Anticipatory planning in object manipulation: A cross-sectional investigation of children, young adults and older adults

by

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Author's Declaration

This thesis consists of material all of which I authored or co-authored: see Statement of Contributions included in this thesis. This is a true copy of the thesis, including any required revisions, as accepted by my examiners. I understand that this thesis may be made electronically available to the public.

- Sara M. Scharoun

Statement of Contributions

Two experiments presented in this dissertation have been adapted from journal articles that are published. I, Sara M. Scharoun, was the main contributor and lead author of this work, and three experiments in preparation for submission. I contributed to the majority of research design, data collection, data processing, data analysis, interpretation, and writing of the thesis.

Dr. Eric A. Roy, Dr. Pamela J. Bryden and Dr. David A. Gonzalez were co-authors with myself, Sara Scharoun, of two published manuscripts entitled, "The influence of action execution on end-state comfort and underlying movement kinematics: An examination of right and left handed adults" and "How the movement context affects behavioural evidence of planning and movement kinematics in aging: End-state comfort in older adults." These manuscripts form the basis of Chapters 2 and 3 in the thesis, respectively. Contributions included support with research design and editorial assistance with the manuscript. In addition, Dr. David A. Gonzalez contributed to data processing.

Abstract

Over a series of five studies, this work aimed to investigate anticipatory planning in object manipulation across the human lifespan. Main objectives were to: (a) understand the influence of the movement context; (b) delineate the role of handedness; (c) characterize the influence of familiarity with an object; (d) investigate independent and cooperative movements; and (e) outline similarities and differences across the lifespan. Chapter 2 established a foundation for the thesis with right and left handed young adults. Findings supported the hypothesis that manual asymmetries do not influence anticipatory planning. Furthermore, despite end-state comfort reaching ceiling, kinematic data provided evidence for an increase in cognitive demand in pantomime compared to actual object use. Chapter 2 therefore served as proof of concept for manipulating contextual information to alter the cognitive demands of the task. Chapter 3 compared data to a group of left and right handed older adults. Similar to Chapter 2, manual asymmetries were not influential. Evidence of end-state comfort did not differ in young and older adults; however, after separating older adults into two groups, those who did not display the effect spent a longer time in the final approach to the target in pure pantomime. This was attributed to the increased reliance on feedback-dependent corrective mechanisms with increasing age. To quantify similarities and differences among children, young and older adults, Chapters 4, 5 and 6 assessed anticipatory planning across the lifespan. The main findings of the thesis are highlighted in the results of Chapter 6. Object use involves the direct perception of affordances, and indirect selection of motor programs based on action intentions. The ability to interact with objects in the environment is thus rooted in learned knowledge. With cognitive development, improvements in multisensory

integration, and familiarity with objects, children become more proficient in anticipatory planning. As such, behaviours emulate a gradual transition from a reliance on habitual actions executed successfully in the past, to the recognition of affordances and incorporation of intentions into actions. Likewise, with decline in cognitive and motor processes, the behaviour of older adults (ages 71+) reflects a gradual transition back to habitual behaviours. Actions thus reflect stimulus-driven responses, as opposed to those which consider affordances and intentions.

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Data from Chapter 2 were presented at the 2013 Société Canadienne D’Apprentissage Psychomoteur et de Psychologie du Sport (Canadian Society for Psychomotor Learning and Sport Psychology – SCAPPS) conference in Kelowna, British Columbia. Observational data

from Chapter 3 were presented at the 2014 SCAPPS conference in London, Ontario and kinematic data were presented at the 25th Annual Rotman Research Institute Conference in Toronto, Ontario. Pilot data from Chapter 4 were presented at the 2013 Motor Development Research Consortium in Philadelphia, Pennsylvania. The final manuscript was presented at the 2015 North American Society for the Psychology of Sport and Physical Activity (NASPSPA) conference in Portland, Oregon. It was acknowledged with the Outstanding Student Paper Award in Developmental Perspectives: Motor Control / Coordination and Rehabilitation. Data from Chapter 5 were presented at the 2015 SCAPPS conference in Edmonton, Alberta. A portion of Chapter 6 (beginning-state comfort data) was presented at the 2015 NASPSPA conference in Montreal, Quebec. In addition, this paper was acknowledged with the Franklin Henry Young Scientist Award for the upcoming 2016 SCAPPS conference in Waterloo, Ontario.

Dedication

To my parents.

Thank you for encouraging me to pursue a PhD and supporting me no matter what life throws my way.

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List of Abbreviations

ANOVA	Analysis of variance
CD	Compact disc
cm	Centimetres
IRED	Infrared-light emitting diode
L	Left
LH	Left-hand
M	Mean
N	Number
ms	Milliseconds
OA	Older adults
R	Right
RH	Right-hand
s	Seconds
SD	Standard deviation
WHQ	Waterloo Handedness Questionnaire
YA	Young adults
YO	Years old

Description of Dependent Measures

Measures of handedness

Waterloo Handedness Questionnaire – Total Score	Sum of responses out of a total +/- 40. Each question permits five potential responses: "left always" (-2), "left usually" (-1), "uses both hands equally often" (0), "right usually" (+1), and "right always" (+2).
Grooved Pegboard – Laterality Quotient	Difference between left- and right-hand time (s) to completion ((left-hand – right-hand) / (left-hand + right-hand)) multiplied by 100.

Kinematic Measures

Reaction time	Time (s) from the onset of the movement until movement initiation (resultant velocity reaching an absolute value of 10mm/s for 20ms)
Movement time in the reach/approach phase	Duration between reaction time and the end of the initial reach (resultant velocity reaching an absolute value below 100mm/s for 20ms).
Resultant peak velocity	Resultant change in displacement in the reach/approach phase over time. *Leftward movements multiplied by negative 1 to help dissociate the different movement components
Grasp/transport time	Duration between the end of reach/approach and the end of the movement towards the object (resultant velocity reaching an

	absolute value below 100mm/s for 20ms in 15cm x 15cm box where action was to be performed). *Grasp time was not separated from transport as it was difficult to distinguish and because of technical problems of only having one IRED per hand and Optotrak camera (i.e., missing data).
Use time	Duration between the end of the grasp/transport phase until the participant made a horizontal movement outside the box (resultant velocity reaching an absolute value below 100mm/s for 20ms).
Observational measures	
End-state comfort	An initially uncomfortable hand posture that facilitates a comfortable end-state posture in object manipulation
Beginning-state comfort	A comfortable initial hand posture in object manipulation
Functional grasp	A hand posture suitable for object use

Chapter 1 – Introduction

1.1. Thesis Overview

Chapter 1 outlines the general thesis objectives followed by a comprehensive literature review. Chapters 2, 3 and 4 describe original research examining how manipulating the movement context influences the end-state comfort effect in young adults (Chapter 2), older adults (Chapter 3) and from a lifespan perspective (Chapter 4). Chapter 5 extends the previous, providing original research examining end-state comfort with a familiar and less familiar object. Chapter 6 assesses anticipatory planning from a broader perspective, investigating independent and joint action as a function of the concept of orders of planning in object manipulation. Finally, Chapter 7 is a general discussion of main findings of the thesis followed by limitations and future directions.

1.2. Problem Statement and General Thesis Objectives

Reaching for an object, such as a coffee mug or juice glass may seem simple, almost second nature. However, goal-directed movements involving the upper limbs are complex (e.g., Elliott, Hansen, Grierson, Lyons, Bennett, & Hayes, 2010). Adults reach for objects in an anticipatory manner, planning the intended action in advance to minimize energy expenditure (e.g., Rosenbaum et al., 2009). This is exemplified behaviourally in the end-state comfort effect (Rosenbaum, Marchak, Barnes, Vaughan, & Jorgensen, 1990; see Rosenbaum, Chapman, Weigelt, Weiss & van der Well, 2012 for a review). Consider the example of grasping an overturned glass to pour juice. Young adults are likely to assume an uncomfortable posture at the start of their movement to allow for a comfortable end-state posture in which the object is reoriented for use. Recent literature proposes young adults display more end-state comfort with the right hand regardless of hand preference (e.g., Janssen, Meulenbroek & Steenbergen, 2011); however, the effect has also been shown regardless of the hand used to complete the task (e.g., Seegelke, Hughes, & Schack, 2014). One aim of the thesis was to continue assessing how manual asymmetries influence motor planning.

Improvements in motor performance have been argued to parallel patterns which emerge in typical motor development (e.g., Elliott et al., 2010), where age-related changes reflect improvements in multisensory integration (e.g., King, Oliveira, Contreras-Vidal, & Clark, 2012). As such, evidence of end-state comfort increases with age, and adult-like patterns have been documented between the ages of 9 and 10 (e.g., Wunsch, Henning, Aschersleben, & Weigelt, 2013). Hand preference has also been shown to influence the development of motor planning skills (e.g., Manoel & Moreira, 2005); however, the literature is generally inconsistent with regards to developmental trends (Wunsch et al., 2013). As such, this thesis aimed to further investigate anticipatory planning in children.

Vast sensoriomotor changes are also evident in aging (e.g., Siedler et al., 2010). Slowness and increased variability in movement (Contreras-Vidal, Teulings, & Stelmach, 1998; Darling, Cooke & Brown, 1989; Diggles-Buckles, 1993) and difficulties with coordination are observed, as older adults are reliant on feedback to continuously and consciously modify their movements to meet action requirements (e.g., Seidler et al., 2010). To our knowledge, prior to embarking on this research the end-state comfort effect had yet to be assessed in older adults; therefore, the thesis aimed to investigate how evidence of the effect compares to reports of children and young adults.

Summarizing, the goal of this doctoral research was to further investigate factors influencing anticipatory planning in object manipulation using a cross-sectional analysis of the human lifespan. The following will provide a comprehensive literature review of: (1) motor planning and control processes; (2) manual asymmetries evident in planning and control; and (3) an overview of the end-state comfort effect. It is intended to introduce concepts, provide evidence supporting the need for investigation and establish a basis for thesis.

1.3. Literature review

1.3.1. Motor planning and control processes

A single goal-directed action generally proceeds with two-components: an initial adjustment phase; and a current control phase (Woodworth, 1899; Elliott et al., 2010; Elliott, Helson, & Chua, 2001). However, the overall movement can be separated into a series of processing events (Elliott et al., 2001, 2010). Prior to the signal to move (i.e., go signal) exists a planning period, including processes specific to the goal of the actor and their environment (Elliott et al., 2010; Glover, 2004). Reaction time corresponds to this movement event (e.g., Elliott et al., 2010) which is characterized by the creation of a "blueprint," or forward model of expected efferent motor commands and afferent consequences. These are stored in the central nervous system for later processing (e.g., Evarts, 1973; Glover, 2004). Rosenbaum, Meulenbroek, Vaughan, and Jansen (2001) describe motor planning such that the actor implicitly orders internal representations in a constraint hierarchy to plan a goal posture which offers the most cost-efficient movement. As such, the initial, planned component of the movement enables the hand to move within proximity of the target object. This phase is under open-loop control and includes a monitoring system, which compares outgoing efferent commands with the existent internal model of expected consequences. If a discrepancy exists, the central nervous system possesses an estimate to adjust the movement. According to Rosenbaum et al. (e.g., Rosenbaum, Meulenbroek, Vaughan et al., 2001; Rosenbaum, Meulenbroek, & Vaughan, 2001; Rosenbaum et al., 2009), goal postures are planned prior to execution; however, if movements cost the motor system (i.e., are not efficient), end postures may be re-assessed. Because adjustments do not require sensory feedback, they occur rapidly (e.g., Elliott et al., 2010; Glover, 2004).

Planning and control phases overlap temporally (e.g., Glover, 2004), where the duration of movement ultimately determines the influence of control. When adequate time does exist, a corrective period decreases spatial discrepancy between hand and target (Elliott et al., 2010). This phase (Cooke, Brown & Cunningham, 1989) is under feedback-based control, in which afferent information about the locations of the hand and target in space enable corrective movements to bring the hand accurately to the target (Woodworth, 1899; Elliott, et al., 2001, 2010). A processing lag is evident before sensory feedback is available; however, feedback control is available both early and late in the movement, thus allowing for error correction before arrival at the target (Elliott et al., 2010). Upon arrival at the target, terminal feedback is processed, enabling the refinement of internal afferent and efferent representations for future motor acts (Elliott et al., 2010).

Optimal movement control reflects a combination of feed-forward and feedback mechanisms (Desmurget & Grafton, 2000; Elliott et al., 2010; Glover, 2004). When asked to perform a movement with speed and accuracy, the overall goal is to identify a compromise between movement velocity and endpoint variability. As such, with practice, the actor gradually adjusts, taking into consideration what is necessary to optimize speed and accuracy, while minimizing the overall energy costs associated with the movement (Elliott, Hansen, &

Grierson, 2009; Elliott et al., 2010). This enables the actor to refine their movement strategy and improve feed-forward processes involving internal models, to reflect the necessary afferent and efferent requirements of the task (Elliott et al., 2010).

1.3.1.1. Neural underpinnings. In addition to literature examining the multiple behavioural processes involved in motor planning and control, neural underpinnings have been extensively assessed. From the moment an object is recognized, until an action has been executed, extensive cortical processing is required. Through vision, light enters the eye and is focused on the fovea of the retina. From here, visual information travels by means of the geniculostriate pathway to the lateral geniculate nucleus of the thalamus, and proceeds to the primary visual cortex of the occipital lobe. From the primary visual cortex, two visual streams have been identified. The ventral stream to inferotemporal cortex, implicated in perception and encoding of object semantics (i.e., giving the object meaning), is described as the “what” pathway. Put simply, the role of the ventral stream is to identify the goal object; therefore, evidence supports a role in planning of action (e.g., Kandal, Schwartz, Jessell, Siegelbaum & Hudspeth, 2013; Milner & Goodale, 2008).

The dorsal stream projects to the partietal lobe. Sub-divided into two unique visual processing streams, the dorsal stream is responsible for using visual information for action, or “detailed programming and real-time control” (Milner & Goodale, 2008, p. 776). As such, dorsal stream function has been linked to programming actions and on-line control (Glover, 2004; Kandal et al., 2013; Milner & Goodale, 2008; Rossetti, Pisella, & Vighetto, 2003). The dorsal-dorsal stream projects visuospatial reach-related information to the superior parietal lobe, and is described as the “where” pathway. As such, middle and ventral intraparietal areas have been shown to activate in perception of peripersonal space (i.e., space around the body).

In comparison, the ventral-dorsal stream projects visuomotor information to the inferior partietal lobe, and is therefore described at the "how" pathway. The anterior intraparietal area has been associated with encoding object's affordances (Kandal et al., 2013.

From the anterior intraparietal area, affordance related information is translated to area F5 of the ventral premotor cortex. It is generally understood that the premotor cortex plays a role in movement selection (Glover, Wall, & Smith, 2012). Canonical neurons in this area discharge during goal-directed hand movements, and in presentation of manipulable objects (e.g., Rizzolatti, Fogassi, & Gallsese, 1997). Direct connections with the primary motor cortex, facilitate execution (i.e., reaching to grasp the object), where descending motor information is primarily sent through the corticospinal tract. Under contralateral controls, the left-hemisphere control right hand movements, and the right-hemisphere control left hand movements (Kandal et al., 2013).

1.3.1.2. The influence of movement context. In light of the aforementioned model of limb control and neural underpinnings, parameters have been shown to be affected by the movement context. The significance of this is demonstrated clinically in apraxia, a disorder of skilled movement that cannot be explained by underlying impairments in sensorimotor functions, verbal comprehension, and/or object recognition (Roy, Black, Stamenova, Herbert, & Gonzalez, 2014). Apraxia frequently arises from left hemisphere damage, including the anterior intraparietal area of the dorsal-dorsal stream, associated with encoding object's affordances (Roy et al., 2014). As such, literature in apraxia commonly describes tool use performance to improve when more contextual information is provided (Baumard, Osiurak, Lesourd & LeGall, 2014). It is argued that pantomime (i.e., performing an action associated with a tool without the use of the object) may serve to convey semantic information about an action, such that individuals are required to form and maintain a mental representation of the tool and action until the gesture is performed. In comparison, actual tool use reduces the cost on the working memory system, while also decreasing the degrees of freedom and likelihood of error (e,g., Baurnard et al., 2014; Roy & Hall, 1992). In other words, movements towards remembered objects and those in real time differ due to changes in the affordances offered for grasping (Goodale, Jakobson, & Keller, 1994). Spatial and temporal features of the movement thus differ (e.g., Hermsdörfer, Hentze, & Goldenberg, 2006). More specifically, pantomime is characterized by less time to peak velocity, more time after peak velocity and higher peak velocity compared to actual tool use, reflecting the altered cognitive demands of the task (Clark et al., 1994; Heath, Westwood, Roy & Young, 2002; Hermsdörfer et al., 2006; Hermsdörfer, Randerath, Goldenberg & Eidenmuller, 2011).

Building from comparisons of pantomime to actual use, it is important to consider that objects can be grasped and manipulated differently, based on the actor's intentions. According to Rosenbaum et al.'s (2012) concept of orders of planning for object manipulation, "if the same object is handled differently depending on a performer's mental state, then his or her mental state can be inferred from the way he or she handles the object" (p. 2). Likewise, Lindemann, Stenneken, van Schie and Bekkering (2006) observed differences in grasp posture based on the intended action. Nevertheless, the perception of affordances has been shown to highlight action capabilities automatically (Ellis & Tucker, 2000; Tucker & Ellis, 1998). Furthermore, neuroimaging studies have revealed activation in motor areas in response to manipulable objects (e.g., Creem-Regehr & Lee, 2005).

In consideration of both top-down and bottom-up processes, van Elk, van Schie, and Bekkering (2014a,b) proposed a unifying framework of action semantics that considers “automatic effects of object affordances as well as context- and intentionally driven effects” (p. 240). From this perspective, action semantics include multimodal object representations that are linked to modality-specific subsystems that include functional (i.e., what) and manipulation (i.e., how) knowledge, and representations of sensory consequences of object use. Hierarchically organized action intentions (which are determined by the action context) guide the selection of outcomes and identify the relevance of sensory consequences. Simultaneously, direct perception of affordances enables the action context to influence the activation and use of action semantics automatically. Throughout the action, progress is monitored, enabling the system to be constantly updated. As such, an important consideration of van Elk et al.’s (2014) framework is the idea that learned knowledge (i.e., knowing-how and knowing-that) is critical.

1.3.1.3. A developmental perspective. Improvements in control processes parallel patterns which emerge in typical motor development (Elliott et al., 2010). Observing prehensile skills in children, different strategies are available before the age of 7 (e.g., Barral & Debû, 2002), where different explanations of age-related improvements have been proposed. Some suggest improvements result from modifications to underlying control mechanisms: a shift from predominantly feed-forward control, to gradual inclusion of feedback-based control (Bard, Hay & Fleury, 1990). Others suggest fine adjustments to internal models, thus improving the relationship between bottom-up and top-down processes (Bo, Contreras-Vidal, Kagerer, & Clark, 2006; Contreras-Vidal, Bo, Boudreau, & Clark, 2005; Jansen-Osmann, Richter, Konczak, & Kalveram, 2002).

King et al. (2012) explain variable movement kinematics due to a reliance on delayed sensory feedback, which limits state estimation. Between the ages of 7 and 8, improvements in proprioceptive feedback are observed; therefore, by 10 to 12, children are able to accurately and reliably predict future states of the system, highlighting the shift to feed-forward control as delays in sensory processing are gradually overcome. Age related improvements can thus be explained by the development of proprioceptive skills and overall proficiency in state estimation (King et al., 2012).

1.3.1.4. Changes with aging. Aging is also associated with vast changes (e.g., Siedler et al., 2010). For example, reduced neuron size and spine density (Anderson & Rutledge, 1996; Masliah, Mallory, Hansen, DeTeresam, & Terry, 1993), and gradual loss of corticospinal (Eisen, Entezari-Taher, & Steward, 1996) and spinal cord (Doherty, Vandervoort, Taylor, & Brown, 1993) motor neurons have been reported. The efficacy of motor neuron recruitment also decreases with age (Erim, Beg, Burke, & deLuca, 1999), where modification in primary motor cortex (Kaiser, Schuff, Cashdollar, & Weiner, 2005) and disruptions of white matter integrity (Madden, Whiting, Huettel, White, MacFall, & Provenzale, 2004) have been shown to alter corto-cortical and corticospinal connectivity. Functional magnetic resonance imaging and positron emission tomography studies display an increase and more bilateral activation in older adults (Cabeza, Anderson, Lacontore, & McIntosh, 2002; Ward, 2006), which manifest behaviourally in slowness and increased variability in movement (Contreras-Vidal et al., 1998; Darling et al., 1989; Diggles-Buckles, 1993) and difficulties with coordination (e.g., Seidler et al., 2002). Motor difficulties negatively impact quality of life and the ability of older adults to perform activities of daily living (e.g., Seidler et al., 2010).

Older adults' performance has been described using hardware and software hypotheses. Proponents of the hardware explanation reference anatomical differences; therefore implicating increased neural noise in the central nervous system (Salthouse, 1982) or peripheral changes to the neuromuscular system (e.g., muscle atrophy; Faulkner, Larkin, Claflin, & Brooks, 2007;

Meyerson, Hale, Wagstaff, Poon, & Smith, 1990) beyond an individual's control (Seidler et al., 2010). In comparison, software accounts describe changes in planning and control which aim to maximize efficiency (i.e., Roy, Weir, & Leavitt, 1996). Roy et al. (1996) contend that both parameters are involved in performance differences. In particular, hardware changes are reflected in sensorimotor constraints which highlight afferent and efferent demands. Furthermore, alterations in software may be most involved in action selection strategies, as movement options may constrain performance. The availability of various software strategies is likely dependent on the integrity of the hardware system (Heath et al., 1999; Roy et al., 1996).

Kinematic analyses of reach-to-grasp movements have described longer movement times, lower amplitudes of peak acceleration and deceleration, and longer deceleration times in older adults (Bennett & Castiello, 1994; Roy et al., 1996). Hardware theorists argue these changes result from neuroanatomical or peripheral changes, such as muscle atrophy (Kallman, Plato & Tobin, 1990), which decrease force production. In comparison, software proponents describe a more cautious movement that is modified to meet the task requirements (Heath et al., 1999). It has been proposed that the ability to use feed-forward control declines with age; therefore, older adults become more dependent on feedback control (Rabbitt, 1982). It has also been suggested that the 15 to 30% increase in movement time (Diggles-Buckles, 1993) results from lengthening of the deceleration phase, to allow for more feedback-dependent corrective mechanisms (Bennett & Castiello, 1994; Roy et al., 1996). In other words, older adults are reliant on feedback to continuously and consciously modify their movements to meet action requirements. This shift in control has been attributed to the increased cost of error-full movement (e.g., Heath et al., 1999).

More recent work has described age-related changes using a supply and demand framework (Siedler et al., 2010). From this perspective, older adults become reliant on cognitive processes (e.g., attention, working memory, visuospatial processing) with increasing age, as a result of structural and functional degradation in motor regions of the brain. Simultaneous decline in the supply of cognitive resources limits the ability to compensate for sensorimotor declines; therefore, older adults appear behaviourally different than young adults.

Notwithstanding the previous, age-related performance differences are not always observed (Carnahan, Vandervoort, & Swanson, 1998; Cicerale, Ambron, Lingnau, & Rumiati, 2014; Varadhan, Zhang, Zatsiorsky, & Latash, 2012). As such, it has been argued that unfamiliar laboratory tasks inaccurately convey changes with age (Bock & Steinberg, 2012; Cicerale et al., 2014; Varadhan et al., 2012).

1.3.2. Manual asymmetries in planning and control processes

Where developmental factors have proven influential, manual asymmetries also play a significant role in planning and control. It is commonly accepted that 90% of people are right handed (Coren & Porac, 1977) and that hand preference is defined as the hand one prefers for unimanual tasks (Annett, 1970a). Furthermore, it is generally understood that handedness derives from an advantage of the contralateral hemisphere (Bishop, 1989). Handedness is described according to direction (i.e., left or right handed) and degree (i.e., strength of hand preference; Steenhuis & Bryden, 1989). Left handers generally display less functional asymmetry than right handers over the course of development (e.g., Springer & Deutsch, 1998; Yahagi & Kasai, 1999); therefore, the degree to which they use their preferred hand is significantly less.

Handedness is subsequently quantified in terms of preference (i.e., the preferred hand for completing a task) and performance (i.e., the differences between left- and right-hands; McManus & Bryden, 1992). Performance abilities typically increase with the preferred hand (Annett, 1970b); especially for right handers (e.g., Lavrysen, Elliott, Buekers, Feys, & Helson, 2007; Roy, Kalbfleisch, & Elliott, 1994). More specifically, higher peak velocities (Annett, Annett, Hudson, & Turner, 1979; Boulinguez, Nougier, & Velay, 2001; Heath & Roy, 2000), less error in the initial acceleration phase (Roy & Elliott,1986), a shorter corrective period (Lavrysen et al., 2007; Roy et al., 1994), better accuracy and an overall shorter movement time (Annett et al., 1979; Elliott, Roy, Goodman, Carson, Chua, & Muraj, 1993; Roy & Elliott, 1989) have been noted. In comparison, the left hand (i.e., non-preferred hand) displays reaction time advantages and shorter time to peak velocity (e.g., Roy et al., 1994). Lavrysen et al. (2012) investigated if left handers also display advantages. Similar to right handers, peak velocity was reached earlier when moving with the left hand (i.e., preferred hand;Lavrysen et al., 2012).

According to the dynamic dominance hypothesis (e.g., Sainburg, 2002, 2005), each hand is specialized for specific aspects of control. The preferred hand is superior for precise control of limb dynamics (i.e., mobilizing). In comparison, the non-preferred hand is more adept at positional control (i.e., stabilizing), evident during the final state of reaching (e.g., Wang & Sainburg, 2007). The dynamic dominance model suggests the two hemisphere/limb systems are differentially specialized for complementary aspects of movement (Wang & Sainburg, 2007), where left handers and right handers display mirrored patterns of interlimb transfer (Wang & Sainburg, 2006).

1.3.2.1. A developmental perspective. Human handedness emerges very early in an infant's life (e.g., Butterworth & Hopkins, 1993), however, the age at which adult-like handedness is attained is debated. It has been suggested that direction of hand preference reaches maturity by age 3, where the degree continues to increase until the age of 9 (Archer, Campbell and Segalowitz, 1988; Longoni & Orsini, 1988; McManus et al., 1988). Scharoun and Bryden (2014a) argue there are three distinct periods of refinement: (1) young children (3- to 5-year-olds) display weak inconsistent tendencies; (2) older children (7- to 10-year-olds) are reliant on the preferred hand; and (3) hand preference is adult-like when the reliance on the preferred hand drops (approximately 10 to 12 years).

Past research has successfully used preference and performance measures to assess handedness in children. Questionnaires have revealed right handers consistently report a right hand preference beginning in early childhood. Left handers display weak preference tendencies that increase with age, although strength of hand preference never reaches levels comparable to right handers (Scharoun & Bryden, 2014a). Handedness inventories thus support the idea that direction of preference is established early in life (e.g., Archer et al., 1988; Longoni & Orsini, 1988; McManus et al., 1988), where degree gradually improves with age (Scharoun & Bryden, 2014a).

Although questionnaires are the most common means of assessing handedness (McManus & Bryden, 1992), given the large verbal requirement and the inability to distinguish how familiar children may be with particular tasks, researchers have also used performance measures. Such measures identify which hand displays superior performance, and subsequently quantify differences between the two hands (Peters & Durding, 1979; Annett, 1985). Performance has been shown to improve with age, such that 3- to 6-year-olds display slow, variable movements; however, performance is comparable to adults between 10 to 12 years of age. Performance differences remain inconclusive, as some have identified notable differences in younger children that decrease with age (e.g., Bryden & Roy, 2005; Bryden, Roy, & Spence, 2007), whereas others have noted similar patterns over the course of development (e.g., Kilshaw & Annett, 1982; Annett, 2002; Dellatolas et al., 2003). Such differences may reflect the tasks used, where learned tasks requiring precision (e.g., pegboard) result in significant effects of age, unlike less complex tasks (e.g., finger tapping). When comparing handedness groups, right handers typically display a right hand advantage, in contrast to left handers, who display similar performance with both hands (e.g., Carlier, Dumont, Beau, & Michel, 1993). Left handers' similarities between the hands may explain why it takes these children longer to establish a hand preference (Scharoun & Bryden, 2014a). Overall, despite successful use of preference and performance measures to quantify handedness in children, Scharoun and Bryden (2014a) argue that handedness as assessed in reaching tasks provides some of the richest data. It is thus necessary to consider these variables in future investigations surrounding the development of hand preference in children.

1.3.2.2. Changes with aging. The hand-arm system is greatly altered with age. A decrease in muscle mass and strength (Janssen, Heymsfield, Wang & Ross, 2000) and a decline of hand movement coordination highlight some of the changes that may affect activities of daily living (e.g., Kinoshita & Francis, 1996). These differences result directly from changes in the peripheral and central nervous systems (e.g., Seidler et al., 2010). For example, a decrease in fine motor skills has been linked to degraded sensory perception (e.g., Warabi, Noda, & Kato, 1986). Nevertheless, the relationship between general age-related declines in hand performance and corresponding hand preference remains inconclusive.

The current literature suggests conflicting ideas about how handedness progresses with age, where various hypotheses have been proposed (e.g., Porac, 1993). One view indicates an increase in preferred hand use with age (Weller & Latimer-Sayer, 1985). Weller and Latimer-Sayer (1985) proposed right handedness increases with age. In other words, aging is associated with an over reliance on the preferred, right hand, similar to highly lateralized patterns observed in adolescence (i.e., 7- to 10-year-olds; e.g., Scharoun & Bryden, 2014a).

A decline in preferred hand use with age has also been proposed (Kalisch, Wilimzig, Kleibel, Tegenthoff, & Dinse, 2006). Kalisch et al. (2006) had right handed 20- to 90-year-olds complete a battery of preference and performance tests, where accelerometers were used to quantify hand use in activities of daily living. Analysis revealed a shift from a general right hand advantage in younger adults to equal performance between the two hands in older adults. Interestingly, despite the reduction in hand preference, older adults professed to be right handed, which indicates that older adults were not aware of the shift in hand use with age (Kalisch et al., 2006).

A recent investigation indicated that hand preference remains consistent throughout adulthood (Gooderham & Bryden, 2013). Gooderham and Bryden (2013) assessed handedness across the lifespan in a cross-sectional analysis of 2- to 4- and 10- to 14-year-old children, 18- to 25-year-old young adults, and older adults over the age of 65. Participants completed the Waterloo Handedness Questionnaire (Bryden, 1977), Tapley-Bryden Dot Marking task (Tapley & Bryden, 1985) and a novel Task Complexity Gradient. Weak hand preference was seen in young children, and strong hand preference in older children, paralleling previous findings (e.g., Bryden & Roy, 2005). Interestingly, no performance differences emerged between young and older adults in any of the tasks (Gooderham & Bryden, 2013).

Overall, the literature reports an increase (Weller & Latimer-Sayer, 1985), decrease (Kalisch et al., 2006) and no change in hand preference (Gooderham & Bryden, 2013) with age. It is thus clear that human hand preference requires further investigation. The previously outlined studies primarily focused on right handed older adults. Although Gooderham and Bryden (2013) did include a small sample of left handers, no direct comparison was completed between handedness groups; therefore, future comparisons are needed to paint a clear picture of handedness across the lifespan.

1.3.3. Anticipatory planning and the end-state comfort effect

The current research used the end-state comfort effect (Rosenbaum et al., 1990) as a behavioural assessment of anticipatory planning. The original task used to quantify the effect consisted of a wooden dowel painted half black and half white, resting horizontally on a cradle. Participants were asked to lift the bar from the cradle and place either end on a target to the left or right. Adults preferred to end their movement with a neutral posture (i.e., thumb-up). Therefore, the initial position of the thumb was associated with the rotation of the bar, where selecting an uncomfortable initial posture (overhand grip; thumb down) enabled the hand to be returned to a comfortable posture (underhand grip; thumb up) upon completion of the movement (Rosenbaum et al., 1990).

Subsequent studies questioned if other factors could account for observed movement patterns. Expanding upon the original task (i.e., completing the task in reverse) Rosenbaum et al. (1990) observed that participants avoided thumb-down postures whenever thumb-up postures could be maintained at the end of object transport, thus revealing that ending comfortably was indeed a driving factor in grasp selection. Participants were also asked to rate the perceived comfort of the grip posture according to a 5-point scale (1: completely comfortable to 5: completely uncomfortable), where support for end-state comfort prevailed over maximizing initial or total comfort (Rosenbaum et al., 1990).

Why do adults demonstrate end-state comfort and what is the functional advantage? According to the elastic-energy hypothesis, individuals assume extreme positions with their arms to enable muscle and tendon stretch in preparation for movement. To test whether the elastic-energy hypothesis could explain end-state comfort, Rosenbaum and Jorgensen (1992) placed the cradle on a numbered target located in a bookcase with 14 shelves. Participants were instructed to pick up the bar with their right hand and move the designated end (black or white) to a numbered target (i.e., dowel-to-shelf task). The elastic-energy hypothesis was refuted, such that end-state comfortable postures were displayed for all targets, regardless of height (Rosenbaum & Jorgensen, 1992).

Continuing to build on this body of work, Short and Cauraugh (1999) added wide targets to the existing narrow targets to assess whether the precision demands of the task could explain the end-state comfort effect (i.e., precision hypothesis). The likelihood of participants assuming initially awkward grasps was greater for narrow targets; therefore precision requirements accounted for grasp selection. Support for the precision hypothesis has since been provided from modifications to the bar transport task (e.g., Hughes, Seegelke, & Schack, 2012), and a handle rotation task (Rosenbaum, van Heugten, & Caldwell, 1996; Rosenbaum, Vaughan, Jorgensen, Barnes, & Stewart, 1993). In this task, participants grasp a handle and rotate a tab to a designated target. Similar to the bar transport task, participants assumed uncomfortable postures at the beginning of the movement to avoid awkward end postures, where Rosenbaum et al. (1993) suggested participants act to maximize control while locating the target.

End-state comfort has also been assessed in more natural settings. Fischman (1997) investigated an overturned glass task involving two objects (a drinking glass and a measuring cup filled with water), where participants poured water in “glass held” (i.e., pickup overturned glass and measuring cup and pour), and “glass down” (i.e., pickup overturned glass, set it down, pick up measuring cup and pour) conditions. End-state comfort was evident when participants assumed an uncomfortable thumb-down grasp to start the movement, allowing for a comfortable thumb-up grasp at the end of the movement. Sensitivity to end-state comfort was seen in 48 of 53 participants in the “glass held”, and 50 of 53 participants in the “glass down” condition. When the task allowed participants to set down the glass, 30 of 50 used the same hand to pick up the glass and pour water from the pitcher. When required to hold the glass, 39 of 50 used the same hand. The majority of adults were thus sensitive to end-state comfort and also displayed a preference for performing with one hand (Fischman, 1997).

