Spatial Neglect; AD = Alzheimer's Disease; MMSE = Mini Mental State Exam; LCVA = left hemisphere stroke; LHL = Left Hemisphere Lesion; RCVA = right hemisphere stroke; RHL = Right Hemisphere Lesion; Crossover Effect = neurologically healthy participants err to the left when bisecting medium and long lines, but err rightward when bisecting short lines.

3.2.3 Landmark Task

Considerable variability in the direction of the perceptual bias was also identified when researchers examined pseudoneglect in older adults using the landmark task. Of the nine studies that examined how performance on the landmark task varied with age, five studies supported an attenuated leftward bias with age, two studies supported a leftward bias, and two studies did not find any significant age-related effects (see Table 2). For example, with respect to an attenuated leftward bias with age, Schmitz and Peigneux (2011) reported differences in response patterns between elderly and younger adult participants. Older adults did not demonstrate a bias and judged evenly bisected lines at chance level (i.e., selected the left section of the line as longer/right as shorter for half of the trials), whereas younger participants judged the left end of the lines as longer at an above chance level, thus demonstrating a leftward bias. Similarly, Benwell, Thut, Grant, and Harvey (2014) examined the effect of age on lateralized visuospatial bias during the landmark task using three different line lengths. Overall, younger and older adults identified different subjective midpoints with younger adults perceiving the midpoint significantly more to the left compared to older participants. Others have also found an attenuated leftward bias with age (Learmonth, Thut, Benwell, & Harvey, 2015b; Harvey et al., 2000; Maerker et al., 2016, August; Schmitz, Dehon, & Peigneux, 2013). Nevertheless, this

finding is not universal. Harvey, Poll, Roberson, and Olk (2000) investigated the effect of visible and invisible cues on the landmark task using asymmetrically transected stimuli in a group of 18 older adults. In the no-cue condition, the older adults demonstrated significantly more leftward responses compared to chance. Similar results in a no-cue condition were reported by Harvey, Milner, and Roberts (1995) when examining healthy older adults. Furthermore, researchers using the landmark task have also failed to identify age-related differences (Learmonth et al., 2017), even when controlling for participants' race, education, total weighted occupational prestige, visual acuity, and WISC-IV Information scale score (McPherron, 2015). For example, Learmonth, Benwell, Thut, and Harvey (2017) analyses of the behavioural responses on the landmark task indicated that participants were accurate in their judgment of the midpoint with both younger and older adults failing to demonstrate a perceptual bias.

Given the variability in reported findings, it is important to note that researchers diverged in their choice of dependent variable and in how biases were calculated. For example, some researchers calculated a leftward perceptual bias as the percentage of left longer/right shorter responses for evenly bisected lines (Schmitz & Peigneux, 2011; Schmitz et al., 2013), others calculated a leftward response based on the number of leftward choices participants made when asked which end of line they thought the transection was closest to (Harvey et al., 1995; Harvey et al., 2000), and still others used a cumulative logistic psychometric function (i.e., a measure of the precision of midpoint judgments) and a point of subjective equality (i.e., the perceived midpoint of the line) for unevenly bisected lines (Benwell et al., 2014; Learmonth et al., 2017).

Table 3-2

Characteristics of included studies examining the landmark task

Author, date of publication	Study Aim	Number of Comparison Groups	Sample Size	Gender (Male%/Female%)	Age (years)
Attenuated leftward bias with age					
Schmitz & Peigneux, 2011	Investigate the suppression or inversion of pseudoneglect in participants over 60 years using the landmark task.	Healthy young adults	32	50%/50%	19-39 ($M = 22.4$)
		Healthy elderly adults	19	47%/53%	60-81 ($M = 69.4$)

Schmitz et al., 2013	Examined whether attentional biases in YA and OA would be predictive for laterality effects in DRM performance using the same populations as (Schmitz & Peigneux, 2011).	Healthy young adults Healthy older adults	32 19	50%/50% 47%/53%	19-39 ($M = 22.4$) 60-81 ($M = 69.4$)
Benwell et al., 2014	Examine how age and line length interact to influence lateralized visuospatial bias as displayed during landmark task.	Young adults Elderly adults	20 20	60%/40% 55%/45%	18-31 ($M = 23.3$) 60-77 ($M = 68.5$)
Learmonth et al., 2015b	Examine how age and line length influence pseudoneglect on the landmark task while recording neural activity using EEG.	Young adults Older adults	20 20	Unspecified	18-25 60-80
Maerker et al., 2016	Investigate the test-retest reliability of five commonly used tasks of spatial attention in older adults.	Cognitively healthy older adults	38	50%/50%	60-86 ($M = 69.7$)

Leftward bias

Harvey et al., 1995	Through the use of cueing, determine whether bisection error is attributable to residual perceptual distortion or directional hypokinesia in neglect patients.	Patients with RCVA Patients with LCVA Healthy subjects	12 12 12	50%/50% 50%/50% 34%/66%	$M = 65.8$ $M = 58.4$ $M = 66.2$
Harvey et al., 2000	Investigate whether invisible cues produced different bisection and landmark performance than visible cues.	Healthy volunteers	18	50%/50%	64-82 ($M = 71$)

Comparable performance between age groups

Learmonth et al., 2017	Investigate whether age-related functional reorganization of neural activity can be observed using EEG during a spatial judgment task.	Young adults Older adults	20 20	50%/50% 50%/50%	18-25 ($M = 20.8$) 60-80 ($M = 68.8$)
McPherron, 2015	Provide confirmation of the HAROLD model using established behavioural measures, explore the generalizability of the HAROLD model using tasks less well established, and examine support for the dedifferentiation and compensation hypotheses.	Young adults Older adults Older adults with mild cognitive impairment	60 13 15	40%/60% 39%/61% 33%/67%	($M = 19.3$) ($M = 67.1$) ($M = 71.3$)

Note. The studies highlighted are considered grey literature (e.g., theses and poster presentations) and were not retrieved from peer-reviewed journals. The terms used to describe the age groups are consistent with the terms used by authors. YA = Young adults; OA = Older adults; DRM = Deese-Roediger-McDermott paradigm.

3.2.4 Greyscales Task

A limited number of studies included in the systematic review examined age-related differences in pseudoneglect using the greyscales task. In contrast to the variability in results when researchers have employed the line bisection and landmark task, research using the greyscales task has generated fairly consistent results (see Table 3). The two journal articles

published in peer-reviewed journals retrieved in the systematic search both reported that older adults demonstrated a significant leftward bias on the greyscales task. For example, Mattingley et al. (2004) compared the performance of neurologically healthy older adults to a sample of patients with a unilateral stroke on the greyscales task found that healthy older adults demonstrated a small leftward bias. Similarly, Friedrich, Hunter, and Elias (2016) compared the performance of seven age groups on the greyscales task and each age group judged the mirrored equiluminant stimulus as darker when the stimulus displayed the darker end on the left. A significant difference was also found between the seven age groups with the oldest age group (80-89 year olds) demonstrating a significantly stronger leftward bias compared to the youngest age group (18-29 year olds). Further, a negative relationship was found between age and a leftward bias with the magnitude of the bias increasing with age. However, in contrast, a poster presented by Maerker et al. (2016, August) examined the test-retest reliability of tasks of spatial attention in older adults, including the greyscales task. In this study, older adults demonstrated a rightward bias.

Table 3-3

Characteristics of included studies examining the greyscales task

Author, date of publication	Study Aim	Number of Comparison Groups	Sample Size	Gender (Male%/Female%)	Age (year)
Attenuated leftward bias with age					
Maerker et al., 2016	Investigate the test-retest reliability of five commonly used tasks of spatial attention in older adults.	Cognitively healthy older adults	38	50%/50%	60-86 ($M = 69.7$)
Leftward Bias					
Mattingley et al., 2004	Replicate earlier finding of a pathological rightward bias in patients with RH damage, examine whether patients with LH lesions exhibit an abnormal leftward bias, compare patients' bias scores with their performance on commonly used clinical tests of neglect, and test whether spatial biases may be due to visual field cuts rather than attentional biases.	Patients with unilateral RH damage	78	64%/36%	21-84 ($M = 60.7$)
		Patients with unilateral LH damage	20	45%/55%	25-87 ($M = 64.4$)
		Neurologically healthy participants	20	Unspecified	65-81 ($M = 75.4$)
Enhanced leftward bias with age					

Friedrich et al., 2016	Examining the stability of pseudoneglect across the adult lifespan using the greyscales task in a large sample of adults.	18-29, 30-39, 40-49, 50-59, 60-69, 70-79, 80-89 Total	493	39%/61%	18-88 ($M = 43.5$)
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Note. The studies highlighted are considered grey literature (e.g., theses and poster presentations) and were not retrieved from peer-reviewed journals. The terms used to describe the age groups are consistent with the terms used by authors. RH = Right Hemisphere; LH = Left Hemisphere.

3.2.5 Tactile Rod Bisection Task

Of the 33 studies retrieved in the systematic search, two examined the developmental trajectory of pseudoneglect using the tactile rod bisection task. In both studies, Brooks and colleagues (2011; 2016) reported that older adults demonstrated a leftward bias that was comparable to younger adult participants (see Table 4). For example, when the side from which the bisection started was counterbalanced, Brooks, Della Sala, and Logie (2011) reported both older (60-96 years) and middle-aged (18-55 years) adults demonstrated a leftward bias (i.e., a negative mean percent deviation score) that was significantly different from zero. It is noteworthy to mention that when comparing the three age groups, including the youngest age group (6-13 years), a trend for a greater leftward bisection bias with age appeared, but fell short of significance. Similarly, Brooks, Darling, Malvaso, and Della Sala (2016) recruited younger (18-40 years) and older (55-90 years) participants and the mean percent deviation demonstrated by both age groups was leftward and significantly different than zero, and bisection biases did not differ between the two age groups.

An additional observation reported by Brooks and colleagues in both studies (2011; 2016) was that the side from which the bisection started was crucial for the magnitude of the bias observed. When bisection started from the right side of the rod participants demonstrated a leftward bias, whereas participants demonstrated accurate bisections when beginning from the left side. Interestingly, Brooks et al. (2011) reported that the oldest age group was the most sensitive to starting side compared to the other two age groups, whereas Brooks et al. (2016) found similar start side effects for both the younger and older age group.

Table 3-4

Characteristics of included studies examining the tactile rod bisection task

Author, date of publication	Study Aim	Number of Comparison Groups	Sample Size	Gender (Male%/Female%)	Age (year)
Comparable performance between age groups					
Brooks et al., 2011 (Experiment 1)	Examine representational forms of pseudoneglect across the lifespan and how performance is mediated by the spatial direction from which the judgement was made.	3-6 years	72	Unspecified	$M = 5.4$
		7-8 years	108		$M = 7.5$
		9-10 years	95		$M = 9.5$
		11-12 years	59		$M = 11.3$
		13-20 years	22		$M = 15.5$
		22-40 years	86		$M = 35.0$
		41-60 years	79		$M = 47.1$
61-84 years	28	$M = 70.8$			
Brooks et al., 2011 (Experiment 2)	Examine representational forms of pseudoneglect across the lifespan and how performance is mediated by the spatial direction from which the judgement was made while controlling for gender.	6-13 years	24	Unspecified	$M = 9.4$
		18-55 years	24		$M = 30.3$
		60-96 years	24		$M = 74.2$
Brooks et al., 2016	Investigate pseudoneglect in older adults across three different bisection tasks: visuospatial line bisection, tactile rod bisection and mental number line bisection.	Younger adults	60	20%/80%	18-40 ($M = 24.0$)
		Older adults	60	38%/62%	55-90 ($M = 69.8$)

Note. The terms used to describe the age groups are consistent with the terms used by authors.

3.2.6 Lateralized Visual Detection Task

Only one published study retrieved in the systematic search examined age-related differences in performance on the lateralized visual detection task (see Table 5). During the task, small squares were presented either to the left of a fixation cross, to the right, or bilaterally for 40 milliseconds, and participant's ability to accurately detect the stimuli was examined. At baseline, Learmonth, Thut, Benwell, and Harvey (2015b) found that younger adults were more sensitive to detecting stimuli in the left visual field, reflecting a leftward attentional bias, whereas the older adults did not demonstrate a consistent bias and were equally sensitive to detecting stimuli in the left and right visual field.

Table 3-5

Characteristics of included study examining the lateralized visual detection task

Author, date of publication	Study Aim	Number of Comparison Groups	Sample Size	Gender (Male%/Female%)	Age (year)
Learmonth et al., 2015b	Examine whether atDCS would reinstate an adaptive “youth-like” pattern of right hemispheric dominance for spatial attention in older adults.	Young adults Older adults	20 20	45%/55% 50%/50%	18-24 ($M = 20.9$) 60-77 ($M = 66.6$)

Note. The terms used to describe the age groups are consistent with the terms used by authors. atDCS = anodal transcranial direct current stimulation.

3.2.7 Summary of Results

Within similar tasks, the studies included in the review reported inconsistent findings, as well as variability in the methods used. However, as can be seen in Table 3-6, a number of notable trends appeared within each task included in the review.

Table 3-6

Summary of the different tasks used and the frequency of results that supported an attenuated leftward bias with age, enhanced leftward bias with age, or comparable performance

Task	Attenuated leftward bias with age	Enhanced leftward bias with age	Leftward bias	Comparable performance between age groups
Line Bisection	14	1	1	6
Landmark	5	0	2	2
Greyscales	1	1	1	0
Tactile Rod Bisection	0	0	0	2
Lateralized Visual Detection	1	0	0	0

Studies employing the line bisection task commonly reported an attenuated leftward bias with age (Barrett & Craver-Lemley, 2008; Chen et al., 2011; Choi et al., 2007; Failla et al., 2003; Fukatsu et al., 1990; Fujii et al., 1995; Goedert et al., 2010; Halligan et al., 1990; Harvey et al., 2000; Mendez et al., 1997; Mennemeier et al., 1997; Milano et al., 2014; Nichelli et al., 1989; Pierce, 2000), with the minority of studies reporting older adults demonstrated a stronger leftward bias (Varnava & Halligan, 2007) or no difference in performance between age groups (Andrews et al., 2017; Beste et al., 2006; Brooks et al., 2016; DeAgostini et al., 1999; Hatin et

al., 2012). Similarly, studies using the landmark task most commonly reported an attenuation of the leftward bias with age (Benwell et al., 2014; Learmonth et al., 2015b; Maerker et al., 2016, August; Schmitz & Peigneux, 2011; Schmitz et al., 2013), but again these results were not universal. A subset of studies did not find a difference in performance between older and younger adults (Learmonth et al., 2017; McPherron, 2015), and Harvey et al. (1995; 2000) reported that older adults demonstrated a leftward bias. In contrast, articles published in peer-review journals consistently reported that older adults demonstrated a leftward bias on the greyscales task (Mattingley et al. 2004) and stronger bias compared to younger adults (Friedrich et al. 2016). Consistent findings were also identified in studies using the tactile rod bisection task. Older adults were reported to have demonstrated a leftward bias comparable to younger adults in both studies (Brooks et al., 2011; Brooks et al., 2016).

3.3 Discussion

The aim of the systematic review was to aggregate and summarize age-related differences in performance on tasks used to examine pseudoneglect. Following a systematic search for relevant studies, multiple studies were identified that employed the line bisection task, and a smaller number of studies utilized the landmark, greyscales, tactile rod bisection, and lateralized visual detection tasks. Together, the literature retrieved was characterized by inconsistent results and large variability in study design. Unsurprisingly, this conclusion is identical to the finding reported in Jewell and McCourt's (2000) qualitative review of the line bisection literature. Even when studies employed identical tasks, they varied in methods (e.g., hand used, direction of scanning), stimuli (e.g., stimulus length, number of stimuli viewed), and approach to comparing participants (e.g., gender, handedness), including structure of age groups (e.g., number of age groups, age range within groups). These differences make it difficult to assess the degree to which performance is influenced by age; thus, it is premature to draw conclusions based on the literature included in the review. However, when comparing the identified studies that examined age-related differences in pseudoneglect a number of observations were noteworthy.

All of the studies included in the review used a cross-sectional design. The analysis of cross-sectional samples varying in age is consistent with the research paradigm in gerontology that has been predominately used to understand cognitive aging (Hofer, Silwinski, & Flaherty, 2002). However, researchers have questioned the utility of using cross-sectional studies to understand age-related changes, and have argued that understanding aging also requires analysis

of change within individuals (Hofer et al., 2002). Relying solely on cross-sectional research to understand pseudoneglect across the life span may be misleading and is unlikely to provide an accurate understanding of longitudinal change or the effect of chronological age. Cross-sectional data has been found to provide unreliable estimates of age-related cognitive decline by conflating the effect of age with cohort effects (Singh-Manoux et al., 2012). Further, research examining cognitive aging has commonly reported discrepancies between cross-sectional and longitudinal age trends with between-person cross-sectional comparisons reporting declines in functioning beginning in early adulthood, whereas within-person longitudinal comparisons report stability or increases in cognitive performance (Salthouse, 2010). In an area of research that is dominated by cross-sectional associations between age and pseudoneglect, longitudinal data that are adequately powered are essential for drawing conclusions regarding change with chronological age. To fully understand pseudoneglect across adulthood, future research could benefit from basing conclusions on results derived from multiple methods of data collection and analysis (Salthouse, 2011).

Further, when examining cross-sectional differences, the age ranges studied varied substantially. The majority of studies included in the review used a modal “extreme age group design” (Marsiske & Margaret, 2006, pp. 320) and categorized participants into younger and older adult groups, with the age range within the older adult age group spanning 20 to 30 years (e.g., 60-80 years or older). Comparing extreme groups of younger and older adults is problematic as the variance associated with middle-aged adults is omitted and inflates estimates of age-related differences. Further, because changes in cognitive functioning often occurs continuously across adulthood, results based on lateral biases observed over a large period of older age (e.g., 20-30 years) could be misleading with regards to the origin of age-related differences and whether the identified age relations are linear. Fewer studies included a middle age group, and only three studies included in the review categorized age groups with smaller age ranges (e.g., 10-year cohorts; Beste et al., 2006; Friedrich et al., 2016; Varnava & Halligan, 2007). These three studies reported an enhanced leftward bias with age (Friedrich et al., 2016), particularly as demonstrated by women (Varnava & Halligan, 2007), or reported comparisons between age groups that did not reach levels of significance (Beste et al., 2006).

The use of broad age categories and cross-sectional design may be contributing to the variability of perceptual biases observed in older adults within and between the various tasks

used to examine pseudoneglect, and may be inhibiting researchers' ability to understand *when* changes occur. Improving design by examining age groups with smaller age ranges, or using longitudinal methods, is critical, as the extent of changes in cognitive performance may vary considerably over a large age range (e.g., 20 to 30-year span) in older age. Research on the course of intellectual abilities, including spatial orientation, over the adult lifespan has revealed that performance plateaus after a peak in young adulthood until the late 50's or early 60's, and then declines at a slow pace until the late 70's, when decline is often accelerated (Schaie, 1994). Specifically, research over 35 years (six testing cycles) within the Seattle Longitudinal Study showed that decline in cognitive abilities is not reliably confirmed prior to age 60, and fewer than half of the participants showed reliable decrements at age 74; however, by age 81, most abilities decline by one standard deviation (Schaie, 1993; Schaie, 1994). On this basis, large age ranges spanning from 60 to the late 80's, as typically seen in studies of pseudoneglect, are likely insufficient, and may be resulting in large within group differences leading to the reporting of central or attenuated leftward biases. Thus, the conclusion that pseudoneglect becomes rightward with age may be invalid. Of the studies included in the review, only Friedrich et al. (2016) categorized participants in 10-year age cohorts and examined adults over 80 years of age as a separate age group. Interestingly, of the seven age groups examined by Friedrich et al. (2016), only the oldest age group (80-89 year olds) demonstrated an asymmetry score that was significantly different from the youngest age group (18-29 year olds).

Further, when studies differ in comparison groups (e.g., comparing a sample of younger adults to a sample of older adults, comparing three or more age groups) and focus on different age ranges, it may not be meaningful to treat the results obtained as equally comparable. For example, differences that have been reported to occur at approximately 60 years of age (mean age of participants was 61.6 years; Fukastu et al., 1990) may not involve the same mechanisms as age-related differences that have been reported to occur at 75 years of age (mean age of older participants was 74.6 years; De Agostini et al., 1999). Using smaller age ranges within age groups will likely assist researchers in observing age-related differences, and differentiating an age at which there is a reliably detectable change in pseudoneglect. Understanding when age-related differences begin to occur (i.e., mid-life versus very-late life) and examining the specific age groups identified will assist in enhancing the value and relevance of the research.

Furthermore, a consistent categorization of older adults and specification of whether participants are neurologically healthy in the studies reviewed was limited. Large individual difference in cognitive performance and rate of change observed with aging may also be contributing to the variability in findings. The cognitive status of older adults has been found to have extensive heterogeneity and, despite accounting for clinical diagnoses (e.g., normal cognitive function, MCI, dementia), rates of change can vary from a decline of 0.3 SD per year to improvements of 0.1 SD per year (Mungas et al., 2010). The cognitive status of older individuals is complex and influenced by many variables in addition to age, including, but not limited to, brain injury and disease, mental health, health status, and exposure to substances and medications (Mungas et al., 2010). The multiple deleterious and protective factors that influence the variance in cognitive function and rate of change with age could also be influencing the inconsistent findings revealed in this systematic review.

The majority of studies included in the review examined adults over 60 years of age and did not screen for symptoms of neuropathology, such as mild cognitive impairment or dementia. Of the 32 studies, six screened for mild cognitive impairment and examined whether younger and older age groups differed in general cognitive performance. When cognitive performance was assessed, older adults demonstrated accurate bisections (Barrett & Craver-Lemley, 2008; Chieffi et al., 2014; Mendez et al. 1997) or demonstrated leftward spatial bias that did not differ from younger adults (Brooks et al., 2016; Chen et al., 2011 (female participants); McPherron, 2015), except for Chen et al. (2011) who identified an interaction between sex and age with only male participants demonstrating rightward bisection biases with age. Given that cognitive screening was employed in a limited number of studies included in the systematic review, it is difficult to determine the presence of neuropathology and whether age-related differences are related to *healthy* aging. Future research would benefit from examining lateral biases in healthy older adult populations by incorporating measures that screen for symptoms of mild cognitive impairment. Further, it would be useful to compare the lateral biases of older adults with and without symptoms of cognitive impairment to examine the effects of neuropathology on age-related differences in pseudoneglect and understand the continuum of normal and pathological aging. Of the 32 titles included in the systematic review, only two titles compared the performance of older adults with and without symptoms of pathological aging (McPherron 2015; Mendez et a., 1997) and comparisons did not reach statistical significance.

Individual characteristics in addition to age, such as gender (see Jewell and McCourt, 2000, for review) have also been investigated to understand the association between gender and lateral perceptual biases. Of specific interest, a number of manual line bisection studies that surfaced in this review reported sex-differences in age-related differences on bisection performance. Age effects appeared to be stronger in males, as men typically demonstrated an attenuated leftward bias or rightward bias, whereas women demonstrated a leftward bias comparable in magnitude to younger participants (Barrett & Craver-Lemley, 2008; Chen et al., 2011; Pierce, 2000; Varnava & Halligan, 2007). However, Beste et al. (2006) reported discrepant results, as men in each age group bisected to the left of true centre when using their left hand, whereas women in all age groups bisected to left of true centre except for women 50 to 59 years of age. In contrast, tasks that reduce the influence of motor cuing (e.g., landmark and greyscales task) failed to find differences in the magnitude of pseudoneglect between males and females (Benwell et al., 2014; Friedrich et al., 2016; Learmonth et al., 2017; Schmitz & Peigneux, 2011; Schmitz et al., 2013). Consistent with a hypothesis proposed by Benwell et al. (2014), gender-specific aging effects may be influenced by non-perceptual factors, such as motor cueing. Future research that accounts, or controls, for stimulus factors and experimental methods will assist in deconstructing gender-specific aging effects.

Heterogeneity within tasks with regards to differences in the stimuli used and method used to calculate the dependent variable decreases internal comparability. For example, studies that used the line bisection task differed in the size and the number of stimuli presented to participants, which also influenced the number of trials used to calculate lateral biases. In the studies included in the review, stimulus length varied from 20 to 400 mm in length, the number of different lengths presented varied from two to 13 different lengths, and presentation of the lines varied from presentation of a single line to multiple lines on a page. Studies that used the line bisection task also differed with regards to which hand participants were instructed to use. Some studies specified using the right, left, or both hands (i.e., bimanual), whereas hand use was not specified in other studies. Studies that used similar tasks also differed in how perceptual biases were calculated. For example, studies that used the landmark task calculated a leftward perceptual bias as the percentage of left longer/right shorter responses for evenly bisected lines (Schmitz & Peigneux, 2011; Schmitz et al., 2013), others calculated a leftward response based on the number of leftward choices participants made when asked which end of the line they thought

the transection was closest to (Harvey et al., 2000), and still others used a cumulative logistic psychometric function (i.e., a measure of the precision of midpoint judgments) and a point of subjective equality (i.e., the perceived midpoint of the line) for unevenly bisected lines (Benwell et al., 2014; Learmonth et al., 2017). Differences in the duration of the stimulus presentation and examination of response time also varied. Stimulus presentation ranged from 150 ms to 1000 ms, and instructions regarding responses varied from no time limits to instructions that emphasized responding as quickly as possible. Such differences in task instructions, administration, and scoring may affect participants performance. Standardization of stimuli and methods of analyses will assist in internal comparability between studies that use similar tasks. Standardization is a requirement for basic experimental control to minimize biased results and the influence of extraneous variables on participants' performance (Fischer & Milfont, 2010). To further understand age-related differences in pseudoneglect within each task discussed, standardization of instructions, administration, and scoring will be imperative. Similar to the administration of standardized psychometric testing, researchers examining pseudoneglect may benefit from the development of and standardization of visuospatial tasks. Standardized stimuli, administration, and scoring would assist in enhancing the internal comparability between studies, and the validity and reliability of the results obtained from testing.

Furthermore, the heterogeneity among the types of tasks used to assess pseudoneglect, including differences in task demands, decreases comparability between tasks. Previous research has failed to find evidence for the inter-task reliability of the line bisection, landmark, greyscales, and lateralized visual detection tasks, and this is proposed to result from differences in task demands (Learmonth et al., 2015a; Rueckert et al., 2002). The line bisection and landmark task have been considered to rely on *global size judgment* as both tasks involve assessing the midpoint along a horizontal line, whereas the greyscales task involves a *luminance judgment* and the lateral visual detection task involves a *stimulus detection* (Learmonth et al., 2015a). Lateralized spatial biases may be task-dependent and assumptions of equivalence in future reviews may be counterproductive.

However, it is also conceivable that improvements in research design, including smaller age ranges, screening for cognitive impairment, and standardization of tasks, may improve internal comparability, but may not improve reported inconsistencies. If the present inconsistencies in research examining age-related changes in pseudoneglect prove robust to

improvements in research methodology, the field may find it necessary to acknowledge this pattern within the results and critically consider the validity of the findings. As such, given the variability in the conclusions reported by the studies included in the current review, the visuospatial tasks examined may not provide valid or reliable estimates of age-related changes in cognitive functioning. Specifically, the tasks included in the current review may not be sensitive enough to reliably differentiate the magnitude of pseudoneglect demonstrated by younger and older adults. Rather, the tasks may provide the greatest utility to clinicians when examining patients with brain injuries to assess for larger systematic biases, such as hemispatial neglect.

3.3.1 Limitations

Arguably, a main limitation of this systematic review is the search strategy and eligibility criteria employed. One might have used additional key words or subject headings to identify the “situation” (i.e., pseudoneglect). However, search terms used in the current study were identified in collaboration with a university librarian and content expert (LE) to enhance the identification of relevant articles. One might have also employed an alternative search strategy. For example, one could have conducted an additional search for studies involving pseudoneglect, regardless of the “population” (i.e., older adults), and subsequently screened for studies examining participants over the age of 60. Following the search employed in the current study and a search using only the “situation”, the studies selected from both searches could be compared to each other to ensure that the search was inclusive. Although this approach was not employed in the current study, forward and backward searching was conducted to enhance the likelihood that the search was exhaustive. Furthermore, with regards to the eligibility criteria, a limitation of the study is that the titles and abstracts were screened and the relevant articles were examined for eligibility by one author (TF); however, if there was doubt regarding whether to include or exclude an article during abstract screening, the article was included for full-text screening.

Another potential limitation of this review is the chance of publication bias. Overall, a large number of studies retrieved and included in the review (10) reported statistical comparisons between age groups that did not reach significance. Thus, there is a high chance that a number of other completed studies may not have been published due to inconclusive results. In an attempt to minimize this bias, grey literature was included in the review. Further, a large number of search terms that are synonymous with pseudoneglect were used and an inclusive inclusion

criterion was used to screen for articles to allow for a broader and comprehensive overview of the research that included grey literature.

3.4 Conclusion

Overall, research to-date has reported an inconsistent relationship between aging and pseudoneglect. A number of recommendations for future research have been outlined throughout the review to enhance the field's understanding. These include using smaller age ranges within age groups and differentiating between neurologically healthy participants and those with clinical diagnoses in an attempt to minimize the variability of spatial biases demonstrated by older adults; continued examination of gender to further investigate gender-specific aging effects; consistent use of stimuli and methods of analyses within each task to improve internal comparability; and, given limited inter-task reliability between the tasks included in the review, conduct future reviews by examining studies within tasks. Based on current evidence, although some age-related trends in visuospatial bias can be identified within each task, no firm conclusions about the effects of age on pseudoneglect can be drawn.

CHAPTER 4

REASSESSING THE SHIFT: AN EXAMINATION OF THE GREYSCALES AND LANDMARK TASK IN YOUNGER AND OLDER ADULTS

4.1 Introduction

The line bisection task, which requires participants to bisect the middle of a horizontal line, has been the primary method used to examine pseudoneglect (Jewell & McCourt, 2000). Recently, additional tasks have been employed, such as the landmark and greyscales tasks. Some researchers have argued that these tasks are superior to the line bisection task, as they minimize motor cuing that results from bisecting the horizontal line by moving one's hand, and addresses problems associated with methods that influence the magnitude and direction of the bias to the left side of space, such as use of the left hand or right hand, and length of the line (Jewell & McCourt, 2000). Previous researchers who have commonly employed both the greyscales and landmark tasks to measure pseudoneglect have assumed that the two tasks are examining a similar perceptual bias. However, the magnitude and direction of the reported biases, particularly by participants over 60 years of age, has been inconsistent. To further understand perceptual biases demonstrated by older adults, outlining the scope of the phenomenon and clarifying the conditions under which age-related differences are observed is an important step for future research.

4.1.1 Age-Related Differences in Pseudoneglect

Age-related change associated with pseudoneglect is a debated issue. Although the phenomenon of pseudoneglect is robust and consistently demonstrated in previous research, demographic differences, such as age, have also been found to influence the magnitude and direction of the lateral perceptual bias (Jewell & McCourt, 2000). Younger adults consistently demonstrate a leftward bias on tasks used to examine pseudoneglect (see Brooks et al., 2014; Jewell & McCourt, 2000 for reviews). Among older adults, findings are less consistent. Researchers using various tasks to examine pseudoneglect have reported: 1) a reduction or directional reversal of pseudoneglect, 2) no effect of aging, or 3) a stronger leftward bias with age (see Chapter 3 for review). Specifically, a shift from a leftward bias to accurate judgments or a rightward bias with age has been demonstrated using the line bisection task (Barrett & Craver-Lemley, 2008; Chen et al., 2011; Failla, et al., 2003; Fujii, et al., 1995; Fukatsu, et al., 1990;

Goedert, et al., 2010) and landmark task (Benwell, et al., 2014; Schmitz & Peigneux, 2011). In contrast, the reverse pattern, a stronger leftward bias with age, has been demonstrated using the line bisection task (Varnava & Halligan, 2007), landmark task (Harvey et al., 2000), and greyscales task (Friedrich et al., 2016; Mattingley et al., 2004).

Although older adults have demonstrated inconsistencies in the direction of pseudoneglect when completing the line bisection and landmark task (Fujii et al., 1995; Harvey et al., 2000; Schmitz & Peigneux, 2011; Varnava & Halligan, 2007), researchers who have used the greyscales task have reported comparable findings. Specifically, Friedrich et al. (2016) found that older adults demonstrated a larger leftward bias on the greyscales task compared to younger adults, a finding consistent with results reported by Mattingley et al. (2004). This pattern of results is contrary to those reported by the majority of researchers, who have identified an attenuation of the leftward bias with age when employing the line bisection and landmark tasks. To further understand age-related differences in pseudoneglect and the inconsistencies reported in prior research, two tasks (greyscales and landmark tasks), which have demonstrated conflicting results but minimize motor cuing and address methodological problems, are examined.

4.1.1.1 Hypothesis 1. (a) Younger adults will demonstrate a small leftward bias, (b) but it is unknown whether older adults will demonstrate a stronger or weaker leftward bias compared to younger adults, as previous research examining age-related differences in pseudoneglect is highly inconsistent.

4.1.2 Pseudoneglect in Atypical Populations

Previous research examining age-related change in pseudoneglect has not typically included screens for symptoms of neuropathology or emphasized, in participation criteria, neurological health. Among the few studies that have included assessment of cognitive performance, neurologically healthy older adults demonstrated accurate bisections on the line bisection task (Barrett & Craver-Lemley, 2008; Chieffi et al., 2014; Mendez et al. 1997) or, in other cases, a leftward spatial bias that did not differ from younger adults (Brooks et al., 2016; Chen et al., 2011; McPherron, 2015). Accurate bisections demonstrated by neurologically healthy older adults are consistent with the hemispheric asymmetry reduction in older adults (HAROLD) model. The model predicts recruitment of the contralateral hemisphere to support cognitive function in aging (i.e., bilateral recruitment), which leads to a reduction in

lateralization and demonstration of a symmetrical perceptual bias on visuospatial tasks. In contrast, the maintenance of pseudoneglect in neurologically healthy older adults is consistent with the compensation-related utilization of neural circuits hypothesis (CRUNCH), which predicts that additional neural resources are recruited in comparison to younger adults (Reuter-Lorenz & Campbell, 2008). With regards to pseudoneglect, functional reorganization for visuospatial attention is proposed to be located in the right hemisphere. Recruitment of additional neural resources in the right hemisphere supports the maintenance of right hemispheric dominance for visuospatial attention and attention to the left hemispace (Brignani, Bagattini, & Mazza, 2018).

It is unclear how pathological aging influences pseudoneglect. To date, three studies have compared the performance of older adults with and without symptoms of pathological aging on tasks examining pseudoneglect. Two studies identified statistically significant differences between these groups (McPherron 2015; Mendez et al., 1997). In a third study involving a visual enumeration task, Brignani et al. (2018) examined older adults in different progressive phases of neuropathology and found that healthy older adults and patients with amnesic mild cognitive impairment (MCI) demonstrated a leftward bias consistent with pseudoneglect, whereas patients with mild Alzheimer's Disease did not demonstrate a leftward bias. This suggests that compensatory mechanisms associated with normal aging are no longer effective in dementia. Age-related neuropathology that affects cortico-cortical connections, including dementia (Delbeuck, Van der Linden & Collette, 2003), has been proposed to decrease right hemisphere dominance through degeneration of right-lateralized fronto-parietal ventral connections (Brignani et al., 2018). Thus, decreased lateralization may lead to rightward shifts in lateral perceptual biases among older adults with symptoms of degenerative neuropathology, as compared to neurologically healthy older adults.

4.1.2.1 Hypothesis 2. Previous research suggests that age-related neuropathology decreases right hemisphere dominance, leading to rightward shifts in the perceptual bias; therefore, it is hypothesized that older adults with symptoms of MCI will demonstrate an attenuated leftward bias, and rightward shifts in the perceptual bias will be associated with non-normative aging.

4.1.3 Inter-Task Reliability

As noted above, researchers have employed both the greyscales and the landmark task to examine pseudoneglect, and assumed that each task was examining a similar perceptual bias. However, older adults typically demonstrate an attenuated leftward bias when completing the landmark task (Benwell, et al., 2014; Schmitz & Peigneux, 2011) and demonstrate a leftward bias when completing the greyscales task (Friedrich et al., 2016; Mattingley et al., 2004). Further, Learmonth, Gallagher, Gibson, Thut, and Harvey (2015a) reported poor inter-task reliability between five tasks commonly used to measure asymmetries of spatial attention. The poor inter-task reliability led the researchers to conclude that pseudoneglect is a multi-component phenomenon that is observed by variation in task demands. Nonetheless, Learmonth and colleagues (2015a) modified the greyscales stimuli significantly by shifting a central zone of interest left or right. Moreover, responses were converted into accuracy scores rather than the standardly used asymmetry scores. Using this method, Learmonth and colleagues (2015a) found that young adult participants demonstrated a weak rightward bias, in contrast to the typical leftward bias observed in younger adult participants (Nicholls et al., 1999). Using an alternative approach to the greyscales task may have influenced the bias observed and the poor inter-task reliability reported between the greyscales and landmark tasks.

4.1.3.1 Hypothesis 3. Given that the current study uses the recommended approach to the greyscales task, participants are expected to demonstrate a leftward bias, as observed in previous research. Since this bias is consistent with the leftward bias observed in the landmark task, it is hypothesized that participants' responses on standardized versions of the greyscales and landmark tasks will correlate.

4.1.4 Age-Related Differences in Cognitive Strategies

Various methods have been used to examine cognitive processes occurring during a task. Some of these methods have included examining behavioural performance, reaction time, neuroimaging, and self-report. Of the methods used to examine cognitive processes utilized during visuospatial tasks, self-report is used infrequently. However, eliciting participants' self-report of their mental experience when completing a task has the unique advantage of identifying previously undefined strategies that are difficult to generate from behavioural performance, reaction time, or neural activation. The strategies identified through self-report can also be examined to assess whether they are associated with age, and whether strategies differentially

predict task performance (i.e., extent of visuospatial bias). For instance, Varnava and Halligan (2009) examined strategies reported by participants performing the line bisection task, and assessed whether the strategies differed by age and gender. By using retrospective self-report, Varnava and Halligan (2009) identified that participants were using non-stimulus centered strategies, such as environmental and body-centered cues to identify the center of the line. It was previously assumed that participants were only explicitly comparing the two segments on either side of the bisection or estimating the center of mass. Further, Varnava and Halligan (2009) reported that males used externally centered strategies more often than females, but had insufficient data to make age-based comparisons.

4.1.4.1 Hypothesis 4. Because there is evidence suggesting that older and younger adults differ in the magnitude and direction of perceptual bias, it is hypothesized that they will describe different cognitive strategies to complete the tasks.

The overarching aim of this study is to clarify the shift in the direction of pseudoneglect with age. By comparing results on the greyscales and landmark tasks, the objectives of the study are to further understand influential methodological (e.g., task demands) and individual factors (e.g., normative and non-normative aging) on performance. These objectives align with hypotheses 1, 2, and 3. In line with hypothesis 4, a final objective is to identify the cognitive strategies reported by participants completing the tasks, and examine whether the strategies differ by age and if they predict the magnitude of the observed perceptual biases.

4.2 Methods

4.2.1 Participants

Based on a power calculation using GPower 3.1.9.2, a minimum total sample size of 81 participants was needed, critical $F(2, 27) = 3.35$, $p < .05$, assuming an effect size of $f = .39$ and power of .95. An effect size of $f = .39$ was based on the difference in performance between younger and older adults on the landmark task ($n_p^2 = 0.133$) reported by Benwell and colleagues (2014). A screening process was used to identify and, when applicable, screen out participants who used medication affecting the central nervous system. No participants were screened out and all participants reported being neurologically healthy. In total, 90 participants were recruited and were divided into three experimental groups: 45 neurologically healthy younger adults (mean age = 19.96; $SD = 2.61$; range = 17-29; 15 males; mean MoCA score = 27.87; MoCA score $SD = 1.16$; 35 right-handed), 30 older adults (mean age = 70.77; $SD = 4.17$; range = 65-80; 13 males;

27 right-handed) without symptoms of MCI (i.e., score above 26 on the Montreal Cognitive Assessment; mean MoCA score = 27.4; MoCA score $SD = 1.52$), and 15 older adults (mean age = 75.27; $SD = 4.88$; range = 67-81; 6 males; 14 right-handed) with symptoms of MCI (i.e., score 26 or below on the Montreal Cognitive Assessment; mean MoCA score = 23.67; MoCA score $SD = 1.54$). The reading direction of all participants was left to right and all participants had normal or corrected-to-normal vision. Participants were naïve to the study's hypotheses.