If a preference for one hand is evident, it is logical to consider that differences between the two hands may exist. Janssen, Beuting, Meulenbroek and Steenbergen (2009) observed that, for right handed participants, the end-state comfort effect was present more often for the right hand. To assess end-state comfort, Janssen et al. (2009) created a *CD-placement task*, consisting of square CD boxes affording CD placement horizontally or vertically. Movements were planned according to end-state comfort, albeit in only 82.0% (*SD* = 20.2%) of right hand trials and 49.8% (*SD* = 9.8%) of left hand trials. Considering that end-state comfort was more often present for the right hand, it was suggested that motor planning may be under left hemisphere control. To test this hypothesis, the study was replicated with left handers, who were also more sensitive to ending comfortably with their right hand (Janssen et al., 2011)

In comparison to Janssen et al. (2011), both Herbort and Butz (2011) and Coelho, Studenka and Rosenbaum (2013) reported that end-state comfort overrides hand preference. Seegelke et al. (2014) also stated that manual asymmetries do not influence motor planning in their short review. Herbort and Butz (2011) had right handed participants complete the overturned glass task with both hands. Coelho et al. (2013) specified the hand to use or the grasp to use in the bar transport task. In both cases grasps that afforded end-state comfort were maintained (Coelho et al., 2013; Herbort & Butz, 2011). In a follow-up experiment, Coelho et al. (2013) asked participants to rate the comfort of each grasp, where hand-grasp combinations which afforded end-state comfort were identified as the most comfortable. It is likely that varying results can be attributed to differences in the tasks. As highlighted by Herbort and Butz (2011), an everyday task such as the overturned glass may involve little online planning (e.g., McCarty, Clifton, & Collard, 1999). Children begin to drink from cups from 8- to 20-months, where lids are typically removed by the second birthday (Carruth & Skinner, 2002). This task can therefore be considered over learned, to the point of being a habitual behaviour (Herbort & Butz, 2011). As such, it is possible that Janssen et al.'s (2009, 2011) task involved uncommon grasps which involved more extensive motor planning.

Summarizing then, observations of end-state comfort are useful, as they can be used to investigate, observationally, how movements are planned prior to initiation (Rosenbaum et al., 1993). Adults are observed to plan their movements in advance to assure a comfortable end-state, where investigations speak to inconsistent reports of hand preference in relation to motor planning. The end-state comfort effect has also been applied to a joint action paradigm, in order to better understand how one person anticipates the motor intentions of another (e.g. Gonzalez, Studenka, Glazebrook & Lyons, 2011; Ray & Welsh, 2011). Gonzalez et al. (2011)

investigated whether an individual will incur the cost of a movement to maximize the benefit—or beginning-state comfort—for another person. Participants were asked to use or place a tool (toy hammer, a calculator, and a stick painted half black and half white) and, directly, or indirectly pass the tool to a confederate, who would use the tool or leave it in place. Participants facilitated beginning-state comfort for the confederate; however, they did not sacrifice their own end-state comfort to do so (Gonzalez et al., 2011). Similar results were observed by Ray and Walsh (2011), which exemplify adults' ability to plan according to their own end-state comfort, while also considering the beginning state comfort of another in joint coordination tasks.

1.3.3.1 A developmental perspective. Since Rosenbaum's early studies, the end-state comfort effect has continued to be used to quantify anticipatory motor planning skills (see Rosenbaum et al., 2012 for a review), and similar to the adult literature, various tasks have been implemented with children (see Wunsch et al., 2013 for a review). Studies have used Rosenbaum et al.'s (1990) original bar-transport task. Hughes (1996) noted 14.3% of 3-year-old and 71.42% of 4-year-olds displayed end-state comfortable grasps in the underhand grasp condition, supporting the idea that end-state comfort is not an innate characteristic, but a motor skill that improves with age. Similarly, albeit in different proportions, Weigelt and Schack (2010) observed 18% of 3-year-olds, 47% of 4- year-olds and 70% of 5-year-olds displayed end-state comfort. Smyth and Mason (1997) completed the task with 4- to 8-year-old children, revealing a general trend for improvement with age; however, no statistically significant differences between the age groups emerged. Investigating an older group of children, Stöckel, Hughes, & Schack, (2011) observed 50% of 7-year-olds, 67% of 8-year-olds and 92% of 9-year-olds displayed end-state comfort. This study was the first to observe adult-like patterns of end-state comfort in 9-year-olds, further indicating that cognitive representations of grasp posture (i.e., uncomfortable vs. comfortable) unfold throughout development, and are associated with the acquisition of motor planning skills (Stöckel et al., 2011). Overall, these studies highlight a pattern of improvement, which are likely linked to the development of general cognitive control processes that appear between the ages of 5 and 6 (Weigelt & Schack, 2010). Nevertheless, as noted by Wunsch et al. (2013) the inability to consistently replicate the end-state comfort effect in children of the same ages complicates our understanding of end-state comfort in typical development, which appears adult-like at age 9 (Stöckel et al., 2011).

Modifications to the original paradigm add to the confusion. Manoel and Moreira (2005) investigated how right handed 2.5- to 6-year-old children inserted the distal end of a bar into a box of the same shape from a horizontal resting position to a vertical end position. Both low precision (distal ends of bar were cylindrical) and high precision (distal ends of bar were semi-cylindrical) conditions were implemented. All children displayed a right overhand grip in both low and high precision conditions. Consequently, it was suggested that hand preference constrains motor planning in young children, in comparison to adults, who typically plan a movement in order to end in a comfortable posture. Therefore, it is likely that children between the ages of 2.5- and 6-years did not consider end-state comfort in this context (Manoel & Moreira, 2005).

Thibaut and Toussaint (2010) also assessed the influence of precision in 4-, 6-, 8-, 10-year-olds and adults, adding pointing-with-pencil and tracing-with-pencil tasks to the mix. Results offered further support to previous suggestions (e.g. Manoel & Moreira, 2005; Weigelt & Schack, 2010) that the effect emerges with age. Six-year-olds moved faster and with improved accuracy than 8-year-olds in the less constraining task (bar-transport); however, the opposite was true for more constraining task (tracing-with-pencil). As such, it was suggested that 8-year-old children display motor re-organization patterns, which enable them to incorporate external cues in order to successfully plan a movement. This lays the foundation for adult-like patterns of end-state comfort observed in 80 to 90% of 10-year-olds in this context (Thibaut & Toussaint, 2010). Therefore, evidence of end-state comfort develops in conjunction with sensory-motor development.

In addition to bar-transport tasks, end-state comfort has been assessed in children using the handle rotation task (Rosenbaum, et al., 1993, 1996). In an unpublished study, Rosenbaum, Jorgensen and Koplan (1993, as cited by Smyth and Mason, 1997, p. 1023) documented that, unlike 3- to 4-year-olds who assumed an initially comfortable posture, some 5- to 6-year-olds displayed end-state comfort, although significantly less than adult participants. Smyth and Mason (1997) implemented the same task with 4- to 8-year-olds, where 7- to 8-year-olds displayed a higher proportion of end-state comfort than 5- to 6-year-olds. van Swieten et al. (2010) investigated 5- to 14-year-olds and adults. The majority of 9- to 14-year-olds were sensitive to end-state comfort; however, only half of 5- to 8-year-olds displayed the motor planning phenomenon. These results are in line with results of bar-transport task investigations (e.g., Stöckel et al., 2011; Thibaut & Toussaint, 2010), which have noted a gradual increase in end-state comfort with age, where adult-like patterns emerge between the ages of 9 and 10.

Similar to the previous studies, Adalbjornsson, Fischman, & Rudisil (2008) failed to observe planning abilities in this context in young children; however, the authors used the overturned glass task (Fischman, 1997). Preschoolers (2- to 3-year-olds) and kindergarteners (5- to 6-year-olds) displayed five unique patterns for grip selection, where only 11 of 40 children displayed end-state comfort. Scharoun and Bryden (2014b) included an upright glass in addition to the overturned glass, and also added a joint-action motor coordination paradigm (similar to Gonzalez et al., 2011). Three- to 12-year-olds and adults were asked to pick-up a cup and (a) pour a glass of water from a pitcher or (b) pass it to the researcher to pour a glass of water. Both self- and other-directed movements were investigated, as research has shown children are better able to relate objects to their own body (Lockman & Ashmead, 1983; Rochat, 1998). Furthermore, using a joint-action paradigm enabled investigation of beginning-state comfort (Gonzalez et al., 2011).

Paralleling previous observations (Stöckel et al., 2011; van Swieten et al., 2010) adult-like patterns of end-state comfort were evident in 9- to 10-year-olds. Interestingly, evidence of beginning state comfort emerged earlier, such that 7-year-olds considered the actions of a confederate when planning a movement. However, children did not coordinate a posture which ensured a comfortable end state until the age of 9. Similar to Manoel and Moreira (2005), hand preference influenced sensitivity to end-state comfort. For example, left handed 7- to 8-year-olds displayed significantly less end-state comfort than their right handed counterparts (Scharoun & Bryden, 2014b). Of additional interest, greater planning for end-state comfort was observed in young children in self-directed actions (i.e., actions directed toward the individual actor). These observations were concurrent with a series of studies that investigated the development of spoon use in infant’s feeding behaviours (Claxton, McCarty, & Keen, 2009; McCarty et al., 1999; McCarty, Clifton, & Collard, 2001). Spoon-use and cup-use occur during similar stages of development (Carruth & Skinner, 2002); therefore, considering that both are familiar actions it must be acknowledged that grasp selection in a cup task may be a habitual, stimulus-driven action, as opposed to one which reflects anticipatory planning (Herbort & Butz, 2011).

It has been suggested that discrepancies in documented “adult-like” patterns of end-state comfort could be due to experience and familiarity with a task. To explore this idea, Knudson, Henning, Wunsch, Weigelt, & Aschersleben (2012) used the bar-transport and overturned-glass tasks with 3- to 8-year-old children, where participants completed an equal number of trials with the preferred and non-preferred hands. An increase in end-state comfort was observed with age from 13% in 3-year-olds to 94% in 8-year-olds in the bar-transport task. Observing the overturned-glass task, sensitivity to end-state comfort was similarly observed to improve with age; however, differing from results of Adalbjornsson et al. (2008), and Scharoun and Bryden (2014b), 64% of 3-year-olds performed end-state comfortable grasps. Knudson et al. (2012) proposed that familiarity with the object influences end-state comfort, similar to Herbort and Butz’ (2011) notion that habit is involved in determining grasp selection.

Summarizing, as revealed in the previous and summarized by Wunsch et al. (2013), the extant research indicates that end-state comfort comes to be manifested as a result of maturation. In the words of van Swieten et al., (2010) “motor planning works as a blind watchmaker, with actions reflecting a previous history of motor evolution where useful actions have survived and less useful ones have perished” (p. 498). Consequently, young children perform in a manner emphasizing a lack of end-state comfort, which increases significantly between 3- to 5-years and continues until approximately age 10. Nevertheless, it is difficult to identify a specific developmental trajectory, considering differences in the tasks and procedures used. Furthermore, the inability to replicate the effect in children of the same age further complicates our understanding in typical development (Wunsch et al., 2013). This highlights the need for continued investigation and provides a basis for the current dissertation.

1.3.3.2. Changes with aging. Wunsch et al. (2013) summarized that "further research is needed to assess the development of [end-state comfort] planning and to determine the relative influence of motor skills and cognitive factors on its developmental course" (p. 74). Although referencing children, these ideas can also be applied to the opposite end of the developmental spectrum; in particular, to delineate if evidence of end-state comfort is altered in aging. To our knowledge, prior to the thesis proposal, the end-state comfort effect had yet to be explored in older adults. Nevertheless, this research has implications for our understanding of motor planning and control processes in the aging population. According to Statistics Canada (2014), approximately five million Canadians were 65 years of age or older in 2011. This number is predicted to double in the next 25 years, where one in four Canadians is expected to be 65 or over by 2051 (Statistics Canada, 2014). As such, this research is timely and worthwhile.

Understanding such processes also has implications for our understanding of stroke. In Canada, there are an estimated 50,000 strokes each year, which equates to one stroke every ten minutes (Hakim, Silver, & Hodgson, 1998). Approximately 30% of individuals in the acute phase of stoke will suffer from apraxia (Donkervoort, Dekker, Stehmann-Saris & Deelman, 2001). One of the most commonly used assessments of apraxia is to ask an individual to pantomime and demonstrate tool use, where superior performance is observed during execution with real tools and objects (e.g., Hermsdörfer et al., 2006). Since Rosenbaum's early studies, the end-state comfort effect has been used continually to quantify behavioural evidence of anticipatory motor planning skills which underlie purposeful movement (see Rosenbaum et al., 2012 for a review). As such, investigations in older adults will help to shed light on the healthy aging process and provide a foundation for studying age-related deficits in tool use (i.e., apraxia) following stroke.

1.4. Summary of literature and statement of purpose

As summarized in the previous section, goal-directed movements, such as reaching, grasping and object manipulation are characterized by multiple processes that can be influenced by the movement context. Advancement is marked by improvements in feed-forward control that parallel patterns which characterize typical motor development (e.g., Elliott et al., 2010), and aging is associated with a gradual slowing of movement, enabling feedback-dependent corrective mechanisms to ensure accurate movements (e.g., Seidler et al., 2010). An advantage in movement for the preferred hand of right handers has also been documented (e.g., Lavrysen et al., 2007). The dynamic dominance hypothesis (e.g., Sainburg, 2002, 2005) posits that each hand is specialized for specific aspects of control. More specifically, the preferred hand is superior for precise control of limb dynamics, whereas the non-preferred hand is more adept at positional control. As such, the two-hemisphere/limb systems are differentially specialized for complementary aspects of movement (Wang & Sainburg, 2007).

The end-state comfort effect is commonly used in the literature to demonstrate anticipatory planning (see Rosenbaum et al., 2012 for a review). The bulk of research to date has relied on young adult participants, and to our knowledge, prior to the thesis the effect had not yet been explored in older adults. Nevertheless, this research has implications for furthering our understanding of motor planning and control processes in the aging population, with applications to stoke and individuals with limb apraxia. Studies have investigated end-state comfort in children (see Wunsch et al., 2013 for a review). The developmental literature highlights that end-state comfort emerges with age. Young children demonstrate a variety of grip selection strategies as they become more familiar with comfortable and uncomfortable postures, and learn to plan according to end-state comfort. Adult-like patterns of end-state comfort have thus been observed between the ages of 9 and 10. Recent investigations have expanded the concept of end-state comfort with application to joint action paradigms (e.g. Gonzalez et al., 2011). Although limited, research to date has shown that participants as young as 7-years-old ensure an object is passed in a manner that facilitates beginning-state comfort for the recipient.

The overall goal of this doctoral research was to further investigate anticipatory planning in object manipulation. Together, the studies used a cross-sectional approach to investigate similarities and differences across the lifespan. The main objectives were to: (a) understand the influence of the movement context; (b) delineate the role of handedness; (c) characterize the influence of familiarity with an object (i.e., familiar vs. less familiar objects); (d) investigate independent and cooperative movements; and (e) outline similarities and differences across the lifespan, all with respect to the end-state comfort effect and the concept of orders of planning for object manipulation. Several of these objectives were addressed concurrently within each study; therefore specific research questions and hypotheses are addressed in the following chapters.

Chapter 2 – The influence of movement context on end-state comfort and underlying movement kinematics: An examination of right and left handed adults

Adapted from:

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Chapter Research Objectives:

This chapter aimed to address the following thesis objectives: (a) understand the influence of the movement context; and (b) delineate the role of handedness. Specific research questions and hypotheses will be outlined in section 2.2.

2.1. Abstract

People typically move in an anticipatory manner, planning the intended action in advance to minimize the energy costs associated with producing the action (e.g., Rosenbaum et al., 2009). This is exemplified in the end-state comfort effect, which is characterized by the selection of an uncomfortable initial posture to enable a comfortable posture upon completion of the movement (Rosenbaum et al., 1990). The main objective of Chapter 2 was to further investigate the end-state comfort effect in left and right handers (*N* = 20). More specifically, to: (a) understand the influence of movement context; and (b) delineate the role of handedness. The overturned glass task (Fischman, 1997) was used as means of assessment, where participants were asked to demonstrate picking up a glass to pour water in four movement

contexts: (1) pantomime without a stimulus; (2) pantomime with image of the glass as a guide; (3) pantomime with glass as a guide; and (4) grasping the glass. End-state comfort was displayed regardless of movement context, hand used to complete the task or handedness group. However, kinematic analysis revealed distinct differences, highlighting how movement parameters are altered as a result of the movement context.

2.2. Introduction

Reaching for a glass to pour a drink of water may seem like a simple task. However, goal-directed movements are complex in nature as they involve a series of processing events (e.g., Elliott et al., 2001, 2010). As an almost infinite number of movement options are available to complete any given task, of particular interest is how an individual plans and executes such movements in a specific way. The goal of this study was to investigate how left and right handers plan and control reach-to-grasp movements to an upright or overturned glass within four movement contexts: pantomime without a stimulus, pantomime with image or glass as a guide, and actual grasping.

A single goal-directed action generally proceeds with two-components: an initial adjustment phase, and a current control phase. However, the overall movement can be separated into a series of processing events (Elliott et al., 2001, 2010; Woodworth, 1899)). Prior to the signal to move exists a planning period, including processes specific to the goal of the actor and their environment (Elliott et al., 2010; Glover, 2004). It is generally understood that individuals reach for objects in an anticipatory manner, planning the intended action in advance to minimize the energy costs associated with producing the movement (e.g., Rosenbaum et al., 2009). Rosenbaum, Meulenbroek, Vaughan et al. (2001) describe motor planning in light of Bernstein’s (1967) degrees of freedom problem, such that the actor implicitly orders internal representations in a constraint hierarchy to plan a goal posture which offers the most cost-efficient movement. Cost-efficiency in grasp selection is determined by control; therefore, hand postures are planned by deriving a total cost from the weighted sum of movement velocity and endpoint variability (Rosenbaum et al., 2012). With practice, the performer gradually adjusts to refine their movement strategy. If a motor plan ends up costing the motor system, postures are re-assessed for future movement (Rosenbaum, et al., 2001a; Rosenbaum, Meulenbroek, & Vaughan, 2001; Rosenbaum, et al., 2009), improving feed-forward processes to meet the necessary afferent and efferent requirements of the task (Elliott et al., 2010).

The ability to perform in such a way is dependent on the ability to perceive an object (or tool) according to its physical features and act upon it (Tucker & Ellis 1998). The importance of this link is exemplified clinically in apraxia, a neurological disorder of skilled movement that cannot be explained by an underlying deficit in basic sensorimotor functions, verbal comprehension, or object recognition (e.g., Roy, Black, Stamenova, Herbert & Gonzalez, 2014). One factor in understanding deficits in apraxia relates to the modality, or movement context. As demonstrated by Randerath, Goldenberg, Spijkers, Li, and Hermsdörder (2011), accuracy of tool use performance of individuals with apraxia improves with more contextual information (pantomime, to movement with a tool, to movement with tool and object).

In light of these findings, and others (see Baumard et al., 2014 for a review of tool use after left brain damage), it is argued that pantomime, (i.e., performing an action associated with a tool without the use of the object) may serve to convey semantic information about an action, such that individuals are required to form and maintain a mental representation of the tool and action until the gesture is performed. In comparison, actual tool use reduces the cost on the working memory system, while also decreasing the degrees of freedom and likelihood of error (e,g., Baurnard et al., 2014; Roy & Hall, 1992). As such, semantic tool information is only activated in a task when there is an intention to use the tool (e.g., Randerath, Li, Goldenberg, & Hermsdörfer, 2009; Roy & Hall, 1992; Roy et al., 2000). Spatial and temporal features of the movement are thus different when comparing pantomime and actual tool use in individuals with apraxia and healthy controls (e.g., Hermsdörfer et al., 2006). More specifically, pantomime is characterized by less time to peak velocity, more time after peak velocity and higher peak velocity compared to actual tool use (Clark et al., 1994; Heath et al., 2002; Hermsdörfer et al., 2006, 2011).

The current study sought to further explore how the movement context influences reach-to-grasp movements with regards to the end-state comfort effect (Rosenbaum et al., 1990; see Rosenbaum et al., 2012 for a review). End-state comfort is characterized by the selection of an uncomfortable initial posture to enable a comfortable posture upon completion of the movement (Rosenbaum et al., 1990). For example, when asked to pick up an overturned glass, people are likely to assume an uncomfortable, thumb-down posture at the start of their movement to allow for a comfortable, thumb-up end-state posture, in which the glass is re-oriented for use. The overturned glass task (Fischman, 1997) was used as means of assessment in the current study.

In Fischman’s (1997) original study, participants poured water in “glass held” (i.e., pickup overturned glass and measuring cup and pour), and “glass down” (i.e., pickup overturned glass, set it down, pick up measuring cup and pour) conditions. End-state comfort was evident when participants assumed an uncomfortable thumb-down grasp to start the movement, allowing for a comfortable thumb-up grasp at the end of the movement. Sensitivity to end-state comfort was seen in 48 of 53 participants in the "glass held", and 50 of 53 participants in the "glass down" condition. When the task allowed participants to set down the glass, 30 of 50 used the same hand to pick up the glass, and subsequently pick up the pitcher to pour water. When required to hold the glass, 39 of 50 used the same hand to pick up the glass as the "glass down" condition leaving the other hand to pick up the pitcher. Participants were sensitive to end-state comfort and also displayed a preference for performing with a particular hand (Fischman, 1997).

The notion that hand preference influences motor planning and control processes is prevalent in the literature. According to the dynamic dominance hypothesis (e.g., Sainburg, 2002, 2005), each hand is specialized for specific aspects of control. The preferred hand of right handers is superior for precise control of limb dynamics and reliant on feed-forward control (e.g., Wang & Sainburg, 2007). As such, higher peak velocities (Annett et al., 1979; Boulinguez et al., 2001; Heath & Roy, 2000), less error in the initial acceleration phase (Roy & Elliott, 1989), a shorter corrective period (Lavrysen et al., 2007; Roy et al., 1994), better accuracy, and an overall shorter movement time (Annett et al., 1979; Elliott et al., 1993; Roy & Elliott, 1989) have been noted for the preferred hand. In comparison, the non-preferred hand is more adept at positional control and is more dependent on feedback (e.g., Wang & Sainburg, 2007). The non-preferred-hand thus displays a planning advantage, evident in faster reaction time and shorter time to peak velocity (e.g., Roy et al., 1994).

A recent study (Lavrysen et al., 2012) investigated if left handers also display preferred hand (i.e., left-hand) advantages. Similar to right handers, peak velocity was reached earlier when moving with the left-hand, thus suggesting results are independent of hand preference. It has been suggested that the two hemisphere/limb systems are differentially specialized for complementary aspects of movement (Wang & Sainburg, 2007), where left handers and right handers display mirrored patterns of interlimb transfer; however differences between the limbs in smaller for left handers (Wang & Sainburg, 2006; Przybyla, Good & Sainburg, 2012).

If a preference for one hand is evident from a kinematic perspective, it is logical to consider that differences may also exist behaviourally in motor planning; specifically, with respect to the end-state comfort effect. Between-hand differences have been investigated in both bimanual and unimanual tasks. Bimanual tasks assess whether symmetry or end-state comfort take precedence when manipulating one object with each hand (e.g., Hughes & Franz, 2008; Janssen et al., 2009; van der Well & Rosenbaum, 2010). In congruent trials, both are observed; however for incongruent trials sensitivity to end-state comfort has been shown to remain (Weigelt, Kunde, & Prinz, 2006), decrease (Janssen et al., 2009) be absent (Hughes & Franz, 2008), or favour a changing preference (van der Well & Rosenbeum, 2010). Janssen et al. (2009, 2011) observed end-state comfort was present more often for the right hand in both right and left handers and therefore suggested that motor planning may be under left hemisphere control. This was in contrast to Weigelt et al (2006), who noted both hands of right handers were sensitive to end-state comfort. Hughes, Reißig and Seegelke (2011) also demonstrated that hand preference and the hand used to complete the task do not influence end-state comfort.

Similar findings were reported by Herbort and Butz (2011) and Coelho et al. (2013) in unimanual tasks, where right handed participants completed the overturned glass task (Herbort & Butz, 2011) and bar transport task (Coelho et al., 2013). Herbort and Butz (2011) had participants complete the task with both hands. In comparison, Coelho et al. (2013) either specified the hand/grasp to use or enabled participants to select which hand/grasp to use, depending on the experiment. In all cases grasps that afforded end-state comfort were maintained (Coelho et al., 2013; Herbort & Butz, 2011). In a follow-up experiment, Coelho et al. (2013) asked participants to rate the comfort of each grasp, where hand-grasp combinations which afforded end-state comfort were identified as the most comfortable.

It is likely that the conflicting results can be attributed to differences in the tasks. As highlighted by Herbort and Butz (2011), an everyday task such as the overturned glass may involve little online planning. Children begin to drink from cups from 8- to 20-months, where lids are typically removed by the second birthday (Carruth & Skinner, 2002). This task can therefore be considered over learned, to the point of being a habitual behaviour (Herbort & Butz, 2011). Although bar-transport, for example is not a habitual movement, it is possible that tasks with uncommon grasps, such as the one used by Janssen et al (e.g., Janssen et al., 2009, 2011) involve more extensive motor planning.

The current study aimed to extend the previous literature to examine whether differences in pantomime and actual tool use in healthy left and right handers would be evident in everyday object manipulation, within a commonly used end-state comfort paradigm (i.e., overturned glass task). Summarizing then, the main objective of this study was to analyze movement kinematics and sensitivity to end-state comfort in left and right handed participants when manipulating the movement context. The following research questions were examined:

1) How does the movement context (e.g., pantomime vs. actual use) influence end-state comfort and underlying movement kinematics? It was hypothesized that kinematics would differ within the various movement contexts (e.g., Hermsdörfer et al., 2006). That said, considering the link between habitual and goal-directed factors in everyday

object handling (Herbort & Butz, 2011), it was hypothesized that end-state comfort would be seen in all movement contexts.

2) How does handedness influence end-state comfort and underlying kinematics? Janssen et al. (2009, 2011) proposed that individuals are more sensitive to end-state comfort with their right hand regardless of hand preference; therefore it was hypothesized that similar results would be displayed. However, Herbort and Butz (2011) and Coelho et al. (2013) indicated end-state comfort prevails over hand preference, thus it was also likely that no difference between the two hands and handedness groups would be obtained. In regards to movement parameters, Lavrysen et al. (2012) have noted performance differences between the two hands are independent of hand preference. Therefore it was hypothesized that previously identified manual asymmetries in planning and control would be replicated.

2.3. Methods

2.3.1. Participants

A convenience sample from the university community participated in this study. This included 10 right (6 male, 4 female; M_{age} = 25.40, *SD* = 4.60) and 10 left handed (6 male, 4 female; M_{age} = 24.90, *SD* = 4.63) undergraduate and graduate students matched according to sex and comparable in chronological age. The office of research ethics at the University of Waterloo and the Wilfrid Laurier University research ethics board approved all recruitment and testing procedures. Informed consent was obtained from all participants.

2.3.2. Apparatus and procedures

Participants were seated at a table, as they completed each task (see Figure 2.1). Each participant was first asked which hand was used for writing to denote self-report hand preference. All participants completed a modified overturned glass task (Fischman, 1997), the 20-item Waterloo Handedness Questionnaire (Cavill & Bryden, 2003) and the Grooved Pegboard (Lafayette Instruments, Model # 3205; Matthews & Klove, 1964).

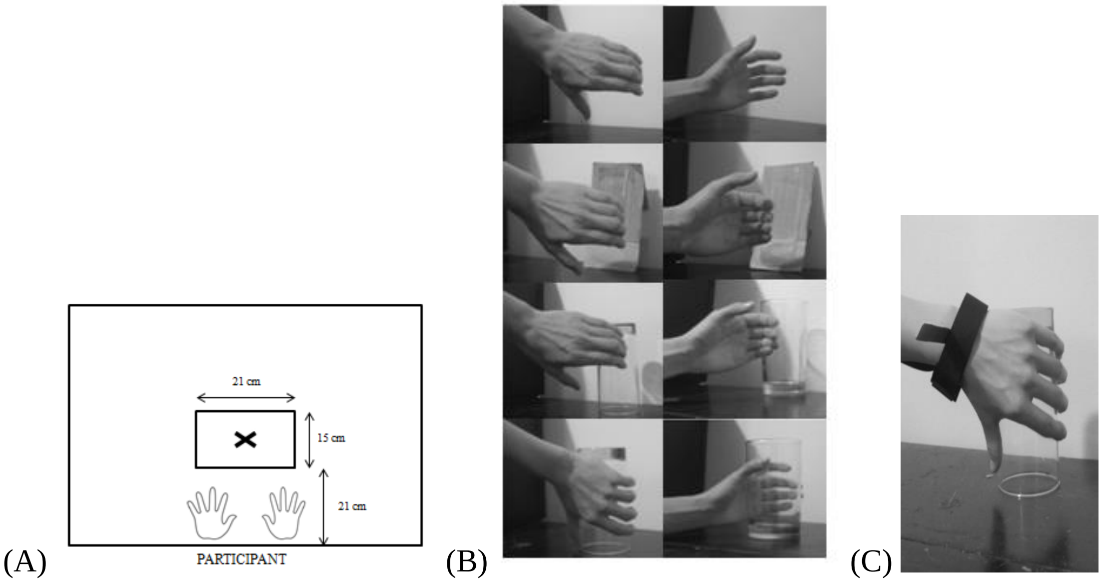

Figure 2.1. (A) Study set up (B) Participants were asked to demonstrate the action of picking up a glass, or to actually pick up a glass as if to pour water within four different movement contexts: (1) pantomime without a stimulus; (2) pantomime with image of the glass as a guide; (3) pantomime with glass as a guide; and (4) grasp glass (C) To ensure markers were visible during wrist rotation, participants wore a 9cm 'fin' attached with a Velcro strap, which was wrapped around each wrist.

2.3.2.1. Overturned glass task

It has been suggested that semantic tool information is only activated in a task when there is an intention to use the tool (e.g., Randerath et al., 2009; Roy & Hall, 1992; Roy et al., 2000). Therefore, participants were asked to demonstrate the action of picking up a glass (or to actually pick up a glass) as if to pour water within four different movement contexts (see Figure 2.1): (1) pantomime without a stimulus (i.e., demonstrating the action of picking up a glass as if to pour water; (2) pantomime with image of the glass as a guide (i.e., using the image as a guide, demonstrating the action of picking up a glass as if to pour water); (3) pantomime with glass as a guide (i.e., using the glass as a guide, demonstrating the action picking up the glass as if to pour water); and (4) grasp glass (i.e., picking up the glass as if to pour water). The tasks which used the image and glass as a guide were counterbalanced between participants. Pantomimed actions were performed prior to tool-use to avoid providing cues as to correct pantomime performance (e.g., Heath et al., 2002). A total of 80 trials (five trials by four movement contexts by two glass orientations by two hands) were completed.

One Optotrak camera (Northern Digital Inc., Waterloo, Ontario), mounted to the wall, recorded three-dimensional displacement data at 200 Hz for 10 seconds. Two infrared emitting diode markers were used; one affixed to each of the participants' wrists. To ensure markers were visible during wrist rotation, participants wore a 9cm 'fin' attached with a Velcro strap, which was wrapped around each wrist. An 'X' marked a spot within a box, where participants were instructed to reach to that location, perform the designated action, move horizontally outside the box, and return to the home position (see Figure 2.1). Each trial started with participants' eyes closed and hands in a fixed position at the body midline. Participants were instructed to demonstrate the action of picking up a glass as if to pour water. Verbal instructions from custom software designed with E-prime (Version 1.1a) indicated the hand to be used (left or right; e.g., please use your left hand). Upon hearing a ‘beep’, participants opened their eyes and completed the movement based on the orientation of the stimulus (upright or overturned glass). Within the ‘pantomime without a stimulus’ condition, participants were provided with verbal information about the orientation of the glass, in addition to the hand to be use used, from the same E-prime software (e.g., please use your right hand for overturned cup). A video camera was used to record participants grip selection, where sensitivity to end-state comfort was quantified by subsequent video coding. For the overturned glass condition, a starting thumb-down to ending thumb-up was coded as evidence of end-state comfort; whereas, with the upright glass, a thumb-up grasp throughout the task was deemed to show sensitivity to end-state comfort. The percentage of end-state comfortable grasps was computed.

2.3.2.1.1. Data reduction.

Optotrak data were collected at 200Hz for 10 seconds. Custom MATLAB® software was used for filtering using a third-order Butterworth dual pass filter at 10Hz. Movement kinematics were calculated from three-dimensional displacement data. The movement was divided into three different phases: a reach/approach phase, a grasp/transport phase and a use phase. Movement time in the reach/approach phase was computed as the duration between reaction time (resultant velocity reaching an absolute value of 10mm/s for 20ms) and the end of the initial reach (resultant velocity reaching an absolute value below 100mm/s for 20ms). Resultant peak velocity was computed in the reach/approach phase, with leftward movements being multiplied by negative 1 to help dissociate the different movement components. Grasp/transport time was defined as the duration between the end of reach/approach and the end of the movement towards the object (resultant velocity reaching an absolute value below 100mm/s for 20ms in 15cm x 15cm box where action was to be performed). Grasp time was not separated from transport as it was difficult to distinguish and because of technical problems of only having one IRED per hand and Optotrak camera (i.e., missing data). Finally, use time was defined as the duration between the end of the grasp/transport phase until the participant made a horizontal movement outside the box (resultant velocity reaching an absolute value below 100mm/s for 20ms). Trials with missing raw data greater than 20 ms and where the reaction time fell below 100 ms or above 1500 ms were removed prior to analyses. These are derived from the aiming literature (similar to Glazebrook, Elliott & Lyons, 2006; see Figure 2.2 for schematic).

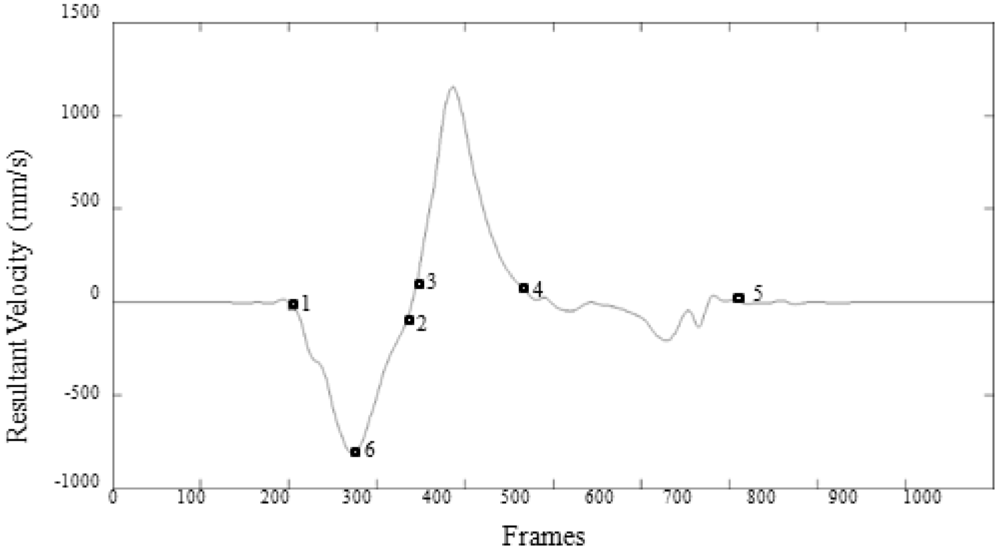

Figure 2.2. A sample right-hand trial to demonstrate kinematics, which were measured using 3D displacement data. Movements to left are represented by negative values, and movements to the right by positive values, based on the origin established: (1) Represents the reaction time,

(2) the end of the reach phase, (3) the end of the grasp, (4) the end of the transport phase, (5) the end of the use phase, (6) peak velocity for reach phase.