4.2.2 Procedure and Stimuli

The experimental protocol and stimuli were approved by the University of Saskatchewan Research Ethics Board (Appendix C). Following written consent, participants answered a demographic questionnaire, as well as a series of questions regarding handedness and footedness. Handedness was determined with the Waterloo Handedness Questionnaire-Revised (Elias, Bryden, & Bulman-Fleming, 1998). The questionnaire required participants to report preferred hand use on 15 different tasks by selecting one of five responses: left always, left usually, equally, right usually, or right always. The laterality quotient provided by the questionnaire ranged from -30 to +30 with a score of -30 indicating exclusive left-handedness and a score of +30 indicating exclusive right-handedness. After participants completed the questionnaire, the experimenter administered the Montreal Cognitive Assessment (MoCA) to screen for MCI (Nasreddine, et al., 2005). The MoCA is widely used as a screening tool to detect MCI and Alzheimer's Disease. Using a cutoff score of 26, the MoCA has 90% sensitivity in identifying participants with MCI, and is superior to other screening tools such as the Mini-Mental State Examination (Nasreddine, et al., 2005).

Following the screening, participants completed the greyscales task and the landmark task, which were counterbalanced across participants. Stimuli for each task were presented by Experiment Center 3.0 (SMI) and were displayed in a 1024 x 768 resolution 19-inch LCD display. A chin rest located 700 mm away from the computer display was used to maintain participants' head position so that the center of the monitor was in line with the participants' mid-sagittal plane and their eyes were in line with the center of the screen.

4.2.2.1 Greyscales task. Participants simultaneously viewed two greyscales stimuli that were constructed using instructions from Nicholls, Bradshaw, and Mattingley (1999). The stimuli were two mirror reversed luminance gradients that changed in brightness from white on one end to black on the other. The rectangles were outlined with a thin black line and presented

against a grey background. The stimuli measured 79 pixels high and changed in brightness over 80 increments. To create a smooth change in brightness, the vertical position of the pixels in each increment were randomized. The horizontal midlines of the stimuli were aligned with the middle of the screen and there was a vertical distance of 100 pixels between the upper and lower stimulus. The stimuli were presented in six different lengths (e.g., 320, 400, 480, 560, 640, and 720 pixels) in two different orientations (e.g., upper stimulus dark on left/lower stimulus dark on right and vice versa). Each stimulus pair was presented eight times, resulting in 96 trials and 12 practice trials. During each trial, the participants were presented with a fixation cross for 1000ms, followed by the stimulus pair for 1000ms. The trial concluded with a forced choice question asking the participant which stimulus appeared darker overall, top or bottom. Responses were made using a mouse.

After completing the 96 trials, participants were asked about the strategies they used to complete the task using methods similar to those provided by Varnava and Halligan (2009). Specifically, participants were asked: “I now want you to think carefully about how you did the task. Think about how you determined which rectangle was darker. What strategy did you use to identify which rectangle was darker? Take the next few minutes to write down whatever comes into your mind about how you selected which rectangle was darker.” Given that the objective of the study was to generate new knowledge about cognitive strategies used, participants were not primed in advanced to use a particular strategy.

4.2.2.2 Landmark task. Participants completed a computerized version of the landmark task (see Figure 1; Milner, Brechmann, & Pagliarini, 1992) adapted from Schmitz and Peigneux (2011). The stimuli were horizontal 100% Michelson contrast lines that were 14 pixels high and presented in six different lengths (320, 400, 480, 560, 640, and 720 pixels) against a grey background. The Michelson contrast lines were presented in two orientations where the upper left and lower right sections were shaded black, and where the upper left and lower right were white. In total, the landmark task consisted of 96 trials and 12 practice trials. All lines were evenly bisected and the transector was located at the vertical center, which was aligned with the vertical midline of the display and with the fixation cross that preceded the stimuli. Similar to the greyscales task, during each trial the participant was presented with a fixation cross for 1000ms, followed by the stimulus for 1000ms. The trial concluded with a forced choice question asking

the participant to determine which end of the line was the shortest, left or right. There was no time limit for responding and responses were indicated with a mouse.

After the 96 trials, participants were asked about the strategy they used to complete the task using the following instructions: “I now want you to think carefully about how you did the task. Think about how you determined which end of the line was shorter. What strategy did you use to identify the shorter end of the line? Take the next few minutes to write down whatever comes into your mind about how you selected which end of the line was shorter.”

4.2.3 Scoring Procedures

Responses on the greyscales task were categorized based on which stimulus was selected as having the darker feature on the left or the right. A leftward response was indicated when the participant chose the stimulus with the darker feature on the left, whereas a rightward response was indicated when the participant chose the stimulus with the darker feature on the right, irrespective of whether the stimulus was situated on the top or bottom (Nicholls et al., 1999; Nicholls, Bradshaw & Mattingley, 2001; Mattingley et al., 2004). The asymmetry score, the dependent variable, was calculated by identifying the number of leftward responses demonstrated on the greyscales task and converting the score to a percentage (i.e., dividing the frequency by 96 trials). Scores could range from 0 to 1, and scores greater than 0.50 indicated a leftward bias.

Responses on the landmark task are typically characterized by a left perceptual bias score (Schmitz & Peigneux, 2011). A bias to the left hemisphere in healthy participants exaggerates the leftward extent of the line on the line bisection task and minimizes or underestimates the right, leading to an illusion that the central bisecting mark is to the right. As a result, a leftward perceptual bias on the landmark task was demonstrated when participants selected the right half of the line as shorter compared to the left (Manly, Dobler, Doods & George, 2005; Milner et al., 1992; Schmitz & Peigneux, 2011). To facilitate comparison of performances on the greyscales and the landmark task, and to compare performance on the landmark task to results previously reported by Schmitz and Peigneux (2001), the asymmetry score, the dependent variable was calculated as the percentage of responses that indicated participants selected the right end of the line as shorter, with scores ranging from 0 to 1. Similar to the interpretation of the asymmetry score on the greyscales task, scores greater than .50 indicated a leftward bias.

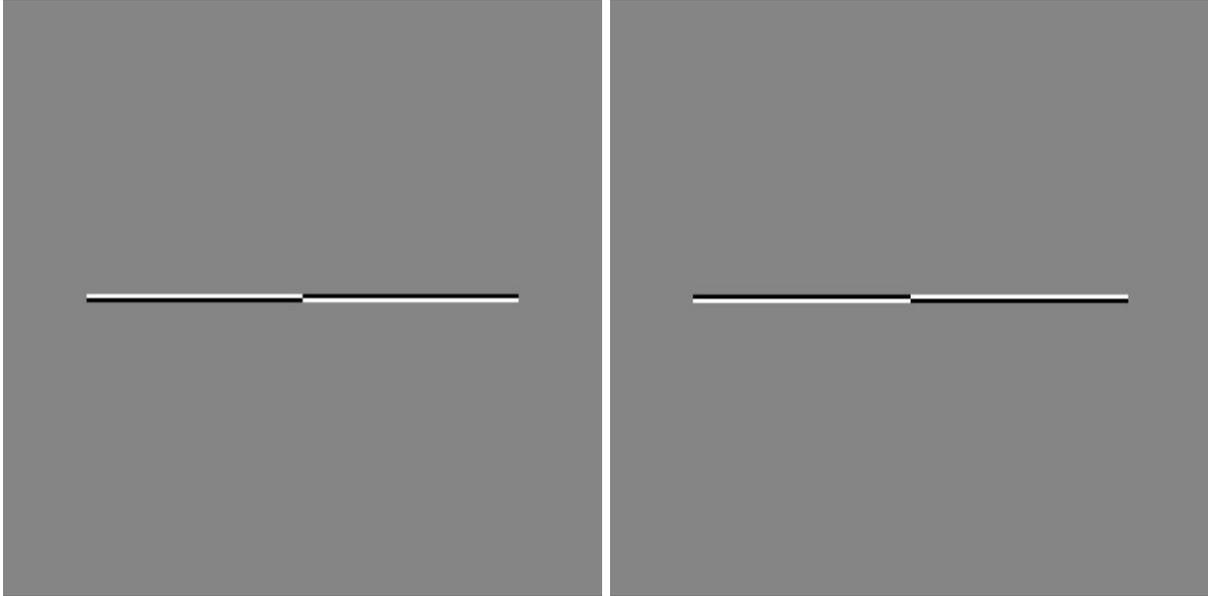


Figure 4-1. Sample stimuli 720 pixels in length used for the landmark task. All lines were evenly bisected and were 320, 400, 480, 560, 640, or 720 pixels in length. Each length was presented in two orientations: (1) where the upper left and lower right were white, and (2) where the upper left and lower right sections were shaded black. The lines were displayed with the transector centered on the vertical midline of the display (i.e., aligned with the central fixation cross that preceded the presentation of the stimulus). The stimulus was presented singularly and participants completed a total of 96 trials (i.e., 16 trials per line length). The order of appearance was randomized.

4.2.4 Analyses

4.2.4.1 Preliminary analyses. Prior to conducting the analyses, the dependent variables (asymmetry scores and left perceptual bias) were examined for the presence of outliers and normality. A stem-and-leaf plot was used to assess for the presence of outliers and identified one extreme value in the greyscale task. Grubbs' outlier test was conducted to determine whether the observation was different than the sample population (Grubbs, 1969). Outliers were also assessed by examination of studentized residuals for values greater than ± 3 (Howell, 2013). Grubbs' outlier test failed to meet the criteria, and the extreme observation identified had a studentized residual value of 3.05, just at the cut point. The identified value was therefore included in the analysis. The asymmetry scores were normally distributed, as assessed by Shapiro-Wilk's test ($p > .05$) and Normal Q-Q Plots.

4.2.4.2 Hypotheses 1 and 2. The asymmetry scores were analyzed with a 2 (Task [Greyscales, Landmark]) x 3 (Group [Younger adults, Older adults with MoCA scores above 26, Older adults with MoCA scores 26 and below]) GLM mixed measures ANOVA to test whether younger and older adults demonstrated a perceptual bias that differed in magnitude (hypothesis 1), and whether older adults with symptoms of MCI demonstrated an attenuated bias (hypothesis 2). These hypotheses were tested by comparing the scores under different task conditions and between the experimental groups. Further, one-sample *t*-tests were also used to compare each group's asymmetry score on both tasks to a test value of 0.50. Statistically significant one-sample *t*-tests with a mean greater than 0.50 indicated a bias to the left side of space, whereas statistically significant tests with a mean below 0.50 indicated a bias to the right side of space. The one-sample *t*-tests indicated whether biases were present, and the associated direction, to assist in interpreting the results of the mixed measures ANOVA.

4.2.4.3 Hypothesis 3. A Pearson product-moment correlation coefficient was calculated to measure the association between participants' performance on the greyscales and landmark tasks (hypothesis 3).

4.2.4.4 Hypothesis 4. A conventional approach to content analysis was employed to understand mental processes used when completing the greyscales and landmark tasks. Conventional content analysis involved creating a code corresponding to each meaning unit of text (i.e., response or part of a response), and subsequently categorizing codes within overarching themes (Hsieh & Shannon, 2005). This inductive approach allows themes to be generated from the data rather than from preconceived categories (Hsieh & Shannon, 2005). If participants reported more than one strategy, each was included in the analysis.

The frequency of each strategy reported and the corresponding mean asymmetry score for each experimental group was examined to identify the strategy most commonly used when completing the tasks. The descriptive statistics were also calculated to conduct a Chi-square analysis that was proposed to analyze the relationship between the three experimental groups and strategy choice. Asymmetry scores demonstrated on the greyscales were analyzed with 3 (Group [Younger adults, Older adults with MoCA scores above 26, Older adults with MoCA scores 26 and below]) x 5 (Strategy Type) between-subjects ANOVA, to examine asymmetry scores as a function of experimental group and strategy type. Specifically, the ANOVA was used to test whether older and younger adults described different cognitive strategies (hypothesis 4).

Similarly, asymmetry scores demonstrated on the landmark task was examined with a 3 (Group [Younger adults, Older adults with MoCA scores above 26, Older adults with MoCA scores 26 and below]) x 6 (Strategy Type) between-subjects ANOVA.

4.3 Results

To determine whether a bias was present, the mean asymmetry score demonstrated by each experimental group for both tasks was compared to a test-value of 0.50 (no bias). All participant groups demonstrated a leftward bias on the greyscales task. In contrast, younger adults demonstrated a leftward bias on the landmark task and older adult groups demonstrated a bias slightly to the right, but not significantly different from center (see Table 4-1).

Table 4-1

One-sample t-tests examining asymmetry scores

Task	Age Group	<i>t</i>	df	<i>p</i>	Bias Direction
GS	Younger adults	4.957	44	< .001	Left
GS	Older Adults without MCI	4.111	29	< .001	Left
GS	Older Adults with MCI	4.036	14	.001	Left
LDM	Younger adults	5.002	44	< .001	Left
LDM	Older Adults without MCI	-1.685	29	.103	Central
LDM	Older Adults with MCI	-.900	14	.383	Central

4.3.1 Comparison of Asymmetry Scores

To examine the difference in pseudoneglect under different task conditions and between experimental groups, the asymmetry scores demonstrated by each group on the greyscales and landmark tasks were compared. Homogeneity of variance was assessed with Levene’s test. The asymmetry scores demonstrated on the greyscales task varied equally across groups ($p > .05$), but the biases demonstrated on the landmark task did not have equal variances ($p = .016$).

Homogeneity of covariance was present among the within-subject variables, as assessed by Box’s test of equality of covariance matrices ($p = .131$). The GLM mixed measures ANOVA revealed that there was a statistically significant interaction between task and age group, $F(2, 87) = 8.311, p < .001$, partial $\eta^2 = .160$. To interpret the interaction, simple main effects were examined. There was a statistically significant difference in asymmetry scores between groups

on the landmark task, $F(2, 87) = 11.286, p < .001$, partial $\eta^2 = .206$, but not on the greyscales task, $F(2, 87) = .586, p = .559$, partial $\eta^2 = .013$. Because group means on the landmark task did not have homogeneous variances, a Games-Howell post hoc test was used to compare the three experimental groups. Asymmetry scores were leftward for younger adults ($M = 0.62, SD = 0.16$) than older adults without symptoms of MCI ($M = 0.40, SD = 0.24, p = .001$), but were not significantly greater than older adults with symptoms of MCI ($M = 0.43, SD = 0.30, p = .074$). There was also no difference in asymmetry scores between the older adult groups ($p = .923$). Further, there was a statistically significant effect of task on asymmetry score for older adults without symptoms of MCI, $t(29) = 4.792, p < .001$, and older adults with symptoms of MCI, $t(14) = 2.886, p = .012$. For both groups of older adults a leftward bias was demonstrated on the greyscales and accurate judgments were demonstrated on the landmark task. There was no significant effect of task on asymmetry score for younger adults, $t(44) = 0.357, p = .723$. Together, the simple main effects revealed that the older adults' asymmetry scores on the landmark task best explain the observed interaction effect (see Figure 4-2). Older adults demonstrated accurate judgments on the landmark task and a leftward bias on the greyscales task. Further, on the landmark task, compared to younger adults ($M = 0.62, SD = 0.16$), older adults without symptoms of MCI had an asymmetry score that was significantly different and more rightward ($M = 0.40, SD = 0.24$).

The results regarding the asymmetry score support hypothesis 1a, that younger adults would demonstrate a leftward bias. However, hypothesis 1b, that younger adults would demonstrate a bias that is different than older adults without symptoms of MCI, was dependent on the task and was only supported by the landmark task. Further, hypothesis 2, that older adults with symptoms MCI would demonstrate an attenuated leftward bias compared to older adults without symptoms of MCI, was not supported.

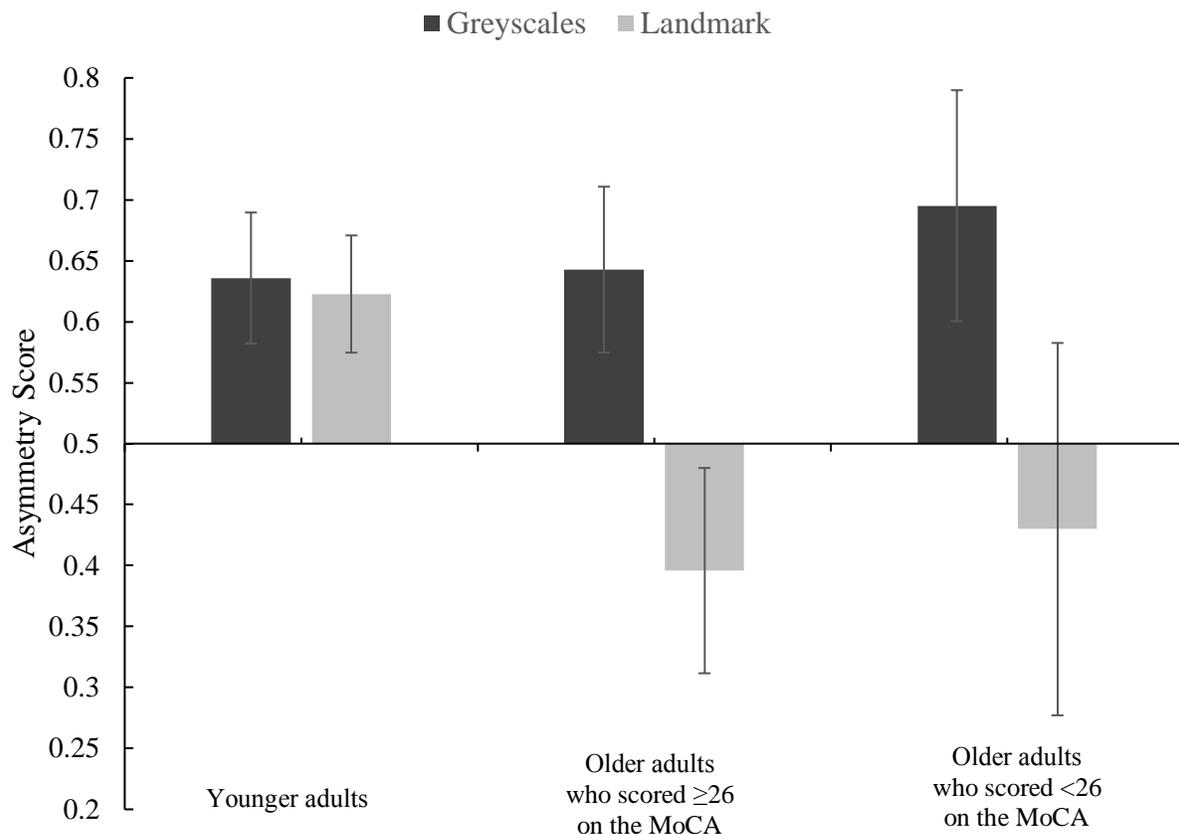


Figure 4-2. Mean asymmetry scores for each experimental group demonstrated on the greyscales and landmark tasks. Chance level is 0.50 and scores greater than .50 indicate a leftward bias. Error bars represent 95% confidence intervals.

4.3.2 Assessing Inter-Task Reliability

To determine whether the biases demonstrated on the greyscales and landmark tasks were similar, the asymmetry scores were correlated. Pearson's r showed no association between the greyscales and landmark asymmetry scores, $r(90) = .014$, $p = .898$. Given these results, hypothesis 3, that the greyscales and landmark tasks would elicit comparable asymmetry scores (i.e., inter-task reliability) and that the mean biases would be significantly correlated, was not supported.

4.3.3 Self-Reported Strategies on the Greyscales and Landmark Tasks

Self-reported strategies for completing the greyscales and landmark tasks were identified using conventional content analysis. All participants were able to provide one or more self-reported strategies for both tasks. When reporting strategies used to complete the greyscales task, 59 participants reported employing a single strategy, 22 reported employing two strategies, eight reported employing three strategies, and one reported employing four. When reporting strategies used to complete the landmark task, 55 participants reported employing a single strategy, 29 reported employing two strategies, three reported employing three strategies, and three reported employing four. In total, 131 strategies were reported when completing the greyscales task and 134 strategies were reported when completing the landmark task. Of the responses, 13.7% ($n = 18$) regarding the greyscales task were categorized as non-strategic (e.g., ‘I went with a gut instinct’, ‘I didn’t use a strategy’, ‘I mostly found myself guessing’) and 26.9% ($n = 36$) regarding the landmark task were categorized as non-strategic (e.g., ‘I didn’t use a strategy because I couldn’t figure it out’, ‘I merely went with my quick gut reaction’, ‘I thought they were all the same; guessed’). The remaining responses were considered strategic.

Participants reported using four types of strategies to complete the greyscales task. The strategies identified included: (1) participants compared parts of the rectangles (e.g., ends, middle); (2) participants viewed each rectangle as a whole and compared the rectangles; (3) participants generated a rule for responding to all trials; and (4) participants manipulated their vision. Examples of each strategy are listed in Table 4-2. Overall, viewing each rectangle of the pair of stimuli separately and comparing parts of the rectangles was the most commonly reported strategy (61.8%), followed by viewing each rectangle as a whole and comparing the rectangles (i.e., viewing the top or bottom rectangle as a whole; 14.5%), followed by responding using a rule (6.9%), and manipulating vision (3.1%). There was insufficient data to analyze the relationship between the three experimental groups and strategy choice, as a Chi-Square analysis assumes a minimum of five or more expected counts in each cell. The frequency of strategy reported and corresponding mean asymmetry scores for each experimental group is presented in Table 4-3.

Table 4-2

Examples of strategies used to complete the greyscales task

Compared parts of the rectangles

I started comparing the white ends to see which appeared to have more black.
 I started by looking for the intensity of the black and tried to take more notice of the amount of white.
 I focused on the density of dots in the middle portion.

Viewed each rectangle as a whole and compared them

I tried to look at both [rectangles] and compare overall presentation.
 I let my eyes rest between the two rectangles and sought an “impression” of relative darkness.
 I looked at the overall darkness of the whole box and tried to compare one box and then the second box.

Generated a rule for responding

When I looked left to right the one on the left usually looked darker.
 If the dark appeared on the left I felt it was the darker one.
 My eyes focused on the left side of the rectangle so whichever side was black was darker.

Manipulated vision

I blurred my vision and stared directly into the middle of each line and based my guess on apparent contrast as they appeared.
 I tried not focusing.
 I tried not to focus my eyes, but direct my gaze near the center of the screen.

Table 4-3

Frequency of strategies reported and corresponding asymmetry score on the greyscales task

Type of Strategy	Younger Adults		Older Adults without MCI symptoms		Older Adults with MCI symptoms	
	Frequency (<i>n</i>)	Asymmetry Score (<i>SD</i>)	Frequency (<i>n</i>)	Asymmetry Score (<i>SD</i>)	Frequency (<i>n</i>)	Asymmetry Score (<i>SD</i>)
Non-strategic	7	-26.29 (51.66)	8	-26.25 (33.76)	3	-54.00 (30.79)
Compared parts of rectangles	41	-23.71 (30.06)	28	-26.93 (35.83)	12	-19.67 (29.98)
Compared whole rectangles	8	-17.25 (39.60)	10	-13.80 (19.26)	1	-6.00 (0.00)
Response rule	4	-17.00 (70.74)	1	-94.00 (0.00)	4	-69.00 (20.30)
Manipulated vision	2	-32.00 (11.31)	1	16.00 (0.00)	1	-82.00 (0.00)

Similar strategies were identified to complete the landmark task. Specifically, five types of strategies were identified: (1) participants viewed parts of the stimuli and compared them (e.g., ends, ends to middle, colour segments); (2) participants viewed the stimuli as a whole to judge the shorter end; (3) participants used external cues to assist with judgment (e.g., fixation cross, computer screen edge, background); (4) participants generated a rule for responding to all trials; and (5) participants manipulated their vision. Examples of each strategy are provided in Table 4-4. Comparing parts of the stimuli was reported most frequently (46.3%), followed by viewing the stimuli as a whole to judge the shorter end (12.7%), followed by using external cues

to assist with judgment (7.5%), followed by responding using a rule (4.5%), and manipulating vision (2.2%). Again, there was insufficient data to analyze the relationship between the three experimental groups and strategy choice. The frequency of strategy reported and corresponding mean asymmetry scores for each experimental group is presented in Table 4-5.

Table 4-4

Examples of strategies used to complete the landmark task

Compared parts of the stimuli

I tried to put one half over the other to determine which was shorter.
 I tried to quickly compare the black portions.
 Compared lines from the midpoint.

Viewed the stimuli as a whole to judge the shorter end

I tried to look at the lines as a whole to see the differences instead of looking from side to side.
 Relative difference at a glance.
 I ignored the differently coloured bars and looked at it as a unity.

Used external cues

I measured the end of each lines from the sides of the monitor.
 I tried to identify the grey space difference on either end of the lines in order to see which had more.
 I focused on the center cross and then tried to pick out the shorter line.

Generated a rule for responding

The lines with the black on top seemed longer.
 I thought the ends were even, so I selected right for all of my answers.
 I typically chose the side with the white line on the top and I noticed I picked the right side a lot.

Manipulated vision

I left my eyes unfocused.
 I tried to measure length by blurring my vision and focusing on the center.
 I tried to focus more with one eye.

Table 4-5

Frequency of strategies reported and corresponding asymmetry score on the landmark task

Type of Strategy	Younger Adults		Older Adults without MCI symptoms		Older Adults with MCI symptoms	
	Frequency (n)	Asymmetry Score (SD)	Frequency (n)	Asymmetry Score (SD)	Frequency (n)	Asymmetry Score (SD)
Non-strategic	7	14.57 (38.74)	19	-9.26 (47.44)	10	-17.20 (55.27)
Compared parts	32	24.50 (27.25)	22	-14.64 (34.46)	8	-18.25 (61.00)
Viewed whole stimuli	6	36.00 (37.91)	9	-30.44 (45.81)	2	-61.00 (41.01)
External cues	9	17.78 (28.80)	1	76.00 (0.00)	0	0.00 (0.00)
Response rule	5	22.00 (47.14)	1	-26.00 (0.00)	0	0.00 (0.00)
Manipulated vision	2	6.00 (16.97)	1	-16.00 (0.00)	0	0.00 (0.00)

A between-subjects ANOVA was used to examine asymmetry scores as a function of strategy type and experimental group. There were no significant differences in asymmetry scores on the greyscales task between experimental group, $F(2, 116) = 1.493, p = .229$, or strategy type, $F(4, 116) = 2.135, p = .081$, and there was no interaction, $F(8, 116) = 1.445, p = .185$. Similar to the results regarding asymmetry scores on the landmark task, there was a significant difference between experimental groups, $F(2, 119) = 5.098, p = .008$. Pairwise comparisons with Bonferroni-adjusted p -values revealed a significant difference between asymmetry scores demonstrated by younger adults ($M = 0.61, SD = 0.16$) and both groups of older adults (without symptoms of MCI $M = 0.41, SD = 0.22$; with symptoms of MCI $M = 0.39, SD = 0.29, p < .001$). There were no significant differences between strategy type, $F(5, 119) = 1.121, p = .353$, and no interaction, $F(7, 119) = 1.275, p = .268$. Therefore, hypothesis 4, that younger and older adults would employ different cognitive strategies to complete the tasks, was not supported.

4.4 Discussion

The primary objectives of this study were to further understand discrepancies in age-related differences in pseudoneglect, address modulating factors (e.g., task demands and non-normative aging) that have been identified as influencing the magnitude of the leftward bias observed, and identify cognitive strategies employed during the tasks. Overall, in the current study, observations of poor inter-task reliability and discrepancies in the observed extent of perceptual bias among older adults suggest that task demands are an important consideration when examining pseudoneglect.

4.4.1 Age-Related Differences in Pseudoneglect

Young adults typically demonstrate a leftward perceptual bias on tests of visuospatial attention. Consistent with previous research (Nicholls et al., 1999), younger adult participants in the current study displayed a group level systematic leftward bias during both the greyscales and landmark tasks. Despite the consistency of younger adults' performance on tests of visuospatial attention, comparisons between older and younger adults' performance have been less consistent.

In this study, the performance demonstrated by two groups of older adults (i.e., those with and without symptoms of MCI) was compared with that of younger adults. Separating older adults based on symptoms of MCI was proposed to allow for age-related comparisons in the context of healthy aging. Healthy older adults (i.e., those without symptoms of MCI) showed no leftward bias on the landmark task, consistent with previous research that has identified a

suppression of pseudoneglect with healthy aging when employing the landmark task (Benwell et al., 2014; Learmonth et al., 2015b; Maerker et al., 2016; Schmitz & Peigneux, 2011). Despite the attenuation of leftward bias on the landmark task among healthy older adults, a leftward bias was demonstrated on the greyscales task, and it was similar in magnitude to the bias observed by younger adults. This result replicated previous findings of a robust leftward bias in younger and older adults when employing the greyscales task (Friedrich et al., 2016; Mattingley et al., 2004)². In summary, younger adults consistently demonstrated pseudoneglect irrespective of task; however, the magnitude of perceptual biases demonstrated by healthy older adults was not systematically modulated in a similar way across tasks.

How can the different performances of older adults on the greyscales and landmark tasks be reconciled? One possibility is that pseudoneglect is a robust, multi-componential phenomenon, particularly with age. Learmonth et al. (2015a) proposed that the variability in perceptual biases demonstrated by patients with hemispatial neglect and healthy older adults might be due to the multi-faceted nature of hemispatial neglect and pseudoneglect. Rather than using a single measure to identify a unitary deficit, hemispatial neglect is often diagnosed using a battery of tests, which is consistent with evidence that multiple brain regions have been implicated in the neglect syndrome at the cortical and subcortical level (Verdon, Schwartz, Lovblad, Hauert, & Vuilleumier, 2010). Further, differences in the magnitude of spatial biases appear to be task-dependent and related to distinct regions of the right hemisphere that are responsible for perceptual biases, as well as partially overlapping regions (Learmonth et al., 2015a). Specifically, using a battery of standard tests to assess neglect symptoms in patients with right hemisphere lesions, Verdon, Schwartz, Lovblad, Hauert & Vuilleumier (2010) identified three distinct components of neglect related to three distinct sites of brain damage.

If pseudoneglect is also multi-componential, it could be speculated that age-related compensation could occur in various neural regions and differentially affect behavioural expression on tasks with distinct task demands. For instance, the HAROLD model, hypothesizing bilateral recruitment of cerebral hemispheres to maintain cognitive performance, has been commonly proposed to account for age-related changes on tasks that require judgments of size (e.g., landmark task; Barrett & Craver-Lemley, 2008; DeAgostini et al., 1999; Learmonth

² These studies did not assess whether participants exhibited symptoms of cognitive impairment.

et al., 2015; Learmonth et al., 2015b; Learmonth et al., 2017; Milano et al., 2014; Schmitz & Peigneux, 2011), whereas the CRUNCH hypothesis, suggesting recruitment of additional brain regions (e.g., right hemisphere) in response to task demands, has been proposed to account for age-related changes on tasks that require judgments in luminance, such as the greyscales task (Friedrich et al., 2016; Mattingley et al., 2004). Differences in task demands may result in recruitment of different neural regions to compensate for age-related changes (i.e., contralateral recruitment when judging size, and ipsilateral recruitment when judging luminance), leading to different behavioural biases on distinct tasks. Thus, patterns of age-related compensation and recruitment may be task dependent within the distributed networks subserving spatial attention, despite eliciting the same phenomenon - pseudoneglect.

Given that the magnitude of perceptual bias demonstrated by older adults was not modulated in a similar way across tasks, current models of cognitive aging are unable to fully account for the results of the present study. The maintenance of leftward bias demonstrated by older adults on the greyscales task in the current study is consistent with the CRUNCH hypothesis, and the proposal that additional ipsilateral neural regions have been recruited to support visuospatial attention (Reuter-Lorenz & Campbell, 2008). Specifically, recruitment of additional neural regions in the right hemisphere is proposed to maintain orientation of attention to the left hemispace and the leftward bias (Brignani et al., 2018; Pagano, Fait, Brignani, & Mazza, 2016), as demonstrated by older adults in the current study. In contrast, the symmetrical perceptual bias observed in older adults in the present study on the landmark task is consistent with the HAROLD model (Cabeza, 2002), and the hypothesis of bilateral recruitment of neural regions to support visuospatial attention. More specifically, a lack of bias has been proposed to result from recruitment of the contralateral hemisphere to support cognitive function in aging, leading to a reduction in lateralization. In sum, CRUNCH and HAROLD result in inconsistent hypotheses when applied to visuospatial attention, and are under-specified when accounting for findings of the current study. The current models of cognitive aging (i.e., HAROLD, RHAM, CRUNCH) do not appear to be well-specified to the phenomenon of pseudoneglect, and are unable to account for the variability of perceptual biases demonstrated by older adults, which seems to be influenced by task demands. To strengthen predictive claims, a model of cognitive aging that can incorporate the multi-componential nature of pseudoneglect, and account for task and stimulus factors is needed.

4.4.2 Inter-Task Reliability

The proposal that pseudoneglect is a robust, multi-componential phenomenon, and that task demands influence performance, was also supported in the current study by the low inter-task reliability between the greyscales and landmark tasks. Despite attempts to increase the similarity between the methods and stimuli used during both tasks (i.e., forcing a choice between equally bisected lines and equiluminant greyscales), the Pearson's r correlation on the mean asymmetry scores did not reach significance. Previous findings of poor inter-task reliability were hypothesized to result from differences in task demands (Learmonth et al., 2015a). For example, the landmark task is considered to demand a judgment of global size, whereas the greyscales task is considered to demand a judgment of luminance (Learmonth et al., 2015a). Consistent with the hypothesis proposed by Learmonth et al. (2015a), the poor inter-task reliability found in the current study may suggest that perceptual asymmetries involve multiple components and partially-overlapping regions of the brain that are associated with different task demands.

4.4.3 Pseudoneglect in Atypical Populations

Given that comparisons of older and younger adults' performance on tasks examining pseudoneglect have been inconsistent, it is important to examine potential factors that influence these discrepancies. One potential reason for previous variability in results is that the cognitive status of older adult participants has commonly been overlooked. It is important to consider whether non-normative aging might influence pseudoneglect; for instance, by influencing the rightward shift of the bias observed. For this reason, participants in the current study were screened for symptoms of MCI (i.e., MoCA scores of 26 or higher), and the performance of both older adult subgroups (MCI and neurologically healthy) was compared with the performance of young adults. The influence of symptoms of cognitive impairment on pseudoneglect was negligible. The performances of older adults with and without symptoms of MCI were comparable on both the greyscale and landmark tasks. These findings are consistent with previous research that examined the effect of pathological aging on pseudoneglect and did not find statistical differences between experimental groups (McPherron, 2015; Mendez et al., 1997).

A potential explanation for the similar biases demonstrated by older adults with and without symptoms of MCI, is that, at a group level, cognitive changes due to neuropathology may appear in performance variability rather than aggregated means. Large individual differences in performance may be related to the extent of degeneration and functional

reorganization that has taken place due to pathological changes (Learmonth et al., 2015a). The performance of older adults with symptoms of MCI on both the greyscale and landmark task were characterized by large 95% confidence intervals. Variability in performance on various visuospatial tasks that involve different task demands has also been demonstrated by patients with hemispatial neglect (Bailey et al., 2000). As a result, hemispatial neglect has been conceptualized as a multi-component disorder, rather than a single deficit of spatial attention, with various components elicited by different task demands and correlated with distinct patterns of brain damage (Verdon et al., 2010). The distributed networks subserving attention that are used to complete perceptual tasks, and the multi-faceted nature of pseudoneglect, may also influence the comparable biases demonstrated by both groups of older adults. It could be speculated that increased variability resulting from age-related compensation could occur in various brain regions to maintain performance on both tasks.

4.4.4 Age-Related Differences in Cognitive Strategies

The final aim of the study was to identify cognitive strategies used to complete the tasks to inform the understanding of behavioural performance on the greyscales and landmark tasks. A number of strategies were identified for each task. These were generally comparable, including ‘viewing stimuli as parts and comparing them’, ‘viewing stimuli as a whole to inform judgments’, ‘developing a response rule’, and ‘manipulating vision’. Nevertheless, the strategy ‘used an external cue’ was unique to the landmark task. Specifically, participants’ comments suggested that they used cues external to the task, such as the fixation cross, computer screen edge, or background, to assist with judgment. This finding is consistent with findings previously generated during qualitative research using the line bisection task. Specifically, Varnava and Halligan (2009) reported that a similar theme, ‘externally centered strategies’, represented a novel approach to the task that had not been considered in previous literature, and proposed that the manual component of the line bisection task elicited the strategy. However, findings in the current study suggest that environmental cues are also utilized in the landmark task, which is a task that minimizes motor cuing. Because the ‘use of external cue’ was the only theme not identified as a strategy in the current study during the greyscale task, it could be argued that externally centered strategies are utilized when the task requires a global size judgment, but not when tasks require judgement of luminance.

Some of the themes identified in the current study have also been reported in prior research. Specifically, Varnava and Halligan (2009) similarly indicate that some participants view the stimuli as wholes (e.g., compute the center of mass), others look at separate aspects of the stimuli for comparison (e.g., comparing two segments), and still others manipulated their vision prior to making a judgment (e.g., “let the line blur in vision and judge the middle”). However, in contrast to the results seen in this study, Varnava and Halligan (2009) did not report participants using a rule to inform responses on all trials (e.g., “If the dark appeared on the left I felt it was darker,” “I thought the lines were even, so I selected right for all my answers.”). The distinctiveness of this finding in the current study may have been due to the high response rate (i.e., 100% of participants provided a strategy) compared to Varnava and Halligan’s (2009) 56% response rate. Another possibility is that these responses were considered non-strategic by Varnava and Halligan (2009); however, it is difficult to determine what types of responses were considered non-strategic as only two examples were given (e.g., ‘I guessed’, ‘It was obvious’). Still another possibility is that using a response rule is specific to the landmark and greyscales tasks, and not used when completing the line bisection task. The identification of this distinct strategy in the current study is a benefit of using retrospective self-reports and an inductive approach to analysis.

With regards to the associated hypothesis (4), it was proposed that self-reported strategies would differ between experimental groups and inform behavioural differences on the perceptual tasks; however, the observed results did not lend credibility to this hypothesis. Previous research has also failed to determine whether different cognitive strategies predict bisection performance (Fink et al., 2002; Varnava & Halligan, 2009). For example, when asked to employ different mental strategies (e.g., line-center judgments versus line length comparison) to complete the landmark task, participants demonstrated similar rates of bisection errors; however, participants demonstrated different task completion times and activated different neural regions (Fink et al., 2002). The lack of difference in asymmetry as a function of strategy in the current study suggest that asymmetry scores may lack sensitivity and be insufficient in size to differentiate the behavioural effects of different cognitive strategies.

Although there was insufficient data to examine the relationship between the three experimental groups and strategy choice, the descriptive statistics calculated provided the opportunity to identify patterns in the strategies reported. In particular, it is interesting to note

that ‘comparing separate parts of the stimuli’ was most frequently reported by all participants on both tasks, except for older adults with symptoms of MCI who reported a high frequency of strategies that were non-strategic, particularly during the landmark task. Based on these results, it could be speculated that utilization of a strategy is influenced by neuropathology. Further, given that older adults with symptoms of MCI reported a higher number strategies compared to non-strategic responses during the greyscales task, symptoms of neuropathology may influence the use of strategies when the task requires a global size judgment, but not when tasks require judgement of luminance. Future investigation into cognitive strategies used by older adults with and without symptoms of cognitive impairment may generate alternative explanations, and further the understanding of neuropathological mechanisms mediating perceptual biases.