2.3.2.2. Waterloo Handedness Questionnaire.

Participants were asked to indicate their preferred hand for 20-unimanual tasks (Cavill & Bryden, 2003). Each question permits five responses: "left always" (-2), "left usually" (-1), "uses both hands equally often" (0), "right usually" (+1), and "right always" (+2), thus enabling an overall handedness score to be computed by summing the responses. As expected, right handers had positive scores (*M* = 28.8, *SD* = 3.26), and left handers had negative scores (*M* = -21.4, *SD* = 4.55).

2.3.2.3. Grooved Pegboard.

Participants were asked to complete both the place and replace components of the task (Bryden & Roy, 2005). In the place task, participants were asked to move 25 key-shaped pegs, individually, from a receptacle to an end position. In the replace task, participants were asked to remove the pegs and return them to the receptacle. The replace task is suggested to be a measure of motor speed, whereas the place task required motor precision (e.g., Bryden & Roy 2005). Participants completed the place and replace task three times with the left and right hand. Laterality quotients were computed by taking the difference between left- and right-hand performance ((left-hand – right-hand) / (left-hand + right-hand)) and multiplying the result by 100. The size of the performance difference between the hands is thought to reflect the strength of hand preference (Provins & Magliaro, 1993), As expected, left handers displayed negative laterality quotients in the place (*M* = -3.57, *SD* = 4.59) and replace (*M* = -2.41, *SD* = 8.61) tasks; whereas right handers displayed positive laterality quotients in the place (*M* = 6.25, *SD* = 2.96) and replace (*M* = 2.92, *SD* = 3.82) tasks.

2.4. Results

2.4.1. Percentage of end-state comfortable grasps

Video coding revealed thumb-up grasp postures were maintained in all control trials (i.e., upright glass). In critical trials (i.e., overturned glass) end-state comfortable postures (i.e., initial uncomfortable thumb-down posture) were demonstrated for all right handed participants (n = 10) and 7 of 10 left handed participants (see Table 2.1 for percentage of end-state comfort). One female left handed participant displayed a comfortable grasp posture with the right hand in one of five trials which required pantomime without a stimulus; however, end-state comfortable postured were displayed in remaining trials. Two male left handed participants displayed an initial comfortable posture (i.e., thumb-up) throughout the duration of the study. Upon completion of the study, participants were asked to confirm what action they performed to ensure understanding of the task. Each re-iterated the instructions provided, that was to pick up the glass as if to pour water. Despite plans to analyze end-state comfort data statistically, due to the ceiling effect observed in 17 of 20 participants, this was not feasible. Percentages of end-state comfort for each hand preference group are presented in Table 2.1.

Table 2.1

Percentage of end-state comfortable grasps as a function of hand preference, hand used to complete the task and movement context

Hand preference	Hand used	Movement context	Mean, Standard deviation
Left Handers	Left-hand	Pantomime without stimulus	*M* = 78.00, *SD* = 41.59
		Pantomime with image	*M* = 80.00, *SD* = 42.16
		Pantomime with glass	*M* = 80.00, *SD* = 42.16
		Grasping	*M* = 80.00, *SD* = 42.16
	Right-hand	Pantomime without stimulus	*M* = 80.00, *SD* = 42.16
		Pantomime with image	*M* = 80.00, *SD* = 42.16
		Pantomime with glass	*M* = 80.00, *SD* = 42.16
		Grasping	*M* = 80.00, *SD* = 42.16
Right Handers	Left-hand	Pantomime without stimulus	*M* = 100.00, *SD* = 0.00
		Pantomime with image	*M* = 100.00, *SD* = 0.00
		Pantomime with glass	*M* = 100.00, *SD* = 0.00
		Grasping	*M* = 100.00, *SD* = 0.00
	Right-hand	Pantomime without stimulus	*M* = 100.00, *SD* = 0.00
		Pantomime with image	*M* = 100.00, *SD* = 0.00
		Pantomime with glass	*M* = 100.00, *SD* = 0.00
		Grasping	*M* = 100.00, *SD* = 0.00

2.4.2. Analysis of kinematic variables

Each of the dependent kinematic measures (i.e., reaction time, movement time in approach, resultant peak velocity, grasp/transport and use times) were analyzed using two handedness group by four movement context by two glass orientation by two hand used to complete the task mixed design analysis of variance tests, with repeated measures on the last three factors. Mean and standard deviation values are reporteded for all main effects and interactions

2.4.2.1. Reaction time

Reaction time was shortest during pantomime without a stimulus (F (3, 36) = 33.18, $p <$ .001, η^2 = .734; see Figure 2.3). No differences emerged when comparing pantomime with image and glass as a guide; however, these two movement contexts displayed significantly greater reaction times than pantomime without a stimulus and grasping.

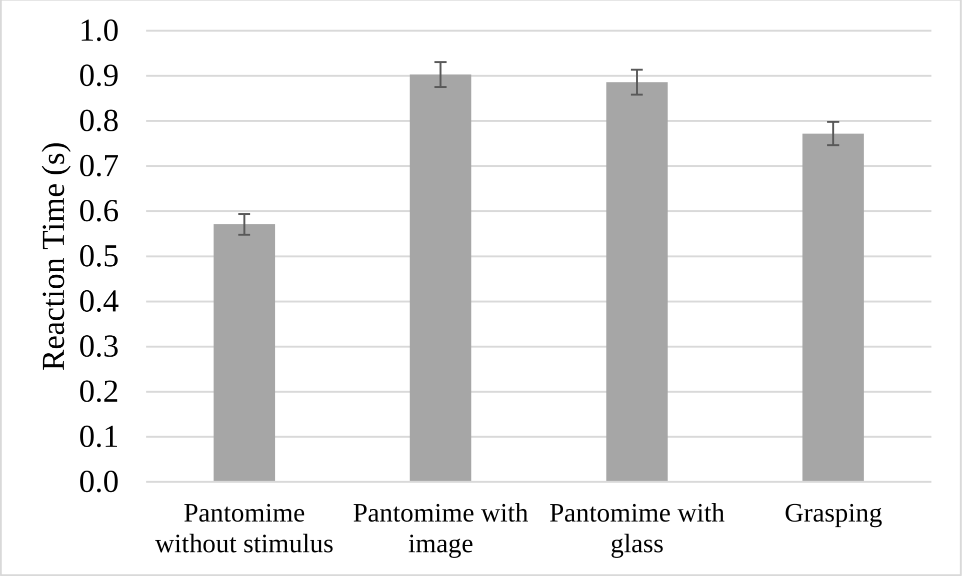

Figure 2.3. Reaction time was fastest in pantomime without a stimulus. Error bars represent standard error.

2.4.2.2. Movement time in approach

A main effect of movement context, F (3, 30) = 7.03, p = .001, η^2 = .413, revealed movement time in the approach phase was longest in pantomime without a stimulus (M = 0.820, SD = 0.178), and shortest in grasping (M = 0.715, SD = 0.129), where no differences emerged within pantomime with an image (M = 0.759, SD = 0.159) and glass (M = 0.748, SE = 0.151) as a guide. A main effect of hand used to complete the task, F (1, 10) = 5.28, p = .044, η^2 = .346, revealed movement time was significantly shorter in left hand (M = 0.736, SD = 0.158) than right hand performance (M = 0.788, SD = 0.162). Finally, a main effect of glass orientation, F (1, 10) = 27.69, p < .001, η^2 = .741, revealed movement time was shorter when reaching for the upright glass (*M* = 0.740, *SD* = 0.156) compared to the overturned glass (*M* = 0.782, *SD* = 0.163).

2.4.2.3. Resultant peak velocity

Analysis of resultant peak velocity, revealed a main effect of hand, *F* (1, 12) = 6.31, *p* = 0.027, η^2 = .345, such that significantly higher resultant peak velocity for the left hand (*M* = 617.80, *SD* = 235.07) compared to the right hand (*M* = 518.43, *SD* = 292.63). Additionally, a main effect of glass orientation, *F* (1, 12) = 72.43, *p* = .001, η^2 = .858, revealed resultant peak velocity was significantly higher when reaching for the overturned glass (*M* = 749.03, *SD* = 243.567) compared to the upright glass (*M* = 387.21, *SD* = 178.60).

A two-way interaction of hand used to complete the task and glass orientation, *F* (1, 12) = 10.57, *p* = .007, η^2 = .468, revealed that resultant peak velocity was significantly faster in the overturned cup condition for both left- (*M* = 758.58, *SD* = 217.70) and right-hand (*M* = 739.48, *SD* = 264.38) performance. When manipulating the upright cup, the left-hand (*M* = 477.03, *SD* = 171.54) was significantly faster than the right-hand (*M* = 297.39, *SD* = 100.10). Furthermore, a two-way interaction of movement context and glass orientation, *F* (3, 36) = 5.72, *p* = .003, η^2 = .323, revealed that resultant peak velocity was significantly greater when manipulating the overturned glass, where pantomime without a stimulus (*M* = 664.59, *SD* = 203.04) was significantly slower than pantomime with image (*M* = 775.97, *SD* = 253.67), and glass (*M* = 766.29, *SD* = 246.43) as a guide and actual grasping (*M* = 789.28, *SD* = 261.97). In the upright cup condition, resultant peak velocity was significantly faster in pantomime with an image (*M* = 416.22, *SD* = 205.11) as a guide compared to pantomiming without a stimulus (*M* = 354.02, *SD* = 139.56). Pantomime with glass as a guide (*M* = 391.13, *SD* = 181.65) and actual grasping (*M* = 387.46, *SD* = 162.89) did not differ from the other movement contexts. Finally, a three-way interaction of movement context, hand used to complete the task, and hand preference, *F* (3, 36) = 2.96, *p* = .045, η^2 = .198, was also revealed. Overall, resultant peak velocity was significantly greater in grasping (*M* = 588.37, *SD* = 291.05), compared to pantomime without a stimulus (*M* = 509.30, *SD* = 229.14; *F* (3, 36) = 7.22, *p* = .001, η^2 = .376). This was true for both left handers in left hand performance and right handers in right hand performance (see Figure 2.4).

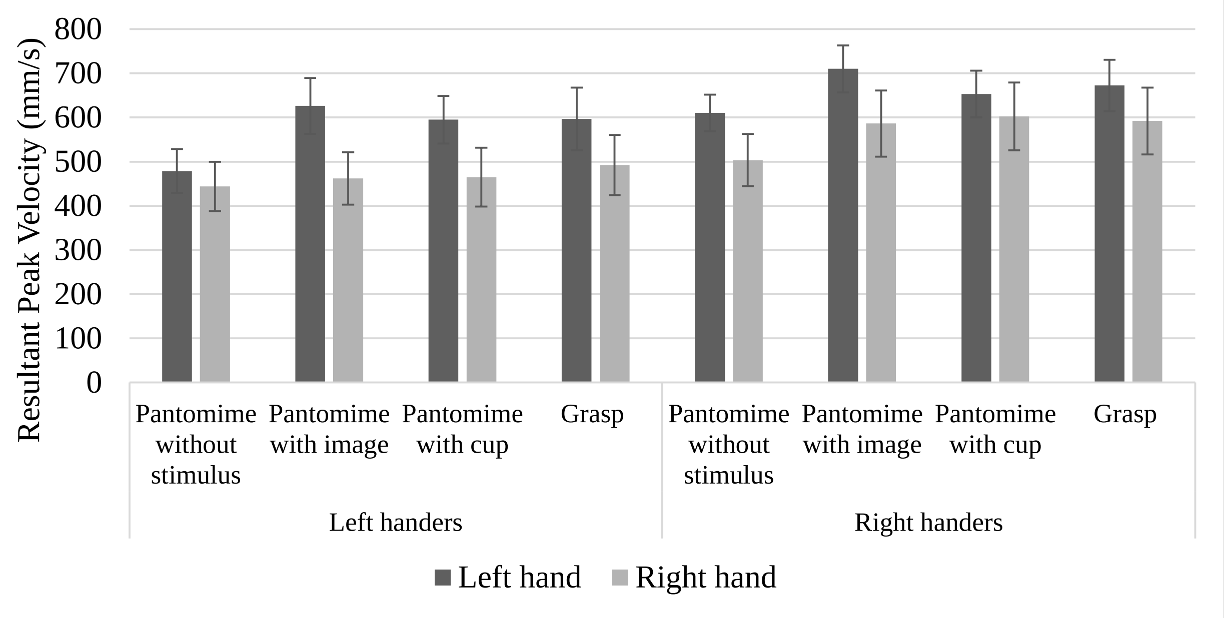

Figure 2.4. Both left and right handers were slowest in the pantomime without a stimulus movement context. Error bars represent standard error.

2.4.2.4. Grasp/transport and use times

Grasp/transport time was significantly shorter for pantomime without a stimulus (*M* = 0.942, *SD* = 0.290) versus pantomime with image (*M* = 1.226, *SD* = 0.301) and glass (*M* = 1.242, *SD* = 0.308) as a guide and grasping (*M* = 1.115, *SD* = 0.291; *F* (3, 24) = 23.99, *p* < .001, η^2 = .750).

Use time was longest in pantomiming without a stimulus (*M* = 1.595, *SD* = 0.308), and shortest in grasping (*M* = 1.380, *SD* = 0.243; *F* (3, 24) = 25.642, $p < .001$, $\eta^2 = .762$). Additionally, use time was longer when manipulating the overturned glass (*M* = 1.501, *SD* = 0.300) compared to the upright glass (*M* = 1.422, *SD* = 0.290; *F* (1, 8) = 6.184, $p = .038$, $\eta^2 = .436$). An interaction between glass orientation and hand, (*F* (1, 8) = 6.794, $p = .031$, $\eta^2 = .459$, revealed use time for the right-hand was longer when manipulating the overturned glass (*M* = 1.503, *SD* = 0.259) compared to the upright glass (*M* = 1.368, *SD* = 0.260). There was no difference in left-hand performance (overturned: *M* = 1.462, *SD* = 0.330; upright: *M* = 1.403, *SD* = 0.286). Finally, there was an interaction between movement context and hand. Mauchley's Test of Sphericity was violated ($\chi^2(5) = 25.962$, $p < .001$); therefore a Greenhouse-Geisser correction was applied (*F* (1.184, 13.175) = 5.554, $p = .005$, $\eta^2 = .410$). Between-hand differences were only evident in actual grasping, such that use time was longer with the right-hand. When acting with the left-hand, use time was longer in pantomime (*M* = 1.578, *SD* = 0.321) compared to pantomime with image (*M* = 1.408, *SD* = 0.328) and glass (*M* = 1.376, *SD* = 0.274), and actual grasping (*M* = 1.344, *SD* = 0.250). Pantomime with image and glass did not differ; however, use time was shortest in actual grasping. In right-hand performance, use time was longer in pantomime (*M* = 1.532, *SD* = 0.288) compared to pantomime with image (*M* = 1.400, *SD* = 0.264) and actual grasping (*M* = 1.381, *SD* = 0.229). Pantomime with glass (*M* = 1.439, *SD* = 0.268) did not differ; however, use time here was similarly longer than actual grasping.

2.5. Discussion

The main objectives of this study were to: (a) understand the influence of movement context; and (b) delineate the role of handedness in the end-state comfort effect. The following will reflect on previous literature in light of the original hypotheses and results obtained.

2.5.1. Understanding the influence of movement context

2.5.1.1. Sensitivity to end-state comfort.

As hypothesized, a ceiling effect was seen in 17 of 20 participants. One female left handed participant did not display end-state comfort in one trial of pantomime without a stimulus and two male left handed participants did not display end-state comfort at all. This is in line with Herbort and Butz (2011). Regardless if asked to pantomime, demonstrate the action of, or actually pick up a glass to pour water, the goal-directed and habitual systems coordinated to display an end-state comfortable grasp, in most cases. In light of these remarks, it is not understood why two left handed participants did not display end-state comfort, despite confirming task comprehension. With respect to previous research, Fischman et al. (1997) noted that 5 of 53 participants in a “glass held” condition, and 3 of 53 participants in a “glass down” condition did not display end-state comfort; therefore it is likely that not all people are sensitive to the effect.

Beyond these observations, findings cannot be generalized to ‘neutral’ objects, such as a bar-transport task (e.g., Rosenbaum et al., 1990). Further research is required to delineate if the movement context influences end-state comfort to the same extent when manipulating ‘natural’ versus ‘neutral’ objects as evidenced by Knudson et al.’s (2012) study with children. Three to 4-year-olds were more sensitive to end-state comfort with the overturned-glass compared to bar-transport, likely because of the familiarity with the object and task. Research presented in Chapter 5 builds upon the current study to examine familiarity with an object (i.e., familiar vs. less familiar) influences end-state comfort in varying movement contexts.

2.5.1.2. Kinematic analysis of movement contexts

Next, addressing movement characteristics, Hermsdörfer et al. (2006) have proposed that the movement context leads to different movement kinematics. In particular, “while pantomiming may be symbolic representation of an action, actual execution may be governed by movement goals and external constraints” (Hermsdörfer et al., 2006, p. 1649). In line with the previous literature, distinct performance differences were revealed in the current study when comparing the four movement contexts. More specifically, movement time in the approach phase was longest in pantomime without a stimulus and shortest in grasping. Furthermore, grasp time (duration between the end of the approach phase and the end of the movement towards the object) was shortest in pantomime without a stimulus, whereas use time (duration between the end of the grasp/transport phase until the participant made a horizontal movement and left the box) was longest in this movement context. Goodale et al. (1994) have indicated that movements should vary towards remembered objects and those in real time due to changes in the affordances offered for grasping. During pantomime without a stimulus, participants are dependent on perceptual representations of objects, rather than cues that normally guide a visuomotor act (Goodale et al., 1994). As such, during pantomime without a stimulus, information required to scale a grasp must be extracted from working memory (i.e., an internal representation of the object), as opposed to online cues (Goodale et al., 1994; Randerath et al., 2011). With the increase in contextual information, movements become more similar to actual grasping. This was true for pantomime with image and glass as a guide, which did not differ. These findings parallel observations in apraxia. More specifically, impaired purposeful movements are improved when a tool is present to guide action, as the cognitive demand on working memory is decreased (e.g., Randerath et al., 2011; Roy et al., 1996; Roy & Hall, 1992; Stamenova, Black & Roy, 2012).

Unlike the aforementioned findings, which were interpreted in light of previous reports, differences in reaction time and resultant peak velocity can be attributed to study design. Reaction time was fastest in pantomiming without a stimulus, and subsequently in actual grasping. Unlike other movement contexts, pantomime without a stimulus provided pre-cue information about both hand used to complete the task and orientation of the glass. It is likely that this additional information enabled movements to be planned in advance based on a habitual response (e.g., Herbort & Butz, 2011). Furthermore, it is likely reaction time was slowest in pantomime with image and glass as a guide as participants had to inhibit a habitual response to grasp the object. Anecdotally, some participants did grasp the image, and were reminded that it was meant as a guide. In line with this idea it is likely peak velocity was greatest in grasping as a result of the blocked design. Pantomimed actions were performed prior to tool-use to avoid providing cues as to correct pantomime (e.g., Heath et al., 2002); however, it is likely that this design provided the opportunity to achieve the same spatial goal, with increased speed, as the target and action did not change. In other words, participants became more proficient as the task progressed. Therefore, the current study revealed findings opposite to previous reports of higher peak velocity in pantomime compared to actual tool use (e.g., Heath et al., 2002).

2.5.2. Delineating the role of handedness

2.5.2.1. Sensitivity to end-state comfort

Literature to date presents with conflicting findings regarding the influence of hand preference on end-state comfort (e.g., Coelho et al., 2013; Janssen et al., 2011; Herbort & Butz, 2011). Results of the current study support the notion that the desire to end comfortably prevailed over hand preference (Coelho et al., 2013; Herbort & Butz, 2011) as 17 of 20 participants reached a ceiling effect. Two left handed participants did not display end-state comfort with either hand; however as discussed previously, it is likely that not all people are sensitive to the effect. As Herbort and Butz's (2011) and Coelho et al.'s (2013) studies were limited to right handed participants, results of the current study add to the literature and our understanding of the influence of hand preference on end-state comfort in left and right handed participants.

It is likely that tasks constraints are involved in explaining the differing results with regard to hand effects reported in the literature. As expressed by Janssen et al. (2009, 2011), planning according to end-state comfort "depends on the complexity of the task" (p. 72). Janssen et al. (2009, 2011) implemented a novel CD-placement task, whereas Herbert and Butz (2011), Coelho et al. (2013) and the current study implemented traditional assessments of end-state comfort (i.e., bar transport and overturned glass task). As highlighted by Herbort and Butz (2011), an everyday task such as the overturned glass may involve little online planning (e.g., McCarty et al., 1999). It is thus likely that Janssen et al.'s (2009, 2011) task involved uncommon grasps which involved more extensive motor planning.

2.5.2.2. Kinematic analysis of movement contexts

Lavrysen et al. (2012) have documented “differential specialization of the left and right hemispheres/hand systems” (p. 1823). In particular, differences in left- and right-hand performance are independent of hand preference, where functional imaging results have displayed more extensive perceptuomotor processing for the left hand in both handedness groups. Therefore, it was originally hypothesized that manual asymmetries in planning and control would be replicated between the two hands and handedness groups.

It is first important to highlight that no differences emerged between the hands or handedness groups with respect to reaction time. As the left hand characteristically displays reaction time advantages (e.g., Roy et al., 1994), this was a surprising finding. That said, previous reports have been based on manual aiming (e.g., Roy et al., 1994), for example, which, unlike an overturned glass task, is not an everyday, habitual (Herbort & Butz, 2011) movement. It is thus likely that participants were adept at performing this habitual task with both preferred and non-preferred hands. Previous literature has noted people display more preferred hand use when they performed a skilled action with a tool, as opposed to simply picking up the tool, where there is an increase in non-preferred hand use (e.g., Bryden, Mayer & Roy, 2011). As reaching to grasp a glass does not require a great deal of skill or precision, it is likely that this action is performed habitually with both hands; therefore, reaction time is comparable with both hands.

During left hand performance, movement time in the approach phase was shorter and resultant peak velocity was higher. These results are in line with previous research which has noted left hand advantages in time to peak velocity for both right (e.g., Roy et al., 1994) and left handers (e.g., Lavrysen et al., 2012). This finding provides support for the notion of a specific left hand advantage that is independent of hand preference.Also during left hand performance, grasp time was significantly longer when manipulating the overturned glass. As discussed previously, left hand advantages are limited to the initial movement parameters, including reaction time advantages and shorter time to peak velocity (e.g., Lavrysen et al., 2012; Roy et al., 1994). It was therefore not surprising that the left hand displayed disadvantages during the grasp phase of the movement. The right hand, in comparison, displays a shorter corrective period (Lavrysen et al., 2007; Roy et al., 1994), better accuracy and an overall shorter movement time (Annett et al., 1979; Elliott et al., 1993; Roy & Elliott, 1989); thus explaining superior performance of the right hand in the later stages of movement.

Observing performance differences that emerged between the two handedness groups, when performing with their preferred-hand, resultant peak velocity was lowest in pantomime without a stimulus for both left and right handers compared to the other three movement contexts. The preferred hand is believed to be specialized for the specification and control of the arm’s trajectory (e.g., Sainburg, 2002). Therefore, this was a surprising finding. Nevertheless, as discussed previously, the lack of difference between the two hands it likely due to the habitual (e.g., Herbort & Butz, 2011), over-learned nature of the overturned glass task. Pantomime is also typically characterized by higher peak velocity compared to actual tool use (Clark et al., 1994; Heath et al., 2002; Hermsdörfer et al., 2006, 2011), thus one would have expected a greater resultant peak velocity in pantomime. This deviation from previous findings likely results from the blocked design, which provided participants with the opportunity to optimize speed and maintain accuracy through practice.

2.6. Summary and Conclusions

In summary, end-state comfort was displayed in all movement contexts for 17 of 20 participants. This finding falls in line nicely with the Herbort and Butz's (2011) proposal that both the habitual and goal-directed systems contribute to grasp selection for object manipulation. Nevertheless, as outlined previously, findings cannot be generalized to 'neutral' objects, such as in a bar-transport task (e.g., Rosenbaum et al., 1990), thus further research is required to delineate how the movement context influences end-state comfort more generally. Kinematic analysis revealed distinct performance differences. In particular, results provide further support for the distinction between pantomime and actual use with respect to underlying movement kinematics. Addressing the influence of hand preference, no differences emerged in sensitivity to end-state comfort between the handedness groups or within the two hands. In line with Herbort and Butz (2011) and Coelho et al. (2013), results add to the literature, explaining that end-state comfort prevails over handedness in both left and right handers. Performance differences in movement highlight distinct differences within left- and right-hand performance and between handedness groups.

This research has obvious implications for our understanding of the end-state comfort effect and underlying movement kinematics. Beyond that which is apparent, these results can also be used as a basis for investigations beyond adulthood. According to Statistics Canada (2014), approximately five million Canadians were 65 years of age or older in 2011. This number is predicted to double in the next 25 years, where one in four Canadians is expected to be 65 or over by 2051 (Statistics Canada, 2014). Canada is just one example; however, similar trends are likely in other developed nations. As such, aging research is timely and worthwhile.

To our knowledge, prior to the thesis end-state comfort had yet to be explored in older adults. It is generally understood that aging is associated with a gradual slowing of movement (e.g., Roy et al., 1996). Furthermore, the ability to use feed-forward control declines with age, therefore, older adults become more dependent on feedback control to continuously and consciously modify their movements to meet the increased cost of error-full movement (e.g., Heath et al., 1999). Based on this, it is possible that older adults may not be sensitive to end-state comfort in pantomime conditions, in the absence of feedback. On the contrary, older adults may perform behaviourally similar to young adults, where differences in control will be reflected kinematically in the speed of planning and control. As such, Chapter 3 completed the entire battery with a group of left and right handed older adults.

Chapter 3 – How the movement context affects behavioural evidence of planning and movement kinematics in aging: End-state comfort in older adults.

Adapted from:

Scharoun, S. M., Gonzalez, D. A., Roy, E. A. & Bryden, P. J. (2016). How the mode of action affects behavioural evidence of planning and movement kinematics in aging: End-state comfort in older adults. *Developmental Psychobiology*, 58(4), 439-449. doi:10.1002/dev.21386

Chapter Research Objectives:

This chapter aimed to address the following thesis objectives: (a) understand the influence of the movement context; (b) delineate the role of handedness; and (e) outline similarities and differences across the lifespan. Specific research questions and hypotheses will be outlined in section 3.2.

3.1. Abstract

Motor deficits are commonly observed with age; however, it has been argued that older adults are more adept when acting in natural tasks and do not differ from young adults in these contexts. This study assessed end-state comfort and movement kinematics using the same methods as Chapter 2 to examine this further. With increasing age, a longer deceleration phase (in pantomime without a stimulus) and less end-state comfort (in pantomime without a stimulus and image as a guide) were displayed as the amount of contextual information available to guide movement decreased. Changes in movement strategies likely reflect an increased reliance on feedback control and demonstration of a more cautious movement. A

secondary aim of this study was to assess hand preference and performance, considering conflicting reports of manual asymmetries with age. Performance differences in the Grooved Pegboard place task indicate left handers may display a shift towards right handedness in some, but not all cases. Summarizing, this study supports age-related differences in planning and control processes in a familiar task, and changes in manual asymmetries with age in left handers.

3.2. Introduction

Aging is associated with vast neuromuscular and sensorimotor changes. These changes may manifest behaviourally in motor performance deficits, characterized by slowness, an increased variability in movement and difficulties with coordination, balance and gait (see Siedler et al., 2010 for a review). Functional ability of the human hand—arguably the most important component of the upper limb-appears to be preserved until approximately age 65, after which a gradual decline is observed (see Carmeli, Patish & Coleman, 2003 for a review). For example, a decrease in velocity and longer movement times in goal-directed hand and arm movements are commonly reported changes in kinematics as a function of age (i.e., pointing, aiming, reaching and grasping; Contreras-Vidal et al., 1998; Darling et al., 1989; Diggles-Buckles, 1993; Ren, Wu, Chan & Yan, 2013; Siedler et al., 2010). These motor difficulties have been reported to negatively impact quality of life and the ability for older adults to perform activities of daily living.

A recent review by Siedler et al. (2010) uses a “supply and demand” framework to explain age-related performance differences in motor control. From this perspective, the reliance on cognitive resources (e.g., attention, working memory, etc.) increases to compensate for structural and functional degradation in motor regions and reduced availability of neurotransmitters. However, simultaneous decline in the availability of cognitive resources limits compensatory mechanisms; therefore older adults modify planning and control strategies and thus appear behaviourally different than young adults (Siedler et al., 2010). In reaching and grasping, differences in performance have been attributed to lengthening of the deceleration phase, which corresponds to the final approach to the target goal. This allows for more feedback-dependent corrective mechanisms, as the ability to use feed-forward control declines with age (Bennett & Castiello, 1994; Diggles-Buckles, 1993; Roy et al., 1996; Seidler-Dobrin & Stelmach, 1998). A more conservative or "play-it-safe" strategy is thus observed, enabling older adults to reach the target accurately and without error (Bennett & Castiello, 1994; Siedler et al., 2010; Welsh, Higgins & Elliott, 2007).

In spite of these reports, age-related performance differences are not always observed (Carnahan et al., 1998; Cicerale et al., 2014; Varadhan et al., 2012). Therefore, an alternate argument is that older adults display poor performance because of the unfamiliarity of the laboratory tasks they have been asked to perform (Carnahan et al., 1998; Bennett & Castiello, 1994; Bock & Steinberg, 2012; Cicerale et al., 2014; Varadhan et al., 2012). In other words, older adults are more adept when acting in natural tasks and do not differ from young adults in these contexts. To date the majority of studies investigating the effect of age on the kinematics of reaching and grasping have used meaningless objects, while examination of more ecologically relevant objects, such as tools is predominantly used in the assessment of apraxia (Cicerale et al., 2014).

The current study sought to further elucidate age-related changes in older adults' ability to plan and control reaching and grasping with a familiar object, where complexity was manipulated as a function of the movement context. More specifically, participants were asked to pick up a glass in pantomime without a stimulus, pantomime with image or glass as a guide, and actual grasping. It is argued that pantomime (i.e., no stimulus) requires the formation and maintenance of a mental representation of object and action until the gesture is performed, thus increasing cognitive demand. In comparison, the presence of an object in actual use reduces the cost on the working memory system (Heath et al., 2002; Randerath et al., 2009; Roy et al., 2014), decreases the complexity of the task, and improves performance. Considering older adults are more reliant on cognitive resources, manipulating the amount of contextual information enabled us to assess complexity within the context of an everyday task.

Participants completed the aforementioned manipulations with an upright and overturned glass. An upright glass offered a control condition that could be compared to previous reports; whereas the inclusion of an overturned glass task also enabled an observational assessment of second-order planning through the end-state comfort effect (Fischman, 1997; Rosenbaum et al., 1990; see Rosenbaum et al., 2012 for a review). When asked to pick up an overturned glass, young adults typically assume an uncomfortable thumb-down posture at the start of their movement to allow for a comfortable thumb-up end-state posture, in which the glass is re-oriented for use (Fischman, 1997; Rosenbaum et al., 2012). Chapter 2 reported this effect in young adults (M_{age} = 25.15, *SD* = 4.50) regardless of the movement context, hand used to complete the task, or participant hand preference. Nevertheless, differences in movement kinematics (e.g., longer movement times, shorter grasp/transport time and longer use time in pantomime without a stimulus compared to actual grasping) emphasized the increased reliance on working memory necessary for pantomime (e.g., Baumard et al., 2014). To our knowledge, prior to the thesis, end-state comfort had yet to be explored in older adults; therefore, building from Chapter 2, this study aimed to investigate if older adults would perform observationally similar to young adults, considering the everyday nature of the task, or different, considering the increase in cognitive demand on working memory.

This study also aimed to shed light on the effects of aging on manual asymmetries as the literature currently presents with conflicting findings. More specifically, reports highlight that asymmetries are not affected by age (Chua, Pollock, Elliott & Swanson, 1995; Francis & Spirduso, 2000; Gonzalez, Flindall & Stone, 2015; Gooderham & Bryden, 2014); however, others have noted both greater manual asymmetries (Weller & Latimer-Sayer, 1985) and attenuation (Kalisch et al., 2006; Przybyla, Haaland, Bagesteiro & Sainburg, 2011) in older adults. A recent study (Sivagnanasunderam, Gonzalez, Bryden, Young, Forsyth & Roy, 2015) reports that conflicting findings are attributed to task differences; therefore, this study sought to differentiate between these hypotheses in the context of an everyday task.

Summarizing, the purpose of the current study was to use end-state comfort as a means to assess planning and control processes in left and right handed older adults. A familiar task was selected to delineate whether age-related performance differences are context specific. This study also sought to examine the effects of aging on manual asymmetries. The specific research questions and hypotheses for this study were as follows:

1) How do end-state comfort planning and movement kinematics in older adults compare to young adults as a function of the movement context? Older adults are generally more dependent on feedback control; therefore it was hypothesized that older adults' performance would differ in pantomime. That said, considering the habitual nature of the task, it was hypothesized that older adults would display end-state comfort planning similar to young adults, where differences would emerge exclusively in kinematic measures.

2) How do end-state comfort planning and movement kinematics in older adults compare to young adults as a function of hand preference and hand used to complete the task? The literature presents with conflicting findings with respect to the effects of aging on manual asymmetries; therefore this study sought to examine whether manual asymmetries remain consistent, attenuate or increase with age in everyday object manipulation.

3.3. Methods

3.3.1. Participants

Twenty-two older adults were recruited from a research in aging participant pool. This included 11 right handers (8 female; M_{age} = 71.18, *SD* = 6.63) and 11 left handers (7 female; M_{age} = 74.00, *SD* = 6.56). Data were compared to young adults from Chapter 2. This included 10 right handers (4 female; M_{age} = 25.40, *SD* = 4.60) and 10 left handers (4 female; M_{age} = 24.90, *SD* = 4.63). All participants were without any known neurologic or musculoskeletal impairments that may have influenced performance. All had normal or corrected to normal vision and hearing. The office of research ethics approved all recruitment and testing procedures. Informed consent was obtained.