4.5 Conclusion

The overarching aim of this study was to further understand discrepancies in age-related differences in pseudoneglect, and address modulating factors (e.g., task demands and non-normative aging) that have been identified as influencing the magnitude of the leftward bias observed. This study contributed to outlining the scope of pseudoneglect by examining age-related differences in pseudoneglect under two task conditions. The extent of older adults’ perceptual bias was different across the two tasks, with older participants demonstrating a leftward bias on the greyscales task and no bias on the landmark task, compared to younger adults, who demonstrated a leftward bias on both tasks. The distinct perceptual biases demonstrated by older adults on the greyscales and landmark task and low inter-task reliability support the proposal that pseudoneglect is a robust, multi-componential phenomenon that is influenced by task demands. Differences in task demands may prompt recruitment of different neural regions to compensate for age-related changes, leading to the differences in lateral biases on the greyscales and landmark tasks observed in the current study and in prior research. Further observation of age-related changes in pseudoneglect is required, and this research suggests that task demands are important considerations when examining pseudoneglect and developing models of cognitive aging.

CHAPTER 5

CRASHING LEFT VERSUS RIGHT: EXAMINING NAVIGATION ASYMMETRIES USING THE SHRP2 NATURALISTIC DRIVING STUDY DATA

This chapter has been previously published:

Friedrich, T., Elias, L., & Hunter, P.V. (2017). Crashing Left versus Right: Examining Navigation Asymmetries Using the SHRP2 Naturalistic Driving Study Data. *Frontiers in Psychology*, 8, 1-11. doi:10.3389/fp-syg.2017.02153

Estimating the centre between two points to avoid a collision is a seemingly simple task that is required to complete many everyday activities. These activities include walking through doorways and crowds of people, parking vehicles, and taxiing an airplane. Nevertheless, laboratory researchers who study simple tasks that require estimating the centre, such as bisecting lines, document a small but consistent bias to the left side of space among neurologically healthy individuals (Jewell & McCourt, 2000; Nicholls et al., 1999). This bias to the left hemifield within peripersonal space is a robust phenomenon known as pseudoneglect (Bowers & Heilman, 1980), and has been demonstrated in a variety of manual bisection and perceptual tasks.

Although pseudoneglect is widely considered to be a systematic bias in attention to the left side of space (i.e., midpoint estimations deviate to the left of the true centre; Jewell & McCourt, 2000), research examining pseudoneglect in older adults documents apparent inconsistencies. Some researchers have identified an attenuation of the leftward bias with age, some have identified a rightward bias (i.e., perception that midpoint estimations deviate to the right of true centre), and still others have found that older adults have a stronger leftward bias compared to younger adults. For example, a shift from a leftward bias to a rightward bias with age has been demonstrated using the line bisection task (Barrett & Craver-Lemley, 2008; Chen, et al., 2011; Failla et al., 2003; Fujii et al., 1995; Fukatsu et al., 1990; Goedert et al., 2010) and landmark task (Benwell et al., 2014b; Schmitz & Peigneux, 2011). In contrast, the reverse pattern, a stronger leftward bias with age, has been demonstrated using the line bisection task (Beste et al., 2006; De Agostini et al., 1999; Hatin et al., 2012; Varnava & Halligan, 2007),

landmark task (Harvey, Milner, & Roberts, 1995), tactile rod bisection task (Brooks et al., 2011), and greyscales task (Friedrich et al., 2016; Mattingley et al., 2004).

A number of models have been proposed to account for age-related changes in pseudoneglect. These models support the attenuation of the leftward bias with age. The hemispheric asymmetry reduction in older adults (HAROLD) model proposes that aging is associated with a decrease in lateralized activity in frontal regions that results from recruitment or reduced inhibition of the left (non-dominant) hemisphere to compensate for impairment in the right hemisphere (Cabeza, 2002). During visuospatial tasks, activation of the left hemisphere results in lateralization of pertinent features to the right and an absence or reversal of pseudoneglect. Similarly, the right hemi-aging model (RHAM), suggests that the right hemisphere is more sensitive to aging, resulting in a reduction of attentional inhibitory mechanisms (Chieffi, et al., 2014), and a more pronounced decline in right hemisphere dominant cognitive functions including spatial processing (Dolcos et al., 2002). Reduced arousal and down-regulation of the attention network in the right hemisphere is suggested to be related to change in dopamine neurotransmission (Ebersbach, et al., 1996; Greene et al., 2010; Midgley & Tees, 1986). Dopamine transporter density has been shown to decrease with age (Lavalaye et al., 2000), which may also account for a rightward shift in attentional biases across the lifespan.

Beyond peripersonal space, pseudoneglect has also been associated with tasks that involve extrapersonal space, such as navigating through one's environment. In contrast to the modest leftward bias identified during manual bisection perceptual tasks, a subtle rightward asymmetry during navigation has been found when participants interact with their environment (Jang et al., 2009; Nicholls et al., 2010; Nicholls, Jones, & Robertson, 2016; Nicholls et al., 2007; Nicholls et al., 2008; Robertson et al., 2015; Turnbull & McGeorge, 1998). The investigation of asymmetry in navigation was initiated by Turnbull and McGeorge (1998) who used a self-report design to inquire about participants' recent collisions with objects, and the side of the body that he or she collided with. Participants tended to report a greater number of collisions on the right side of their body and those who collided on the right demonstrated larger deviations to the left of centre on the line bisection task (Turnbull & McGeorge, 1998). Turnbull and McGeorge (1998) suggested that individuals who demonstrate a stronger leftward bias are less likely to attend to the right hemisphere and, as a result, have a greater number of rightward collisions. The behavioural effect of lateral attention, the collisions, were presumed to be

associated with pseudoneglect and analogue to the behaviour demonstrated by patients with hemispatial neglect (Turnbull & McGeorge, 1998). Similarly, laboratory-based experiments have found predominant right-sided veering and collisions when walking through a narrow doorway (Nicholls, et al., 2007), as well as a correlation between bumping and line bisection. Specifically, individuals who bumped the right of the doorway had a larger leftward bias on the line bisection task (Nicholls, et al., 2008).

Rightward veering, ranging from 10 to 36 mm, and rightward deviation in navigation has also been demonstrated when navigating an electric wheelchair and scooter through a doorway (Nicholls, et al., 2010; Robertson, et al., 2015). Similarly, rightward veering and collisions have been found among participants driving a miniature remote vehicle, particularly when navigating through wider apertures (Nicholls, et al., 2016), and while driving a car in a driving simulator (Jang et al., 2009). Although the rightward deviations reported are small, systematic asymmetries in navigation are important to note, as they can lead to inaccurate perceptual judgments and collisions (Nicholls, et al., 2016).

Very few studies have extended research on age-related differences in pseudoneglect to the investigation of asymmetry in navigation, nor have many studies extended laboratory-based research on navigational asymmetries to naturalistic settings where participants have greater task demands and navigation is more complicated. Driving is a complex task that requires controlling an approximately 3,000-pound projectile while navigating road, traffic, pedestrians, and technology demands. Attentional lapses and deviations have devastating consequences. In 2013, motor vehicle collisions account for 1,923 deaths and 10,315 serious injuries in Canada (Transport Canada, 2015), and cost approximately 2 to 3% of the country's Gross Domestic Product (World Health Organization, 2004). Further, developed countries have rapidly-aging populations (Cohen, 2003) resulting in a growing number of older drivers. Hence, it is of interest to examine the association between aging and asymmetries in navigation during motor vehicle collisions.

Among the most common methods used to analyze motor vehicle collisions are self-report, epidemiological data (e.g., crash databases, police reports), and empirical data from driving simulators and driving courses (Klauer, Dingus, Neale, Sudweeks, & Ramsey, 2006). However, the most significant shortcoming of these approaches is that the data can only be said to approximate true driving behaviour. In addition, a full picture of the context surrounding a

crash incident is typically missing, since data focuses on very specific periods surrounding crash incidents (i.e., pre or post-crash; Klauer et al., 2006). A method that addresses these shortcomings is a large-scale naturalistic driving study, which allows for direct and more complete examination of driver behaviour, driving performance, and the relationship between these variables. Further, naturalistic driving studies take place in a naturalistic setting, which enhances the external validity of the study and minimizes the influence of factors associated with the awareness of participation (Carsten, Kircher, & Jamson, 2013). Driving behaviour is observed by installing unobtrusive instrumentation devices (e.g., global positioning system (GPS), high frequency cameras, radar) directly linked to vehicle inputs (e.g., steering, breaking, acceleration) from key-on to key-off (Shankar, Jovanis, Aguero-Valverde, & Gross, 2008). The instrumentation techniques employed in naturalistic driving studies allow researchers to monitor driving behaviours and kinematic signatures, and detect critical-incident events in a manner that is quantifiable and objective (Manning & Schultheis, 2013). The collection of objective pre-crash information is particularly valuable as it can complement previous research observed in laboratory environments and generate new hypotheses that can be tested under controlled conditions (Carsten et al., 2013).

The recently completed second Strategic Highway Research Program (SHRP 2) is the largest naturalistic driving study (NDS) of its kind. The study included approximately 3,500 participants (16 - 98 years) from six states across the United States of America (Florida, Indiana, North Carolina, New York, Pennsylvania, and Washington). Participants' personal vehicles were instrumented with a Next Generation data acquisition system (DAS) that included multiple camera views, GPS, speedometer, three-dimension accelerometer and rate sensor, forward radar, illuminance and passive cabin alcohol presence sensors, turn signal state, vehicle network data, and an incident push button. Over the course of 12 to 24 months, driving data collected from participants encompassed 35 million vehicle miles and consumed two petabytes of storage space. A detailed description of the study recruitment, participants, and methodology is outlined in Antin, Lee, Hankey, & Dingus (2011).

Previous research examining pseudoneglect in younger, middle, and older adults have identified changes in perceptual biases with age (Benwell et al., 2014b; Friedrich, et al., 2016; Fukastu, et al., 1990; Schmitz & Peigneux, 2011; Varnava & Halligan, 2007). Because rightward veering and collisions are thought to be associated with pseudoneglect (Nicholls et al., 2008;

Turnbull & McGeorge, 1998), it was hypothesized that age-related differences in navigation asymmetries would also be present. Additionally, given that rightward navigational asymmetries are repeatedly identified in laboratory experiments (Jang et al., 2009; Nicholls et al., 2010; Nicholls et al., 2016; Robertson et al., 2015), it was hypothesized that the position of impact of crashes and near crashes would occur more frequently on the right side of the vehicle (see locations B, C, D, and E in Figure 1). It was also hypothesized that the frequency of the rightward position of impact of crashes and near crashes would differ between younger and older adults, since laboratory experiments show a relationship between rightward deviations in navigation and perceptual biases, and since individuals who exhibit more frequent rightward collisions also demonstrate a larger leftward bias on the line bisection task (Nicholls et al., 2008; Turnbull & McGeorge, 1998).

5.1 Method

5.1.1 SHRP2 NDS

To examine navigation asymmetries across the adult life span in a naturalistic setting, the frequency of the location of impact on the participants' vehicle during crashes and near crashes in a large sample of drivers from the SHRP 2 NDS was examined. The data retrieved from the SHRP 2 NDS were standardized variables that are outlined in the SHRP 2 Researcher Dictionary for Video Reduction Data (Virginia Tech Transportation Institute, VTTI, 2015). Safety-critical events (e.g., crash, near crash) were classified based on kinematic and video analysis using automatic crash notification algorithms on the DAS, and controller area network algorithms on ingested data. These identified events were then reviewed on video by trained analysts, who categorized the events for severity and related characteristics, including precipitating events, evasive maneuvers, and position of impact. Details regarding the SHRP 2 NDS database and DAS instrumentation are outlined in Dingus et al. (2016).

The SHRP 2 NDS was sponsored by the Transportation Research Board of the National Academy of Sciences. Initially, a website housing the data was accessed to determine the coded variables of interest for the study. Subsequently, to obtain user-access to the data, a Data Use License from the VTTI outlining variables of interest from the SHRP2 NDS was requested, following approval from the Behavioural Research Ethics Board of the University of Saskatchewan.

5.1.2 SHRP2 NDS Variables Examined

A number of variables related to the outcome of crashes and near crashes that occurred over the duration of the SHRP 2 NDS were examined. The SHRP2 Researcher Dictionary for Video Reduction Data (VTTI, 2015) identifies the outcome of events and incidents as a variable labeled *event severity*. Of the seven possible outcomes for event severity (crash, near crash, crash relevant, non-conflict, non-subject conflict, baseline, not applicable), crashes and near crashes were investigated. A crash was identified as any contact that the participant vehicle had with another object that was either moving or stationary. Road departures, where at least one tire left the roadway, were also considered crashes (VTTI, 2015). A near crash was identified as a circumstance that required a rapid evasive maneuver, either by the participant or any other vehicle, pedestrian, cyclist, or animal, to avoid a crash. In these circumstances, a crash did not occur, and a non-premeditated, rapid, evasive maneuver (e.g., steering, braking, accelerating) was made to avoid the crash (VTTI, 2015). Over the course of SHRP 2 NDS, 1,465 crashes and 2,272 near crashes were identified, which were examined in the current study.

Of the 3,545 participants who participated in SHRP 2 NDS, 1,748 participants were involved in a crash and/or near crash. Demographic information for each participant was provided by the SHRP 2 NDS data set; however, the age of each participant in the data set was categorized into a five-year age cohort. To ensure that a minimum of five crashes or near crashes occurred in each age group, five-year age cohorts were combined to form 20-year age cohorts. Specifically, participants were separated into one of five age categories: 16 to 19 years, 20 to 39 years, 40 to 59 years, 60 to 79 years, and over 80 years of age. This categorization resulted in 332 (18.99%) participants between 16 and 19 years of age, 736 (42.11%) participants between 20 and 39 years of age, 270 (15.45%) participants between 40 and 59 years of age, 289 (16.53%) participants between 60 and 79 years of age, 97 (5.55%) participants above 80 years of age, and 24 (1.37%) participants who did not specify their age. Participants who did not specify his or her age were excluded. Of the 1,748 participants 841 (48.11%) were male, 896 (51.26%) were female, and 11 (0.63%) participants did not specify their sex. Participants who were 16 to 19 years of age had an average of 1.70 years of driving experience, participants 20 to 39 years of age had an average of 7.80 years of driving experience, participants between 40 to 59 years of age had an average of 33.58 years of driving experience, participants between 60 to 79 years of age had an average of 52.10 years of driving experience, and over 80 years of age had an average

of 62.05 years of driving experience. On average, participants drove approximately 14,683.12 kilometers per year. Table 5-1 compares the characteristics of the total SHRP 2 NDS sample and those who were involved in crashes and near crashes.

Table 5-1

Characteristics of the SHRP 2 NDS sample and participants who were involved in crashes and near crashes

Characteristic	Total Sample (n = 3545)	Crash/Near Crash Sample (n = 1748)
Sex		
Male	1,668 (47.1%)	841 (48.1%)
Female	1,820 (51.3%)	896 (51.3%)
Missing	57 (1.6%)	11 (0.6%)
Age		
16-19	541 (15.3%)	332 (19.0%)
20-39	1317 (37.2%)	736 (42.1%)
40-59	576 (16.2%)	270 (15.4%)
60-79	798 (22.5%)	289 (16.5%)
80 and above	225 (6.3%)	97 (5.5%)
Missing	88 (2.5%)	24 (1.4%)
Average annual mileage (km)	12,482.34	14,683.12
Previous years driving	27.17	22.34

The location of the other vehicle, pedestrian, animal, or object that was involved in the event, or that restricted the participant’s ability to maneuver (i.e., in the participant’s path of travel) at the precipitating event, was recorded in one of ten different locations (see Figure 1). The SHRP2 Researcher Dictionary for Video Reduction Data (VTTI, 2015) specifies that medians, barriers, and curbs were excluded and not considered to be objects in this category. If there was no motorist, non-motorist, animal, or object involved in the event, the location was

categorized as *not applicable*, as there was no location to categorize (e.g., single-vehicle road departure, hitting a median, barrier, or curb). The location was coded as *unknown* if the position of the motorist/non-motorist could not be determined because of limitations in the video view, lighting, visual obstructions, or limited perspectives (VTTI, 2015). To ensure an adequate number of safety-critical events occurred in each location to complete statistical analyses, the location categories were reduced from ten to four by combining the locations on the right side of the vehicle (i.e., position B, C, D, E; see Figure 5-1) into a single right-side of the vehicle category and combining the locations on the left of the vehicle (i.e., position G, H, I, J; see Figure 1) into a single left-side of the vehicle category.

A unique advantage of a naturalistic driving study is the continuous monitoring of driving behaviour, which provides detailed information preceding crashes. Variables from the SHRP 2 NDS data base that provide information preceding a crash included, the environmental state or the action by the participant, another vehicle, person, animal, or object that was critical to the participant being involved in a crash (i.e., precipitating event), the type of conflict the participant had with another object (i.e., incident type), and the participant’s reaction or maneuver in response to the incident (i.e., evasive maneuver). Crashes of interest were therefore examined in further detail to determine the context in which the crash took place.



Figure 5-1. The subject vehicle is pictured. The position of impact is the location of the conflicting vehicle, person, animal, or object in relation to the subject vehicle. The position of impact was coded as one of ten (A-J) possible locations on the vehicle.

5.1.3 Relative Risk Analyses

Relative risk examines a dichotomous variable and is calculated by comparing the probability of one event occurring to the probability of another event occurring (e.g., left vs. right crashes). The relative risk values calculated are greater than or equal to zero. A value of 1 indicates that the events are equally likely to occur, whereas a value greater or less than one indicates that one of the outcomes is more or less likely to occur, respectively. The estimates of relative risk are accompanied by a lower and upper 95% confidence interval. Relative risk values are considered statistically significant if the confidence interval does not include 1.0. Further, when the relative risk upper and lower confidence intervals for a given age group are outside the upper and lower confidence intervals of any other age group, it can be taken with 95% confidence that there is a statistically significant difference in relative risk between the two age groups.

5.2 Results

5.2.1 Location of Impact Analyses

Tables 5-2 and 5-3 outline the frequency and percentage (in parentheses) of the location of the conflicting vehicle, person, animal, or object in relation to the participants' vehicle for five age categories (16-19, 20-39, 40-59, 60-79, 80+) during crashes and near crashes, respectively. A high percentage of crashes did not involve a motorist, non-motorist, animal, or object, and did not have an applicable location to categorize (i.e., "not applicable" category). These were largely attributed to safety-critical events, including road departures that were classified as crashes but did not have an applicable location of impact on the vehicle (i.e., instances in which the participant's vehicle exited the roadway beyond the shoulder, beyond the end of the roadway, or onto the median). Given that there was no location of impact to analyze, these were excluded from further analysis, leaving 2,611 near crashes and 433 crashes to analyze.

Table 5-2

Frequency of position of impact in crashes

Age (years)	Right side of subject vehicle	Left side of subject vehicle	Front of subject vehicle	Rear of subject vehicle	Not applicable	Unknown	Total (N)
16-19	30 (8.5%)	32 (9.0%)	56 (15.8%)	20 (5.6%)	216 (61.0%)	0 (0.0%)	354
20-39	46 (8.2%)	49 (8.7%)	70 (12.5%)	37 (6.6%)	359 (64.0%)	0 (0.0%)	561
40-59	6 (3.4%)	13 (7.3%)	15 (8.4%)	21 (11.7%)	123 (68.7%)	1 (0.6%)	179
60-79	14 (5.8%)	10 (4.1%)	25 (10.3%)	14 (5.8%)	177 (73.1%)	2 (0.8%)	242
80+	7 (6.1%)	10 (8.8%)	14 (12.3%)	7 (6.1%)	76 (66.7%)	0 (0.0%)	114

Table 5-3

Frequency of position of impact in near crashes

Age (years)	Right side of subject vehicle	Left side of subject vehicle	Front of subject vehicle	Rear of subject vehicle	Not applicable	Unknown	Total (N)
16-19	95 (18.0%)	109 (20.6%)	282 (53.3%)	3 (0.6%)	40 (7.6%)	0 (0.0%)	529
20-39	340 (26.4%)	327 (25.4%)	574 (44.6%)	9 (0.7%)	37 (2.9%)	0 (0.0%)	1287
40-59	111 (26.7%)	115 (27.6%)	182 (43.8%)	0 (0.0%)	8 (1.9%)	0 (0.0%)	416
60-79	130 (37.4%)	106 (30.5%)	105 (30.1%)	3 (0.9%)	4 (1.1%)	0 (0.0%)	348
80+	35 (31.8%)	37 (33.6%)	37 (33.6%)	1 (0.9%)	0 (0.0%)	0 (0.0%)	110

Table 5-4 shows the frequency of left and right crashes that participants in each of the five age categories were involved in, and the relative risk of crashing on the right and corresponding 95% confidence intervals. The confidence intervals for the relative risk for each age group was not outside the upper and lower confidence intervals of any other age group, suggesting the likelihood of a rightward crash was equal between the age groups. To specifically compare the age categories with the largest age difference, the relative risk of a younger (16-19 years) and older adult (over 80 years) crashing on the right was calculated. The relative risk of

younger adults compared to older adults crashing on the right was 0.89, 95% CI [0.40-1.99], indicating that younger and older adults had an equal risk of crashing on the right. Further, examination of the relative risk for each age group revealed that only 16 to 19-year-old participants had a statistically significant difference between the frequency of left and right crashes. Participants in the youngest age group were 0.52 times as likely to crash on the right compared to the left, 95% CI [0.29 – 0.94]. A statistically significant difference between the frequency of left and right crashes was not found among the other four age groups (see Table 5-4).

Table 5-4

Frequency of position of impact during crashes without road departure incidents, and relative risk of crashes on the right side of participants' vehicles with corresponding 95% confidence intervals

Age (years)	Right side of subject vehicle	Left side of subject vehicle	No. of Crashes	Relative Risk of Rightward Crash	Lower Confidence Interval	Upper Confidence Interval
16-19	14	27	112	0.52	0.29	0.94
20-39	33	41	173	0.80	0.54	1.21
40-59	6	11	59	0.55	0.22	1.38
60-79	10	9	39	1.11	0.51	2.43
80+	5	8	50	0.63	0.22	1.78

Similarly, Table 5-5 shows the frequency of left and right near crashes that participants in each of the five age categories were involved in, and the relative risk of crashing on the right and corresponding 95% confidence intervals. Again, the relative risk upper and lower confidence intervals for each age group were not outside the upper and lower confidence intervals of any other age group, suggesting that each age group had an equal risk of crashing on the right side of the vehicle. Additionally, the 95% confidence intervals for the relative risk calculation in each age group included 1.0 and did not reveal a statistically significant difference between the frequency of left and right near crashes (see Table 5-5).

Table 5-5

Frequency of position of impact during near crashes without road departure incidents, and relative risk of near crashes on the right side of participants' vehicles with corresponding 95% confidence intervals

Age (years)	Right side of subject vehicle	Left side of subject vehicle	No. of Near Crashes	Relative Risk of Rightward Near Crash	Lower Confidence Interval	Upper Confidence Interval
16-19	94	106	497	0.89	0.69	1.14
20-39	337	326	1255	1.03	0.91	1.18
40-59	111	114	406	0.97	0.78	1.22
60-79	129	105	343	1.23	1.00	1.52
80+	35	37	110	0.95	0.65	1.38

Overall, examining the frequency of crashes on the right ($n = 68$) and left ($n = 96$) of participants' vehicles revealed a statistically significant difference. However, unlike results from experiments examining navigation asymmetries in laboratory environments, leftward crashes were significantly more frequent than rightward crashes. Crashes were 1.41 times as likely to occur on the left compared to the right side of participants' vehicles, 95% CI [1.07 – 1.87].

5.2.2 Characteristics of Crashes

Of the 96 crashes that occurred on the left side of the participants' vehicle, 89 (92.7%) occurred in position J (see Figure 1). Crashes on the left were most often preceded by the participant turning left at an intersection (16.7%), an animal on the roadway (15.6%), and another vehicle entering the intersection straight across the participant's lane of travel (10.4%). These precipitating events are consistent with the most common types of conflicts (i.e., incident types). The types of conflicts most common when crashes were on the left of the participant's vehicle were contact with a living animal (20.8%), the participant or other vehicle crossed in front of the other vehicle when turning left or right (16.7%), and interactions that were not coded in one of the other 18 incident type categories (15.6%). In an attempt to avoid the crash, the most common reactions and maneuvers (i.e., evasive maneuver) were braking that resulted in skidding

(33.3%), braking and steering right (26.0%), and no reaction or change in driving behaviour (26.0%).

Sixty-eight crashes occurred on the right side of the participants' vehicle. Crashes on the right were most often preceded by an animal approaching the roadway (11.8%), an animal on the roadway (8.8%), another vehicle entering the intersection straight across the participant's lane of travel (5.9%), and participant backing their vehicle (5.9%). The types of conflicts (i.e., incident types) that most commonly occurred when crashes were on the right of the participant's vehicle were contact with a living animal (20.6%), interactions that were not coded in one of the other 18 incident type categories (20.6%), and turned into path of another vehicle (11.8%). To avoid the crashes, the most common reactions and maneuvers (i.e., evasive maneuver) were braking with no brake lockup (26.5%), no reaction or change in driving behaviour (23.5%), and braking and steering left (20.6%).

Although crashes on both the left and right of participants' vehicles were often commonly preceded by a conflict with an animal, there was a difference in common scenarios preceding crashes that potentially involved human error. Crashes that occurred on the left were commonly preceded by turning left at an intersection, whereas crashes on the right occurred more often prior the participant backing their vehicle or another vehicle entering the intersection and traveling across the participant's travel lane. However, due to the low frequency of precipitating events we were unable to statistically compare the frequency of the common precipitating events, or across age groups. Rather, the frequency of precipitating events on the left and right of participants' vehicles in each age group are displayed graphically (see Figures 5-2 and 5-3).

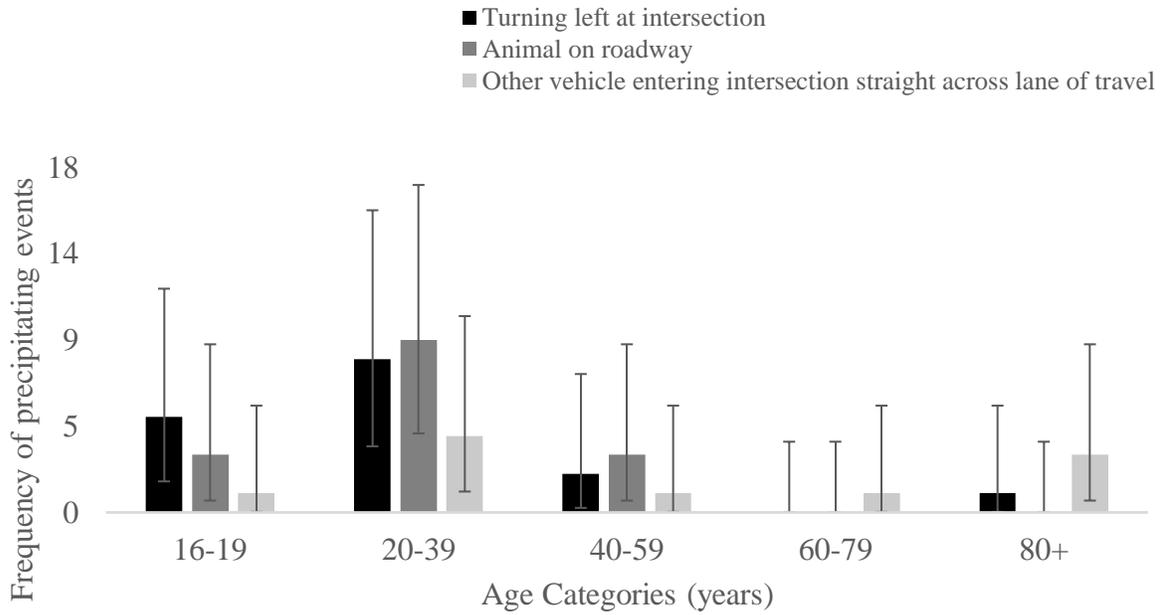


Figure 5-2. The frequencies and 95% Poisson confidence intervals of the most common precipitating events preceding crashes on the left of participants' vehicles in the five age categories.

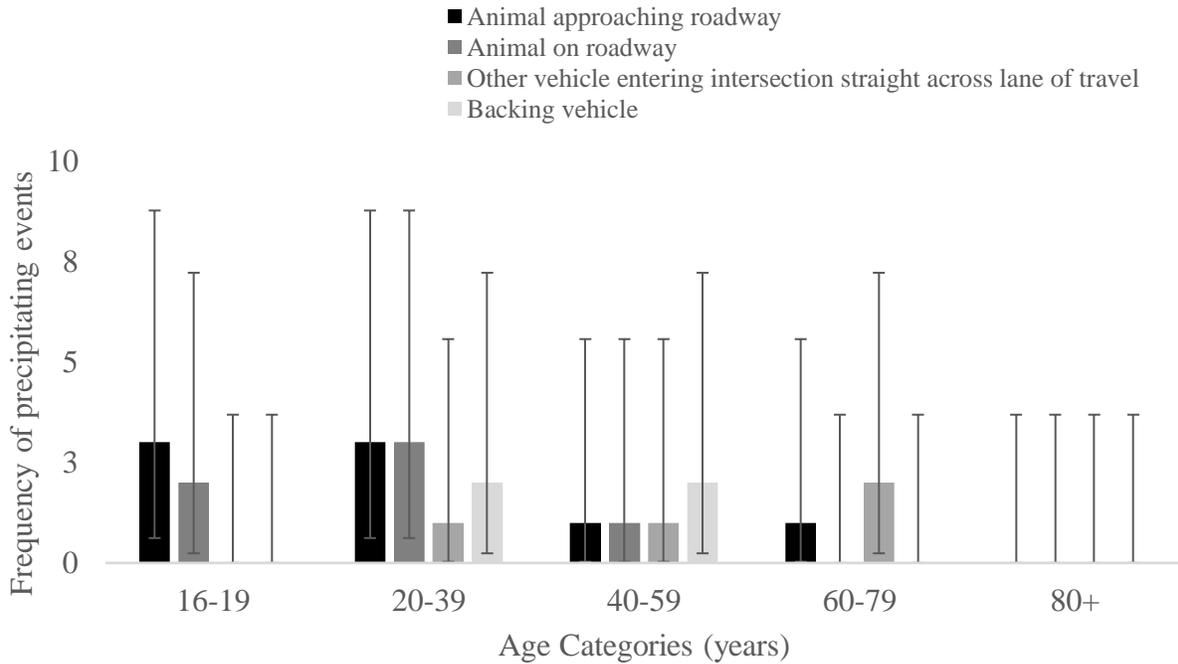


Figure 5-3. The frequencies and 95% Poisson confidence intervals of the most common precipitating events preceding crashes on the right of participants' vehicles in the five age categories.

5.3 Discussion

The aim of the study was to examine if age-related differences in pseudoneglect are also present in navigation asymmetries, and whether navigation asymmetries found in laboratory environments are present while driving in a naturalistic setting. Prior research examining asymmetry in navigation has primarily examined younger adults through retrospective reports or through experiments in controlled laboratory settings. Findings from these experiments has consistently identified veering asymmetries that result in small (10 to 36 mm), but consistent deviations to the right (Jang et al., 2009; Nicholls et al., 2010; Nicholls et al., 2016; Robertson et al., 2015). These small, systematic deviations in a controlled environment have been proposed to result in collisions in naturalistic settings (Nicholls et al., 2016) where navigation is more complex (e.g., parking a car in parkades or garages, and driving over narrow bridges). This study is the first (to our knowledge) to extend laboratory research, and examine the association between age-related differences in pseudoneglect and navigation asymmetry using crash analysis in a naturalistic setting. Data available from the SHRP 2 NDS resulted in examining the location of position of impact during crashes and near crashes, which is distinct from measures of veering that can identify subtle asymmetries when navigating. However, when examining a large sample and 35 million vehicle miles, it was hypothesized that subtle rightward biases in veering would result in a greater number of rightward compared to leftward crashes and near crashes.

Despite previous observational studies documenting rightward veering when walking (Nicholls, et al., 2007; Nicholls, et al., 2008), navigating an electric vehicle through a doorway (Nicholls, et al., 2010; Nicholls, et al., 2016; Robertson, et al., 2015), or while driving a car in a driving simulator (Jang, et al., 2009), the location of impact on the participants' vehicle during crashes and near crashes did not occur more frequently on the right side. In contrast, during crashes the other vehicle, non-motorist, animal, or object was more likely to be located on the left side of the vehicle. Of the age groups examined, participants 16 to 19 years of age had a greater risk for leftward crashes. Further, in contrast to previous laboratory experiments that have identified age-related differences in pseudoneglect, it is unclear whether age was related to position of impact due to the null association between age category and position of impact. Before conclusions are drawn regarding whether asymmetries in navigation are present in naturalistic settings, and whether age is related to navigation asymmetry, additional research is needed. The following explanations could account for our contradictory and null findings,

including the measure of navigation asymmetry used, complexity of left turns, and allocation of attention.

One of the most likely reasons for the weak findings of asymmetry in the position of impact during crashes and the lack of asymmetry in near crashes is the sensitivity of the outcome measure. Veering to the right when walking and navigating electric wheelchairs, scooters, and miniature vehicles is a subtle, but systematic, asymmetry that may not be detected when examining the location of the impact on the participants' vehicle during crashes and near crashes. Researchers extending laboratory findings of asymmetries in navigation to a naturalistic setting may benefit from using sensitive measures of asymmetry while driving, such as lane position data. Tracking where participants drive within their lane could provide data akin to veering in laboratory environments. Radar located on the vehicles collected lane positioning data, however, at the time of the analysis, such data was not available from the SHRP2 NDS database.

The measure of navigation asymmetry may have also impacted the crash and near crash symmetry demonstrated by each age group. From our analysis and the null association between age category and position of impact, it appears that age is not related to position of impact, as the symmetry of crashes and near crashes on the left and right side of participants' vehicles was consistent across the five age groups examined. This empirical observation is at odds with the notion that younger adults demonstrate rightward veering when navigating (Nicholls, et al., 2010; Nicholls, et al., 2016; Robertson, et al., 2015) and that older adults typically fail to demonstrate the presence of pseudoneglect compared to younger adults (Barrett & Craver-Lemley, 2008; Benwell, et al. 2014b; Chen, et al., 2011; Failla, et al., 2003; Fujii, et al., 1995; Fukatsu, et al., 1990; Goedert, et al., 2010; Schmitz & Peigneux, 2011). It is hypothesized that utilizing a measure with enhanced sensitivity to navigation asymmetry would assist in examining the subtle attenuation or intensification of pseudoneglect as participants age.

Certainly, the availability of more precise data about navigational asymmetries will not change the fact of the crashes themselves. What it will help with is understanding competing explanations for the crashes, including attentional bias effects, driving experience effects, effects of the driving environment (e.g., traffic directionality, driving environment), and interactions among these effects. For example, a possible explanation for the unexpected finding of a greater frequency of crashes on the left of participants' vehicles, is the complexity of left turns. Examining circumstances that precipitate crashes gives an indication of actions that made the

crash possible. The SHRP2 Researcher Dictionary for Video Reduction Data (VTTI, 2015) identified 76 possible precipitating events. Of the actions that compare left and right turns (e.g., turning left or right at an intersection, departing a lane to the left or right), participants turning left from its roadway to another roadway resulted in the highest percentage of crashes on the left of the participants' vehicle (16.7%), whereas turning right from its roadway preceded 3.1% of crashes. As expected, the evasive maneuver (i.e., drivers' reaction) in response to the event or incident was most often to brake and steer to the right of initial travel direction (26%) in an attempt to avoid a crash on the left side of the vehicle. Braking and steering to the left of the initial travel direction occurred in 3.1% of crashes on the left of the participants' vehicle.

In countries, such as the United States of America, which have right-sided traffic directionality (i.e., citizens drive on the right side of the road), left turns require greater attention to and observation of the left hemifield, compared to left-sided traffic directionality (Foerch & Steinmetz, 2009). When turning left, attention is shifted rightward, and motorists may have difficulty attending to other motorists and non-motorists in oncoming traffic who are located in the left visual field. The bisection model of navigation asymmetries proposes that rightward veering and collisions results from participants moving towards the perceived centre (i.e., right of true centre) without updating their trajectory when moving towards a target or aperture (Nicholls, et al., 2010). The theory has been supported by eye tracking data gathered during navigation tasks that have identified mean eye position to the right when moving a wheelchair through an aperture (Robertson et al., 2015), and positive associations between perceived midpoint of an aperture and where the vehicle passed through the aperture (Nicholls et al., 2016). Thus, the high proportion of crashes during left turns and the higher frequency of leftward crashes in the SHRP2 NDS may be explained by the rightward attentional bias, as participants' attention may have been shifted rightward during left turns.

An alternative explanation for the overall leftward bias during crashes is allocation of attention in the upper or lower visual field due to the visual environment (Hatin, et al., 2012). Location of the stimuli in the upper or lower visual field has been found to modulate the directional bias in collision behaviour (Thomas, Stuckel, Gutwin, & Elias, 2009). Further, when navigating, research has proposed that participants are biased to move towards locations where their attention is directed rather than moving away from attended areas (Hatin et al., 2012; Nicholls, et al., 2010), as drivers have been found to have a tendency to steer in the direction

they are looking, even when it is dangerous to do so (Wilkie, Kountouriotis, Merat, & Wann, 2010). Together, shifts in vertical allocation of attention and moving towards attended areas may result in collisions on the side that is attended (Hatin et al., 2012).

Laboratory experiments that involve navigating an electric vehicle through a doorway (Nicholls, et al., 2010; Nicholls, et al., 2016; Robertson, et al., 2015) direct participants' attention downward. Downward shifts in attention to the lower visual field have also been associated with shifts in attention to the right visual field over the left visual field (Nicholls, Mattingley, Berberovic, Smith, & Bradshaw, 2004), which has been suggested to result in rightward collisions (Hatin et al., 2012). In contrast, attention to the upper visual field has been associated with biases to the left visual field (Nicholls et al., 2004). Biases in attention to the upper-left visual field have been supported in a number of studies. For example, targets are identified significantly faster when they appear to be lit from the upper-left (McManus, Buckman, & Woolley, 2004; Sun & Perona, 1998) and when they are located in the upper-left quadrant (Smith, Szelest, Friedrich, & Elias, 2015) compared to other lighting directions and locations. Leftward biases are also strongest during the line bisection task when the lines are presented in the upper visual field (McCourt & Jewell, 1999; McCourt & Garlinghouse, 2000). Consequently, variations in the vertical visual field in which the task is carried out may account for differences in the direction of collisions between previous research in laboratory environments and the current findings.

Unlike previous research that has examined navigation asymmetries where participants may have been biased to direct their attention downwards, participants in the SHRP2 NDS may direct their attention to the upper visual field when driving in a naturalistic setting. For example, while driving a vehicle, the roadway is likely in the participant's upper visual field, whereas the dashboard of the vehicle is in his or her lower visual field. As a result, participants' attention may be biased to the upper left visual field, as found in previous research (Nicholls et al., 2004), resulting in a shift in attention to the left, leading to a leftward crash bias. In contrast to hypothesizing that biases in collisions are associated with pseudoneglect or perceptual asymmetries, biases in collisions to the left or right may also result from situational variables that influence the allocation of attention to the upper or lower visual field.