3.3.2. Apparatus and procedures

Participants were seated at a table and asked the hand used for writing to denote self-report hand preference. The 20-item Waterloo Handedness Questionnaire (Cavill & Bryden, 2003) the Grooved Pegboard (Lafayette Instruments, Model # 3205; Matthews & Klove, 1964) and an overturned glass task (Fischman, 1997) were then performed.

3.3.2.1. Waterloo Handedness Questionnaire

Participants selected one of five responses for 20-unimanual items: "left always" (-2), "left usually" (-1), "uses both hands equally often" (0), "right usually" (+1), and "right always"

(+2). A handedness score was computed by summing the responses (Cavill & Bryden, 2003). Scores (reported in Table 3.1) were used to confirm participant hand preference and to help delineate the effect of age on manual asymmetries.

3.3.2.2. Grooved Pegboard

Place (i.e., move 25 key-shaped pegs from receptacle to end position) and replace (i.e., remove pegs from holes and return to receptacle) tasks were completed three times with the left and right hand to assess manual speed and precision (Bryden & Roy 2005). Laterality quotients were computed by taking the difference between average left- and right-hand times ((left-hand time – right-hand time) / (left-hand time + right-hand time)) and multiplying the result by 100 (Table 3.1). This measure does not have a unit. Mean laterality quotients (reported in Table 3.1) were used to shed light on the effects of age on manual asymmetries, as the grooved pegboard is a standard assessment of motor performance.

Table 3.1

Handedness scores from the Waterloo Handedness Questionnaire and laterality quotients computed from the Grooved Pegboard place and replace tasks [Mean (standard deviation)]

	Older Adults		Young Adults	
	Left handed	Right handed	Left handed	Right handed
Waterloo Handedness Questionnaire	-19.63 (22.46)	31.91 (4.41)	-21.40 (4.55)	28.80 (3.26)
Grooved Pegboard Place	6.25 (14.04)	5.60 (5.88)	-3.57 (4.59)	6.25 (2.96)
Grooved Pegboard Replace	0.05 (6.17)	3.36 (7.29)	-2.41(8.62)	2.92 (3.82)

3.3.2.3. Overturned glass task

Participants demonstrated or performed the action of picking up a glass as if to pour water in four movement contexts: (1) pantomime without a stimulus; (2) pantomime with an image of the glass as a guide; (3) pantomime with glass as a guide; and (4) actual grasping. Trials that used an image and glass as a guide were counterbalanced between participants.

Pantomimed actions were performed prior to actual use to avoid providing cues as to correct performance (e.g., Heath et al., 2002). Eighty trials were captured on video and coded offline. In critical trials (overturned glass), an initially uncomfortable posture that ended with a comfortable thumb-up end-state was coded as end-state comfort; whereas, in control trials (upright glass), a thumb-up grasp throughout the task was identified as end-state comfort. The percentage of end-state comfortable grasps was computed.

One Optotrak camera (Northern Digital Inc., Waterloo, Ontario) mounted to the wall recorded three-dimensional displacement data at 200 Hz for 10 seconds. To ensure each of the two infrared emitting diode markers were visible during wrist rotation a 9cm ‘fin’ was attached to each wrist with a Velcro strap. Each trial started with eyes closed and hands at the body midline. Participants were instructed to demonstrate the action of picking up a glass as if to pour water. Custom E-prime software (Version 1.1a) provided verbal instruction of which hand to use (left or right; e.g., please use your right hand). After hearing a ‘beep’, participants opened their eyes, reached to an ‘X’ marked within a box, performed the action (based on the orientation of the stimulus), moved horizontally outside the box, and returned to the home position (see Figure 3.1). Within ‘pantomime without a stimulus’ an additional verbal cue prior to the ‘beep’ specified the orientation of the glass (e.g., please use your left hand for overturned cup).

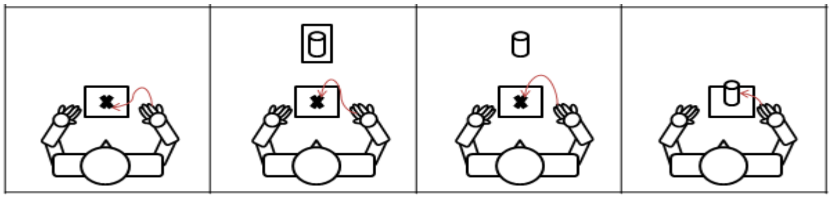

Figure 3.1. Study set up for: (1) pantomime without a stimulus, (2) pantomime with image as a guide; (3) pantomime with glass as a guide; and (4) actual grasping.

Optotrak data were collected at 200Hz. A third-order Butterworth dual pass filter at 10Hz was used with custom MATLAB® software. Each action was divided into reach/approach, grasp/transport, and use. Movement time in reach/approach was defined as the duration between reaction time (resultant velocity reaching an absolute value of 10mm/s for 20ms) and the end of the initial reach (resultant velocity reaching an absolute value below 100mm/s for 20ms). Resultant peak velocity was computed in this phase. Grasp/transport time was defined as the duration between the end of reach/approach and the end of the movement towards the 'X' (resultant velocity reaching an absolute value below 100mm/s for 20ms in box where action was to be performed). Grasp time was included with transport because of technical problems of only having one IRED per hand and one Optotrak camera (i.e., missing data). Finally, use time was defined as the duration between the end of the grasp/transport phase until the participant made a horizontal movement and exited the box (resultant velocity reaching an absolute value below 100mm/s for 20ms). Trials with missing raw data greater than 20 ms and where the RT fell below 100 ms or above 1500 ms were removed prior to analyses. These are derived from the literature (i.e., similar to Gnanaseelan, Gonzalez & Niechwiej-Szwedo, 2014).

3.4. Results

All dependent variables were analyzed with sex (male x female) as a factor. However, no significant effects or interactions emerged. As such, sex will not be discussed further.

3.4.1. Waterloo Handedness Questionnaire

A 2 age group (older adults x young adults) by 2 handedness group (left handers x right handers) two-way analysis of variance test (ANOVA) was used to assess scores computed from the Waterloo Handedness Questionnaire. An effect of hand preference emerged (*F* (1,

38) = 186.597, $p < .001$, $\eta^2 = .831$; see Table 3.1), such that mean scores of left handers were significantly lower (i.e., more negative, indicative of left hand preference) than right handers (i.e., more positive, indicative of right hand preference). There was no interaction between age group and handedness group, indicating that the direction and strength of hand preference was comparable for the two age groups.

3.4.2. Grooved Pegboard

Two separate 2 age group (older adults x young adults) by 2 handedness group (left handers x right handers) two-way ANOVAs were used to assess laterality quotients computed from the place and replace components of the grooved pegboard task. For the place task, there was an interaction between age group and handedness group (F (1, 38) = 4.223, $p = .047$, $\eta^2 = .100$; see Table 3.1). Observing right handed participants, no differences emerged between young and older adults. In comparison, for left handed participants, the laterality quotient of older adults was significantly more positive than that of young adults. In other words, left handed older adults were more proficient with the right-hand. In light of this, no differences emerged between right and left handed older adults; however, the laterality quotients of left handed young adults were more negative (indicative of superior left-hand performance) and those of right handed young adults were more positive (indicative of superior right-hand performance). Analysis of the replace task revealed a main effect of handedness group (F (1, 38) = 4.347, $p = .044$, $\eta^2 = .103$; see Table 3.1). Laterality quotients computed from left handers' performance were significantly more negative than right handers.

3.4.3. Overturned glass task: End-state comfort

Video coding revealed a thumb-up grasp posture was maintained by all participants in control trials (upright glass). Therefore, observational analysis was performed exclusively on the proportion of trials that participants demonstrated end-state comfort in critical trials (overturned glass). A mixed design ANOVA was used for analysis. Between subjects factors included age group (older adults x young adults) and handedness group (left handers x right handers), whereas within subjects factors included movement context (pantomime without stimulus x with image x with glass x actual grasping) and hand used to complete the task (left x right). Post hoc analyses were performed using a Bonferroni adjustment for multiple comparisons. Levene's Test of Equality of Error Variance was significant (p = .001); therefore indicating that the variability was significantly different. An arc sine transformation was applied to the data (Field, 2013); however, this did not correct for heterogeneity of variance (i.e., Levene's test remained significant). Tests of within and between-subjects effects were the same for both transformed and untransformed data. As there is no known non-parametric equivalent for a mixed design ANOVA and, considering that ANOVA is robust to these violations, results are presented from un-transformed data, in percentages.

There was a significant interaction between the movement context and age group in critical trials (F (3, 114) = 3.044, p = .032, η^2= .074; see Figure 3.2). Pairwise comparisons indicated older adults' sensitivity to end-state comfort did not differ from young adults. However, as a group, older adults displayed less end-state comfort as a function of movement context; specifically, in pantomime without a stimulus (p = .004), and with image (p = .022) compared to pantomime with glass. Less end-state comfort was also displayed in pantomime without a stimulus (p = .004) and with image (p = .028) compared to actual grasping.

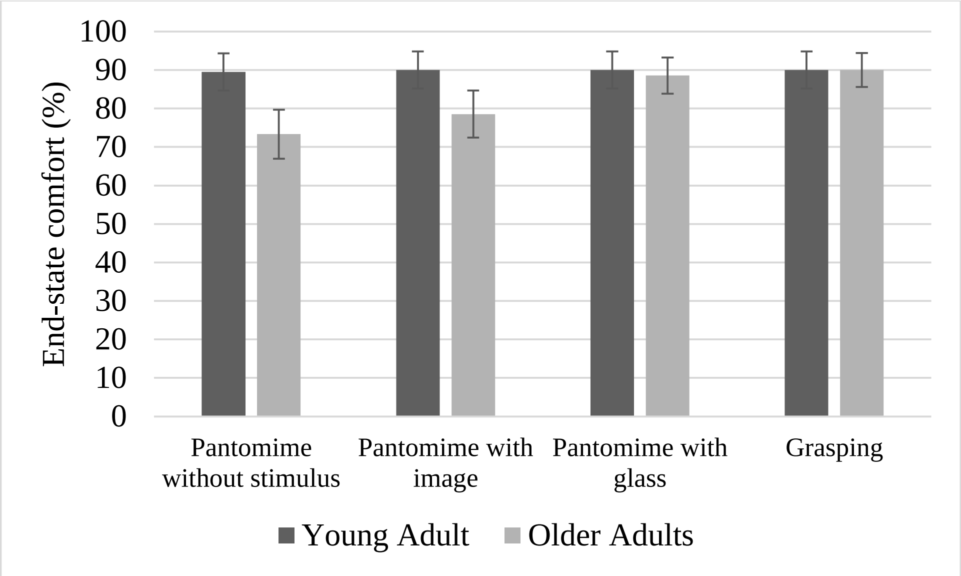

Figure 3.2. Mean percentage of end-state comfortable grasps displayed by young and older adults as a function of movement context. Error bars represent standard error.

3.4.4. Overturned glass task: Kinematic measures

Kinematic analyses revealed unexpected technical problems resulting from only one IRED per hand and one Optotrak camera. This prevented the inclusion of one left handed older adult, as there was too much missing data. Furthermore, despite pre-emptive measures (i.e., attaching a 9cm fin to participants' wrists) wrist rotation in critical trials obstructed the view of the IRED in some cases. This is reflected in varying degrees of freedom. The amount of missing data varied as a function of all factors (i.e., group, hand used, movement context, glass orientation). When collapsed, 4% of data was missing for young adults, and 3% for older adults.

Participant grasp posture also influenced analyses. In critical trials (overturned glass), an initial grasp that satisfied end-state comfort required wrist rotation; however, participants who were not sensitive to end-state comfort maintained a thumb-up posture. Participants who did not reliably display end-state comfort were excluded from analysis of critical trials to ensure comparison based on the same movement. Two groups of older adults thus emerged: those who did (*n* = 13) and did not reliably (*n* = 9; i.e., 100% of the time) display end-state comfort. An independent samples t-test was performed to assess if the two groups of older adults differed as a function of age. Older adults who did not reliably display end-state comfort (M_{age} = 76.78, *SD* = 7.29) were significantly older than those who did (M_{age} = 69.68, *SD* = 4.29; *t* (20) = -2.874, *p* = .009).

Dependent measures (reaction time, movement time in reach/approach, resultant peak velocity, grasp/transport time, use time) were analyzed with mixed ANOVAs. Within subjects factors included the movement context and hand used to complete the task. Between subjects factors included handedness group and participant group. For critical trials (overturned glass) 2 participant groups were assessed (young adults, older adults who did display end-state comfort). To elucidate differences in older adults who did and did not reliably display end-state comfort (beyond the effect of age), control trials (upright glass) were analyzed as a function of 3 groups (young adults, older adults who did and did not display end-state comfort). Finally, in recognition of differences emerging from the movement context (i.e., advanced information of glass orientation in pantomime) separate analyses were performed for pantomime without a stimulus. Post hoc analyses were performed using a Bonferroni adjustment for multiple comparisons.

Due to the plethora of significant main effects and interactions that emerged, only results that speak to the two main research questions are elaborated upon in the text. Control and critical trials are discussed with respect to each of the dependent measures. Other significant effects and interactions that emerged in analysis can be found in the supplementary material (Tables 3.2 and 3.3).

3.4.4.1. Reaction time

No significant effects or interactions emerged in critical trials with respect to the two research questions (see Supplementary Material Table 3.2 for other significant effects). Nevertheless, in control trials (upright glass), a 3-way interaction between movement context, hand preference and participant group (F (6, 90) = 2.582, p = .024, η^2 = .147; see Figure 3.3) emerged. Pairwise comparisons revealed that, for older adults who displayed end-state comfort, left handers' reaction time was longest in pantomime with image compared to all other movement contexts. For right handers, reaction time was shortest in pantomime without a stimulus compared to pantomime with image and glass and longer in pantomime with glass compared to image. Next, for older adults who did not reliably display end-state comfort, no differences emerged for left handers; however, for right handers, reaction time was shorter in actual grasping than pantomime without a stimulus and with image and in pantomime with a glass compared to image. A longer reaction time was displayed in pantomime without a stimulus compared to both other groups. Finally, for young adults, no differences emerged in left handers; however, for right handers, reaction time was shorter in pantomime without a stimulus compared to the other movement contexts.

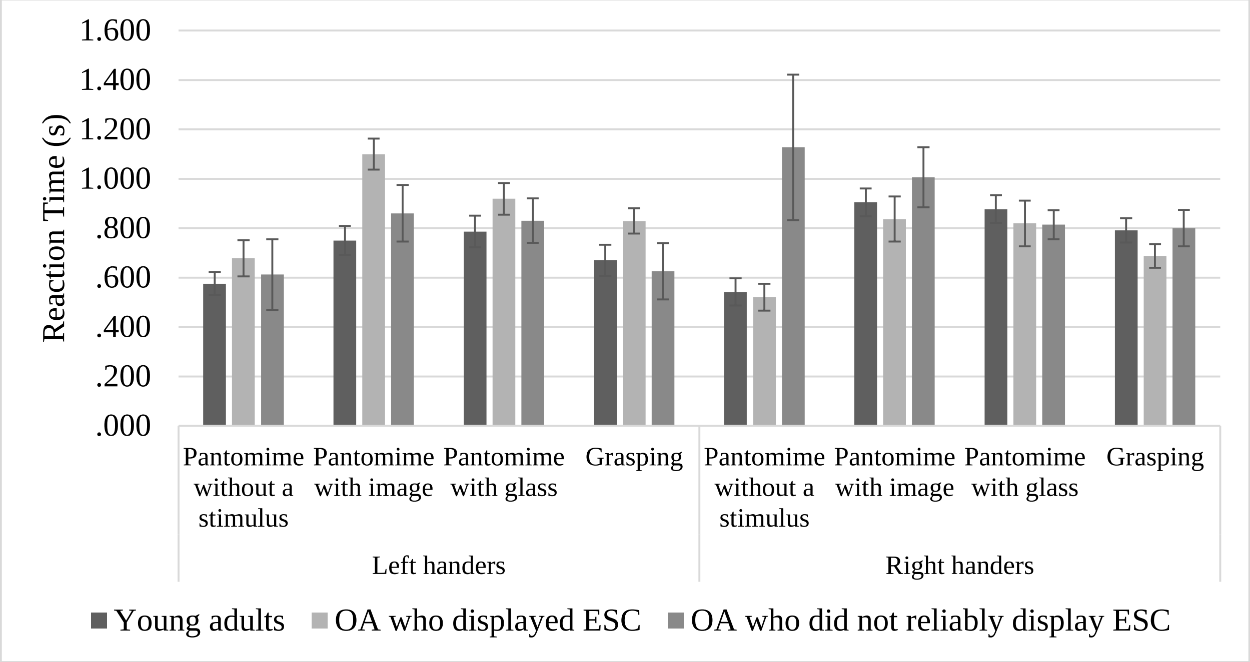

Figure 3.3. A 3-way interaction between group, hand preference and movement context revealed no differences between left and right handers; however, differences as a function of group and movement context emerged. Error bars represent standard error.

3.4.4.2. Movement time in reach / approach

No significant main effects or interactions that related to the research questions and hypotheses were obtained. All others can be found in Supplementary Material Tables 3.2 (critical trials) and 3.3 (control trials).

3.4.4.3. Resultant peak velocity

No significant effects or interactions emerged in critical trials with respect to the two research questions (see Supplementary Material Table 3.2 for other significant effects). In control trials, there was a significant interaction between participant group and hand for resultant peak velocity (overturned glass; F (2, 30) = 6.044, p = .006, η^2 = .287; see Figure 3.4). Pairwise comparisons revealed that, in left-hand performance the resultant peak velocity of young adults was significantly greater than older adults who did not reliably display end-state comfort. No other differences emerged.

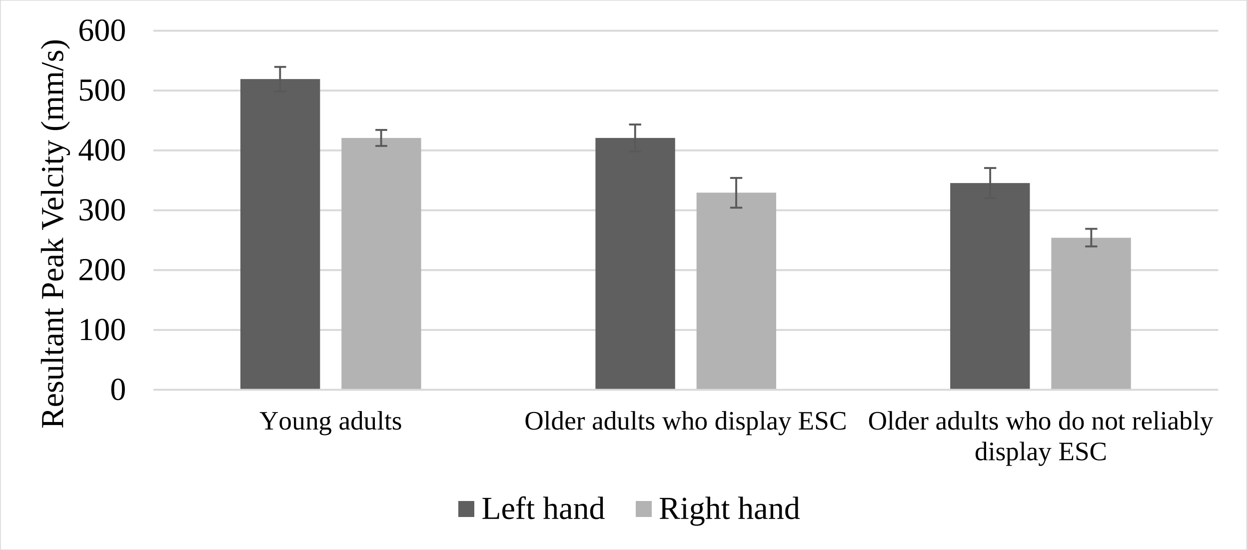

Figure 3.4. Analysis of resultant peak velocity in control trials revealed left-hand resultant peak velocity of young adults was significantly greater than older adults who did not reliably display end-state comfort. No other differences emerged. Error bars represent standard error.

3.4.4.4. Grasp / transport time

An interaction between movement context and group emerged in critical trials (F (3, 42) = 3.624, p = .021, η^2 = .206; see Figure 3.5). Pairwise comparisons revealed that grasp / transport time did not differ between older adults and young adults. For older adults, no differences emerged between pantomime without a stimulus and actual grasping; however, grasp / transport time was shorter than pantomime with image and glass as a guide, which also did not differ. For young adults, grasp / transport time was shorter in pantomime without a stimulus compared to all other movement contexts.

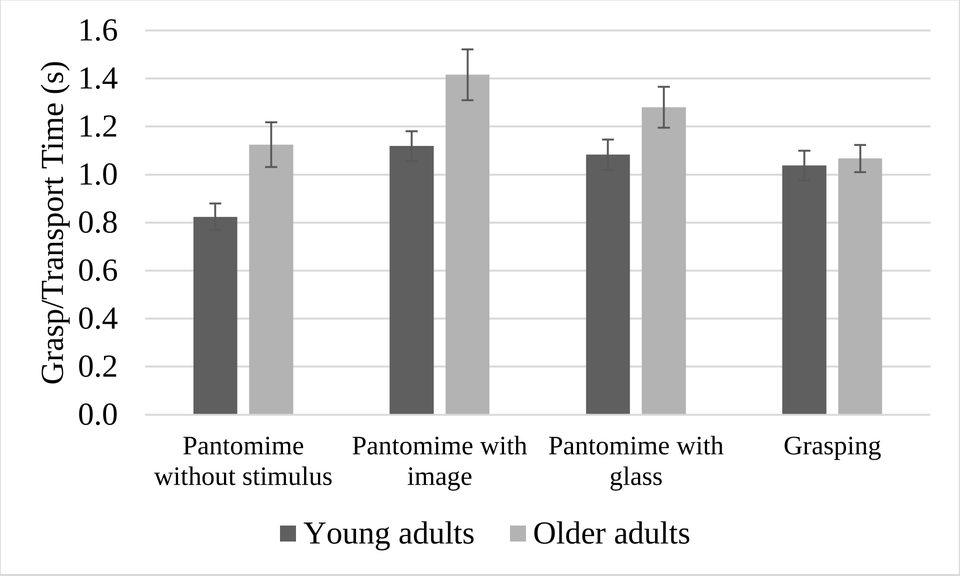

Figure 3.5. Analysis of grasp/transport time in critical trials revealed no overall difference between older and young adults; however, differences emerged within each group as a function of movement context. Error bars represent standard error.

Analysis of control trials revealed a main effect of group (*F* (2, 30) = 3.963, *p* = .030, η^2 = .209); however, post hoc analyses using a Bonferroni correction for multiple comparisons revealed no statistically significant differences between young adults (*M* = 0.990, *SD* = 0.313) and older adults who did (*M* = 1.291, *SD* = 0.526; *p* = .068) or did not (*M* = 1.477, *SD* = 0.514; *p* = .081) reliably display end-state comfort. A main effect of participant group also emerged when analyzing pantomime without a stimulus exclusively (*F* (2, 30) = 5.539, *p* = .009, η^2 = .270). Here, grasp/transport time was longer for older adults who did not display end-state comfort (*M* = 1.695, *SD* = 0.682) compared to young-adults (*M* = 0.831, *SD* = 0.287). Older adults who displayed end-state comfort (*M* = 1.135, *SD* = 0.425) did not differ from the other groups.

3.4.4.5. Use time

Defined as the duration between the end of the grasp/transport phase until the participant made a horizontal movement and exited the box (resultant velocity reaching an absolute value below 100mm/s for 20ms), no significant effects or interactions emerged in critical trials with respect to the two research questions (see Supplementary Material Table 3.2 for other significant effects). Analysis of control trials revealed a significant interaction between participant group, hand preference and hand when pantomime without a stimulus was assessed independently (*F* (1, 21) = 6.119, *p* = .022, η^2 = .226; see Figure 3.6). Pairwise comparisons revealed that left handed older adults had a longer use time with the right- than left-hand. Use time did not differ within the two hands for left handed young adults, right handed older adults or young adults.

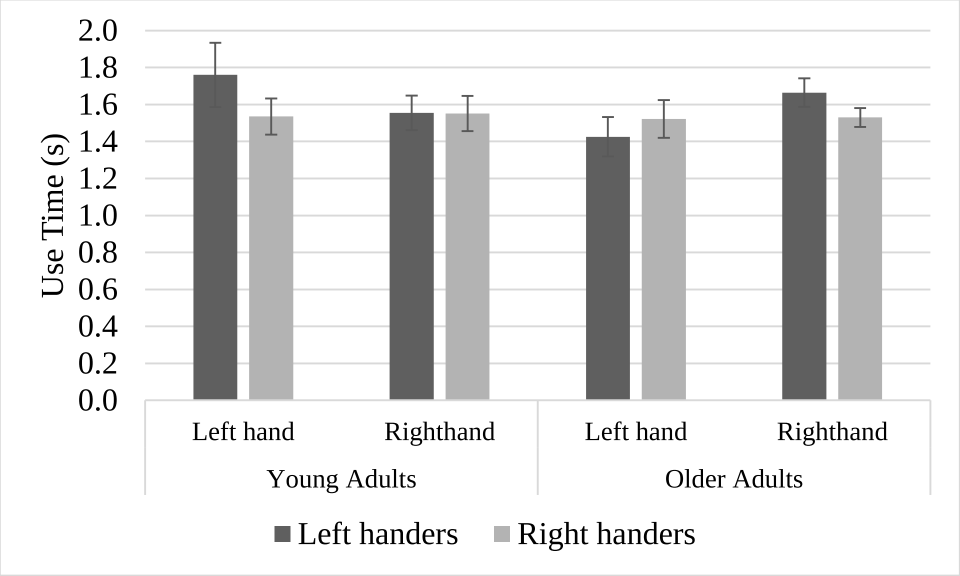

Figure 3.6. Analysis of use time in pantomime without a stimulus revealed left handed older adults had a longer use time with the right- than left-hand. Error bars represent standard error.

3.5. Discussion

Changes in the kinematics of reaching and grasping as a function of age are commonly reported (e.g., Contreras-Vidal et al., 1998; Darling et al., 1989, Diggles-Buckles, 1993); however, age-related performance differences are not always observed (Carnahan et al., 1998; Cicerale et al., 2014; Varadhan et al., 2012). It has therefore been argued that poor performance emerges due to the inability of older adults to deal with unfamiliar, ecologically atypical tasks as aging studies have typically used meaningless objects (Cicerale et al., 2014). As such, this study sought to investigate the effects of aging on planning and control processes in an everyday task (i.e., picking up a glass).

3.5.1. Movement context

As a group, older adults did not differ from young adults with respect to sensitivity to end-state comfort. Paralleling previous reports of reaching and grasping in other natural tasks, performance was observed to be conserved with age (Carnahan et al., 1998; Varadhan et al., 2012). This supports our hypothesis that older adults would display the same sensitivity to end-state comfort as young adults, as a result of the habitual nature of the task (Herbort & Butz, 2011).

That said, within the older adult group, less end-state comfort was displayed in pantomime without a stimulus and with image as a guide compared to pantomime with glass as a guide and actual grasping. In other words, the increase in available contextual information was coupled with an increase in end-state comfort planning, providing evidence for our alternate hypotheses. In support of the “supply and demand” framework (Siedler et al., 2010), it can be argued that, without direct vision of the object, age-related decline in cognitive resources—such as working memory—limited compensatory mechanisms guiding activation of the motor program needed to plan movement to an imagined object (Randerath et al., 2009; Cicerale et al., 2014). Nevertheless, as more contextual information was provided with the image, older adults were increasingly less reliant on feed forward control and performance improved. In turn, presence of the object, whether used as a guide or in actual grasping, enabled older adults to plan in the same manner as young adults.

In order to elucidate differences within older adults, participants were separated into two groups based on sensitivity to end-state comfort. Older adults who did not reliably display end-state comfort were significantly older than those who did by approximately 7 years, providing support for gradual changes with increasing age. Kinematics were analyzed in critical trials (i.e., overturned glass) to examine performance differences between young and older adults who were sensitive to end-state comfort. In addition, control trials (i.e., upright glass) were examined to differentiate between older adults who did and did not display end-state comfort, in comparison to young adults.

Older adults who reliably displayed end-state comfort performed similar to young adults in both control and critical trials. Therefore, in addition to displaying the same behavioural evidence of motor planning, movement kinematics also did not differ from young adults. As discussed previously, this is likely attributed to the everyday nature of the task (e.g., Varadhan et al., 2012). For older adults who did not display end-state comfort, this was not entirely the case, as there was a trend towards an increase in grasp/transport time (i.e., young adults< older adults who displayed end-state comfort< older adults who did not display end-state comfort) in control trials. Furthermore, independent assessment of pantomime without a stimulus revealed older adults who did not display end-state comfort had a significantly longer grasp/transport time than young adults. The average grasp/transport time (in pantomime without a stimulus) of older adults who displayed end-state comfort fell in the middle of both groups, and did not differ from either group. As grasp/transport time was defined as the duration between the end of reach/approach phase and the end of the movement towards the ‘X,’ the measure is representative of the final deceleration phase of movement.

Lengthening of the deceleration phase is reported to lead to a 15 to 30% increase in movement time for older adults (e.g., Diggles-Buckles, 1993) and has been attributed to an increase in feedback-dependent corrective mechanisms needed to continuously and consciously modify movements to meet action requirements (Bennett & Castiello, 1994; Roy et al., 1996). According to Cicerale et al. (2014) older adults’ strategy reflects compensation, whereby a “play it safe” strategy, characterized by a longer deceleration phase and less wrist rotation, is assumed to reduce the likelihood of error. Cicerale et al. (2014) also discuss the possibility that older adults display less wrist rotation due to a decrease in flexibility typically observed around the age of seventy (Carmeli et al., 2003). Although a cautious strategy and less wrist rotation likely combine to influence older adults’ movement strategies in some cases, considering older adults performed similar to young adults in actual grasping, differences are arguably attributed to differences in feedback provided when interacting with a real object (Randerath et al., 2009)

In summary, when provided with direct vision of an object, older adults perform the same as young adults in natural tasks. However, with age, we see a longer deceleration phase and less end-state comfort with less contextual information to guide movement. These changes in movement strategies reflect an increased reliance on feedback control, and thus the demonstration of a more cautious movement.

3.5.2. Hand preference and hand used to complete the task

Beyond the assessment of end-state comfort and movement kinematics, the current study also sought to differentiate between conflicting findings regarding manual asymmetries and aging. More specifically, whether they: (1) are not affected by age (Chua et al., 1995; Francis & Spirduso, 2000; Gonzalez et al., 2015; Gooderham & Bryden, 2014); (2) increase with age (Weller & Latimer-Sayer, 1985); (3) attenuate with age (Kalisch et al., 2006; Pryzbyla et al., 2011); or (4) are task-dependent (Sivagnanasunderam, et al., 2015). For the most part, results of the current study support the notion that asymmetries are not affected by age (Chua et al., 1995; Francis & Spirduso, 2000; Gooderham & Bryden, 2014). Looking at behavioural evidence of planning, in end-state comfort, no differences emerged between young and older adults as a function of hand used to complete the task, or hand preference. Furthermore, differences between the two hands and handedness groups that emerged in analyses of kinematic measures were not attributed to age-related differences. Finally, analyses of scores computed from the Waterloo Handedness Questionnaire and replace component of the Grooved Pegboard task revealed no differences as a function of age.

Nevertheless, analyses of the Grooved Pegboard place task revealed that left handed older adults were more proficient with the non-preferred, right hand than the preferred, left hand. This result supports Sivagnanasunderam et al. (2015) who argue that the effect of age on manual asymmetries manifest differently as a function of task. Sivagnanasunderam et al. (2015), like many others, limited their analyses to right handed individuals. Results of the current study thus add the perspective of aging left handers. Previous reports indicate that, with age there is a shift toward right hand use in left handers (e.g., Kumar, Misra, Suman, Suar & Mandal, 2010). For example, Kumar et al. (2010) speak to the idea that left handed individuals, living in a right handed world, may shift their natural hand preference toward the right side due to covert (social) and overt (environmental) influences (Coren & Halpern, 1991; Kumar et al., 2010). This is particularly true for older left handed individuals, who may have been pressured to use the right-hand during childhood, and had limited exposure to left handed tools over the course of development (Galobardes, Bernstein & Morabia, 1999). Anecdotally, many of the left handed older adults spoke to childhood experiences in school and how teacher and parent perceptions could have shaped differences in hand selection for particular tasks. This is particularly important to consider when working with the aging population.

3.6. Summary and Conclusions

The current research provides evidence to support the notion that, early in the aging process, there are no differences in older adults' movements. However, with increasing age, differences in the ability to plan and control movements gradually appear, as cognitive demand increases and compensatory mechanisms become limited. Age-related performance differences are not always observed in the literature, where it has been argued that poor performance can be attributed to the unfamiliarity of the laboratory task that older adults have been asked to perform. Using an everyday task, the current research helps to clarify that age-related differences are indeed present. This was seen observationally, through sensitivity to end-state comfort and kinematically in lengthening of the deceleration phase in pantomime. Findings from the current study indicate that, for the most part, there are no between-hand differences in left and right handers with age; however, as revealed in the place phase of the Grooved Pegboard task, left handers may display a shift towards right handedness in some cases.

As summarized by Seidler et al. (2010)

> The ability to mitigate or even reverse age-related motor deficits will be critical for successful aging in our graying society. By preventing or compensating for brain changes and motor performance deficits, older adults will be better able to perform activities of daily living such as operating a motor vehicle safely, avoiding a potentially injurious fall, and performing daily chores around the house. (p. 12).

Continued research in this area will help to shed light on the healthy aging process and provide a foundation for future research examining age-related deficits that emerge following stroke (i.e., apraxia).