5.3.1 Limitations

In an attempt to enhance the external validity of laboratory research examining navigation asymmetry, in the present study we examined the position of impact following crashes and near crashes in a naturalistic setting. The naturalistic driving data used provided the prevalence of crashes and near crashes at different positions on participants' vehicles and pre-collision information, which allowed examination of the association between the lateralized behaviour and pseudoneglect in a real-world environment. However, utilizing data from a naturalistic driving study involves methodological limitations, particularly with regards to confounds and noise in the data, as we were unable to control the variables examined (Carsten, et al., 2013). For example, the frequency of crashes and near-crashes on the left or right side of the participants' vehicle may have been influenced by additional variables such as, the overall frequency of left and right turns – a variable that we were unable to examine. Naturalistic driving studies also focus on the human element in event causation, which limited our ability to examine traffic-system-based problems and the role of other drivers, pedestrians, or animals in the frequency of crashes. As a result, we cannot isolate a cause and effect relationship between the variables, but are able to discuss observed associations. Further, because data from naturalistic driving studies are used for a broad range of research questions, we were limited to the nonparametric retrospective nature of the data (i.e., a safety critical event are identified first and contributory factors are examined second) and the data collected. For instance, age was provided as a categorical variable, we were unable to examine the number of attempted turns, and, as mentioned above, data regarding participants' lane position was unavailable. Nonetheless, traffic safety is complex issue and examining real-world behaviour contributes to the literature examining navigation asymmetries in controlled environments. The use of naturalistic driving data also provided objective pre-collision characteristics (e.g., common precipitating events) that can be used to generate new hypotheses and subsequently tested under controlled conditions such as, test-tracks or driving simulators (Carsten, et al., 2013).

5.4 Conclusion

The current study and findings from the SHRP2 NDS add to the growing body of research on navigation asymmetry. The present investigation documents an overall leftward collision bias and a failure to find a difference in a collision bias between age groups. These findings are in contrast to rightward collisions predicted by the pseudoneglect hypothesis and

previous results demonstrated in laboratory experiments. Extending laboratory research findings to naturalistic settings enhances the external validity of results, and informs future research of the complexities and limitations associated with naturalistic observation research. Utilizing measures that are not sensitive enough to examine asymmetries in navigation, the complexity of driving in natural settings, and allocation of attention to the upper visual field may account for the disparities among rightward collisions reported in the literature and the current results. Researchers who conduct future research in naturalistic settings would likely find utility in examining lane positioning data that has the ability to examine subtle changes in veering, as well as crash and near crash data to enhance the understanding and practical impact of asymmetries in navigation.

CHAPTER 6

GENERAL DISCUSSION

A small but consistent bias towards stimuli in the left hemispace is a robust phenomenon known as pseudoneglect (Bowers & Heilman, 1980). The aim of this dissertation was to explore pseudoneglect across adulthood. Additional aims included addressing modulating factors that have been identified as influencing the magnitude of the leftward bias observed, including task demands and non-normative aging, and extend research on age-related differences in pseudoneglect to navigation asymmetries. The results provide further evidence for age-related differences in pseudoneglect, and through employing two commonly used visuospatial tasks in a within-subjects design, began to disentangle prior discrepancies in the observed direction of age-related differences in pseudoneglect. These results support a recent conceptualization that pseudoneglect is a multi-component phenomenon, which may offer an explanation for the discrepant age-related differences in lateral perceptual biases observed in prior research. Further, the age-related differences in the expression of pseudoneglect were extended in application to a naturalistic setting. In contrast with results from laboratory environments that have consistently found rightward crashes, overall, crashes were over-represented on the left side of participants' vehicles. Explanations proposed to account for these contradictory findings in navigation asymmetry, included the measure of navigation asymmetry used, complexity of left turns, and allocation of attention. Together, the results contribute to the current body of literature regarding aging and pseudoneglect, and provide directions to explore in future research conducted in both laboratory and naturalistic settings.

The objective of the study presented in Chapter 2 was to understand the stability in pseudoneglect across adulthood using a task that addresses some of the modulating stimulus factors that are known to influence the magnitude of the leftward bias, and discuss the results in the context of current cognitive models of aging. To examine pseudoneglect across the adult lifespan, rather than examining differences that occur in a particular decade of life, the study included a large sample (493 participants 18-88 years of age) and employed the greyscales task through an online survey. Unlike previous research using the line bisection and landmark tasks that have found an attenuated leftward bias with age, the performance on the greyscales task indicated that lateralized biases become stronger with age. Specifically, all age groups

demonstrated a leftward bias; moreover, older adults (80-89 year olds) demonstrated a significantly stronger leftward bias than younger adults (18-29 year olds). Importantly, differences in the lateralized bias began to appear in the seventh decade of life with strongest lateralized bias observed in the eighth decade of life. These results are inconsistent with cognitive models of aging that are typically used, such as the HAROLD and RHAM models. Instead the results from the current study are consistent with CRUNCH and suggest that compensation may result in increased lateralization (Reuter-Lorenz & Cappell, 2008). The larger attentional bias demonstrated with aging could represent functional reorganization or redistribution in response to age-related atrophy and/or neurotransmitter reduction (e.g., dopamine), leading to recruitment of additional neural resources and greater activation of the right hemisphere (Reuter-Lorenz & Cappell, 2008; Schmitz & Peigneux, 2011). Consistent with the activation-orientation hypothesis, asymmetrical activation of the right hemisphere increases attention applied to the left hemisphere, and consequently a larger leftward bias is observed during the task (Reuter-Lorenz et al., 1990).

Building upon the findings presented in Chapter 2, the primary aim of the study described in Chapter 4 was to clarify the leftward bias demonstrated by older adults and further understand the scope of phenomenon using multiple task conditions. Additional aims of this study were to examine the impact of neuropathology on pseudoneglect, and further understand the perceptual biases demonstrated by older adults by exploring cognitive strategies used. The study involved younger and older adults with and without symptoms of MCI completing the landmark and greyscales tasks. Participants were also asked to report retrospectively on the cognitive strategies used to complete the two tasks. The results revealed that younger adults consistently demonstrated a leftward bias irrespective of task; however, the biases demonstrated by older adults without symptoms of MCI was not systematically modulated in a similar way across tasks. Older adults demonstrated a leftward bias on the greyscales task, similar to young adults, but showed suppression of pseudoneglect on the landmark task, unlike young adults.

A hypothesis proposed to account for the distinct perceptual biases demonstrated by older adults on the greyscales and landmark task is that pseudoneglect is a multi-componential phenomenon, with neurological correlates that are differentially sensitive to age-related compensation. Although both tasks elicit the same phenomenon, differences in task demands may result in recruitment of different neural regions to compensate for age-related differences

(i.e., contralateral recruitment when judging size during the landmark task, and ipsilateral recruitment when judging luminance during the greyscales task), leading to older adults demonstrating different perceptual biases on distinct tasks. This hypothesis is consistent with the models commonly proposed to account for age-related changes on the separate tasks. For example, the HAROLD model, hypothesizing bilateral recruitment of cerebral hemispheres to maintain cognitive performance, has been commonly proposed to account for age-related differences elicited by the landmark task (Barrett & Craver-Lemley, 2008; DeAgostini et al., 1999; Learmonth et al., 2015; Learmonth et al., 2015b; Learmonth et al., 2017; Milano et al., 2014; Schmitz & Peigneux, 2011), whereas the CRUNCH hypothesis, recruitment of alternative brain regions (e.g., right hemisphere) in response to task demands, has been proposed to account for age-related differences elicited during the greyscales task (Friedrich et al., 2016). The proposal that pseudoneglect is a multi-componential phenomenon, and that task demands influence performance was also supported by the low inter-task reliability between the greyscales and landmark tasks. This finding is consistent with previous researchers who have reported poor inter-task reliability between lateralized visuospatial tasks and have proposed that pseudoneglect may have distinct components that are related to distinct neural regions, which differentially affect behavioural expression depending on task demands (Learmonth et al., 2015; Verdon et al., 2010).

Further, the hypothesis that pseudoneglect is a multi-componential phenomenon, particularly with age, was supported by the similar the biases demonstrated by older adults with and without symptoms of MCI. Although the influence of non-normative aging on pseudoneglect, as represented in the current experiment by symptoms of MCI, was negligible compared to healthy older adults, the performance of older adults with symptoms of MCI was characterized by large confidence intervals. The comparable biases demonstrated by both groups of older adults may be influenced by the distributed networks subserving attention that are used to complete perceptual tasks, with various components elicited by different task demands and correlated with distinct patterns of aging. It could be speculated that increased variability resulting from age-related compensation could occur in various brain regions to maintain performance on similar tasks.

The study presented in Chapter 4 also explored the cognitive strategies used to complete the tasks and a number of strategic themes were identified for each task. The strategies identified

on both tasks were comparable, including ‘viewing stimuli as parts and comparing them’, ‘viewing stimuli as a whole to inform judgments’, ‘developing a response rule’, and ‘manipulating vision’; however, ‘used an external cue’ was unique to the landmark task. Differences in task demands may have also influenced the cognitive strategies used to complete the landmark and greyscales tasks reported by participants. ‘Using an external cue,’ has also been reported by previous research (Varnava & Halligan, 2009) that used the line bisection task, and because it was not identified as a strategy during the greyscales task, it could be argued that externally centred strategies are utilized when the task requires a global size judgment, but not when tasks require judgement of luminance. Further, a distinct strategy, the use of a rule to inform responses on all trials, was identified in the current study that had not been reported in previous research findings. It could be speculated that the distinctiveness of this finding is specific to the landmark and greyscales task, both of which involved a forced choice decision, and not used when completing the line bisection task. In addition to generating distinct strategies, it was hypothesized that self-reported strategies would differ between experimental groups and inform behavioural differences on the perceptual tasks; however, this was not evident, suggesting that the asymmetry scores lack the sensitivity to identify the behavioural effects of different cognitive strategies.

Last, the objective of the naturalistic study, which was discussed in Chapter 5, was to examine if age-related differences in pseudoneglect were associated with asymmetries in navigation during everyday tasks that require spatial attention, such as driving. Very few studies have extended research on age-related differences in pseudoneglect to the investigation of asymmetry in navigation, nor have many studies extended laboratory-based research on navigational asymmetries to naturalistic settings where participants have greater task demands and navigation is more complicated. The study presented in Chapter 5 examined the association between age and asymmetries in motor vehicle collisions, and whether navigation asymmetries found in laboratory environments were present while driving in a naturalistic setting. The study involved examining the relative risk of participants enrolled in the SHRP2 NDS crashing on the right side of their vehicle, and compared the relative risk across five different age groups. In contrast to results from experiments examining navigation asymmetries in laboratory environments that have consistently found rightward veering and crashes, overall, leftward crashes were 1.41 times as likely to occur compared to crashes on the right side of participants’

vehicles. Further, the results revealed that the likelihood of a rightward crash was equal across all age groups and that a significant difference in the frequency of left and right crashes was only observed in participants 16-19 years of age, who were more likely to crash on the left. There are several possible explanations that may account for disparities among rightward collisions reported in the literature and the current results. These explanations included the measure of navigation asymmetry used that may not have been sensitive to capture asymmetries in navigation; the complexity of left turns in right-sided traffic directionality; and allocation of visual attention in the upper visual field when driving compared to the lower visual field when navigating an electric object through a doorway in a laboratory. Importantly, the results of the study provided pre-collision characteristics that can be used to generate new hypothesis that can be tested, and informs future research investigating navigation asymmetries in naturalistic settings regarding the type of variables to examine, such as lane positioning data that has the ability to examine subtle changes in veering.

Together, the results of the studies extend inconsistent findings identified in previous research examining pseudoneglect and aging (see Chapter 3 for review), and propose that the differences in the magnitude of the leftward bias observed in older adults may be influenced by task demands. During the quasi-experiments presented in Chapter 2 and 4, older adults demonstrated a leftward bias when completing the greyscales task, whereas the bias was suppressed during the landmark task. These results and the low inter-task reliability, support the hypothesis that pseudoneglect, like hemispatial neglect (Verdon et al., 2010), is a multi-componential phenomenon that is influenced by task demands (Learmonth et al., 2015a). Differences in task demands may prompt recruitment of different neural regions to compensate for age-related changes, leading to the differences in lateral biases on the greyscales and landmark tasks observed in the study presented in Chapter 4 and in prior research. Further, the consequences of age-related differences in pseudoneglect examined in Chapter 5 were not evident and it was unclear whether age was related to navigation asymmetry due to the null association between age category and position of impact. These findings can also be extended to support the hypothesis that pseudoneglect is a multi-componential phenomenon that is influenced by task demands, particularly with age. The demands of driving may recruit different neural regions associated with pseudoneglect to compensate for age-related changes, minimizing potential negative consequences that could result from a shift in the perceptual bias. Future

research and models of cognitive aging that conceptualize pseudoneglect as a multi-componential phenomenon and account for task demands will likely assist in explaining age-related changes in pseudoneglect.

6.1 Directions for Future Research

Since Jewell and McCourt's (2000) meta-analysis, an increasing emphasis has been placed on understanding age-related changes in pseudoneglect. Indeed, researchers have expanded their examination of pseudoneglect in older adults from using the line bisection task to additional tasks, including the landmark, greyscales, tactile rod bisection, and lateralized visual detection tasks. However, as outlined in Chapter 3 and the findings presented in Chapter 4, the magnitude of pseudoneglect demonstrated by older adults is not systematically modulated in a similar way across tasks. Given the discrepancy in the direction of the perceptual bias demonstrated by older adults, a future approach could be to investigate both convergent and discriminant validity of pseudoneglect in older adults. Using factor analysis to identify reliable shared variance among the tasks used to examine pseudoneglect could identify components that represent a common construct (Salthouse, 2011). It will be important for future research to clarify whether age differences observed in tasks are due to distinct task-specific age-related processes, or if changes are due to more general influences. Understanding the scope of age-related changes in pseudoneglect, and convergent and discriminant validity, could assist in identifying general age-related processes that are operating.

Another valuable direction for future research to understanding age-related differences in pseudoneglect is the introduction of neuroimaging techniques. Given the poor correlation between visuospatial tasks, previous research has proposed that each task may only assess part, or a component of the phenomenon (Learmonth et al., 2015). Using an approach similar to Verdon et al. (2010) to identify functional components of hemispatial neglect, researchers may find utility in administering a battery of visuospatial tasks to assess pseudoneglect in older adults, and subsequently use statistical factor analysis of behavioural performance across all tasks to identify distinct functional components of the phenomenon. Following identification of the components, neural correlates corresponding to the associated behavioural components can be investigated using neuroimaging and voxel-based mapping analysis. This approach has been used to clarify the multi-componential nature of hemispatial neglect by identifying various components with distinct patterns of brain lesions, which has reconciled discrepancies between

studies that have reported variable cortical and subcortical areas for neglect symptoms (Verdon et al., 2010). Employing a variety of visuospatial tasks with different task demands, and identifying behavioural and associated neurological components of pseudoneglect could assist in clarifying the conceptualization of pseudoneglect as a multi-faceted phenomenon.

Neuroimaging techniques could also be utilized to further understand models of cognitive aging associated with perceptual biases. Given that the current models of cognitive aging are not well-specified to the phenomenon of pseudoneglect, and are unable to account for the variability of perceptual biases demonstrated by older adults or the conceptualization of pseudoneglect as a multi-component phenomenon, neuroimaging would be advantageous in understanding interhemispheric interaction. Identification of age-related changes in the involvement of the left and right hemisphere during visuospatial tasks would provide evidence for the HAROLD model (i.e., involvement of the left hemisphere with age) or CRUNCH (i.e., increased involvement of the right hemisphere with age). Another possibility is to use neuroimaging to identify age-related changes in the corpus callosum to understand if performance differences on tasks are influenced by age-related decline within the right-hemisphere or influenced by decline in callosal connectivity. For example, if age-related changes in the connectivity of the corpus callosum is greater relative to age-related decline within the right hemisphere, older adults may show a larger within-hemisphere advantage (e.g., larger leftward bias) compared to younger adults (Hellige, 2008). As well, the opposite could be expected (e.g., smaller leftward bias) if age-related decline within the right hemisphere is relatively larger than the age-related decline in callosal connectivity. Further, behavioural biases and interhemispheric interaction may be influenced by task demands and task complexity. Together, the investigation of such hypotheses with neuroimaging may be beneficial in developing new models of cognitive-aging that account for the variability in the perceptual biases demonstrated by older adults.

Furthermore, a limitation of current research examining age-related changes in pseudoneglect and the proposed models of aging, is that they are solely based on results from cross-sectional studies with individuals varying in age. Cross-sectional studies approach aging as a between-person characteristic. Examining age differences assumes that between-person differences represent within-person changes and reflect a continuous change occurring within individuals; however, aging is a within-person process and may be discontinuous (Hofer & Sliwinski, 2006). For example, previous longitudinal studies have found significant within-

person variation in different processes, including areas that have been considered highly stable, such as personality (Mroczek & Spiro, 2003). Through comparing age groups, cross-sectional designs also underestimate variability within groups and overestimate differences between groups. Comparisons between cross-sectional and longitudinal age trends have commonly reported discrepancies with between-person cross-sectional findings reporting declines in cognitive functioning beginning in early adulthood, whereas longitudinal comparisons report stability or increases in cognitive functioning (Salthouse, 2010). To understand developmental and age-related changes in pseudoneglect, direct assessment of within-person processes through longitudinal research may be necessary to confirm results from cross-sectional studies. Although longitudinal studies are more difficult and the data is more complex compared to cross-sectional research, the data obtained from longitudinal research allows researchers to gather information that is necessary to directly assess within-person change processes and addresses attrition, cohort effects, and mortality selection that is excluded in cross-sectional research. Longitudinal research can also assist researchers in answering questions regarding causation and in identifying potential factors that may be influencing the observed age-related changes. Utilizing a variety of methodological approaches and converging results from different analytic methods, rather than limiting methodology to cross-sectional approaches, will likely enhance the inferences drawn from the data.

A further challenge of cross-sectional studies, particularly with regards to those identified in Chapter 3, is the difference in spacing between ages. Researchers have been inconsistent in the spacing between ages, and the size of the age ranges examined. Common approaches have involved using a modal extreme age group design, and large age groups that span 20-30 years. Such experimental designs are problematic in aging research as comparison of extreme age groups can inflate estimates of age-related differences, and large age groups can mask the origin of age-related differences and whether the change is linear. Examining large age groups that span 20 to 30 years in older age inhibits researchers' abilities to understand when age-related changes begin to occur and whether differences occur within the age group (e.g., from 60 to 90 years of age). Although the studies presented in Chapter 2 and 5 attempted to address these problems (i.e., Chapter 2 is one of three studies included in the systematic review that examined smaller age ranges), comparing age groups of different sizes is a challenge when using cross-sectional research designs that can also be addressed by longitudinal research. Longitudinal research can

assist in identifying when changes in pseudoneglect begin and the rate of change at different ages in older adulthood. These findings would likely be of benefit in designing and implementing interventions to mitigate potential negative consequences of age-related changes in pseudoneglect.

Future research could also focus on examining visuospatial attention with ecologically valid tasks and investigate whether laboratory-based measures correlate with real-world tasks. There is a lack of research examining whether age-related shifts in pseudoneglect have negative consequences on everyday tasks that involve extrapersonal space, such as spatial navigation (e.g., walking, driving), or on quality of life in older age. The systematic leftward bias demonstrated by younger adults in laboratory settings is subtle, and it is unclear whether shifts in perceptual biases with age are a harmless by-product of healthy aging or have more negative consequences (e.g., higher risk of crashes or falls). Prior to the study presented in Chapter 5, investigations of asymmetry in navigation and associations with pseudoneglect were limited to samples of younger adults. Given the increasing proportion of older persons in society (Statistics Canada, 2011), it is of relevance to examine whether shifts in perceptual biases are harmful through expanding research to topics such as the implications of age-related changes in lateral perceptual biases, and age-related changes in navigation asymmetries. If negative consequences are identified with age-related shifts in perceptual biases, future research could also examine individual and environmental factors associated with older individuals who do not experience such negative consequences. This research may be valuable in generating ideas for potential interventions to mitigate the risk of crashes or falls.

6.2 Conclusion

This series of studies explored pseudoneglect across the adult lifespan, particularly in older adults with and without symptoms of pathological aging using the greyscales task, a task that had not previously been employed to examine age-related differences in pseudoneglect. The studies presented addressed methodological limitations identified in the previous studies as outlined in the systematic review, including: using smaller age ranges within age groups and a larger sample size; identification of participants who had symptoms of cognitive impairment to understand the continuum of normal and pathological aging; and modification of stimuli and methods to enhance internal comparability with previous studies that used similar tasks. In general, the results suggest that age-related differences in pseudoneglect are present, but the

direction of the shift in lateral bias with age appears to be dependent on task demands. This may indicate that pseudoneglect is, itself, a multi-componential phenomenon. In an attempt to extend laboratory research to applied settings, asymmetries in crashes and near crashes in a naturalistic driving study were also examined in this series of studies. Age was not associated with asymmetries in the location of impact during crashes or near crashes, and, in contrast to laboratory findings reporting a higher likelihood of rightward crashes and veering irrespective of age, an overall leftward collision bias was identified. The results of both laboratory and naturalistic studies informs future research regarding the importance of task demands and non-normative aging on age-related differences in the expression of pseudoneglect, and the utility of using additional measures to examine asymmetry in navigation in naturalistic settings.