3.7. Supplementary material

Table 3.2

Main effects and interactions in critical trials (overturned glass) that did not speak to the two main research questions

Critical		Variable 1 *M (SD)*	Variable 2 *M (SD)*	Variable 3 *M (SD)*	Variable 4 *M (SD)*
Reaction Time (s)	**Movement context** F (3, 54) = 31.989, p < .001, η^2 = .640	Pantomime no stimulus	Pantomime with image	Pantomime with glass	Actual Grasping
		0.569(0.189)	0.926(0.272)	0.853(0.238)	0.751(0.218)
Movement time in reach / approach (s)	**Movement context** F (3,48) = 7.268, p < .001, η^2 = .312	Pantomime no stimulus	Pantomime with image	Pantomime with glass	Actual Grasping
		0.900(0.244)	0.848(0.180)	0.818(0.146)	0.789(0.244)
	Hand F (1,16) = 11.176, p = .001, η^2 = .411	Left-hand	Right-hand		
		0.788(0.177)	0.842(0.188)		
Pantomime ONLY	**Hand** F (1, 22) = 5.376, p = .030, η^2 = .196	Left-hand	Right-hand		
		0.864(0.204)	0.933(0.172)		
Resultant peak velocity (mm/s)	**Movement context** F (3,54) = 3.257, p = .028, η^2 = .153	Pantomime no stimulus	Pantomime with image	Pantomime with glass	Actual Grasping
		687.555 (195.165)	762.813 (209.444)	767.553 (203.429)	755.716 (133.259)
	Hand F (1, 18) = 4.844, p = .040, η^2 = .212	Left-hand	Right-hand		
		781.564 (169.501)	708.393 (144.379)		
Grasp / transport time (s)	**Movement context** F (3,42) = 12.292, p < .001, η^2 = .468	Pantomime no stimulus	Pantomime with image	Pantomime with glass	Actual Grasping
		0.964(0.409)	1.259(0.461)	1.176(0.397)	1.052(0.293)
	Hand F (1, 14) = 19.172, p = .001, η^2 = .578	Left-hand	Right-hand		
		1.233(0.438)	1.101(0.358)		
Pantomime ONLY	**Hand** F (1, 21) = 21.736, p < .001, η^2 = .509	Left-hand	Right-hand		
		1.073(0.442)	0.868(0.360)		
Use time(s)	**Movement context** F(3, 42) = 8.505, p = <.001, η^2 = .345	Pantomime no stimulus	Pantomime with image	Pantomime with glass	Actual Grasping
		1.562(0.263)	1.445(0.256)	1.450(0.263)	1.442(0.250)
	Movement context x Hand F (3,42) = 3.268, p = .030, η^2 = .189	Pantomime no stimulus	Pantomime with image	Pantomime with glass	Actual Grasping
	Left-hand	1.547(0.300)	1.432(0.287)	1.373(0.276)	1.391(0.231)
	Right-hand	1.575(0.209)	1.461(0.241)	1.500(0.231)	1.480(0.231)

Table 3.3

Main effects and interactions in control trials (upright glass) that did not speak to the two main research questions

Control		Variable 1 *M (SD)*	Variable 2 *M (SD)*	Variable 3 *M (SD)*	Variable 4 *M (SD)*
Reaction time(s)	**Movement context** *F* (3, 90) = 9.208, *p* < .001, η^2 = .235	Pantomime no stimulus	Pantomime with image	Pantomime with glass	Actual Grasping
		0.657(0.422)	0.905(0.284)	0.864(0.242)	0.760(0.219)
	Movement context x Hand *Assumption of sphericity violated (χ^2 (5) = 14.902, *p* = .015); therefore Greenhouse-Geisser correction applied: *F* (2.224, 66.718) = 3.438, *p* = .033, η^2 = .103	Pantomime no stimulus	Pantomime with image	Pantomime with glass	Actual Grasping
	Left-hand	0.591(0.379)	0.917(0.275)	0.876(0.236)	0.756(0.205)
	Right-hand	0.704(0.459)	0.929(0.295)	0.854(0.251)	0.774(0.235)
Pantomime ONLY	**Hand** *F* (1, 30) = 6.033, *p* = .020, η^2 = .167	Left-hand	Right-hand		
		0.603(0.393)	0.711(0.476)		
Movement time in reach / approach (s)	**Movement context** *F* (3, 90) = 9.985, *p* < .001, η^2 = .250	Pantomime no stimulus	Pantomime with image	Pantomime with glass	Actual Grasping
		0.870(0.385)	0.808(0.218)	0.788(0.189)	0.740(0.140)
	Hand Preference x Hand *F* (1,30) = 7.282, *p* < .011, η^2 = .195	Left-hand	Right-hand		
	Left handers	0.801(0.171)	0.823(0.208)		
	Right handers	0.816(0.203)	0.764(0.166)		
	Movement context x Hand *F* (3, 90) = 4.079, *p* = .009, η^2 = .120	Pantomime no stimulus	Pantomime with image	Pantomime with glass	Actual Grasping
	Left-hand	0.849(0.208)	0.823(0.187)	0.800(0.186)	0.762(0.158)
	Right-hand	0.892(0.249)	0.793(0.185)	0.775(0.146)	0.717(0.166)
Pantomime ONLY	**Hand Preference x Hand** *F* (1, 30) = 25.055, *p* < .001, η^2 = .157	Left-hand	Right-hand		
	Left handers	0.836(0.184)	0.962(0.287)		
	Right handers	0.862(0.230)	0.827(0.193)		
Resultant peak velocity (mm/s)	**Hand** *F* (1, 30) = 34.851, *p* = .006, η^2 = .537	Left-hand	Right-hand		
		437.385 (170.301)	291.357 (131.045)		
Pantomime ONLY	**Hand** F (1, 30) = 25.055, p < .001, η^2 = .455	Left-hand	Right-hand		
		433.596 (165.635)	282.264 (102.995)		
Grasp / transport time (s)	**Movement context** *F* (3, 90) = 9.029, *p* < .001, η^2 = .231	Pantomime no stimulus	Pantomime with image	Pantomime with glass	Actual Grasping
		1.083(0.514)	1.314(0.522)	1.259(0.433)	1.086(0.369)
Use time (s)	**Movement context** *F* (3, 90) = 4.629, *p* = .005, η^2 = .134	Pantomime no stimulus	Pantomime with image	Pantomime with glass	Actual Grasping
		1.535(0.397)	1.502(0.287)	1.437(0.263)	1.345(0.230)
	Hand (1, 30) = 7.350, *p* .011, η^2 = .197	Left-hand	Right-hand		
		1.470(0.292)	1.415(0.319)		

Chapter 4 – End-state comfort across the lifespan: A cross-sectional investigation of how the movement context influences motor planning in an overturned glass task

Chapter Research Objectives

This chapter aimed to address the following thesis objectives: (a) understand the influence of the movement context; (b) delineate the role of handedness; and (e) outline similarities and differences across the lifespan. Specific research questions and hypotheses will be outlined in section 4.2.

4.1. Abstract

Studies with children have linked a pattern of improvement in end-state comfort to the development of cognitive control processes (Wunsch et al., 2013), and studies with older adults attribute a decline in motor planning skills to cognitive decline (Chapter 3; Wunsch, Weigelt & Stöckel, 2015). Building from Chapters 2 and 3, the current study used a cross-sectional design to assess how the movement context influences sensitivity to end-state comfort planning in 5- to 12-year-olds, young adults and two groups of older adults (ages 60 to 70, and ages 71+). Findings provide evidence for adult-like patterns of end-state comfort in 8-year-olds, where improvements in proprioceptive acuity and proficiency in generating and implementing internal representations of action both contribute to age-related changes. For older adults, early in the aging process sensitivity to end-state comfort did not differ from young adults; however, with increasing age, differences reflect challenges in motor planning with increases in cognitive demand. Findings have implications for understanding end-state comfort planning

across the lifespan, which adds to our knowledge of when and at what rate motor planning skills and cognitive function are developing and declining.

4.2. Introduction

Grasping an object seems simple. However, fine-tuned cognitive and sensorimotor processes underlie grasping, and other goal-directed actions performed in everyday life. Examining these processes has important implications for understanding the rate at which motor control is developing and declining (e.g., Elliott et al., 2010). According to the posture-based motion planning theory (Jax, Rosenbaum, Vaughan, & Meulenbroek, 2003; Rosenbaum, Loukopoulos, Meulenbroek, Vaughan & Engelbrect, 1995; Rosenbaum et al., 2001) objects are handled differently based on the intended action. As such, grasp posture can be used to infer how far in advance actions are planned (Rosenbaum et al., 2012). From this perspective, first-order planning involves shaping grip aperture based on the visual appearance of the object. In contrast, second-order planning entails modifying behaviour in anticipation of secondary task demands. For example, grasping an overturned object uncomfortably (thumb down posture) to facilitate end-state comfort (thumb up posture) (Rosenbaum et al., 1990, 2012).

While there is an extensive body of research assessing sensitivity to end-state comfort in young adults (see Rosenbaum et al., 2012 for a review), literature examining the developmental trajectory is not as extensive (see Wunsch et al., 2013 for a review). Studies have implemented Rosenbaum et al.'s (1990) bar-transport task (Hughes, 1996; Jovanovic & Schwarzer, 2011; Knudsen et al., 2012; Manoel & Moreira, 2005; Smyth & Mason, 1997; Stöckel et al., 2012; Thibaut & Toussaint, 2010; Weigelt & Schack, 2010), Fischman's (1997) overturned glass task (Adalbjornsson et al., 2008; Knudsen et al., 2012; Scharoun & Bryden, 2014b) and the handle rotation task (Crajé, Aarts, Nijhuis-van der Sanden, & Steenbergen, 2010; Jongbloed-Pereboom, Nijhuis-van der Sanden, Saraber-Schiphorst, Crajé & Sttenbergen, 2013; Smyth & Mason, 1997; van Swieten et al., 2010). Second-order planning is reported to increase significantly between ages 5 and 8 which then approach an asymptote “somewhere beyond 10 years of age” (Wunsch et al., 2013, p. 69). This pattern of gradual improvement has been associated with maturation of sensorimotor functions and higher cognitive control processes (Wunsch et al., 2013), in line with other developmental research examining upper limb control (e.g., Contreras-Vidal, 2005; Hay, 1979; King et al., 2012). Nevertheless, it is not understood why young children show end-state comfort in some studies and others fail to find the effect in older children up to the age of 14 (van Swieten et al., 2010; Wunsch et al., 2013).

Discrepant results in the literature have been attributed, in part, to children’s familiarity with a task (Wunsch et al., 2013). For example, Knudson et al. (2012) compared 3- to 8-year-olds’ sensitivity to end-state comfort in the bar-transport task (Rosenbaum et al., 1990) to the overturned-glass task (Fischman, 1997). In line with previous reports, an increase in sensitivity to end-state comfort was observed with age in the bar transport task (Weigelt & Schack, 2010; Stöckel et al., 2012). Here, 13% of 3-year-olds were sensitive to end-state comfort, compared to 94% of 8-year-olds. From 3 to 4 years and 4 to 5 years, the proportion of children who displayed end-state comfort doubled; therefore providing evidence that 3- to 5-year-olds undergo a period of significant improvement in motor planning skills. Observing the overturned-glass task, sensitivity to end-state comfort was similarly observed to improve with age; however, the proportion of 3-year-olds who demonstrated the effect was much higher (i.e., 64%), supporting the notion that motor planning skills are more proficient with familiar objects, especially when assessing young children (Knudson et al., 2012). Nevertheless, sensitivity to end-state comfort in the overturned glass task was higher than previous reports

(Adalbjornsson et al., 2008), and in comparison to more recent work (Scharoun & Bryden, 2014b). More specifically, Adalbjornsson et al. (2008) reported end-state comfort in 11 of 40 children (4 preschool, 7 kindergarten). Scharoun and Bryden (2014) measured as a proportion of trials, where end-state comfort was observed in approximately 42% of 3- to 4-year-olds' trials, and 59% of 5- to 6-year-olds'.

In consideration of these, and other discrepant findings, Wunsch et al. (2013) suggested in their systematic review that "further research is needed to assess the development of end-state comfort planning and to determine the relative influence of motor skills and cognitive factors on its developmental course" (p. 74). A recent study by Stöckel and Hughes (2015) reported that working memory ability influences an individual's ability to form and maintain a motor plan sensitive to end-state comfort throughout the duration of execution. While the study was limited to 5- to 6-year-olds, it does provide concrete evidence for a link between the development of cognitive functions and end-state comfort (Stöckel & Hughes, 2015). Additional support derives from recent reports that the development of online control is constrained by executive systems (Ruddock, Hyde, Piek, Sudgen, Morris & Wilson, 2014) and can be predicted, in part, by improved action representation (Fuelscher, Williams & Hyde, 2015). The current study manipulated cognitive demand by means of altering the movement context (e.g., pantomime, actual use) in an overturned glass task. Justification for this manipulation is provided below.

Observing the other end of the lifespan, to our knowledge the study of end-state comfort in older adults is limited to Chapter 3 and one other study (Wunsch et al., 2015). Wunsch et al. (2015) had young-old (60- to 70-year-old) and old-old (71- to 80-year-old) participants perform unimanual (Rosenbaum et al., 1990) and bimanual (Weigelt et al., 2006) bar-transport tasks. In both tasks, sensitivity for end-state comfort displayed evident decline with age. In particular, the proportion of grasps that satisfied end-state comfort in old-old adults was as low as seen in previous studies with 6- to 7-year-old children (e.g., Wunsch et al., 2013). When task demands were increased (i.e., during the bimanual task), the decline in anticipatory planning was further exaggerated. In consideration of the notion that the development of anticipatory planning skill are linked to the development of cognitive skills (Rosenbaum et al., 2001; Weigelt & Schack, 2010; Stöckel & Hughes, 2015), Wunsch et al. (2015) attributed this negative developmental trend in old-older adults to cognitive decline.

Similar findings were reported in Chapter 3, albeit using the overturned glass task (Fischman, 1997). Here, task complexity was manipulated as a function of the movement context. Previous reports indicate that pantomime requires greater cognitive processing, as it requires an actor to form and maintain a mental representation of object and action until the gesture is performed. In comparison, actual use places less demand on working memory (Heath et al., 2002; Randerath et al., 2009; Roy et al., 2014). Manipulating the amount of contextual information available to guide movement, Chapter 3 had older adult participants (11 right handers, $M_{\text{age}} = 71.18$, $SD = 6.63$ and 11 left handers, $M_{\text{age}} = 74.00$, $SD = 6.56$) demonstrate grasping a glass (critical: overturned, control: upright) as if to pour water in pantomime without a stimulus, pantomime with image or glass as a guide, and actual grasping. Two groups of older adults emerged: (1) those sensitive to end-state comfort ($M_{age} = 69.69$, $SD = 4.29$); and (2) those who displayed less end-state comfort ($M_{age} = 76.78$, $SD = 7.29$) in pantomime without a stimulus and with image as a guide compared to glass as a guide and actual grasping. Kinematic analyses of control trials (upright) revealed a significant increase in grasp/transport time in pantomime without a stimulus for older adults who displayed less end-state comfort and a trend toward an increase in grasp/transport time overall. As grasp/transport time represents the final deceleration phase of movement, differences were attributed to the increase reliance on feedback control (Bennett & Castiello, 1994; Roy et al., 1996). Older adults who displayed less end-state comfort were approximately 7 years older; therefore, similar to Wunsch et al. (2015), Chapter 3 argued that differences in planning and control processes gradually appear as cognitive demand increases and compensatory mechanisms are limited (Siedler et al., 2010).

Summarizing, studies with children highlight a pattern of improvement for anticipatory planning skills that are linked to the development of cognitive control processes (Wunsch et al., 2013). In addition, studies with older adults attribute a decline in motor planning skills to cognitive decline (Chapter 3; Wunsch et al., 2015). The current study used the same overturned glass task as Chapters 2 and 3 to assess how the movement context influences sensitivity to end-state comfort planning across the lifespan. A cross-sectional design was implemented to assess end-state comfort in 5- to 12-year-old children, young adults and two groups of older adults (ages 60 to 70, and ages 71+). Based on findings from Chapter 2 that left and right handed young adults are sensitive to end-state comfort regardless of the movement context it was hypothesized that young adults would be at ceiling. Furthermore, it was hypothesized that 9- to 12-year-old children would show sensitivity to end-state comfort similar to adults (Scharoun & Bryden, 2014b), and that sensitivity to end-state comfort would decline with age; therefore less end-state comfort would be observed in older adults ages 71+ (Chapter 3). Finally, it was hypothesized that, when provided with more contextual information (actual cup use > pantomime with cup/image > pantomime with no stimulus), cognitive demand would decrease and thus, greater sensitivity to end-state comfort would be observed in older adults (e.g., Chapter 3) and children (e.g., Stöckel & Hughes, 2015).

A secondary aim of this study was to delineate whether performance differences would exists between the two hands. In Fischman's (1997) original study with the overturned glass task, adults displayed a preference for performing with one hand. More recent investigations (e.g., Janssen et al., 2009, 2011) report end-state comfort is often present for the right hand in adults, regardless of hand preference; however, Herbort and Butz (2011) and Coelho et al. (2014) argue that a desire to end comfortably prevails over a preference for one hand. A short review from Seegelke et al., (2014) also highlights a lack of manual asymmetries in motor planning. Findings from Chapters 2 and 3 provide support for the notion that hand preference does not influence sensitivity to end-state comfort. Despite the aforementioned results with young and older adults, for children, there is evidence that hand preference does indeed influence anticipatory planning skills (Scharoun & Bryden, 2014b; also see Manoel & Moreira, 2005). Participants in the current study thus completed the task with both their preferred and non-preferred hands. It was hypothesized that performance differences would be observed exclusively in children.

4.3. Methods

4.3.1. Participants

Right handed children, and young and older adults (*N* = 129) participated in this study. The University Research Ethics Board approved all recruitment and testing procedures. Informed consent was obtained from all participants and parents/guardians of participating children. In addition, verbal assent was obtained from participating children.

Young adults were undergraduate or graduate students from the university community. Older adults were recruited from an institution research in aging participant pool. Children were recruited from university summer camps, and a local private elementary school. Data collection was conducted during camp/class time, outside of the camp/class setting. Children were given stickers for completing the study.

Participants were separated into 10 age groups: 5-, 6-, 7-, 8-, 9-, 10-, 11- to 12-year-olds, young adults (M_{age} = 24.38, *SD* = 4.07), 60- to 70-year-olds (M_{age} = 64.60, *SD* =76.12) and older adults ages 71+ (M_{age} = 76.12, *SD* = 4.68; Table 4.1). Ten young adult and 11 older adult participants were from Chapters 2 and 3. It is important to acknowledge that groups were unequal in size, which was a limitation of this study. Nevertheless, analysis of variance is robust to unequal sample size, even in the face of heterogeneity of variance.

Table 4.1

Participant demographics

Age Group	N	Male : Female	WHQ_{score} (SD)
5-year-olds	12	7:5	19.83 (10.78)
6-year-olds	14	8:6	21.00 (7.78)
7-year-olds	19	8:11	26.26 (10.14)
8-year-olds	11	4:7	30.36 (7.71)
9-year-olds	8	3:5	25.63 (8.26)
10-year-olds	7	2:5	25.57 (8.26)
11- to 12-year-olds	10	2:8	25.50 (8.21)
Young adults	21	10:11	29.10 (6.07)
60- to 70-year-olds	10	3:7	30.20 (4.10)
71-year-olds+	17	9:8	29.165(7.82)
Total	129	74:55	

4.3.2. Apparatus and procedures

Participants were seated at a table as they completed each task. Each participant was first asked which hand was used for writing (colouring for children) to denote self-report hand preference. The Waterloo Handedness Questionnaire was used to confirm hand preference.

4.3.2.1. Overturned glass task. Participants were asked to demonstrate the action of picking up a cup (or to actually pick up a cup) as if to pour water within four different movement contexts: (1) pantomime without a stimulus (i.e., demonstrating the action of picking up a cup as if to pour water; (2) pantomime with image of the cup as a guide (i.e., using the image as a guide, demonstrating the action of picking up a cup as if to pour water); (3) pantomime with cup as a guide (i.e., using the cup as a guide, demonstrating the action picking up the cup as if to pour water); and (4) grasp cup (i.e., picking up the cup as if to pour water). The tasks which used the image and cup as a guide were counterbalanced between participants. Pantomimed actions were performed prior to tool-use to avoid providing cues as to correct pantomime performance (e.g., Heath et al., 2002). Both upright (control) and overturned (critical) glass conditions were assessed. Adults completed a total of 80 trials (5 trials x 4 tasks x 2 cup orientations x 2 hands), whereas children completed a total of 48 trials (3 trials x 4 tasks x 2 cup orientations x 2 hands). Initial and final grasp postures were recorded using a video camera and coded offline.

Instructions for young adults and older adults were the same as described in Chapters 3 and 4. Here, participants were instructed to demonstrate the action of picking up a glass as if to pour water. Verbal instruction of which hand to use (left or right; e.g., please use your right hand) was provided. Within ‘pantomime without a stimulus’ an additional verbal cue specified the orientation of the glass (e.g., please use your left hand for overturned cup). Instructions for child participants were similar to those of adults, with a few exceptions. Children were first asked to describe the difference between upright and overturned (or right side up and upside down) to confirm understanding. Furthermore, children were asked to identify which hand was left, and which was right. The researcher pointed at each hand if necessary throughout the duration of the study. Children were informed they would be performing the action of picking up a cup and pretending to pour a glass of water. Instructions for the remainder of the study progressed as follows:

(1) Pantomime without a stimulus: *Start with your eyes closed. Do not open them until I say go. Pretend there is a [right side up / upside down] cup on the x. Show me with your [right hand / left hand] how you would pick it up and pretend to pour a glass of water – Go!*

(2) Pantomime with image: *I have two pictures of cups – one is right side up, and one is upside down. Can you please tell me which is [upside down / right side up]? I am going to put one of the pictures on the x. Don't touch it. Just like the last activity, you are going to pretend. Start with your eyes closed. Do not open them until I say go. Show me with your [right hand / left hand] how you would pick it up and pretend to pour a glass of water – Go!*

(3) Pantomime with glass: *Now we are going to use the real cup. Can you please show me what [upside down / right side up] looks like? I am going to put the cup on the x. Don't touch it. Just like the last activity, you are going to pretend. Start with your eyes closed. Do not open them until I say go. Show me with your [right hand / left hand] how you would pick it up and pretend to pour a glass of water – Go!*

(4) Grasping: *This is the last part of the activity. Now we are actually going to pick up the real cup. Start with your eyes closed. Do not open them until I say go. Show me with your [right hand / left hand] how you would pick it up and pretend to pour a glass of water – Go!*

4.3.2.2. Waterloo Handedness Questionnaire. A self-report measure of hand preference, participants were asked to indicate their preferred hand for 20-unimanual tasks (Cavill & Bryden, 2003). Each question permits five responses: "left always" (-2), "left usually" (-1), "uses both hands equally often" (0), "right usually" (+1), and "right always" (+2). Scores were calculated by summing the responses. Left handers are expected to show a negative score while right handers are expected to show a positive score. The questionnaire was administered orally to children by reading each item aloud and explaining the item if necessary. Note that previous research has successfully used oral administration of questions as alterations to the administration of handedness questionnaires for pre-school children (e.g., Karapetsas & Vlachos, 1997).

4.4. Results

The dependent measure was the percentage of grasps that satisfied end-state comfort. Only critical trials (i.e., overturned glass) were analyzed. End-state comfort was identified as selection of an initial uncomfortable posture (i.e., thumb-down) to facilitate a comfortable end posture (i.e., thumb-up). A mixed analysis of variance (ANOVA) was used, with age group (11: 5-, 6-, 7-, 8-, 9-, 10-, 11- to 12-year-olds, young adults, 60- to 70-year-olds and older adults ages 71+), movement context (4: pantomime without a stimulus, pantomime with image/glass as a guide and actual grasping) and hand used to complete the task (2: left- and right-hand) as factors. To perform a mixed ANOVA on percentage data, an arc sine transformation was applied, however violations of homogeneity of variance still remained. As there is, to our knowledge, no known nonparametric equivalent to a mixed ANOVA (Field, 2013), the analysis was performed on the un-transformed data, in percentages. Only significant results with effect sizes equal, or approximately equal to medium (η^2 = 0.06) and large (η^2 = 0.14) benchmarks (Cohen, 1988; Lakens, 2013) will be discussed in detail

A main effect of age (F (9, 119) = 7.843, p < .001, η^2 = .062; see Figure 4.1) revealed that 5-year-olds displayed less end-state comfort than all participants ages 8-years-old and older. The 6-year-old participants displayed less end-state comfort than young adults and 60- to 70-year-olds. Finally, 7-year-olds displayed less end-state comfort than young adults.

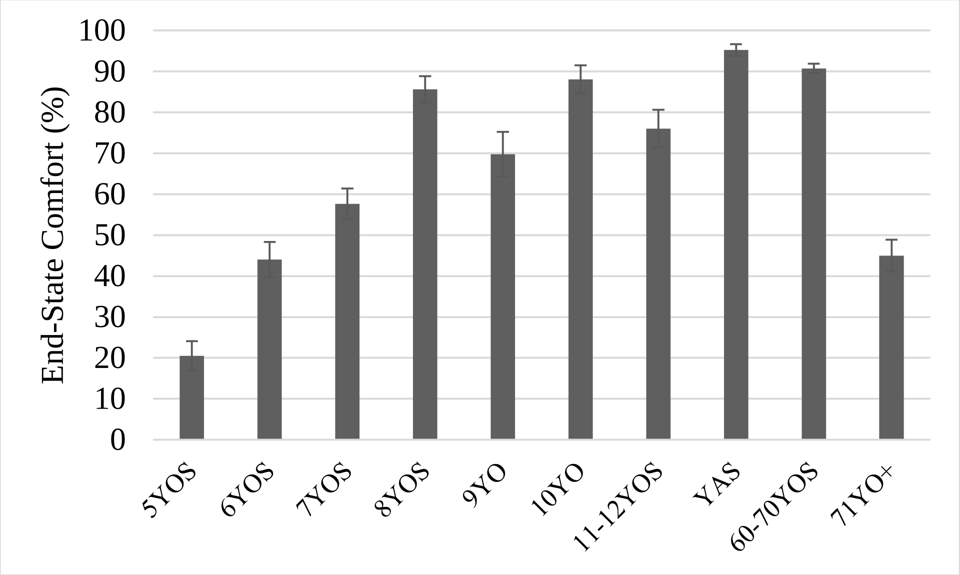

Figure 4.1. When collapsed across the four movement contexts, end-state comfort appeared adult-like in 8- to 12-year-olds. Evidence of decline was observed in older adults ages 71+, where end-state comfort did not differ from 6-year-olds. Error bars represent standard error.

A significant interaction between age and movement context (F (30, 354) = 1.908, p = .003, η^2 = .016; see Figure 4.2) was also revealed. Considering the small effect size (η^2 = .016; Lakens, 2013) it can be argued whether the data, although statistically significant, is practically significant. As such, only the most important findings will be discussed. Looking at how the movement context influenced each age group individually, 5- and 6-year-olds displayed more end-state comfort in pantomime without a stimulus compared to the other three movement contexts. The 7-year-olds also displayed more end-state comfort in pantomime without a stimulus; however, this was only in comparison to pantomime with image and glass as a guide. Observing the opposite end of the lifespan, patterns were opposite that of young children, such that older adults ages 71+ demonstrated more end-state comfort in actual grasping compared to all three other movement contexts. The 8- to 12-year-olds, young adults and 60- to 70-year-olds displayed no differences in end-state comfort as a function of movement context. A summary of how the age groups compared in each movement context can be found in Table 4.2.

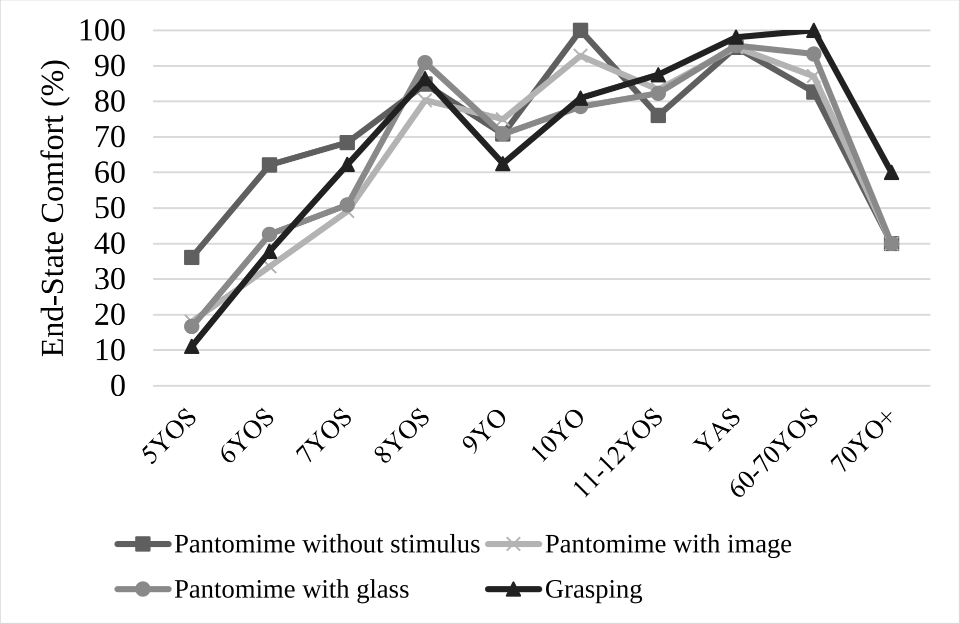

Figure 4.2. The interaction between age and movement context identified a significant increase in planning in 5- to 7-year-olds and decreased evidence in 9- and 11- to 12-year-olds. Furthermore, older adults ages 70+ performed similar to 5-year-olds in all movement contexts except actual grasping.

Table 4.2

A summary of differences that emerged between the age groups as a function of each movement context: (A) pantomime without a stimulus; (B) pantomime with image of the glass as guide; (C) pantomime with glass as a guide; and (D) actual grasping. Boxes marked with a “✘” represent no difference, and those marked with a “✓” represent a difference. The direction of the differences is also indicated. For example, 5<6 indicates that 5-year-olds displayed less end-state comfort than 6-year-olds.

A. Pantomime without a stimulus

■	**5**	**6**	**7**	**8**	**9**	**10**	**11-12**	**YA**	**60-70**	**71+**
5	■	✓ 5<6	✓ 5< 7	✓ 5< 8	✓ 5 < 9	✓ 5< 10	✘	✓ 5 < YA	✓ 5 < 60-70	✘
6	✓ 5<6	■	✘	✘	✘	✓	✘	✓ 6<YA	✓	✘
7	✓ 5<7	✘	■	✘	✘	✘	✘	✓ 7<YA	✘	✘
8	✓ 5<7	✘	✘	■	✘	✘	✘	✘	✘	✘
9	✓ 5<9	✘	✘	✘	■	✘	✘	✘	✘	✘
10	✓ 5<10	✓	✘	✘	✘	■	✓ 11-12<10	✘	✘	✓ 71+<10
11-12	✘	✘	✘	✘	✘	✓ 11-12<10	■	✓ 11-12<YA	✘	✘
YA	✓ 5<YA	✓ 6<YA	✓ 7<YA	✘	✘	✘	✓ 11-12<YA	■	✘	✓ 71+<YA
60-70	✓ 5<60-70	✓ 6<60-70	✘	✘	✘	✘	✘	✘	■	✓ 71+<60-70
71+	✘	✘	✘	✘	✘	✓ 71+<10	✘	✓ 71+<YA	✓ 71+<60-70	■

B. Pantomime with image of the glass as a guide

■	**5**	**6**	**7**	**8**	**9**	**10**	**11-12**	**YA**	**60-70**	**71+**
5	■	✘	✓ 5<7	✓ 5<8	✓ 5<9	✓ 5<10	✓ 5<11-12	✓ 5<YA	✓ 5<60-70	✓ 5<71+
6	✘	■	✘	✓ 6<8	✓ 6<9	✓ 6<10	✓ 6<11-12	✓ 6<YA	✓ 6<60-70	✓ 6<71+
7	✓ 5<7	✘	■	✓ 7<8	✘	✓ 7<10	✘	✓ 7<YA	✓ 7<60-70	✘
8	✓ 5<8	✓ 6<8	✓ 7<8	■	✘	✘	✘	✘	✘	✘
9	✓ 5<9	✓ 6<9	✘	✘	■	✘	✘	✘	✘	✘
10	✓ 5<10	✓ 6<10	✓ 7<9	✘	✘	■	✘	✘	✘	✘
11-12	✓ 5<11-12	✓ 6<11-12	✘	✘	✘	✘	■	✘	✘	✘
YA	✓ 5<YA	✓ 6<YA	✓ 7<YA	✘	✘	✘	✘	■	✘	✓ 71+<YA
60-70	✓ 5<60-70	✓ 6<60-70	✓ 7<60-70	✘	✘	✘	✘	✘	■	✘
71+	✓ 5<71+	✓ 6<71+	✘	✘	✘	✘	✘	✓ 71+<YA	✘	■

C. Pantomime with glass as a guide

	5	6	7	8	9	10	11-12	YA	60-70	71+
5		×	✓ 5<7	✓ 5<8	✓ 5<9	✓ 5<10	✓ 5<11-12	✓ 5<YA	✓ 5<60-70	✓ 5<71+
6	×		×	✓ 6<8	×	✓ 6<10	×	✓ 6<YA	✓ 6<60-70	×
7	✓ 5<7	×		✓ 7<8	×	×	×	✓ 7<YA	✓ 7<60-70	×
8	✓ 5<8	✓ 6<8	✓ 7<8		×	×	×	×	×	×
9	✓ 5<9	×	×	×		×	×	×	×	×
10	✓ 5<10	✓ 6<10	×	×	×		×	×	×	×
11-12	✓ 5<11-12	×	×	×	×	×		×	×	×
YA	✓ 5<YA	✓ 6<YA	✓ 7<YA	×	×	×	×		×	×
60-70	✓ 5<60-70	✓ 6<60-70	✓ 7<60-70	×	×	×	×	×		×
71+	✓ 5<71+	×	×	×	×	×	×	×	×	

D. Actual grasping

	5	6	7	8	9	10	11-12	YA	60-70	71+
5		✓ 5<6	✓ 5<7	✓ 5<8	✓ 5<9	✓ 5<10	✓ 5<11-12	✓ 5<YA	✓ 5<60-70	✓ 5<71+
6	✓ 5<6		✓ 6<7	✓ 6<8	×	✓ 6<10	✓ 6<11-12	✓ 6<YA	✓ 6<60-70	✓ 6<71+
7	✓ 5<7	✓ 6<7		✓ 6<7	×	×	×	✓ 7<YA	✓ 7<60-70	✓ 7<71+
8	✓ 5<8	✓ 6<8	✓ 6<7		✓ 9<8	×	×	×	×	×
9	✓ 5<9	×	×	✓ 9<8		×	×	✓ 9<YA	✓ 9<60-70	×
10	✓ 5<10	✓ 6<10	×	×	×		×	×	×	×
11-12	✓ 5<11-12	✓ 6<11-12	×	×	×	×		×	×	×
YA	✓ 5<YA	✓ 6<YA	✓ 7<YA	×	✓ 9<YA	×	×		×	×
60-70	✓ 5<60-70	✓ 6<60-70	×	×	✓ 9<60-70	×	×	×		×
71+	✓ 5<71+	✓ 6<71+	×	×	×	×	×	×	×	

4.5. Discussion

The primary objective of this study was to assess sensitivity to end-state comfort across the lifespan using an overturned glass task. Here, the movement context was manipulated to assess how contextual information available to guide movement in a familiar task influences the developmental course. In comparison to actual tool use, pantomime has been shown to require greater cognitive processing (Chapters 2 and 3; Heath et al., 2002; Randerath et al., 2009; Roy et al., 2014). As such, manipulating the amount of contextual information available to guide movement enabled us to alter cognitive requirements for end-state comfort planning in an everyday task.

It was hypothesized that patterns of end-state comfort would be similar to adults in 9- to 12-year-olds (Wunsch et al., 2013). When collapsed across the four movement contexts, end-state comfort appeared adult-like in children younger than expected, as no differences emerged when comparing children ages 8 and above to young adult participants. These findings differ from Wunsch et al.'s (2013) systematic review, which includes previous work by our group (Scharoun & Bryden, 2014b). Scharoun and Bryden (2014b) grouped 8-year-old with 7-year-olds; therefore, it is possible that 8-year-olds were more proficient, and sensitivity to end-state comfort was skewed by the performance of 7-year-olds. As such, the separation of children into age groups should be considered a strength of the current study.

Results of the current study are in line with Knudson et al. (2012), who observed adult-like patterns of end-state comfort in 8-year-olds. Together, Knudson et al. (2012), and Scharoun and Bryden (2014b) were the only two studies included in Wunsch et al.'s review to assess end-state comfort in 8-year-olds using the overturned glass task. Other reports with this age group assessed the bar-transport and handle rotation tasks. Knudson et al. (2012) demonstrated higher levels of sensitivity to end-state comfort in the overturned-glass task compared to the bar-transport task; therefore, it can be argued that, within an everyday task like the overturned glass task, adult-like sensitivity to end-state comfort emerges at approximately age 8. This finding parallels previous reports of online control, where the age of 8 years has been found to be a marker in child development (e.g., Ferrel, Bard & Fleury, 2001). Chapter 5 of the thesis thus compared familiar and less familiar objects as a function of the movement context.

When considering the aforementioned findings, it is important to note that analysis of end-state comfort as a function of movement context (i.e., the significant interaction between age and movement context) revealed results that further complicate interpretation. Although 8-year-olds (and 10-year-olds) did not differ from older participants, 9-year-olds displayed less end-state comfort than young adults (in addition to 8-year-olds and 60- to 70-year-olds) in actual grasping, and 11- to 12-year-olds in pantomime without a stimulus. Considering the small effect size of the interaction ($\eta^2 = .016$), and the fact that these age groups only differed in one of four movement contexts, it can be argued whether the difference is practically significant.

Nonetheless, deviations can be interpreted in light of the notion of age-related changes, as opposed to age-determined changes. Age-related improvements in sensorimotor function have been attributed to the development of overall proficiency in state estimation (e.g., King, Kagerer, Contreras-Vidal & Clark, 2009; King, Pangelinan, Kagerer & Clark, 2010; King et al., 2012). Furthermore, recent work indicates that the development of executive control influences online control, and improved action representation contributes to efficiency (Fuelscher et al., 2015; Ruddock et al., 2014). Using these findings as a foundation for interpreting the present results, young children (i.e., 5- to 7-year-olds) likely displayed less end-state comfort due to an inability of the central nervous system to reliably predict future states of the system. By the age of 8 improvements in proprioceptive acuity (King et al., 2012), in conjunction with greater proficiency in generating and implementing internal representations of action (Fuelscher et al., 2015), contribute to more adult-like sensorimotor performance. In this context, adult-like behaviour manifests in the central nervous system's ability to accurately and reliably convert current state and future state into a motor plan sensitive to end-state comfort.

Despite online control being highly efficient by the age of 8 to 9, gradual refinement has been reported to continue into adolescence and early adulthood (Fuelscher et al., 2015; Ruddock et al., 2014; Wilson & Hyde, 2013). Likewise, cortical structures involved in anticipatory control of goal-directed action have been shown to follow a protracted rate of development. More specifically, rapid growth of parietal and frontal white matter volume in early childhood have been shown to lead to significant improvements. Subsequent periods of neural sculpting in middle and later childhood, mediated by experience-driven learning (Casey, Tottenham, Liston, & Durston, 2005), lead to continued improvements in cognitive-motor function (Barnea-Goraly et al., 2005). As such, further changes are reported to occur beyond the age of 12 (Hyde & Wilson, 2013); therefore future work should consider other measures of age (i.e., cognitive age vs. developmental age). Stöckel and Hughes (2015) identified a specific relationship between cognitive and motor function using an end-state comfort task; however, their study was limited to 5-to 6-year-olds. Clearly further research is warranted in this area.

The notion of experience-driven learning influencing end-state comfort planning is not a novel concept (see Wunsch et al., 2013). Nevertheless, providing children with familiarization trials (Crajé, et al., 2010; Hughes, 1996; Jovanovic & Schwarzer, 2011; Knudson et al., 2012; Smyth & Mason, 1997; van Swieten et al., 2010) or withholding this opportunity to explore the task prior (Adalbjornsson et al., 2008; Jongbloed-Pereboom et al., 2012; Manoel & Moreira, 2005; Scharoun & Bryden, 2014b; Stöckel et al., 2012; Thibaut & Toussaint, 2010; Weigelt & Schack, 2010) does not fully explain discrepant results in the literature. In the current study, no familiarization trials were provided; however, age-related differences that emerged as a function of movement context highlight the effects of experience-driven learning.

Opposite to our hypothesis, 5- and 6-year-olds displayed significantly more end-state comfort in pantomime without a stimulus compared to the other movement contexts. Seven-year-olds performed similar; however, end-state comfort in pantomime without a stimulus did not differ from actual grasping. These findings were surprising, considering previous reports that pantomime places greater demand on working memory (e.g., Roy et al., 2014). Nevertheless, pretend play is prominent between ages 3 and 5 (e.g., Singer & Singer, 1992); therefore, it is likely that young children may have been more familiar with planning in pantomime (i.e., pretend) compared to actual grasping. Building from this explanation, one may suggest that young children are in a phase of discovery; therefore, they were exploring "how best to use perceptual information to calibrate the motor system in the service of action" (Fitzpatrick, Wagman, & Schmidt, 2012, p. 28). Although a glass (i.e., cup) is an object that children typically use early in life (Carruth & Skinner, 2002), it is possible that children are more familiar to being handed an upright glass, than having to re-orient it for use.

It can also be argued that end-state comfort planning is limited by physical capabilities. Studies of first order planning (i.e., reaching) have demonstrated that "body-scaled information of object size in relation to hand size influences the emergent reaching patterns for both children and adults" (Huang, Ellis, Wagenaar, & Fetters, 2013, p. 47). It is therefore likely that, when provided with an overturned adult-sized glass, children adopted an immature, first-order planning strategy (i.e., thumb-up) as these children are actively learning how to solve second-order planning problems.

Observing the other end of the lifespan, a lack of second-order planning in older adults ages 71+, comparable to previous reports of young children (e.g., Wunsch et al., 2015), has been attributed to cognitive decline (Cicerale et al., 2014; Chapter 3). As such, it was hypothesized that older adults age 71+ would display less end-state comfort than their younger counterparts (i.e., 60- to 70-year-olds) and young adults. When collapsed across the four movement contexts, both groups of older adults did not differ from young adults. Nevertheless, in support of our hypothesis, older adults ages 71+ displayed significantly more end-state comfort in actual grasping compared to the other three movement contexts. In pantomime without a stimulus, older adults ages 71+ displayed less end-state comfort than 10-year-olds, young adults and 60- to 70-year-olds. Performance in this movement context was no different than 5-year-olds. In pantomime with image as a guide, older adults ages 71+ displayed less end-state comfort than young adults. These results provide additional support for Siedler et al.'s (2010) supply and demand framework. In line with Chapter 3 and Wunsch et al. (2015), an increase in cognitive demand coupled with limited ability to compensate for structural and functional degradation in motor regions manifests behaviourally in motor planning deficits.

A secondary aim of this study was to compare performance between the two hands. It was hypothesized that differences would be observed exclusively in children, as per previous reports that hand preference constrains motor planning skills in children (Scharoun & Bryden, 2014b; Manoel & Moreira, 2005). In contrast to this hypothesis, sensitivity to end-state comfort did not differ between the two hands for children. That said, Scharoun & Bryden (2014b), noted differences in left handed children, who have been shown to be less consistent than their right handed counterparts (e.g., Steenhuis, Bryden, Schwartz, & Lawson, 1990). Right handers in their study, similar to the current work, did not show the effect. Manoel &

Moriera (2005) worked with right handers; however, they assessed a younger group of children (2.5- to 6-year-olds). It has been argued that a clear hand preference cannot be observed until the age of 6 (e.g., Scharoun & Bryden, 2014a); therefore, it is difficult to confirm whether children's hand preference was influencing motor planning. As such, findings from the current study supports previous reports (Coelho et al., 2013; Herbort & Butz, 2011), and current findings in young and older adults reported in Chapters 2 and 3.

4.6. Summary and conclusions

Summarizing, findings from the current study provide evidence for adult-like patterns of end-state comfort in 8-year-old children. Improvements in proprioceptive acuity and proficiency in generating and implementing internal representations of action both contribute to age-related changes in sensorimotor performance. Differences as a function of movement context highlight gradual refinement to continue into adolescence, in line with reports of protracted development of cortical structures involved in anticipatory control (e.g., Ruddock et al., 2014). Early in the aging process, older adult's sensitivity to end-state comfort does not differ from young adults; however, with increasing age, differences in second order planning gradually appear, as compensatory mechanisms are unable to account for increases in cognitive demand. Findings have implications for understanding end-state comfort planning across the lifespan, which adds to our knowledge of when and at what rate motor planning skills and cognitive function are developing and declining. Continued research in this area will provide a foundation for atypical development.

Chapter 5 – End-state comfort in two object manipulation tasks: Investigating how the movement context influences planning in children, young adults and older adults

Chapter Research Objectives:

This chapter aimed to address the following thesis objectives: (a) understand the influence of the movement context; (b) characterize the influence of familiarity with an object (i.e., familiar vs. less familiar objects); and (c) outline similarities and differences across the lifespan. Specific research questions and hypotheses will be outlined in section 5.2.

5.1. Abstract

Chapter 4 demonstrated that the movement context (pantomime, pantomime with image/glass as guide, actual use) influences end-state comfort across the lifespan. In the present study, this work was advanced in two ways: (1) a more familiar object (glass) was compared to a less familiar (hammer) one; and (2) the movement context (pantomime, using a dowel as the tool and actual use) was manipulated differently. Children (ages 6 to 11), young and older adults (ages 60 to 70, and ages 71+) picked up an overturned glass to pour water and a hammer to hit a nail, where the handle faced away from the participant. Findings provide additional support for a positively accelerated increase in end-state comfort with gradual refinement into adolescence, and negative developmental decline with increasing age. Extending findings from Chapter 4, results revealed that affordances influence anticipatory planning skills, in conjunction with the established link between the habitual and goal-directed system.

5.2. Introduction

As demonstrated in the end-state comfort effect, young adults plan reaching and grasping in advance of object manipulation (Rosenbaum et al., 1990). For example, when grasping an overturned glass for use, an uncomfortable start-state posture is typically assumed, characterized by rotating the forearm and pointing the thumb down. This initial grasp enables the actor to facilitate a comfortable end-state posture- where the forearm returns to a neutral position (i.e., thumb-up) and the object is re-oriented for use (Rosenbaum et al., 1990). Such observations have been used repeatedly to demonstrate evidence of second-order (i.e., anticipatory) planning in young adults; that is, planning in anticipation of both immediate and secondary task demands (see Rosenbaum et al., 2012 for a review). Studies assessing the effect in children (see Wunsch et al., 2013 for a review), although not as abundant, discuss a link between the development of sensorimotor and cognitive control processes to explain the positively accelerating pattern of improvement. Nevertheless, inconsistent findings exist regarding when skills are adult-like in nature (e.g., Wunsch et al., 2013). Observing the other end of the developmental lifespan, two recent studies exploring changes with aging highlight negative developmental trends, such that a decrease in sensitivity is attributed to cognitive decline (Chapter 2; Wunsch et al., 2015).

The study presented in Chapter 4 was, to our knowledge, the first to assess the end-state comfort across the lifespan, albeit cross-sectionally. Here, 5- to 12-year-old children, young adults, and two groups of older adults (ages 60- to 70, and ages 71+) performed the overturned glass task in four different movement contexts (Fischman, 1997): (1) pantomime without a stimulus, (2) pantomime with an image of the glass as a guide, (3) pantomime with the glass as a guide, and (4) actual grasping. Previous work identified that, in comparison to actual tool use, pantomime requires greater cognitive processing (e.g., Heath et al., 2002; Randerath et al., 2009). As such, altering the movement context enabled the manipulation of cognitive demands within the context of an overturned glass task (similar to Chapter 2 and Chapter 3).

Findings in older adults paralleled previous reports, supporting the notion of a negative developmental trend, attributable to cognitive decline (Chapter 2; Wunsch et al., 2015). More specifically, older adults ages 71+ displayed a decrease in sensitivity to end-state comfort in comparison to older adults ages 60 to 70 and young adults. Furthermore, performance in pantomime without a stimulus, which placed the greatest demand on cognitive function, revealed no difference between older adults ages 71+ and 5-year-old children. Observing the opposite end of the developmental lifespan, results revealed adult-like patterns of end-state comfort in 8-year-old children. Nevertheless, variability emerged as a function of the movement context, ascribed to the development, and gradual refinement of cognitive and sensorimotor processes, mediated by experience-driven learning. Of particular interest, with respect to experience-driven learning, 5- and 6-year-olds displayed more end-state comfort in pantomime without a stimulus, compared to actual grasping. Contrary to expected results, Chapter 4 explained this observation, in part, to the familiarity of the task, considering the prominence of pretend play in young children (e.g., Singer & Singer, 1992). Furthermore, it was outlined that, when manipulating an adult-size glass, physical capabilities limited anticipatory planning skills; therefore children displayed immature planning strategies in actual grasping. Summarizing, it was reasoned that children were exploring "how best to use perceptual information to calibrate the motor system in the service of action" (Fitzpatrick et al., 2012, p. 2012).

The present work builds upon the idea that task familiarity influences anticipatory planning skills, as suggested in Chapter 4, and other previous research (e.g., Knudsen et al., 2012). In particular, Knudsen et al. (2012) assessed 3- to 8-year-olds` sensitivity to end-state comfort when comparing the overturned glass task to the bar transport task. Findings revealed the effect in 13% of 3-year-olds compared to 94% of 8-year-olds for the bar transport task. Between 3 to 4 years and 4 to 5 years, the proportion of children who displayed end-state comfort doubled; therefore supporting a period of significant improvement in motor planning skills from age 3 to 5. Sensitivity to end-state comfort was also found to improve with age in the overturned glass task; however, a greater number of 3-year-olds demonstrated the effect (i.e., 64%) in this task. Overall findings indicated that motor planning skills are more proficient with familiar objects, especially when assessing young children (Knudsen et al., 2012). Nevertheless, sensitivity to end-state comfort in the overturned glass task was higher than previous reports (Adalbjornsson et al., 2008), and in comparison to more recent work (Scharoun & Bryden, 2014b; Chapter 4); therefore additional research is warranted.

The current study advanced the previous work reported in Chapter 4 in two ways. First, we examined whether we would see more end-state comfort with a more familiar object (glass) relative to a less familiar one (hammer). As expressed by Knudsen et al. (2012), “the child’s familiarity with the object involved pertains to the amount of prior experience children have gathered with that object throughout the lifetime” (p. 7). A glass (i.e., cup) is an object that children manipulate early in life. Children begin to use cups without lids around their second birthday, and the required postural stability to drink from an open cup is mature by a child’s third birthday (Carruth & Skinner, 2002). Although children are exposed to hammer-like tools and banging motions early in life (Barrett, Davis & Needham, 2007; Bourgeois, Khawar, Neal, & Lockman, 2005), experience using an adult-size hammer is garnered later in life.

It has been argued that certain objects, used habitually, are associated with actions that were successful in the past; therefore, grasp selection reflects a stimulus-driven response without consideration of causal relationships (Herbort & Butz, 2011; Stöckel & Hughes, 2015). For example, Creem and Proffitt (2001) observed young adults display prototypical tool grasping behaviours (i.e., grasping by the handle), regardless if the resultant movement was cumbersome. Here, grasp posture reflected a bias towards the habitual system and away from the goal-directed system, which plans action based on object properties, affordances and expected task demands (e.g., Stöckel & Hughes, 2015). According to Stöckel and Hughes (2015), children are biased towards the habitual system when presented with a cognitively demanding task, exemplified in inconsistent motor behaviours. Nevertheless, with age and maturation of motor and cognitive systems, children are better able to balance the interplay between the habitual and goal-directed systems. It is important to note that Stöckel and Hughes (2015) had participants manipulate a wooden dowel, and it was suggested that investigation of everyday objects is necessary "to examine how familiarity and experience with an object alters the relative weight of the goal-directed and habitual systems during object manipulation tasks of varying complexity" (p. 1260).

In consideration of task complexity, we examined how the movement context would influence sensitivity to the effect across these two tasks. In Chapter 4 the most significant effects in children and older adults were observed when comparing pure pantomime and actual tool use, whereas Knudson et al. (2012) demonstrated greater sensitivity to end-state comfort in children when comparing a familiar overturned glass task to a neutral bar-transport task. As such, the current work had participants act in: (1) pure pantomime (i.e., without a stimulus to guide movement), (2) demonstration with a dowel (i.e., bar) as if it were the tool, and (3) actual tool use.

Summarizing, studies assessing end-state comfort describe a positively accelerated function in childhood, linked to the development of cognitive control and sensorimotor processes (e.g., Chapter 4; Wunsch et al., 2013). Furthermore, in older adults, evident decline in sensitivity to the effect has been associated with cognitive decline (e.g., Chapters 3 and 4; Wunsch et al., 2015). The current study aimed to further delineate our understanding of the end-state comfort from a lifespan perspective by means of assessing sensitivity to the effect in 6- to 11-year-olds, young adults, 60- to 70-year-olds and older adults ages 71+. To elucidate factors influencing the effect, participants performed a familiar (pick up a glass as if to pour water) and less familiar (pick up a hammer as if to hit a nail) task in three movement contexts (pure pantomime, demonstration with dowel, actual tool use). It was hypothesized that adult-like patterns of end-state comfort would be evident at approximately age 8, with an evident decrease in sensitivity in older adults ages 71+ (Chapter 4). Secondly, it was hypothesized that more end-state comfort would be displayed in the overturned glass task compared to the hammering task, based on familiarity with the object (e.g., Knudson et al., 2012). Finally, it was hypothesized that the movement context would influence planning, albeit differently when observing performance of young children and old-older adults. In particular, it was hypothesized that young children (i.e., 6-year-olds) would display greater sensitivity in pure pantomime compared to actual grasping, whereas old-older adults (i.e., ages 71+) would display the opposite pattern (Chapter 4).

5.3. Methods

5.3.1. Participants

Children, young adults and older adults (*N* = 112) participated in this study (see Table 5.1). Young adults were undergraduate or graduate students from the university and older adults were recruited from the local community. Children were recruited from university summer camps, and two local private and public elementary schools. Data collection was conducted during camp/class time, outside of the camp/class setting. Children were given stickers for completing the study. A background questionnaire was completed to ensure all participants were without visual impairments, injury, and/or diagnosis that may have influenced performance (see Appendix B and C). The University Research Ethics Board approved all recruitment and testing procedures. Written informed consent was obtained from all participants and parents/guardians of participating children. In addition, verbal assent was obtained from participating children. Participants were separated into nine age groups: 6-, 7-, 8-, 9-, 10-, and 11-year-olds, young adults (M_{age} = 22.86, *SD* = 1.50), 60- to 70-year-olds (M_{age} = 64.00, *SD* = 3.79) and older adults ages 71+ (M_{age} = 74.56, *SD* = 3.43). It is important to acknowledge that groups were unequal in size, which was a limitation of this study. Nevertheless, analysis of variance is robust to unequal sample size, even in the face of heterogeneity of variance.

Table 5.1

Participant demographics

Age	N	Male : Female	RH:LH	M_{WHQ} (SD)
6-year-olds	12	6:6	10:2	17.42 (12.81)
7-year-olds	17	6:11	16:1	26.41 (14.79)
8-year-olds	11	5:6	9:2	20.00 (22.29)
9-year-olds	10	4:6	8:2	14.00 (22.30)
10-year-olds	13	5:8	12:1	20.62 (20.79)
11-year-olds	7	4:3	7:0	23.00 (9.50)
Young adults	21	9:12	21:1	28.19 (9.00)
60- to 70-year-olds	12	3:9	10:2	20.17 (25.60)
Older adults ages 71+	9	6:3	8:1	26.56 (20.35)
Total	112	48:64	100:12	22.50 (17.73)

5.3.2. Apparatus & Procedures

Participants were seated at a table as they completed each task and were asked which hand was used for writing (coloring for children) to denote self-report hand preference. The Waterloo Handedness Questionnaire was used to confirm hand preference, as participants were asked to report their preferred hand for 20-unimanual tasks (Cavill & Bryden, 2003). Each question provides five responses, where a number from -2 to +2 is used to compute a total handedness score from -40 to +40: left always (-2), left usually (-1), uses both hands equally often (0), right usually (+1), and right always (+2). Left handers are expected to show a negative score while right handers are expected to show a positive score. The questionnaire was administered orally to children by reading each item aloud and explaining the item if necessary. Note that previous research has successfully used oral administration of questions as alterations to the administration of handedness questionnaires for pre-school children (e.g., Karapetsas & Vlachos, 1997).

Participants were then asked to perform two actions (pick-up a glass as if to pour water, and pick-up a hammer as if to hit a nail) in three difference movement contexts: (1) pure pantomime (i.e., without a stimulus to guide movement), (2) demonstration with a dowel (i.e., bar) as if it were the tool, and (3) actual tool use (see Figure 5.1). Pantomimed actions were performed first, followed by dowel use and, finally tool-use to avoid providing cues as to correct pantomime performance (e.g., Heath et al., 2002). When acting with the dowel, each end of the tool (i.e., open end of glass, head of hammer) was designated based on colour (i.e., black represents the bottom of the glass, black represents the handle), as each dowel was painted half black. Only critical conditions (overturned glass and handle facing away from the participant) were assessed.

Before data collection started, participants were asked to confirm familiarity with a juice glass and a hammer. In particular, children were asked to describe each object to confirm familiarity with the object. Children were then asked to describe the difference between upright and overturned (or right side up and upside down), and handle facing towards and away to confirm understanding. Finally, children were asked to identify which hand was left, and which was right. The researcher pointed at each hand if necessary throughout the duration of the study. Children were informed they would be performing the action of picking up a cup and pretending to pour a glass of water, or picking up a hammer and hitting a nail. Instructions for the remainder of the study progressed as follows:

(1) Pantomime without a stimulus*: (a) glass: Pretend there is an upside down cup on the x. Show me with your [right hand / left hand] how you would pick it up and pretend to pour a glass of water with this pitcher – Go! (b) hammer: Pretend there is a hammer on the x with the handle facing away from you. Show me with your [right hand / left hand] how you would pick it up and hit this nail – Go!*

(2) Demonstrate with dowel: *(a) glass: Pretend this dowel/stick is a cup. The black end is the bottom. I am going to put it on the x. Show me with your [right hand / left hand] how you would pick it up and pretend to pour a glass of water with this pitcher – Go! (b) hammer: Pretend this dowel/stick is a hammer. The black end is the handle. I am going to put it on the x with the handle facing away from you. Show me with your [right hand / left hand] how you would pick it up and hit this nail – Go!*

(3) Actual tool use: *Now we are going to use the real cup. Show me with your [right hand / left hand] how you would pick it up and pretend to pour a glass of water with this pitcher – Go! (b) hammer: Now we are going to use the real hammer. Show me with your [right hand / left hand] how you would pick it up and hit this nail – Go!*

Participants performed each action three times with both the left- and right-hand. A video camera was used, where videos were coded offline to note the proportion of grasps which satisfied the end-state comfort effect. Within the overturned glass task, sensitivity to the effect was deemed evident when the initial grasp involved rotating the forearm and pointing the thumb down to grasp the glass (or to demonstrate grasping), facilitating a comfortable end-state posture where the thumb pointed up. Likewise, within the hammering task, end-state comfort was characterized by rotating the forearm and pointing the thumb towards the body to grasp the handle (or to demonstrate grasping), facilitating a comfortable and functional grasp posture.

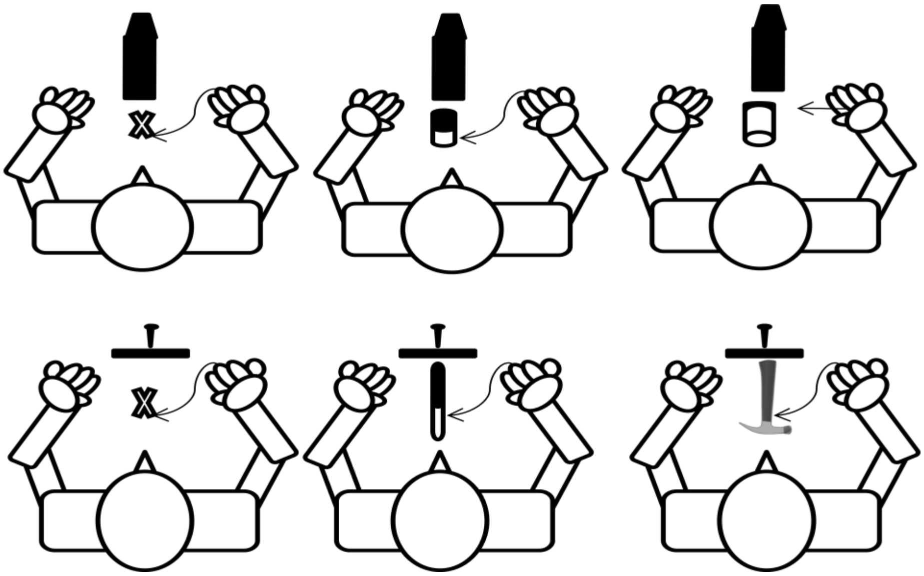

Figure 5.1. Study set-up

5.4. Results

The proportion of grasps which satisfied the end-state comfort effect were submitted to a mixed analysis of variance test (ANOVA). The between subjects factor was age (8: 6-, 7-, 8-, 9-, 10-, and 11-year-olds, young adults, 60- to 70-year-olds, and older adults ages 71+). The within subjects factors were task (2: overturned glass, hammering a nail), movement context (3: pantomime, demonstrate with dowel, actual tool use) and hand used to complete the task (2: left- and right-hand). Levene's test of equality of error variances was significant for all factors ($p < .001$ in all cases). To perform a mixed ANOVA on percentage data, an arc sine transformation was applied. Violations of homogeneity of variance remained regardless of the transformation. As there is, to our knowledge, to known nonparametric equivalent to a mixed ANOVA (Field, 2013), the analysis was performed on the un-transformed data, in percentages. Only significant results will be discussed.

Results will be discussed in reference to the resultant effect sizes, as per medium (η^2 = 0.06) and large (η^2 = 0.14) benchmarks (Cohen, 1988; Lakens, 2013). First, a significant main effect of tool (*F* (1, 103) = 14.685, *p* = .001, η^2 = .125) revealed that participants demonstrated more end-state comfort in the hammering task (*M* = 91.79, *SD* = 26.04) compared to the overturned glass task (*M* = 84.30, *SD* = 32.71).

A significant main effect of age (*F* (8, 103) = 4.299, *p* < .001, η^2 = .040; see Figure 5.2) identified that 6-year-olds displayed less end-state comfort than young adults and 60- to 70-year-olds. No other differences emerged as a function of age. There was also a main effect of condition (*F* (1.870, 192.572) = 3.285, *p* = .043, η^2 = .031). Mauchly's Test of Sphericity was significant (χ^2 (2) = 19.063, *p* < .001); therefore a Huynh-Feldt correction was applied, as ε > .75 (Field, 2013). All three conditions differed, where end-state comfort was greatest in actual tool use (*M* = 91.26, *SD* = 26.26) compared to when manipulating the dowel (*M* = 86.94, SD = 30.71) and in pantomime (*M* = 85.94, *SD* = 31.90).

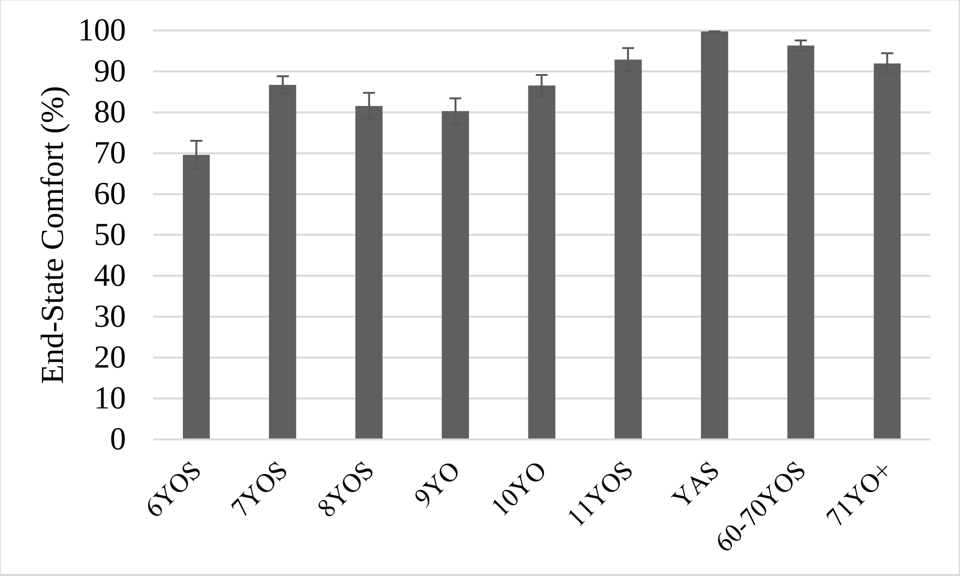

Figure 5.2. When collapsed across tool, condition and hand used to complete the task 6-year-olds displayed less end-state comfort than young adults and 60- to 70-year-olds. Error bars represent standard error.

Finally, there was a significant tool by condition interaction (*F* (1.902, 195.901) = 4.240, $p = .017$, $\eta^2 = .040$; see Figure 5.3). Mauchly's Test of Sphericity was significant (χ^2 (2) = 16.709, $p < .001$); therefore a Huynh-Feldt correction was applied, as $\varepsilon > .75$ (Field, 2013). When manipulating the dowel, more end-state comfort was displayed in the hammering task compared to the overturned glass task. Within the overturned glass task, more end-state comfort was seen in actual tool use compared to manipulating the dowel. No other differences emerged.

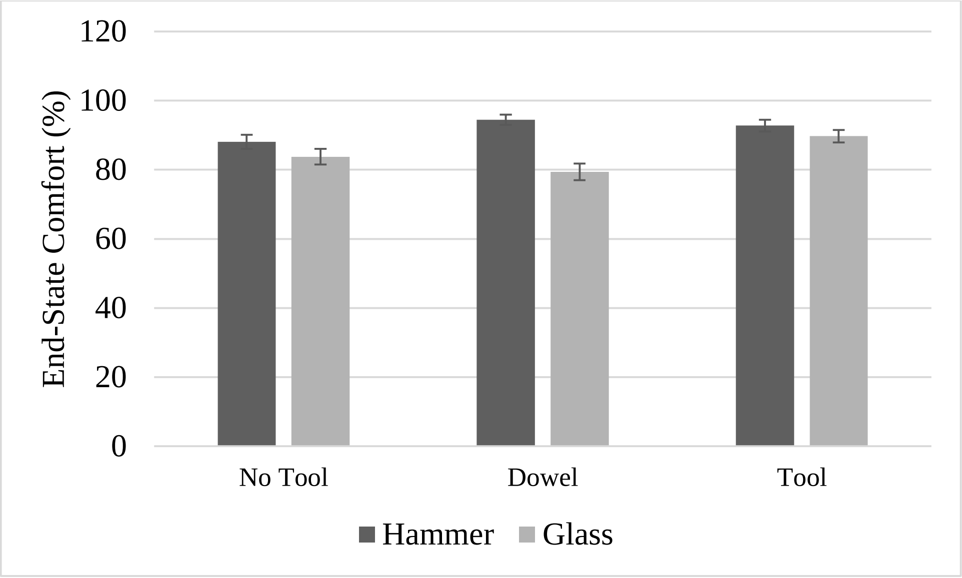

Figure 5.3. In the overturned glass task, more end-state comfort was seen in actual grasping compared to when manipulating the dowel. When manipulating the dowel, there was more end-state comfort in hammering compared to the overturned glass task. Error bars represent standard error.

5.5. Discussion

The present study aimed to examine factors influencing the end-state comfort effect across the lifespan by assessing sensitivity in a familiar and less familiar task in three movement contexts. It was hypothesized that adult-like patterns of end-state comfort would be evident at approximately age 8, with an evident decrease in sensitivity in older adults ages 71+ (Chapter 4). Similar to Chapter 4, 6-year-old children displayed less end-state comfort than young adults and older adults ages 60- to 70. Furthermore, there was no difference between 6-year-olds and older adults ages 71+, indicating that motor planning skills decline with increasing age (Chapter 3; Wunsch et al., 2015). Nevertheless, no other differences emerged as a function of age; therefore, providing evidence for adult-like patterns of sensitivity to the effect in 7-year-old children.

Although sensitivity in children is different from previous reports of end-state comfort in unimanual object manipulation (e.g., Knudson et al., 2012, Chapter 4), findings are concurrent with Stöckel and Hughes (2015) who also observed significantly less end-state comfort in 6-year-olds compared to older children. Here, it was suggested that grasp postures reflected a bias towards the habitual system due to the cognitive demands of the task outweighing available cognitive resources. With age, children are better able to integrate multisensory information to consider future demands and thus balance the interplay between habitual and goal-directed systems when acting in tasks that require second-order planning (Stöckel & Hughes, 2015).

A recent assessment of the effect in a bimanual overturned glass task also revealed no differences in sensitivity between 7- to 12-year-old children (Scharoun, Logan, Bryden, Fischman, & Robinson, under review). The first to examine the effect in bimanual object manipulation, results were interpreted in light of Mason, Bruyn and Lazarus' (2013) findings, as a similar divide in children (i.e., between 4- to 6-year-olds and 7- to 10-year-olds) emerged. Here, participants performed a unimanual or bimanual reach-to-grasp task for cylinders located at near and far positions to examine the cost of performing two simultaneous movements to a single target. Young children compensated for increased movement complexity (i.e., bimanual task) by lengthening movement time. Older children lengthened movement time in congruent bimanual conditions; however, for incongruent conditions, displayed larger non-dominant grip apertures. Attributed to age-related differences in multisensory integration, Mason et al. (2013) speculated that "the transition time between the ages of 7-10 may therefore be used as a testing period to determine the most effective strategies for accomplishing a variety of task goals" (p. 162). More specifically, older children display more proficient movement control as they benefit from the integration of proprioceptive and visual information; whereas young children are overly reliant on visual information (Mason et al., 2013).