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Appendix A

MEDLINE (OvidSP)

1. older adult.mp. (4457)
2. exp AGING/ (225303)
3. senior*.mp. (29084)
4. exp Adult Development/ (0)
5. exp Age Differences/ (0)
6. elder*.mp. (208436)
7. 1 or 2 or 3 or 4 or 5 or 6 (435635)
8. pseudoneglect.mp. (184)
9. exp cerebral dominance/ not exp language/ (64028)
10. "hemispatial neglect".mp. (435)
11. hemineglect.mp. (313)
12. "spatial bias".mp. (297)
13. laterali?ation.mp. not exp language/ (6586)
14. "visuospatial attention".mp. (567)
15. "spatial attention".mp. (2681)
16. exp Visual Attention/ (0)
17. "leftward bias".mp. (198)
18. "hemispheric asymmetry".mp. not exp language/ (1088)
19. "hemispheric speciali?ation".mp. not exp language/ (707)
20. 8 or 9 or 10 or 11 or 12 or 13 or 14 or 15 or 16 or 17 or 18 or 19 (70357)
21. 7 and 20 (2038)
22. limit 21 to (128english and human) (1524)

Appendix B

Grating scales task: The task requires the participant to judge which of two horizontal mirror imaged rectangles composed of sine-wave gratings of increasing and decreasing spatial frequency contains more thin stripes (Carrasco, Figueroa, & Willen, 1986).

Greyscales task: The task requires participants to judge which of two horizontal mirror-imaged equiluminant gradients (i.e., one shaded from black to white and the other shaded from white to black) appears darker (Nicholls, Bradshaw, & Mattingley, 1999).

Landmark task: The task requires the participant to make a two-alternative forced choice decision regarding the length of the two halves of a line that is pre-bisected in the centre. The task is considered a non-manual variant of the line bisection task (Milner et al., 1992).

Lateralized visual detection task: The task requires the participant to detect small dots that briefly appear at the individual's peri-threshold in the left or right side of space and detection accuracy is calculated (Hilgetag, Théoret, & Pascual-Leone, 2001).

Line bisection task: The task requires the participant to place a mark with a pencil through the centre of a horizontal line to divide the line in equal halves (Albert, 1973).

Tactile rod bisection task: The task requires the participant, with their eyes closed, to place their index finger at the perceived middle of a wooden doweling rod after exploring the entire length of the rod (Brooks et al., 2011).

Appendix C

Chapter 2

One sample t-tests examining asymmetry scores demonstrated on the greyscales task to determine if they were different than zero (i.e., no bias)

18-29 year olds

One-Sample Test						
	Test Value = 0					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
ResponseBias	-6.914	220	.000	-7.620	-9.79	-5.45

30-39 year olds

One-Sample Test						
	Test Value = 0					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
ResponseBias	-4.379	37	.000	-10.842	-15.86	-5.82

40-49 year olds

One-Sample Test						
	Test Value = 0					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
ResponseBias	-3.103	33	.004	-7.971	-13.20	-2.74

50-59 year olds

One-Sample Test						
	Test Value = 0					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
ResponseBias	-4.827	35	.000	-12.500	-17.76	-7.24

60-69 year olds

One-Sample Test						
	Test Value = 0					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
ResponseBias	-3.081	53	.003	-9.111	-15.04	-3.18

70-79 year olds

One-Sample Test						
	Test Value = 0					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
ResponseBias	-6.853	55	.000	-15.250	-19.71	-10.79

80-89 year olds

One-Sample Test						
	Test Value = 0					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
ResponseBias	-6.727	53	.000	-16.389	-21.28	-11.50

One sample t-test examining whether participants chose the stimulus on the top more often than the stimulus on the bottom

One-Sample Test						
	Test Value = 0					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
BottomTop	3.656	493	.000	1.77328	.8202	2.7264

Between-subjects ANOVA (7 [age] x 2 [gender]) to compare the magnitude of the leftward bias between age groups and gender

Descriptive Statistics				
Dependent Variable: ResponseBias				
Agegroup	Sex	Mean	Std. Deviation	N
18-29 year olds	Male	-8.91	13.624	55
	Female	-7.19	17.217	166
	Total	-7.62	16.384	221
30-39 year olds	Male	-8.82	15.000	22
	Female	-13.62	15.667	16
	Total	-10.84	15.264	38
40-49 year olds	Male	-11.00	14.422	16
	Female	-5.28	15.354	18
	Total	-7.97	14.980	34
50-59 year olds	Male	-13.40	15.962	20
	Female	-11.38	15.435	16
	Total	-12.50	15.539	36
60-69 year olds	Male	-5.93	21.729	30
	Female	-13.08	21.524	24
	Total	-9.11	21.731	54
70-79 year olds	Male	-17.25	16.835	24
	Female	-13.94	16.864	31
	Total	-15.38	16.777	55
80-89 year olds	Male	-13.29	19.875	24
	Female	-18.87	16.066	30
	Total	-16.39	17.902	54
Total	Male	-10.68	16.902	191
	Female	-9.97	17.499	301
	Total	-10.24	17.256	492

Levene's Test of Equality of Error Variances ^a			
Dependent Variable: ResponseBias			
F	df1	df2	Sig.
1.508	13	478	.110

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

a. Design: Intercept + Agegroup + Sex + Agegroup * Sex

Tests of Between-Subjects Effects								
Dependent Variable: ResponseBias								
Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power ^b
Corrected Model	7348.675 ^a	13	565.283	1.946	.024	.050	25.298	.931
Intercept	44713.043	1	44713.043	153.925	.000	.244	153.925	1.000
Agegroup	4403.244	6	733.874	2.526	.020	.031	15.158	.842
Sex	38.521	1	38.521	.133	.716	.000	.133	.065
Agegroup * Sex	1884.729	6	314.121	1.081	.372	.013	6.488	.429
Error	138852.057	478	290.485					
Total	197830.000	492						
Corrected Total	146200.732	491						

a. R Squared = .050 (Adjusted R Squared = .024)

b. Computed using alpha =

Correlation between magnitude of the leftward bias and age

Correlations			
		Age	ResponseBias
Age	Pearson Correlation	1	-.154**
	Sig. (2-tailed)		.001
	N	493	493
ResponseBias	Pearson Correlation	-.154**	1
	Sig. (2-tailed)	.001	
	N	493	494

** . Correlation is significant at the 0.01 level (2-tailed).

Chapter 4

One sample t-tests against chance (0.5) to examine whether asymmetry scores indicated a leftward bias.

Younger adults asymmetry scores on the greyscales task

One-Sample Test ^a						
	Test Value = 0.5					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
PercentageTrialDarkL	4.957	44	.000	.1358796	.080630	.191129

a. Group = Younger adults

Older adults without MCI Sx asymmetry scores on the greyscales task

One-Sample Test ^a						
	Test Value = 0.5					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
PercentageTrialDarkL	4.111	29	.000	.1427083	.071717	.213700

a. Group = Older adults

Older adults with MCI Sx asymmetry scores on the greyscales task

One-Sample Test ^a						
	Test Value = 0.5					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
PercentageTrialDarkL	4.036	14	.001	.1951389	.091432	.298846

a. Group = Older adults w MCI

Younger adults asymmetry scores on the landmark task

One-Sample Test ^a						
	Test Value = 0.5					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
LPerceptualBiasPercentage	5.002	44	.000	.12269	.0733	.1721
LResponseBiasPercentage	-5.002	44	.000	-.12269	-.1721	-.0733

a. Group = Younger adults

Older adults without MCI Sx asymmetry scores on the landmark task

One-Sample Test ^a						
	Test Value = 0.5					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
LPerceptualBiasPercentage	-1.685	29	.103	-.07431	-.1645	.0159
LResponseBiasPercentage	1.685	29	.103	.07431	-.0159	.1645

a. Group = Older adults

Older adults with MCI Sx asymmetry scores on the landmark task

One-Sample Test ^a						
	Test Value = 0.5					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
LPerceptualBiasPercentage	-.900	14	.383	-.07014	-.2372	.0970
LResponseBiasPercentage	.900	14	.383	.07014	-.0970	.2372

a. Group = Older adults w MCI

GLM mixed measures ANOVA (2 [task] x 3 [group]) used to examine asymmetry scores

Descriptive Statistics				
	Group	Mean	Std. Deviation	N
PercentageTrialDarkL	Younger adults	.635880	.1839006	45
	Older adults	.642708	.1901188	30
	Older adults w MCI	.695139	.1872711	15
	Total	.648032	.1856671	90
LPerceptualBiasPercentage	Younger adults	.622685	.1645355	45
	Older adults	.395833	.2353528	30
	Older adults w MCI	.429861	.3017616	15
	Total	.514931	.2400589	90

Tests of Within-Subjects Effects									
Measure: MEASURE_1									
Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power ^a
Task	Sphericity Assumed	1.129	1	1.129	28.930	.000	.250	28.930	1.000
	Greenhouse-Geisser	1.129	1.000	1.129	28.930	.000	.250	28.930	1.000
	Huynh-Feldt	1.129	1.000	1.129	28.930	.000	.250	28.930	1.000
	Lower-bound	1.129	1.000	1.129	28.930	.000	.250	28.930	1.000
Task * Group	Sphericity Assumed	.649	2	.324	8.311	.000	.160	16.622	.957
	Greenhouse-Geisser	.649	2.000	.324	8.311	.000	.160	16.622	.957
	Huynh-Feldt	.649	2.000	.324	8.311	.000	.160	16.622	.957
	Lower-bound	.649	2.000	.324	8.311	.000	.160	16.622	.957
Error(Task)	Sphericity Assumed	3.395	87	.039					
	Greenhouse-Geisser	3.395	87.000	.039					
	Huynh-Feldt	3.395	87.000	.039					
	Lower-bound	3.395	87.000	.039					

a. Computed using alpha =

Tests of Between-Subjects Effects									
Measure: MEASURE_1									
Transformed Variable: Average									
Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power ^a	
Intercept	47.908	1	47.908	1125.188	.000	.928	1125.188	1.000	
Group	.449	2	.224	5.269	.007	.108	10.538	.823	
Error	3.704	87	.043						

a. Computed using alpha =

Simple main effects of asymmetry scores on the greyscales task

Descriptive Statistics			
Dependent Variable: PercentageTrialDarkL			
Group	Mean	Std. Deviation	N
Younger adults	.635880	.1839006	45
Older adults	.642708	.1901188	30
Older adults w MCI	.695139	.1872711	15
Total	.648032	.1856671	90

Levene's Test of Equality of Error Variances ^a			
Dependent Variable: PercentageTrialDarkL			
F	df1	df2	Sig.
.245	2	87	.783

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

a. Design: Intercept + Group

Tests of Between-Subjects Effects						
Dependent Variable: PercentageTrialDarkL						
Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	.041 ^a	2	.020	.586	.559	.013
Intercept	31.873	1	31.873	915.998	.000	.913
Group	.041	2	.020	.586	.559	.013
Error	3.027	87	.035			
Total	40.863	90				
Corrected Total	3.068	89				

a. R Squared = .013 (Adjusted R Squared = -.009)

Simple main effects of asymmetry scores on the landmark task

Descriptive Statistics			
Dependent Variable: LPerceptualBiasPercentage			
Group	Mean	Std. Deviation	N
Younger adults	.622685	.1645355	45
Older adults	.395833	.2353528	30
Older adults w MCI	.429861	.3017616	15
Total	.514931	.2400589	90

Levene's Test of Equality of Error Variances ^a			
Dependent Variable: LPerceptualBiasPercentage			
F	df1	df2	Sig.
4.312	2	87	.016

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

a. Design: Intercept + Group

Tests of Between-Subjects Effects						
Dependent Variable: LPerceptualBiasPercentage						
Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	1.057 ^a	2	.528	11.286	.000	.206
Intercept	17.164	1	17.164	366.682	.000	.808
Group	1.057	2	.528	11.286	.000	.206
Error	4.072	87	.047			
Total	28.993	90				
Corrected Total	5.129	89				

a. R Squared = .206 (Adjusted R Squared = .188)

Games-Howell post hoc test used to compare the asymmetry score demonstrated by the three experimental groups on the landmark task

Multiple Comparisons						
Dependent Variable: LPerceptualBiasPercentage						
Games-Howell						
(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Younger adults	Older adults	.226852*	.0494769	.000	.107164	.346540
	Older adults w MCI	.192824	.0816840	.074	-.016887	.402535
Older adults	Younger adults	-.226852*	.0494769	.000	-.346540	-.107164
	Older adults w MCI	-.034028	.0889777	.923	-.256995	.188939
Older adults w MCI	Younger adults	-.192824	.0816840	.074	-.402535	.016887
	Older adults	.034028	.0889777	.923	-.188939	.256995

Based on observed means.
The error term is Mean Square(Error) = .047.

*. The mean difference is significant at the

Post-hoc comparisons using paired samples t-tests to examine the effect of task on asymmetry scores demonstrated by younger adults

Paired Samples Test ^a									
		Paired Differences				t	df	Sig. (2-tailed)	
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower				Upper
Pair 1	PercentageTrialDarkL - LPerceptualBiasPercentage	.0131944	.2480630	.0369791	-.0613319	.0877208	.357	44	.723

a. Group = Younger adults

Post-hoc comparisons using paired samples t-tests to examine the effect of task on asymmetry scores demonstrated by older adults without symptoms of MCI

Paired Samples Test ^a									
		Paired Differences				t	df	Sig. (2-tailed)	
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower				Upper
Pair 1	PercentageTrialDarkL - LPerceptualBiasPercentage	.2468750	.2821485	.0515130	.1415190	.3522310	4.792	29	.000

a. Group = Older adults

Post-hoc comparisons using paired samples t-tests to examine the effect of task on asymmetry scores demonstrated by older adults with symptoms of MCI

Paired Samples Test ^a									
		Paired Differences				t	df	Sig. (2-tailed)	
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower				Upper
Pair 1	PercentageTrialDarkL - LPerceptualBiasPercentage	.2652778	.3560190	.0919237	.0681210	.4624345	2.886	14	.012

a. Group = Older adults w MCI

Correlation between the greyscales and landmark tasks

Correlations			
		PercentageTrialDarkL	LPerceptualBiasPercentage
PercentageTrialDarkL	Pearson Correlation	1	.014
	Sig. (2-tailed)		.898
	N	90	90
LPerceptualBiasPercentage	Pearson Correlation	.014	1
	Sig. (2-tailed)	.898	
	N	90	90

Between-subject ANOVA used to examine asymmetry scores as a function of strategy type and experimental group on the greyscales task

Descriptive Statistics				
Dependent Variable: PercentageTrialDarkL				
AgeGroup	GSTheme	Mean	Std. Deviation	N
1.00	1.00	.636905	.2690532	7
	2.00	.588542	.3684321	4
	3.00	.666667	.0589256	2
	4.00	.623476	.1565373	41
	5.00	.589844	.2062348	8
	Total		.619792	.1873458
2.00	1.00	.636719	.1758481	8
	2.00	.989583	.	1
	3.00	.416667	.	1
	4.00	.640253	.1866295	28
	5.00	.571875	.1003286	10
	Total		.628038	.1762006
3.00	1.00	.781250	.1603625	3
	2.00	.859375	.1057176	4
	3.00	.927083	.	1
	4.00	.602431	.1561447	12
	5.00	.531250	.	1
	Total		.688988	.1825232
Total	1.00	.660880	.2106556	18
	2.00	.753472	.2850819	9
	3.00	.669271	.2111571	4
	4.00	.626157	.1658836	81
	5.00	.577303	.1475721	19
	Total		.633906	.1828032

Levene's Test of Equality of Error Variances ^a			
Dependent Variable: PercentageTrialDarkL			
F	df1	df2	Sig.
2.090	14	116	.017

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

a. Design: Intercept + AgeGroup + GSTheme + AgeGroup * GSTheme

Tests of Between-Subjects Effects						
Dependent Variable: PercentageTrialDarkL						
Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	.621 ^a	14	.044	1.381	.173	.143
Intercept	16.960	1	16.960	528.342	.000	.820
AgeGroup	.096	2	.048	1.493	.229	.025
GSTheme	.274	4	.069	2.135	.081	.069
AgeGroup * GSTheme	.371	8	.046	1.445	.185	.091
Error	3.724	116	.032			
Total	56.985	131				
Corrected Total	4.344	130				

a. R Squared = .143 (Adjusted R Squared = .039)

Between-subject ANOVA used to examine asymmetry scores as a function of strategy type and experimental group on the landmark task

Descriptive Statistics				
Dependent Variable: LPerceptualBiasPercentage				
AgeGroup	LDMTheme	Mean	Std. Deviation	N
1.00	1.00	.575893	.2017819	7
	2.00	.614583	.2455109	5
	3.00	.531250	.0883883	2
	4.00	.592593	.1500004	9
	5.00	.619792	.1487798	32
	6.00	.687500	.1974226	6
	Total		.614071	.1641016
2.00	1.00	.404605	.2409448	19
	2.00	.364583	.	1
	3.00	.416667	.	1
	4.00	.895833	.	1
	5.00	.423769	.1794567	22
	6.00	.341435	.2386064	9
	Total		.410574	.2175873
3.00	1.00	.410417	.2878889	10
	5.00	.404948	.3176870	8
	6.00	.182292	.2136052	2
	Total		.385417	.2892680
Total	1.00	.439525	.2505428	36
	2.00	.572917	.2421511	6
	3.00	.493056	.0910093	3
	4.00	.622917	.1708672	10
	5.00	.522513	.2102642	62
	6.00	.444853	.2832147	17
	Total		.499456	.2318224

Levene's Test of Equality of Error Variances ^a			
Dependent Variable: LPerceptualBiasPercentage			
F	df1	df2	Sig.
1.372	14	119	.177

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

a. Design: Intercept + AgeGroup + LDMTheme + AgeGroup * LDMTheme

Tests of Between-Subjects Effects						
Dependent Variable: LPerceptualBiasPercentage						
Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	1.919 ^a	14	.137	3.119	.000	.268
Intercept	7.929	1	7.929	180.451	.000	.603
AgeGroup	.448	2	.224	5.098	.008	.079
LDMTheme	.246	5	.049	1.121	.353	.045
AgeGroup * LDMTheme	.392	7	.056	1.275	.268	.070
Error	5.229	119	.044			
Total	40.575	134				
Corrected Total	7.148	133				

a. R Squared = .268 (Adjusted R Squared = .182)

Chapter 5

Relative risk of younger adults compared to older adults crashing on the right

Age * Position Crosstabulation					
			Position		Total
			left	right	
Age	under 20	Count	27	14	41
		% within Age	65.9%	34.1%	100.0%
		% within Position	77.1%	73.7%	75.9%
		% of Total	50.0%	25.9%	75.9%
	over 80	Count	8	5	13
		% within Age	61.5%	38.5%	100.0%
		% within Position	22.9%	26.3%	24.1%
		% of Total	14.8%	9.3%	24.1%
Total		Count	35	19	54
		% within Age	64.8%	35.2%	100.0%
		% within Position	100.0%	100.0%	100.0%
		% of Total	64.8%	35.2%	100.0%

Chi-Square Tests					
	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	.081 ^a	1	.776	1.000	.512
Continuity Correction ^b	.000	1	1.000		
Likelihood Ratio	.080	1	.777		
Fisher's Exact Test					
Linear-by-Linear Association	.079	1	.779		
N of Valid Cases	54				

a. 1 cells (25.0%) have expected count less than 5. The minimum expected count is 4.57.
b. Computed only for a 2x2 table

Risk Estimate			
	Value	95% Confidence Interval	
		Lower	Upper
Odds Ratio for Age (under 20 / over 80)	1.205	.332	4.381
For cohort Position = left	1.070	.660	1.735
For cohort Position = right	.888	.396	1.992
N of Valid Cases	54		