Findings from Chapter 4 similarly ascribed age-related improvements in sensorimotor function to the development of overall proficiency in state estimation (e.g., King et al., 2009, 2010, 2012). Changes in executive control and improved action representation (Fuelscher et al., 2015; Ruddock et al., 2014) were also implicated. From this perspective, young children are less sensitive to the effect due to the inability of the central nervous system to reliably predict future states of the system, and age-related improvements are characterized by the ability to "accurately and reliably convert current state and future state into a motor plan sensitive to end-state comfort" (Chapter 4, p. 92). The transition period between ages 7 and 11 (Meyer et al. 2013) coupled with gradual refinement into adolescence and early adulthood (Fuelscher et al., 2015; Ruddock et al., 2014; Wilson & Hyde, 2013) thus leads to continued improvement in motor planning skills. Taken together, findings from Stöckel and Hughes (2015), Mason et al. (2013) and Scharoun et al. (Chapter 4) can be used to explains varying reports of *adult-like* planning behaviour and Wunsch et al.'s (2013) suggestion that the end-state comfort effect asymptotes somewhere beyond age 10.

As an extension of Chapter 4, it was also hypothesized that the movement context would influence sensitivity to the end-state comfort effect, albeit differently when observing performance of young children and older adults ages 71+. In particular, it was hypothesized that older adults ages 71+ would display less end-state comfort in pure pantomime, due to the increased cognitive demands of the task. Furthermore, for 6-year-olds, it was hypothesized that the opposite would be true (i.e., greater sensitivity in pure pantomime) due to the prominence of pretend play in young children (Chapters 3 and 4). Interestingly no interaction between group and movement context emerged; however, participants were, overall, more sensitive to the effect in actual grasping compared to when demonstrating action with the dowel, and in comparison to pantomime without a stimulus present. Findings provide additional evidence for the importance of contextual information available to guide motor planning (Chapter 3), albeit without age-related differences (Chapters 3 and 4).

In light of this notion of contextual information guiding movement, it is important to consider other task characteristics that may influence planning and control when interpreting the aforementioned findings. It was hypothesized that more end-state comfort would be displayed in the overturned glass task compared to the hammering task based on the familiarity of the task (Knudson et al., 2012). Nevertheless, results opposite our prediction emerged, such that participants were more sensitive to the effect in the hammering task. In order to interpret such findings, we must turn to studies of tool use in other contexts. Hermsdörfer et al. (2006) have explained that individuals with apraxia perform better during actual tool use in comparison to pantomime, as “the affordances provided by the tool and the object may evoke a particular motor representation” (p. 1642). This was evidenced in the current study, as an increase in sensitivity to end-state comfort was observed in actual tool use compared to demonstration with a dowel and pure pantomime.

Extending this idea to compare the affordances of the two objects used in the present investigation, it can be suggested that the hammer offers the actor more apparent affordance of graspability, considering the clear distinction between the handle and head. The term micro-affordance has been used to describe this relationship between specific object characteristics (e.g., shape, orientation) and activation of a specific motor response (Ellis & Tucker, 2000; Tucker & Ellis, 1998). Lindemann et al. (2006) argued that this only occurs with intention for use (Lindemann et al., 2006); however, van Elk et al. (2014a,b) recently proposed a framework of action semantics the explains "automatic effects of object affordances as well as context- and intentionally driven effects" (p. 240). From a developmental perspective, Scharoun et al. (accepted) have identified that the capacity to perceive affordances increases with age, and the ability to detect some affordances takes longer to refine. It can thus be argued that anticipatory planning in object manipulation involves an interplay between the habitual and goal-directed system, where the detection of affordances is also influential.

5.6. Summary and conclusions

Summarizing, results provide additional support for a positively accelerated rate of development for end-state comfort planning in young children, with gradual refinement into adolescence (Chapter 4). Furthermore, this study provides additional support for a gradual decline in motor planning skills with increasing age (Chapters 3 and 4; Wunsch et al., 2015). Beyond age-related changes, this work adds to our understanding of the relationship between the habitual and goal-directed systems in object manipulation, while highlighting that the perception and detection of affordances also influences our ability to act with objects and tools in the environment. Overall, this adds to our knowledge of when and at what rate motor planning skills are developing and declining; in particular with respect to how familiar and less familiar objects influence action.

Chapter 6 – Orders of planning in object manipulation: An examination of children, young adults and older adults

Chapter Research Objectives:

This chapter aimed to address the following thesis objectives: (a) understand the influence of the movement context; (b) characterize the influence of familiarity with an object (i.e., familiar vs. less familiar objects); (c) investigate independent and cooperative movements; and (d) outline similarities and differences across the lifespan an. Specific research questions and hypotheses will be outlined in section 6.2.

6.1. Abstract

Chapter 5 revealed that the perception of affordances influences anticipatory planning in object manipulation. Considering that objects can be grasped in various different ways based on action intentions, the current study extended the aforementioned work by means of assessing grasp posture in independent and joint action tasks. Participants acted with the same objects manipulated in Chapter 5 (1: glass, and 2: hammer) in two movement contexts (2: demonstration with a dowel as if it were the object, and 3: actual object use). Building upon the previous work, participants performed four actions (1: pick-up – first-order planning, 2: pick-up and use – second-order planning, 3: pick-up and pass – second-order planning, and 4: pick-up and pass for use – third-order planning) to assess how the order of planning influences end-state comfort, functional grasping and beginning-state comfort. Findings support van Elk's (2014a,b) framework for action semantics, such that object manipulation involves the automatic perception and detection of affordances. With experience, the motor system is better able to anticipate the consequences of action, and thus integrate multisensory information from

the environment into a movement plan. Taken in light of developmental factors, children shift from a reliance on previously successful movements, to consideration of affordances and task demands with improvements in multisensory integration. Likewise, with age and cognitive decline, older adults revert back to the habitual system and thus display stimulus-driven responses, as opposed to actions which reflect consideration of action demands.

6.2. Introduction

According to Rosenbaum’s concept of orders of planning for object manipulation (Rosenbaum et al. 2012), the way in which an object is grasped can be used to infer how far in advance the movement was planned. From this perspective, first-order planning involves shaping one’s grip aperture in consideration of immediate task demands (e.g., size, weight, etc.). As an extension, second-order planning involves consideration of both immediate and secondary task demands. This is demonstrated in the end-state comfort effect (e.g., Rosenbaum et al., 1990). When grasping an inverted object, young adults are likely to assume an uncomfortable posture at the start of their movement to allow for a comfortable end-state posture in which the object is reoriented for use. Beyond second-order planning, higher order planning is evident as a function of task complexity (see Rosenbaum et al., 2012 for a review). For example, third-order planning is evident when an individual grasps an inverted object, pours a glass of water and passes it to a recipient. Here, the actor must plan their initial grasp to facilitate their intended action, while also considering the recipient’s initial grasp and intended action.

Less research has been devoted to higher order planning in independent object manipulation in comparison to joint action (e.g., Haggard, 1998; Meyer, Robrecht, van der Wel, & Hunnius, 2013; Rosenbaum et al., 1990). Nevertheless, the manner in which objects are grasped and subsequently passed in joint action has become a topic of interest in recent years (e.g., Gonzalez et al., 2011; Meyer et al., 2013; Ray & Welsh, 2011; Scharoun & Bryden, 2014b). In one example, Meyer et al. (2013) had young adult participants pick up an object with one hand and pass it to their own (independent action) or partner's hand (joint action) before transporting it to a target shelf. Findings revealed evidence of third-order planning in both independent and joint action tasks, attributed to similar neurocognitive planning mechanisms (e.g., Bekkering, De Bruijn, Cuijpers, Newman-Norlund, Van Schie, & Meulenbroek, 2009; Rizzolatti & Sinigaglia, 2010). More specifically, Meyer et al. (2013) argued that their findings may "reflect participants using their own neurocognitive mechanisms of action planning to integrate their action partner into the planning and execution of the whole action sequence" (p. 587). Here, participants displayed an initial grasp that fostered personal end-state comfort, and also facilitated a comfortable and functional grasp for the confederate in joint action. Gonzalez et al. (2011) coined this pattern of behaviour in joint action beginning-state comfort. Interestingly, this was only observed when the confederate intended to use the object (Gonzalez et al., 2011).

Objects can be grasped in various different ways. For example, a coffee mug can be grasped by the handle or through the handle, by placing the hand over the top, across the body and/or across the rim. Tucker and Ellis (1998) revealed that when individuals view a mug in their environment, the typical response is to grasp the handle for use. The term micro-affordance was thus used (Ellis & Tucker, 2000) to describe how perception of tools automatically highlights action capabilities. Neuroimaging studies have also reported motor areas activate in response to the presentation of manipulable objects (e.g., Chao & Martin, 2000; Creem-Regehr & Lee, 2005; Grafton, Fadiga, Arbib, & Rizzolatti, 1997; Martin, Wiggs, Ungerleider, & Haxby, 1996). Nevertheless, Lindemann et al. (2006) identified differences in grasp posture based on an actor's intention for use (Randerath, Goldenbery & Hermsdorfer, 2009; Sunderland et al., 2011). In particular, functional grasping behaviours were coupled with an intention for use. It was thus argued that semantic information is only activated when an actor intends to use the object that is being manipulated (Lindemann et al., 2006).

In consideration of top-down and bottom-up processes, van Elk et al. (2014) recently proposed a framework of action semantics that considers "automatic effects of object affordances as well as context- and intentionally driven effects" (p. 240). From this perspective, action semantics include multimodal object representations that are linked to modality-specific subsystems that include functional (i.e., what) and manipulation (i.e., how) knowledge, and representations of sensory consequences of object use. Hierarchically organized, action intentions, which are determined by the action context, guide the selection of outcomes and identify the relevance of sensory consequences. Simultaneously, direct perception of affordances enables the action context to influence the activation and use of action semantics automatically. Throughout the action, progress is monitored, enabling the system to be constantly updated. An important consideration of van Elk et al.'s (2014) framework is the idea that learned knowledge (i.e., knowing-how and knowing-that) is critical.

In line with van Elk et al.'s (2014) framework, Chapter 5 demonstrated that the perception of affordances influences second-order planning across the lifespan. Six- to 11-year-old children, young adults, and two groups of older adults (young-older adults ages 60 to 70, and old-older adults ages 71+) performed two actions (1: pick-up a glass as if to pour water, and 2: pick-up a hammer as if to hit a nail) in three different movement contexts (1: pantomime, 2: demonstration with a dowel as if it were the object, and 3: actual object use). As expected, end-state comfort was observed more frequently in actual tool use compared to the other movement contexts. This finding paralleled previous work, which has displayed differences in movements towards remembered objects and those in real time, due to changes in the affordances offered for grasping (e.g., Goodale et a., 1994; Hermsdörfer et al., 2006).

However, results emerged opposite the expected findings when comparing grasp behaviours in manipulation of the glass and hammer. It was hypothesized that end-state comfort would be more frequently observed when acting with a more familiar (glass) compared to a less familiar (hammer) object, considering the notion that objects used habitually are linked with actions executed successfully in the past (Herbort & Butz, 2011; Knudsen et al., 2012). In other words, it has been argued that grasp selection is indicative of a stimulus-driven response, instead of an action that reflects anticipatory planning (Herbort & Butz, 2011; Knudsen et al., 2012). Contrary to our hypothesis, findings were ascribed to the hammer offering the actor a more apparent affordance of graspability; thus, explaining why participants, regardless of age, displayed end-state comfort more frequently in this task.

Taken together, findings from Chapter 5 indicate that affordances play a significant role in object manipulation that requires second-order planning. The current study extended the aforementioned work by means of assessing grasp posture in both independent and joint action to assess how the intended action—manipulated as a function of the order of planning (Rosenbaum et al., 2012)—influences motor behaviour. Participants acted with the same objects manipulated in the previous study (1: glass, and 2: hammer); however, only two movement contexts (1: demonstration with a dowel as if it were the object, and 2: actual object use) were assessed. Building upon the previous work, participants performed four actions (1:

pick-up – first-order planning; 2: pick-up and use – second-order planning; 3: pick-up and pass – second-order planning; and 4: pick-up and pass for use – third-order planning).

Methods implemented in the present work were similar to Scharoun, Scanlan, and Bryden (2016), who assessed the propensity for young adult participants to grasp an object (coffee mug) by the handle in independent (i.e., pick-up; pick-up and pour) and joint-action (i.e., pick-up and pass; pick-up, pour and pass) tasks. Unlike the current study, mug location (right-space, midline, and left-space) and handle orientation (toward, away, to left, and to right of the participant) were also manipulated. Findings from Scharoun, Scanlan et al. (2016) revealed grasp postures that reflected an attempt to maximize efficiency. In addition, participants simultaneously considered the confederate's initial comfort in joint action. More specifically, the handle was grasped more often when manipulating the mug independently (i.e., pick-up; pick-up and pour) compared to joint-action tasks (i.e., pick-up and pass; pick-up, pour, and pass). In contrast to Lindemann et al. (2006), no difference emerged when comparing first- (i.e., pick-up) to second-order (i.e., pick-up and use) planning in independent action; thus supporting van Elk et al.'s (2014) framework. Furthermore, when a skilled independent action was required before passing (i.e., pick-up, pour and pass), participants sacrificed the confederate's comfort to ensure their own. As such, Scharoun, Scanlan et al. (2016) concluded that grasp selection reflects consideration of efficiency, where the confederate's comfort will only be considered if the intended action is similar or costs less than that of the participant.

Summarizing, the current study aimed to assess the tendency for participants to display the end-state comfort effect, functional grasping patterns, and facilitate beginning-state comfort for a researcher. Six- to 11-year-olds, young adults and two groups of older adults (ages 60 to 70, and ages 71+) participated in this study to further assess similarities and differences in object manipulation across the lifespan. Based on findings from Chapter 5, it was hypothesized that end-state comfort would be facilitated more often when manipulating an actual object compared to a dowel. Furthermore, participants were expected to be more sensitive to the effect when acting with the hammer compared to the glass, regardless of the movement context (i.e., demonstration with a dowel and actual object use). With respect to functional grasping and beginning-state comfort, it was hypothesized that these behaviours would be displayed more frequently when the final action involved object use (i.e., more often in pick-up and use, and pick-up and pass for use compared to pick-up, and pick-up and pass), and, in the case of beginning-state comfort, when the cost of executing the final action similar or less than that of the participant (Scharoun, Scanlan et al., 2016). Finally, based on work from a lifespan perspective (e.g., Chapters 3, 4 and 5; Wunsch, Weigelt, & Stöckel, 2015), it was hypothesized that 6-year-olds and older adults ages 71+ would act differently (i.e., display less end- and beginning-state comfort and functional grasps) than other participants in this study.

6.3. Methods

6.3.1. Participants

One hundred and twelve 6- to 11-year-olds, young adults (M_{age} = 22.86, *SD* = 1.49) and two groups of older adults (i.e., older adults ages 60 to 70: M_{age} = 63.85, *SD* = 3.67, and older adults ages 71+: M_{age} = 74.60, *SD* = 3.24) participated in this study (see Table 6.1). Young adults were undergraduate or graduate students from the university and older adults were recruited from the local community. Children were recruited from university summer camps, and two local private and public elementary schools. Data collection was conducted during camp/class time, outside of the camp/class setting. Children were given stickers for completing the study. A background questionnaire was completed to ensure all participants were without visual impairments, injury, and/or diagnosis that may have influenced performance (see Appendix B and C). The University Research Ethics Board approved all recruitment and testing procedures. Written informed consent was obtained from all participants and parents/guardians of participating children. In addition, verbal assent was obtained from participating children.

Table 6.1

Participant demographics

Group	N	M:F	RH:LH	M_{WHQ}(SD)
6-year-olds	11	5:6	9:2	18.00(13.26)
7-year-olds	16	6:10	15:1	25.75(15.02)
8-year-olds	11	5:6	9:2	20.00(22.19)
9-year-olds	10	4:6	8:2	14.00(22.30)
10-year-olds	13	5:8	12:1	20.62(20.79)
11-year-olds	7	4:3	7:0	23.00(9.50)
Young adults	21	9:12	20:1	28.19(9.00)
60- to 70-year-olds	14	4:10	12:2	22.00(24.03)
Older adults 71+	9	5:4	8:1	24.78(20.12)
Total	112	47:65	100:12	22.52(17.66)

6.3.2. Apparatus and procedures

Participants were seated at a table for the duration of the study. To begin, participants were asked to identify the preferred hand for writing (colouring for children) to denote self-report hand preference (see Table 6.1). To confirm hand preference, the Waterloo Handedness Questionnaire was used. Here, participants report their preferred hand for 20-unimanual tasks (Cavill & Bryden, 2003) by selecting one of five responses: left always (-2), left usually (-1), uses both hands equally often (0), right usually (+1), and right always (+2). A number from -2 to +2 is used to compute a total handedness score from -40 to +40. Left-handers are expected to show a negative score while right-handers are expected to show a positive score. Adult participants completed a pen and paper version of the questionnaire; whereas the questionnaire was read aloud to children and items were explained, if necessary. Note that previous research has successfully used oral administration of questions as alterations to the administration of handedness questionnaires for pre-school children (e.g., Karapetsas & Vlachos, 1997).

Participants performed four actions (pick-up, pick-up and use, pick-up and pass, pick-up and pass for use) in two different movement contexts (demonstration with a dowel as if it were the tool and actual object use) with a familiar (glass) and less familiar (hammer) object. Actions varied as a function of the type of object manipulation (independent and joint action) and order of planning (first-, second-, or third-order planning; see Table 6.2 for summary). When demonstrating the action, each dowel was painted half black enabling each end to be related to part of the actual object based on colour (i.e., black represents the bottom of the glass, black represents the handle; see Figure 6.1). Only critical conditions (i.e., overturned glass and handle facing away from the participant) were assessed.

Before data collection started, participants were instructed they would be asked to show the researcher how they would pick up an object, pick up an object and us it, pick up an object and pass it to the researchers, and pick up an object and pass it to the researcher to use. Children were asked to confirm familiarity with a juice glass (i.e., cup) and a hammer. In particular, children were asked to describe each object to confirm familiarity with the object. Children were then asked to describe the difference between upright and overturned (or right side up and upside down), and handle facing towards and away to confirm understanding. Finally, children were asked to identify which hand was left, and which was right. The researcher pointed at each hand if necessary throughout the duration of the study. Children were informed they would be performing the action of picking up a glass (i.e., cup) and pretending to pour a glass of water, or picking up a hammer and hitting a nail. Instructions for the remainder of the study progressed as follows:

(1) Demonstrate with dowel: *(a) glass: Pretend this dowel/stick is a cup. The black end is the bottom. I am going to put it on the x. Show me with your [right hand / left hand] how you would [i. pick it up; ii. pick it up and pretend to pour a glass of water with this pitcher; iii. pick it up and pass it to me; and iv. pick it up and pass it to me so I can pretend to pour a glass of water with this pitcher] – Go! (b) hammer: Pretend this dowel/stick is a hammer. The black end is the handle. I am going to put it on the x with the handle facing away from you. Show me with your [right hand / left hand] how you would [i. pick it up; ii. pick it up and hit this nail; iii. pick it up and pass it to me; and iv. pick it up and pass it to me so I can hit the nail] – Go!*

(2) Actual tool use: *Now we are going to use the real cup. Show me with your [right hand / left hand] how you would [i. pick it up; ii. pick it up and pretend to pour a glass of water with this pitcher; iii. pick it up and pass it to me; and iv. pick it up and pass it to me so I can pretend to pour a glass of water with this pitcher] – Go! (b) hammer: Now we are going to use the real hammer. Show me with your [right hand / left hand] how you would [i. pick it up; ii. pick it up and hit this nail; iii. pick it up and pass it to me; and iv. pick it up and pass it to me so I can hit the nail] – Go!*

Participants performed each action three times with both the left- and right-hand. A video camera was used to record each session. Videos were coded offline to note: (1) the proportion of grasps which satisfied the end-state comfort effect (i.e., where the participant ended with a comfortable grasp posture); (2) the percentage of functional grasps (i.e., suited for object use); and (3) the proportion of grasps which facilitated beginning state comfort for the researcher in joint action tasks (i.e., where the researcher could grasp the object comfortably without further manipulation).

Table 6.2

A breakdown of task requirements according to the type of object manipulation

Action	Type of object manipulation	Order of planning
Pick-up	Independent	First-order
Pick-up and use	Independent	Second-order
Pick-up and pass	Joint action	Second-order
Pick-up and pass for use	Joint action	Third-order

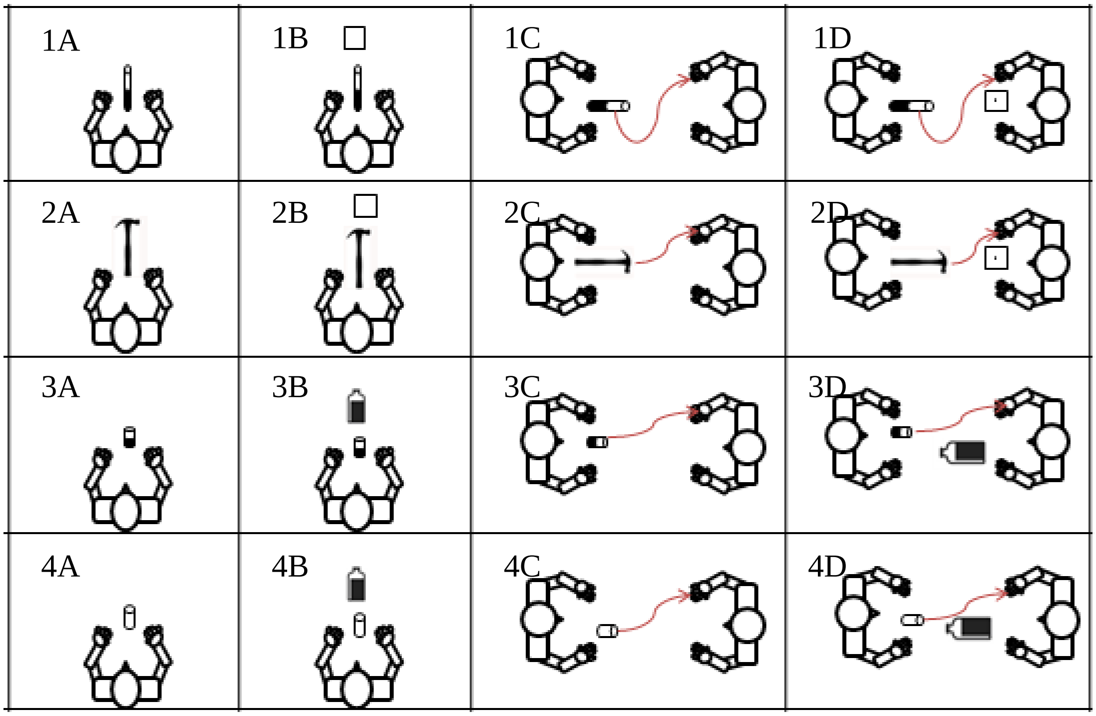

Figure 6.1. Study set-up. Participants performed four different actions: (A) pick-up, (B) pick-up and use, (C) pick-up and pass, and (D) pick-up and pass for use. Actions were performed with: (1) a dowel with similar dimensions as a hammer, (2) a hammer, (3) a glass, and (4) a dowel with similar dimensions as a glass.

6.4. Results

It is important to acknowledge that groups were unequal in size, which was a limitation of this study. Nevertheless, ANOVA is robust to unequal sample size, even in the face of heterogeneity of variance. As such, each dependent measure (1: proportion of grasps sensitive to end-state comfort, and 2: proportion of functional grasps) was submitted to a mixed ANOVA. For each ANOVA the between-subjects factor was age group (8: 6-, 7-, 8-, 9-, 10-, and 11-year-olds, young adults, 60- to 70-year olds, and older adults ages 71+). The within-subjects factors were object (2: glass, hammer), movement context (2: demonstrate with dowel, actual use), action (4: pick-up, pick-up and use, pick-up and pass, pick-up and pass for use) and hand used to complete the task (2: left- and right-hand). The effect of hand was non-significant for end-state comfort ($F(1, 103) = 1.132$, $p = .290$, $\eta^2 = .001$) and functional grasping ($F(1, 103) = 2.405$, $p = .124$, $\eta^2 = .023$); therefore, to simplify analyses, data were collapsed as a function of hand and re-analyzed. Levene's test of equality of error variances was significant for all factors. An arc tan transformation was applied (Field, 2013); however, violations of homogeneity of variance remained. As there is, to our knowledge, no known nonparametric equivalent to a mixed ANOVA (Field, 2013), analyses were performed on the non-transformed data, in percentages.

The proportion of participant grasps that facilitated beginning state comfort for the researcher was also submitted to a mixed ANOVA. The between subjects factor was age group (8: 6-, 7-, 8-, 9-, 10-, and 11-year-olds, young adults, 60- to 70-year-olds, and older adults ages 71+). The within subjects factors were object (2: glass, hammer), movement context (2: demonstrate with dowel, actual use), action (2: pick-up and pass, pick-up and pass for use) and hand used to complete the task (2: left- and right-hand).

Due to the plethora of significant main effects and interactions, only those with effects close to medium in size (or larger) based on traditional benchmarks ($\eta^2 = 0.06$, Cohen, 1988; Lakens, 2013) will be discussed in text. However, other relevant statistics can be found in Tables 3 to 5.

6.4.1. End-state comfort

A significant main effect of group, $F(8, 103) = 4.556$, $p < .001$, $\eta^2 = .042$, revealed 6-year-olds (*M* = 71.35, *SD* = 41.01) displayed less end-state comfort than 7- (*M* = 92.81, *SD* = 21.74) and 10-year-olds (*M* = 90.06, *SD* = 26.34), young adults (*M* = 97.57, *SD* = 13.94), and 60- to 70-year-olds (*M* = 94.39, *SD* = 21.10; see Figure 6.2).

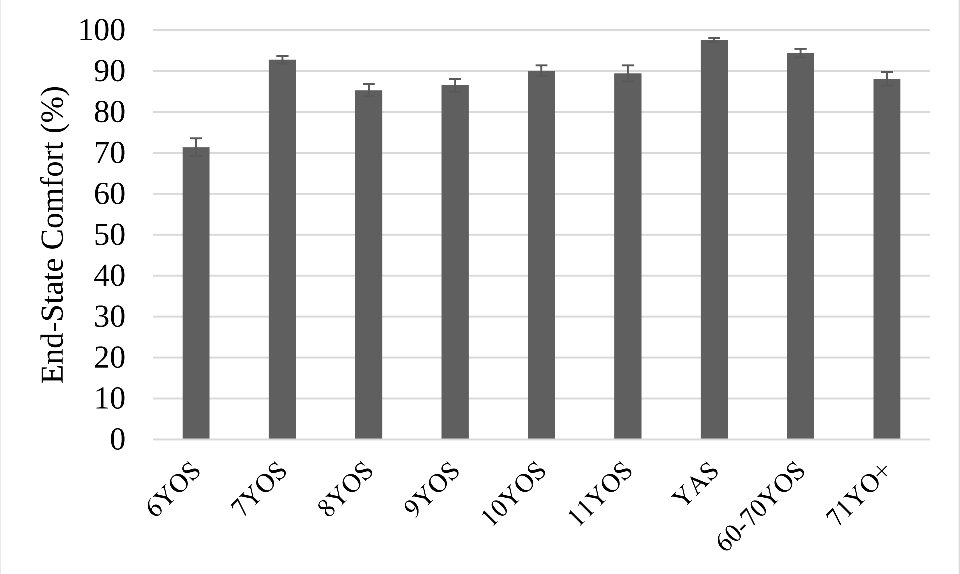

Figure 6.2. Six-year-old displayed less end-state comfort than 7- and 10-year-olds, young adults and 60- to 70-year-olds; however, sensitivity to the effect did not differ from other age groups. Error bars represent standard error.

A two-way interaction between object and movement context also emerged, $F(1, 103) = 6.036$, $p = .016$, $\eta^2 = .055$. When acting with a dowel, more end-state comfort was displayed when using it as a hammer ($M = 90.44$, $SD = 25.49$), compared to a glass ($M = 87.11$, $SD = 29.72$). Furthermore, within the glass task, sensitivity to the effect was greater when acting with the actual object ($M = 90.68$, $SD = 25.78$) compared to the dowel. When acting in the hammer task, end-state comfort did not differ as a function of the movement context ($M_{actual\ hammer} = 89.90$, $SD = 26.93$).

An interaction between object and action was also revealed. Mauchly's test of sphericity was violated, $\chi^2(5) = 33.097$, $p < .001$ ($\varepsilon > .75$); therefore, a Huynh-Feldt correction was applied, $F(2.806, 289.019) = 13.835$, $p < .001$, $\eta^2 = .118$. In pick-up and use (i.e., second-order planning), more end-state comfort was displayed within the hammer task ($M = 96.35$, $SD = 16.95$), compared to the glass task ($M = 84.04$, $SD = 32.49$). In the hammer task, evidence of the effect was greatest in pick-up and use compared to all other actions. The opposite (i.e., least end-state comfort) was observed in the glass task (see Figure 6.3).

Figure 6.3. The interaction between object and action revealed more end-state comfort in the hammer glass overall; in particular, within the pick-up and use task. Error bars represent standard error.

Finally, there was an interaction between the movement context and action. Mauchly's test of sphericity was violated, $\chi^2(5) = 13.016$, $p = .023$ ($\varepsilon > .75$); therefore, a Huynh-Feldt correction was applied, $F(3, 309) = 5.942$, p = .001, $\eta^2 = .055$. In pick-up and use, more end-state comfort was displayed when acting with the actual tool (*M* = 92.78, *SD* = 23.06) compared to the dowel (*M* = 87.17, *SD* = 30.11). When acting with the actual tool, evidence of the effect was greatest in pick-up and use compared to pick-up (*M* = 90.10, *SD* = 26.36), pick-up and pass (*M* = 89.36, *SD* = 28.06) and pick-up and pass for use (*M* = 87.13, *SD* = 29.48). When acting with the dowel, end-state comfort did not differ when comparing pick-up (*M* = 88.69, *SD* = 23.40), pick-up and use (*M* = 87.17, *SD* = 30.11), pick-up and pass (*M* = 87.35, *SD* = 29.39) and pick-up and pass for use (*M* = 89.36, *SD* = 25.88). Please see Table 6.3 for additional main effect and interaction effect statistics.

Table 6.3

For end-state comfort, significant interactions without effect sizes equal, or approximately equal to medium and large benchmarks

Interaction	F-Statement
Object x movement context x age group	F (8, 103) = 2.529, p = .015, η^2 = .024
Object x action x age group	F (24, 309) = 2.384, p < .001, η^2 = .023
Movement context x order x age group	F (24, 309) = 2.207, p = .001, η^2 = .021
Object x movement context x action	F (3, 309) = 3.670, p = .013, η^2 = .034

6.4.2. Functional grasping

A main effect of movement context, *F* (1, 103) = 5.647, *p* = .019, η^2 = .052, revealed more functional grasps when acting with the actual tool (*M* = 65.81, *SD* = 45.01) compared to the dowel (*M* = 64.73, *SD* = 44.95). A main effect of action also emerged. Mauchly’s test of sphericity was violated, χ^2 (5) = 58.492, p < .001 (ε > .75); therefore, a Huynh-Feldt correction was applied, *F* (2.635, 271.364) = 65.610, *p* < .001, η^2 = .389. Functional grasping was seen most often in pick-up and use (*M* = 87.14, *SD* = 30.36) and least often in pick-up and pass (*M* = 49.12, *SD* = 47.92) compared to pick-up (*M* = 65.04, *SD* = 44.91) and pick-up and pass for use (*M* = 64.05, *SD* = 44.84), which did not differ.

A two-way interaction between object and age group, *F* (8, 103) = 6.775, *p* < .001, η^2 = .062 (see Figure 6.4) was revealed. Within the glass task 6- and 9- to 11-year-old participants displayed less functional grasps than young adults and 60- to 70-year-olds. Also, 6- and 9-year-olds displayed less functional than 8-year-olds, and 6-year-olds less than 7-year-olds. In the hammer task, 7- to 10-year-olds displayed more functional grasps than young adults and 60- to 70-year-olds and 7- and 9-year-olds more than 6-year-olds. The 9-year-olds displayed more functional grasps in the hammer task compared to the glass task; whereas young-adults and 60- to 70-year-olds displayed the opposite effect.

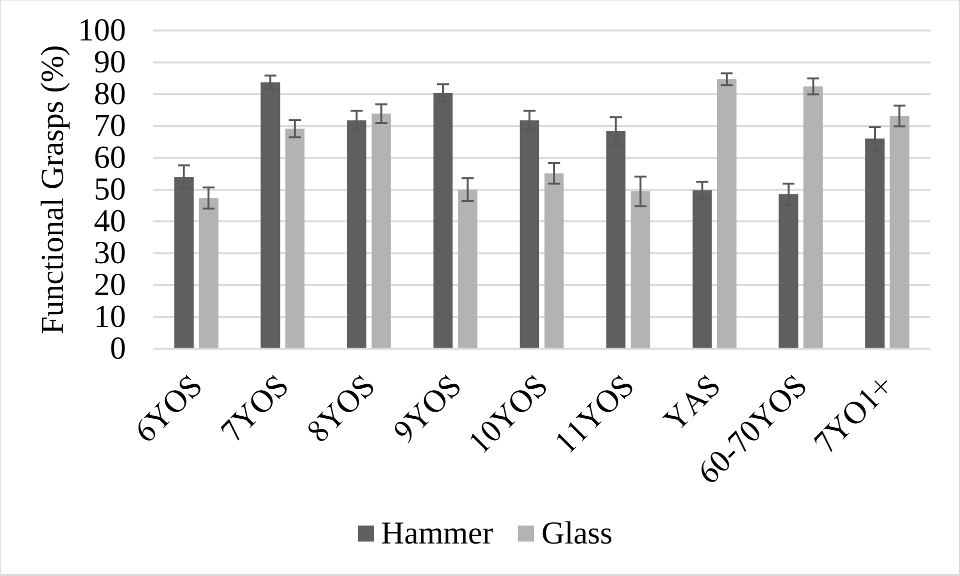

Figure 6.4. The two-way interaction between object and age group revealed young adults and 60- to 70-year-olds displayed less functional grasps than 7- to 10-year-olds, among other differences. Error bars represent standard error.

A two-way interaction between object and movement context, *F* (1, 103) = 14.658, $p < .001$, $\eta^2 = .125$, revealed more functional grasps with the actual object (*M* = 72.21, *SD* = 41.96) compared to the dowel in the glass task (*M* = 63.80, *SD* = 45.08). No differences emerged when comparing the actual object (*M* = 63.69, *SD* = 46.17) and dowel (*M* = 66.26, *SD* = 44.80) in the hammer task. Finally, there was an interaction between object and action. Mauchly's test of sphericity was violated, χ^2 (5) = 49.724, p < .001 (ε > .75); therefore a Huynh-Feldt correction was applied, *F* (2.662, 274.206) = 54.641, $p < .001$, $\eta^2 = .347$ (see Figure 6.5). Analyses revealed that, in pick-up and pick-up and use functional grasping was more evident in the hammer task compared to the glass task; whereas in pick-up and pass for use, the opposite was revealed. Looking specifically at the glass task, functional grasping was greatest in pick-up and use, and pick-up and pass for use compared to pick-up and pick-up and pass. Finally, with respect to the hammer task, functional grasping was greatest in pick-up and pick-up and use compared to pick-up and pass, and pick-up and pass for use. Please see Table 6.4 for additional main effect and interaction effect statistics.

Figure 6.5. Functional grasping was most evident in pick-up and pick-up and use when acting in the less familiar hammer task, compared to the familiar glass task, where it was most evident in pick-up and pass, and pick-up and pass for use. Error bars represent standard error.

Table 6.4

For functional grasping, significant interactions without effect sizes equal, or approximately equal to medium and large benchmarks

Interaction	F-Statement
Action x age group	F (24, 309) = 2.421, $p < .001$, $\eta^2 = .023$
Object x movement context x age group	F (8, 103) = 2.288, $p = .027$, $\eta^2 = .022$
Object x action x age group	F (24, 309) = 3.069, $p < .001$, $\eta^2 = .029$
Movement context x action x age group	F (24, 309) = 1.766, $p = .016$, $\eta^2 = .017$

6.4.3. Beginning-state comfort

A significant main effect of group, $F(8, 103) = 5.794$, $p < .001$, $\eta^2 = .053$ (see Figure 6.6), revealed 6- to 10-year-olds displayed less beginning-state comfort than young adults, and

6- and 9-year-olds less than 60- to 70-year-olds. Main effects of object ($F(1, 103) = 31.982$, $p < .001$, $\eta^2 = .237$) and action ($F(1, 103) = 82.464$, $p < .001$, $\eta^2 = .445$) also emerged. These will be discussed with respect to the significant two-way interactions, where they are embedded.

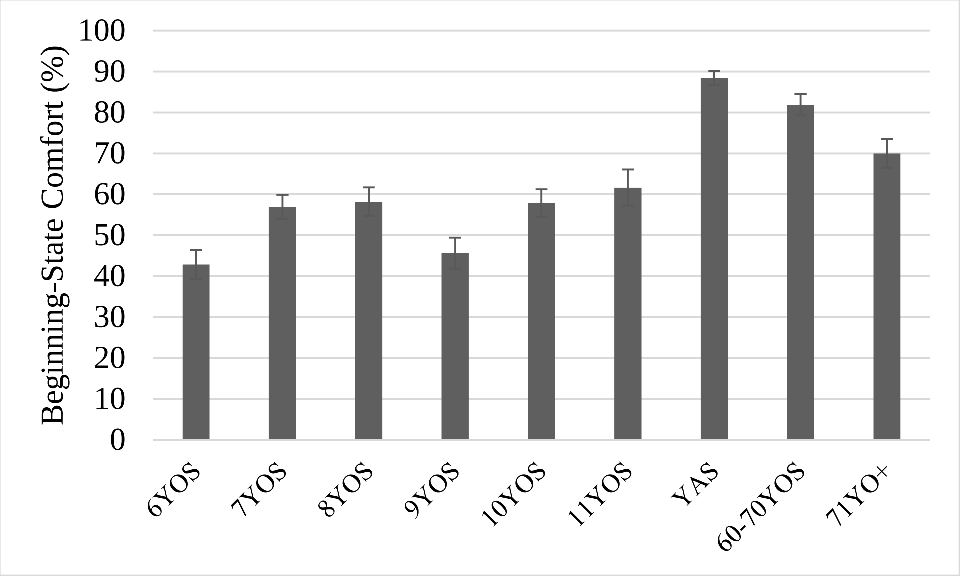

Figure 6.6. Six- to 10-year-olds displayed less beginning-state comfort than young adults, and 6- and 9-year-olds less than 60- to 70-year-olds. Error bars represent standard error.

A two-way interaction between object and action, $F(1, 103) = 44.619$, $p < .001$, $\eta^2 = .302$ (see Figure 6.7), revealed participants facilitated beginning-state comfort more often when passing an object for use, rather than simply passing it, regardless of the familiarity with the task. When passing for use, beginning-state comfort was facilitated more often with the glass than the hammer. An interaction between object and movement context also emerged, $F(1, 103) = 6.009$, $p = .016$, $\eta^2 = .055$. Regardless if participants were manipulating the dowel or actual object, more beginning-state comfort was facilitated in the glass task; however, in this task, beginning-state comfort was facilitated more often with the actual object ($M = 79.61$, $SD = 39.71$) compared to the dowel ($M = 73.36$, $SD = 43.23$). In the hammer task, beginning-state comfort did not differ when comparing the actual tool (*M* = 52.68, *SD* = 47.57) to the dowel (*M* = 54.39, *SD* = 47.90). Finally, an interaction between movement context and action (*F*(1, 103) = 6.436, *p* = .013, η^2 = .059) revealed that, regardless if manipulation a dowel or actual object, there was more beginning-state comfort when passing for use (M_{dowel} = 75.30, SD_{dowel} = 41.23; M_{object} = 74.41, SD_{object} = 42.48) compared to simply passing (M_{dowel} = 52.46, SD_{dowel} = 48.48; M_{object} = 57.89, SD_{object} = 47.90). Please see Table 6.5 for additional main effect and interaction effect statistics.

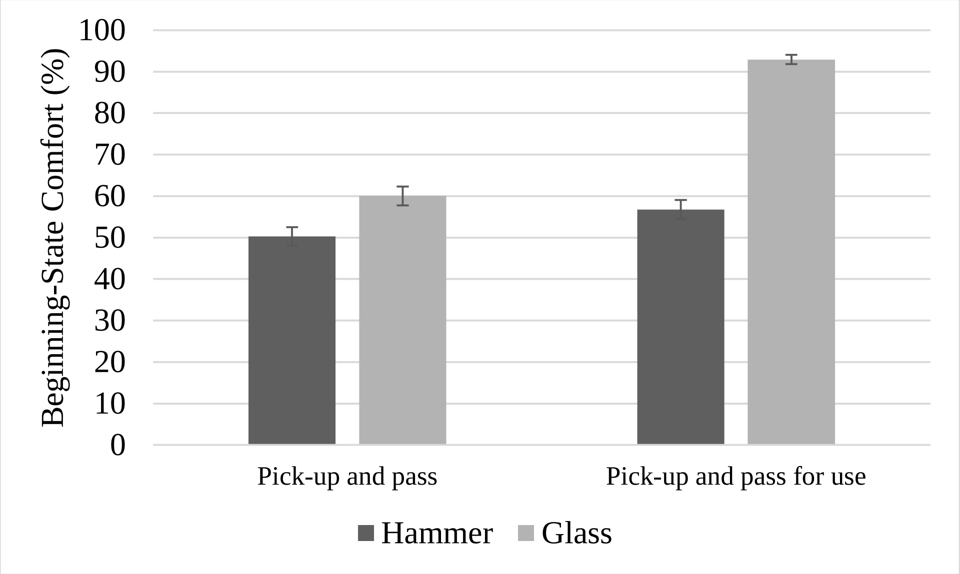

Figure 6.7. Beginning-state comfort was facilitated most often what passing the glass for use. Error bars represent standard error.

Table 6.5

For beginning-state comfort, significant interactions without effect sizes equal, or approximately equal to medium and large benchmarks

Effect / Interaction	F-Statement
Hand	*F* (1, 103) = 4.854, *p* = .033, η^2 = .045
Object x age group	*F* (8, 103) = 2.884, *p* = .006, η^2 = .027
Object x movement context x age group	*F* (8, 103) = 2.601, *p* = .012, η^2 = .025
Object x action x age group	*F* (8, 103) = 3.182, *p* = .003, η^2 = .030

6.5. Discussion

The current research assessed the propensity for 6- to 11-year olds, young adults, and two groups of older adults (older adults ages 60 to 70, and older adults ages 71+) to display end-state comfort, functional grasping patterns, and facilitate beginning-state comfort for a researcher. It was hypothesized that 6-year-olds and older adults ages 71+ would perform differently (i.e., demonstrate less end- and beginning-state comfort and functional grasps) than other participants in this study. A main effect of group revealed 6-year-olds displayed less end-state comfort than 7- and 10-year-olds, young adults and 60- to 70-year-olds. Similar to Chapters 4 and 5, 6-year-olds did not differ from older adults ages 71+, attributed to negative developmental trends with increasing age (e.g., Chapter 3; Wunsch et al., 2015). Unlike the previous work, 6-year-olds displayed less end-state comfort than 7- and 10-year-olds. Although evidence in children is different (i.e., adult-like in younger children) from previous reports of end-state comfort in unimanual object manipulation (e.g., Knudson et al., 2012; Chapter 4), findings are concurrent with Chapter 5 and Stöckel and Hughes (2015) who also observed significantly less end-state comfort in 6-year-olds compared to older children.

The age of 7 has been identified as an important age in sensorimotor development. Recent accounts discuss increased proprioceptive acuity between the ages of 7 and 8 that fuels a shift to feed-forward control as sensory processing delays are gradually overcome (King, Kagerer, Contreras-Vidal, & Clark, 2009; King et al., 2012; King, Pengelinan, Kagerer, & Clark, 2010). Likewise, a study assessing the end-state comfort effect discussed an increased (albeit not yet proficient) ability to integrate multisensory information at this age in anticipation of future demands; therefore enabling a better balance between habitual and goal-directed systems in action planning (Stöckel & Hughes, 2015). Nevertheless, variability between the ages of 7 and 10 has been described as a transition period, thus explaining age-related differences (Mason, Bruyn, & Lazarus, 2013).

Stöckel and Hughes (2015) proposed that young children's (i.e., ages 6 and younger) motor behaviour reflects a bias towards the habitual system and away from the goal-directed system; therefore, grasp selection reflects a stimulus-driven response (i.e., based on a previously successful action with the object, likely involving first-order planning), as opposed to an action which reflects consideration of affordances and task demands (i.e., higher order planning). Likewise, in reference to van Elk et al.'s (2014) framework for action semantics, Glenberg and Soliman (2014) argued that proficient object use emerges "by the instrument's incorporation into the multisensory and motor representations of the body" (p. 253). Furthermore, the authors discuss the parallel between motor learning and changes that occur due to physical growth and maturation. More specifically, experience and acquisition of multisensory feedback update the hand-tool body schema, thus benefitting the forward model and ability to anticipate forthcoming movements (Glenberg & Soliman, 2014; van Elk et al., 2014).

Assessments of functional grasping and beginning-state comfort provide further support for the previous, while also providing evidence that with age, older adults (ages 71+) revert back to biasing the habitual system with an increase in cognitive demands. As evidenced in Figure 6.4, (the interaction between object and age group), children and older adults ages 71+ approached the task differently than young adults and 60- to 70-year-olds with respect to functional grasping. In most cases, children displayed more functional grasps when manipulating the hammer compared to the glass, and older adults ages 71+ displayed no difference; however, young adults and 60- to 70-year-olds displayed the opposite effect. Here, it can be argued that the habitual system biased children to grasp the hammer by the handle and grasp the glass with a thumb-up posture regardless of the action intention. In contrast, for young-adults and 60-to 70-year-olds, the manner in which an object is grasped reflects the goal-directed system, and consideration of intentions. For example, grasping the handle (of hammer or dowel) in independent action, thus demonstrating a functional grasp, and grasping the head in joint action, to facilitate a comfortable and functional beginning state grasp for the researcher.

In support of this (as displayed in Figure 6.6), a main effect of age revealed less beginning-state comfort was facilitated by children in comparison to young adults and 60- to 70-year-olds, where no differences emerged when assessing older adults ages 71+. Findings in children differ from Scharoun & Bryden (2014b) who observed children as young as 7 facilitated beginning-state comfort for a researcher. Nevertheless, their study was limited to the manipulation of an actual glass. Therefore, it is likely that the inclusion of the hammer (i.e., less familiar object) and manipulating dowels as if they were objects influenced grasp behaviours in joint action. It is generally understood that children are more proficient in self-directed compared to other-directed tasks, as it is easier to interpret action consequences (e.g., Claxton et al., 2009; McCarty et al., 2001). According to Piaget’s (1953) notion of egocentrism, young children are limited in their ability to visualize the perspective of others; therefore, are more proficient in independent compared to joint action tasks.

The aforementioned findings will be discussed in greater detail in the following; however, it is first important to highlight other influential factors prior to this discussion. In Chapter 5 it was argued that when object affordances were more easily detected, differences in behaviours emerged. As such, in the current study it was hypothesized that end-state comfort would be more evident in actual object use compared to when manipulating a dowel, and when acting with the hammer compared to the glass, regardless of the movement context. Furthermore, it was hypothesized that functional grasping and beginning state comfort would be more evident when the final action involved object use (i.e., more often in pick-up and use, and pick-up and pass for use compared to pick-up, and pick-up and pass), and, in the case of beginning-state comfort, when the cost of executing the final action was similar or less than that of the participant (Scharoun, Scanlan et al., 2016).

Evidence in support of these hypotheses emerged in interactions between object and movement context, movement context and action, and object and action. In particular, the interaction between object and movement context revealed that, within the glass task, end-state comfort, functional grasping and beginning-state comfort were more frequently observed in actual object use compared to when acting with a dowel. Furthermore, when manipulating a dowel, end-state comfort was displayed more often in the hammering task compared to the glass task. Such findings can be attributed to the ease of affordance detection (e.g., Ellis & Tucker, 2000; Scharoun et al., accepted; Tucker & Ellis, 1998). The hammer offers the actor a more apparent affordance of graspability, considering the clear distinction between the handle and head. Anecdotally, when manipulating the dowel as a hammer, the distinction between head and handle was easily interpreted by participants. However, differentiating between the top and bottom of the glass was more frequently confused (and had to be clarified), despite the dowels both being painted half black. Future work would benefit from use of eye tracking technology to identify the location and sequence of fixations (i.e., allocation of visual-spatial attention; Karatekin, 2007).

Interestingly, regardless of the movement context, beginning-state comfort was facilitated more often in the glass task compared to the hammer task. Gonzalez et al. (2011) suggested that beginning-state comfort is facilitated as a function of learned social norms, such that actions reflect being polite. It has also been suggested that one will increase effort (i.e., facilitate beginning-state comfort) based on the belief that such action will decrease the overall effort required by the recipient (Santamaria & Rosenbaum, 2011). Nevertheless, others have reported that grasp selection in joint action reflects consideration of efficiency (e.g., Scharoun, Scanlan et al., 2016); therefore, people are more willing to reciprocate helpfulness, if they have been helped before (Bartlett & DeSteno, 2006). It can therefore be argued that beginning-state comfort was facilitated more often in the familiar glass task, as most participants were familiar with passing a glass for use (i.e., with the opening facing up), and being passed an object for use. As such, the action was reciprocated. In contrast, when manipulating the hammer, a less familiar object, attention was focused on the detection of affordances.

It is likely that this pattern of results is driven by the performance of children. A three-way interaction between object, movement context and age was revealed; however, due to the small effect size ($\eta^2 = .025$) findings were not discussed in detail. Nevertheless, considering the main effect of age, it can be speculated that children's behaviour reflects the automatic detection of affordances, where consideration of action intentions in joint action emerge gradually with age and physical maturation (Glenberg & Soliman, 2014; van Elk et al., 2014). Such explanation can also be used to explain why, in contrast to the current study, Scharoun and Bryden (2014b) observed children ages 7 to 12 facilitated beginning-state comfort to the same extent as young adults, as their study was limited to manipulating a glass.

Interactions between movement context and action (end- and beginning-state comfort) and main effects of movement context and action (functional grasping) provide further evidence to support for automatic detection of affordances and consideration of action intention (van Elk et al., 2014). Here, functional grasps were displayed more frequently when manipulating an actual object, and in pick-up and use compared to the other actions. Similar observations emerged when assessing end-state comfort; however, this was limited to manipulation of the actual object, as no differences emerged when acting with the dowel as a function of the movement context. Nevertheless, end-state comfort was exclusively observed more often in actual object use within the pick-up and use task. Finally, beginning-state comfort was facilitated more often when passing the object for use, as opposed to simple passing the object to the research without a related action intention.

With respect to the interaction between object and action, within the hammering task, end-state comfort was observed more frequently in pick-up and use compared to all other movement contexts. Interestingly, the opposite was observed in the glass task, where less end-state comfort was also observed when comparing the glass task to the hammering task in this movement context. Nevertheless, end-state comfort was displayed in 83.6% of pick-up and use trials; therefore, although statistically different, it can be argued whether this is interpreted as a relevant difference. Thibaut and Toussaint (2010) categorized children's stability across trials by classification into one of four categories: 0-20%, 20-50%, 50-80%, and 80-100%. The proportion of children in each extreme were identified as those who displayed grasps inconsistent (i.e., 0-20%) or consistent (i.e., 80-100%) to the end-state comfort effect. In light of the current findings, it should be acknowledged that participants behaved differently when acting in the hammering task compared to the glass task. This is likely attributed to task familiarity and experience (e.g., Herbort & Butz, 2011). Future studies should assess participants experience and familiarity with the objects that are being manipulated.

6.6. Summary and conclusions

In summary, findings from the current study provide support for van Elk's (2014) framework for action semantics, in the context of object manipulation and orders of planning. In particular, results highlight the automatic perception and detection of affordances for action. Furthermore, as expressed by Glenberg and Soliman (2016), "practice and feedback with the new system (e.g., growth or tool) changes a forward model that predicts consequent multisensory afference of the updated system and thus anticipates the consequences of joint hand-tool motor plans" (p. 253). In other words, with age, experience, and familiarity, children are better able to integrate multisensory information in anticipation of an intended action. As such, children shift from relying on the habitual system, to utilizing the goal-directed system and considering affordances and task demands (e.g., Stöckel & Hughes, 2015). Likewise, with increasing age and cognitive decline, older adults ages 71+ revert back to reliance on the habitual system, and thus demonstrate a stimulus-driven response (i.e., based on a previously successful action with the object, likely involving first-order planning), as opposed to an action that reflects higher order planning (e.g., Scharoun, Gonzalez, et al., 2016). Taken together, these findings add to van Elk's (2014) framework for action semantics from a lifespan perspective.

Chapter 7 – General Discussion

7.1. Summary and interpretation of main findings

The goal of this doctoral work was to further investigate anticipatory planning in object manipulation. A cross-sectional approach was used in a series of five studies to investigate planning and control processes. The main objectives were to: (a) understand the influence of the movement context; (b) delineate the role of handedness; (c) characterize the influence of familiarity with an object; (d) investigate independent and cooperative movements; and (e) outline similarities and differences across the lifespan.

Chapter 2 established a foundation for the thesis. Right and left handed young adults were asked to pick-up an overturned glass as if to pour water in pantomime without a stimulus, pantomime with image of the glass or actual glass as a guide, and actual grasping. The use of various movement contexts enabled the cognitive demands of the task to be manipulated, considering previous reports that actual object use, in comparison to pantomime, reduces the demand on working memory (e.g., Heath et al., 2002; Randerath et al., 2009; Roy et al., 2014). Anticipatory planning was assessed observationally by means of the end-state comfort effect. No differences emerged as a function of participant hand preference or hand used to complete the task, supporting the idea that end-state comfort prevails over hand preference (e.g., Seegelke et al., 2014). Evidence of end-state comfort was also unaffected by the movement context, likely attributed to the habitual nature of the task (Herbort & Butz, 2011). Nevertheless, kinematic data provided support for the manipulation. In particular, movement time in the approach phase was longest in pantomime without a stimulus and shortest in actual grasping. Furthermore, grasp time was shortest and use time was longest in pantomime without a stimulus. Such findings providing support for an increased cognitive demand (e.g., Hermsdörfer et al., 2006). Findings from Chapter 2 served as proof of concept for the manipulation, and established a basis for investigation from a lifespan perspective.

Extending the aforementioned work, Chapter 3 compared data to a group of left and right handed older adults. Similar to Chapter 2, no differences in end-state comfort emerged as a function of participant hand preference or hand used to complete the task (e.g., Seegelke et al., 2014). Young and older adults did not differ; however, as a group, older adults displayed less end-state comfort in pantomime without a stimulus and with image of the glass as a guide. Older adults were thus separated into two groups: (1) older adults who displayed end-state comfort, and (2) older adults who did not display the effect. Not only were older adults who did not display the effect significantly older than those who did, they also spent a longer time in the final approach to the target in pure pantomime. Findings were attributed to the increased reliance on feedback-dependent corrective mechanisms with increasing age (e.g., Seidler et al., 2010). In other words, without contextual information to guide movement, an increase in cognitive demand coupled with a decrease in available cognitive resources resulted in a decrease in end-state comfort.

At approximately the same time this study was published, Wunsch et al. (2015) similarly attributed a decrease in end-state comfort in older adults (albeit comparing unimanual and bimanual bar-transport tasks) to cognitive decline, considering the link between the development of anticipatory planning skills and cognitive skills in children (Rosenbaum et al., 2001; Weigelt & Schack, 2010; Stöckel & Hughes, 2015). Separating older adults into young-old (age 60 to 70) and old-older (age 71 to 80) groups, Wunsch et al. (2015) noted the proportion of end-state comfort in old-older adults (ages 71 to 80) was comparable to previous reports of 6- and 7-year-old children (e.g., Wunsch et al., 2014). Findings from Wunsch et al., (2015), and results of Chapter 3 were used to separate older adults into two groups for the remaining thesis studies.

To quantify similarities and differences between young children and older adults, Chapter 4 assessed the end-state comfort effect in right handed children ages 5 to 12, young adults, and two groups of older adults (ages 60 to 70 and ages 71+) using the aforementioned methods (Chapters 2 & 3). Similar to Chapters 3 and 4 performance differences between the two hands were non-existent (e.g., Seegelke et al., 2014). Adult-like patterns of end-state comfort emerged in 8-year-olds, in line with Knudson et al. (2012) and previous reports of online control that highlight the age of 8 to be a marker in child development (e.g., Bary & Hay, 1983). Also of particular interest, older adults ages 71+ displayed more end-state comfort in actual grasping compared to the other movement contexts, providing additional support for the idea of negative developmental decline with age (e.g., Chapter 3; Wunsch et al., 2015) Finally, and contrary to expected results, 5- to 6-year-olds displayed more end-state comfort in pantomime without a stimulus, ascribed to familiarity with pretend play (e.g., Singer & Singer, 1992) considering the role of the habitual system in action planning (Herbort & Butz, 2011).

Chapter 5 continued with the idea of the habitual and goal-directed system influencing action planning by means of assessing the end-state comfort effect when manipulating a more familiar (glass) and less familiar (hammer) object in pantomime, demonstration with a dowel, and actual use. Similar to Chapter 4, children ages 6 to 12, young adults, older adults ages 60 to 70 and older adults ages 71+ participated in this study. Unlike Chapter 4, differences in end-state comfort (i.e., less evidence of the effect) were exclusively seen in 6-year-olds. Nevertheless, findings were concurrent with recent reports (e.g., Scharoun, Logan, et al., under review; Stöckel & Hughes, 2015) that 7 is a transition year, and with age, children are better able to integrate multisensory information to test and identify the most effective motor strategy (see also Meyer et al., 2013).

Beyond the effect of age, as expected, end-state comfort was more prevalent in actual use compared to demonstration with a dowel and pantomime; however, contrary to the hypothesis, the effect was demonstrated more often within the less familiar hammer task. Results were associated with affordances. More specifically, in comparison to the glass, the hammer offers a more apparent affordance of graspability, considering the clear distinction between head and handle. In light of the previous suggestion, findings from Chapter 5 were interpreted using van Elk et al.'s (2014a,b) framework for action semantics, which proposes that the ability to use tools and objects emerges from "automatic effects of object affordances as well as context- and intentionally driven effects" (p. 240). It was thus argued that anticipatory planning in object manipulation includes the detection and perception of affordances in conjunction with interplay between the habitual and goal-directed system. Interpreted from a developmental perspective, it was argued that the capacity to perceive affordances increases (e.g., Scharoun et al., accepted) and children are better able to balance the habitual and goal-directed systems with age.

The final study of the thesis broadened the scope of research by means of assessing grasp posture in both independent and joint action, in order to assess how the intended action influence anticipatory planning as a function of the action. In Chapter 6, children ages 6 to 12, young adults, older adults ages 60 to 70 and older adults ages 71+ performed four actions (pick-up, pick-up and use, pick-up and pass, pick-up and pass for use) in two different movement contexts (demonstration with a dowel as if it were the tool and actual object use) with a familiar (glass) and less familiar (hammer) object. End-state comfort, functional grasping and beginning-state comfort were assessed. Similar to Chapter 5, results provided support for van Elk et al.'s (2014a,b) framework, while also adding to our understanding of the interplay between the habitual and goal-directed system from a lifespan perspective.

Findings from Chapter 6 highlight the main findings of the thesis. More specifically, results revealed that with age, experience and familiarity, children become more proficient in object manipulation with "improvements" in multisensory integration. As such, children's behaviour reflects a shift from relying solely on the habitual system and actions executed successfully in the past, to the consideration of affordances (e.g., Scharoun et al., accepted) and task demands with the goal-directed system (e.g., Stöckel & Hughes, 2015). Likewise, observing the other end of the lifespan, the behaviour of older adults ages 71+ likely emulates reversion back to reliance on the habitual system. Therefore, with increasing age and cognitive decline, older adults' actions reflect stimulus-driven responses, as opposed to those which consider affordances and intentions (e.g., Wunsch et al., 2015).

Taken together, findings from the thesis indicate that object manipulation can shed light on the sensorimotor and cognitive requirements for planning and control processes across the lifespan. Although the focus of this thesis was squarely on furthering our understanding of the behavioural underpinnings of anticipatory planning, this research has implications for clinical management and treatment across the lifespan. In particular, as expressed throughout the thesis, the decision to manipulate the movement context was based on literature on apraxia pertaining to tool use impairments (e.g., Baunard et al., 2014). Approximately 30% of individuals in the acute phase of stroke will suffer from apraxia (Donkervoort et al., 2001), and with age there exists an increased risk of stroke. Most common in individuals over the age of

70, the last decade has reported a 25% increase for individuals in their 50s and 13% in their 60s (Heart and Stroke Foundation, 2014). As expressed in Chapter 2, Statistics Canada (2014) reported that approximately five million Canadians were aged 65 or older in 2011, and the number is expected to double in the next 25 years. As such, this research has implications for understanding changes in motor behaviour with age, and serves as a basis for investigating age related disorders and deficits, such as stroke, and more specifically, apraxia.

Implications for this research also exist from a developmental perspective. Not only does this research serve to increase our understanding of motor behaviour in typical development, but also serves as a foundation for the study of developmental disabilities. In particular, it is known that individuals with Autism Spectrum Disorder have challenges executing goal-directed movements (e.g., Fornier, Hass, Naik, Lodha, & Cauraugh, 2010; Gowen & Hamilton, 2013; Markoulakis, Scharoun, Bryden, & Fletcher, 2012; Scharoun & Bryden, 2015), and difficulties with anticipatory planning are commonly reported (e.g., Hughes, 1996; Gowen & Hamilton, 2013). For 2012, the prevalence of Autism Spectrum Disorder was estimated at one in every 68 children (Christensen et al., 2016), thus highlighting the importance of continued research in this area.

7.2. Limitations and future directions

Notwithstanding the significance and implication of the aforementioned findings, it is important to acknowledge that the thesis was limited by several factors including (but not limited to): (a) sample size, variability and statistical power; (b) the exclusive use of observational assessment in lifespan studies; (c) object characteristics; and (d) the general understanding of children’s perception of comfort. These limitations are discussed in the following sections. Potential future directions are also outlined.

7.2.1. Sample size, variability, and statistical power

As expressed in Chapter 4, the separation of children into age groups should be considered a strength of the thesis. Nevertheless, it is also important to acknowledge the inclusion of unequal groups with low sample sizes, which may have confounded results. Several statistically significant differences were identified in this thesis, and discussed with reference to effect sizes; however, it is possible that studies lacked the appropriate power to determine significant results in some cases. Nevertheless, the observed statistically significant differences with moderate to high effect sizes suggest this was not a major limitation.

It is also essential to address the inherent variability, as evidenced in high standard deviations. Future work should consider other measures of age (e.g., cognitive age vs. developmental age) to account for variability. Stöckel and Hughes (2015) identified a specific relationship between cognitive and motor function using an end-state comfort task; however, their study was limited to 5-to 6-year-olds. Future work implementing direct assessments of cognitive and motor function are recommended.

7.2.2. The exclusive use of observational assessment in lifespan studies

As evidenced in Chapters 2 and 3 with young and older adults task constraints do not affect motor planning (grasp postures) and execution (kinematic measures) equally (see also Hughes et al., 2011; Seegelke et al., 2011, 2015). It was the intention to collect kinematic data in all studies of the thesis; however, pilot work with 11 children (ranging in age from 5 to 8) revealed that there was too much missing data, resultant from children's movement behaviours (e.g., wrist rotation) and limitations of the motion tracking system. As such, in consideration of this, and the attempt to maximize the potential sample size of children, the decision was made to move forward with observational measures. Nevertheless, it is suggested that future work attempt to overcome such obstacles to provide a more in-depth analysis of reaching and grasping behaviours across the lifespan.

7.2.3. Object characteristics

As expressed in Chapter 4, it can be argued that the propensity for children to display end-state comfort may have been limited by physical characteristics of the object, in relation to physical capabilities. Studies of first order planning (i.e., reaching) have demonstrated that "body-scaled information of object size in relation to hand size influences the emergent reaching patterns for both children and adults" (Huang et al., 2013, p. 47). It is therefore possible that, when provided with an overturned adult-sized glass, children adopted an immature, first-order planning strategy (i.e., thumb-up) as these children are actively learning how to solve second-order planning problems. The question of whether object dimensions influence evidence of end-state comfort was beyond the scope of the current investigation; therefore all participants acted with the same objects. Nevertheless, future research should consider the influence of object dimensions on motor planning.

7.2.4. The general understanding of children's perception of comfort

Recent work from Rosenbaum, Herbort, van der Wel, and Weiss (2014) discussed the origins of grasp planning, and similarities and differences in the way chimpanzees execute anticipatory planning tasks as a means to explain the behaviours of children. Rosenbaum et al. (2014) expressed that "although chimps have the intelligence to plan for second order grasp planning, they tend to plan only as far as needed" (p. 369). As such, it was argued that perhaps chimpanzees disregard end-state comfort because they do not mind uncomfortable end-state postures. Likewise, "if children don't find extreme joint angles uncomfortable, and they have little difficulty controlling their limbs at those joint angles, there would be no need for them to plan grasps that avoid extreme postures” (p. 369). Rosenbaum et al. (2014) expressed the desire to assess posture comfort ratings and preferences. Moving forward, coupling the assessment of anticipatory planning with ratings of comfort may shed light on variability in children’s performance, and inconsistent reports of adult-like patterns of the effect here, and elsewhere (e.g., Wunsch et al., 2013).

Chapter 8 – References

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Appendix A – Waterloo Handedness Questionnaire

Each of the questions below offers five possible responses: RA (right always), RU (right usually), EQ (equal), LU (left usually), and LA (left always).

1. Which hand would you use to spin a top?
LA LU EQ RU RA

2. With which hand would you hold a paintbrush to paint a wall?
LA LU EQ RU RA

3. Which hand would you use to pick up a book?
LA LU EQ RU RA

4. With which hand would you use a spoon to eat soup?
LA LU EQ RU RA

5. Which hand would you use to flip pancakes?
LA LU EQ RU RA

6. Which hand would you use to pick up a piece of paper?
LA LU EQ RU RA

7. Which hand would you use to draw a picture?
LA LU EQ RU RA

8. Which hand would you use to insert and turn a key in a lock?
LA LU EQ RU RA

9. Which hand would you use to insert a plug into an electrical outlet?
LA LU EQ RU RA

10. Which hand would you use to throw a ball?
LA LU EQ RU RA

11. In which hand would you hold a needle while sewing?
LA LU EQ RU RA

12. Which hand would you use to turn on a light switch?
LA LU EQ RU RA

13. With which hand would you use the eraser at the end of a pencil?
LA LU EQ RU RA

14. Which hand would you use to saw a piece of wood with a hand saw?
LA LU EQ RU RA

15. Which hand would you use to open a drawer?
LA LU EQ RU RA

16. Which hand would you turn a doorknob with?
LA LU EQ RU RA

17. Which hand would you use to hammer a nail?
LA LU EQ RU RA

18. With which hand would you use a pair of tweezers?
LA LU EQ RU RA

19. Which hand do you use for writing?
LA LU EQ RU RA

20. Which hand would you turn the dial of a combination lock with?
LA LU EQ RU RA

21. Is there any reason (e.g. injury) why you have changed your hand preference for any of the above activities?
YES NO (circle one) Explain.

22. Have you ever been given special training or encouragement to use a particular hand for certain activities?
YES NO (circle one) Explain.

Appendix B – Background Questionnaire (Adult)

Participant code: ___________________________________ Date: ____________

Age: _______________________ Gender: Male / Female

1. Do you wear glasses/contacts? YES / NO

2. Do you have a visual impairment?
   YES/NO
   If yes… what type of visual impairment do you have (i.e. macular degeneration, cataracts, etc.)? _______________________

3. Have you had a hand/wrist/shoulder injury/surgery within the last year? YES/NO

4. Are you a varsity athlete or do you train with a competitive sports team? YES/NO

   If yes, what is your sport? __________________

5. Do you exercise? YES/NO
   How many hours a week are you physically active? __________
   What types of exercises do you do?
   ____

6. Have you experienced or been diagnosed with any of the following? Please check all boxes that apply.
   - ☐ Multiple Sclerosis
   - ☐ Parkinson's disease
   - ☐ Attention Deficit Disorder/Attention Deficit Hyperactive Disorder
   - ☐ Autism Spectrum Disorder
   - ☐ Sensory processing disorder
   - ☐ Hearing impairment
   - ☐ Visual impairment
   - ☐ Osteoporosis
   - ☐ Traumatic brain injury (i.e. concussion)
   - ☐ Neurological problems (i.e., stroke, seizure)
   - ☐ Severe hand, wrist, shoulder pain

Appendix C – Background Questionnaire (Child)

ID (to be determined by researcher): ______________________Date: ____________

Child's Age*:* ______________________ Gender: Male / Female

Child's Hand Preference: _________________________

7. Does your child wear glasses/contacts? YES / NO

8. Does your child have a visual impairment?
   YES/NO
   If yes… what type of visual impairment does your child have?
   ____

9. Has your child had hand/wrist/shoulder injury/surgery within the last year YES/NO

10. Does your child train with a sports team? YES/NO\
    If yes, what is his/her sport? __________________
    What level does your child train at (e.g., rec, competitive)?______________

11. Does your child exercise? YES/NO
    How many hours a week is your child physically active? __________
    What types of exercises does your child do?
    ____

12. Has your child experienced or been diagnosed with any of the following? Please check all boxes that apply.
    - ☐ Attention Deficit Disorder/Attention Deficit Hyperactive Disorder
    - ☐ Autism Spectrum Disorder
    - ☐ Development Coordination Disorder
    - ☐ Sensory processing disorder
    - ☐ Hearing impairment
    - ☐ Visual impairment
    - ☐ Traumatic brain injury (i.e. concussion)
    - ☐ Neurological problems (i.e., stroke, seizure)
    - ☐ Severe hand, wrist, shoulder pain