Effects of Aging in Reaching and Grasping Movements:
A Kinematic Analysis of Movement Context

by

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AUTHOR'S DECLARATION

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

ABSTRACT

Although several studies have investigated the effects of aging on aspects of motor planning and control, there remains a lack of consensus about the underlying mechanisms responsible for the motor slowing associated with aging. This may, at least partially, be due to the fact that few studies have kinematically examined both the transport and grasp components in both younger and older adults, and furthermore, even fewer have examined these movements when the context of the task is changed, such as when the movement is performed in isolation compared to when it is embedded in a sequence. Therefore, the purpose of this thesis was threefold: 1) to investigate how aging affects performance on a single reach-to-grasp movement, 2) to examine how movement context affects performance on the reach-to-grasp movement when it is performed alone or as the first movement in a two-movement sequence- in other words, are older adults able to plan the first motor task movement in anticipation of performing a subsequent task, and 3) whether younger and older adults are able to plan, execute, and modify that movement in accordance with the extrinsic properties of the subsequent movement task (near versus far target for second movement). To address this, the movement profiles of both younger (N=14; mean age= 20.7 years; 4 males, 10 females) and older (N=11; mean age= 75.1 years; 3 males, 8 females) healthy right-handed adults were compared on performing a reach-to-grasp movement under 3 different movement conditions: single-movement task, two-movement sequence to near target, and two-movement sequence to far target. For the two-movement sequence conditions, participants were instructed to reach and grasp the object (like the single-movement task), but then to move and place it on either a closer (near condition) or farther (far condition) target location. Overall, the results from this study are in agreement with the literature showing older adults to have slower movements in general and consistently taking longer to both initiate and execute the reach-to-grasp movement than the younger adults for all conditions. There were no other differences between groups on the single-movement condition. For all participants, the reach-to-grasp movement took longer when it was performed in isolation than when it was embedded as the first part of a two-movement sequence. This finding can be explained by the movement termination effect and is consistent with findings from studies on aiming movements showing that when the movement plan involves stabilizing the arm at the first target (single-movement) as opposed to merely slowing it down (two-movement sequence tasks), the constraint of achieving a stabile position imposes a greater demand, thus requiring the movement

to be made more slowly. The results obtained from the study indicate that the movement termination effect is also seen in the context of prehensile movements and furthermore, this effect on performance persists with age. Not only do the findings from this study show that this effect persists with age, but also that this effect increases with age, as revealed by a Group by Condition effect for reaction time, movement time, and relative timing of the velocity profile, indicating greater changes in reaching performance between single- and two-movement conditions for the older adults than for the younger adults. Upon further examination of the details of the movement, it is apparent this movement termination effect is reflected in the ballistic phase of the movement. This last notion is inconsistent with previous studies, which showed the increased movement time associated with the movement termination effect was the result of changes in the amount of time spent in the deceleration phase toward the end of the movement rather than the beginning of the movement. Lastly, when reach-to-grasp performance was compared between moving to a near- compared to a far-target in the two-movement conditions, no differences were found between any of the movement features for either group. This suggests that the increased proportion of time spent in deceleration for the dual-movement conditions compared to the single-movement condition in older adults is due to online feedback control for terminating the first movement rather than online planning of the second movement. Despite the changes seen in the transport component, the findings for the manipulation component indicate that the formation of the grasp and its relative coupling with the transport component remains intact with age.

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LIST OF ABBREVIATIONS

RT = Reaction time

MT = Movement time

PV = Peak velocity

PA = Peak aperture

OTA = One-target advantage

YA = Younger adults

OA = Older adults

LED = Light-emitting diode

IRED = Infrared emitting diode (markers)

3MS = Modified Mini Mental Status Examination

GP = Grooved Peg Board Task

1. INTRODUCTION

1.1 General Introduction

It is well established that aging is accompanied by a gradual slowing of motor and cognitive processes over time. One method that is often used to investigate the effects of aging on motor function is to compare the characteristics/details of reaching movements in younger and older adults. More specifically, by examining the kinematic features of a goal-directed movement task, such as a reaching movement, a movement profile can be created based on the trajectory formation. The formation of movement trajectories for tasks like reaching and grasping targeted objects is believed to reflect aspects of motor planning and control processes. Although many studies have investigated the effects of aging on aspects of motor planning and control, there remains a lack of consensus about the underlying mechanisms responsible for the motor slowing associated with aging.

1.1.1 Overview of Types of Reaching Movements

The study of reaching movements typically involves one of two types of movements: pointing and aiming movements or reaching-to-grasp movements. Aiming movements (non-prehensile) involve pointing to targets in visual space, while reach-to-grasp movements (prehensile) involve reaching toward an object and grasping it. One type of prehensile task involves just a single reach-to-grasp action. Another type involves a two-movement sequence in which the reach-to-grasp movement is followed by a second movement where the performer picks up the object and then subsequently performs an action with it, such as placing it on a target or tossing it away in a receptacle.

1.1.2 Overview of Planning and Control of Reaching Movements

In order to understand how these movements are planned and controlled, researchers have examined various performance measures. Reaction time (RT) and movement time (MT) are the basic and most commonly used measures, with RT representing the time to plan and initiate movement and MT reflecting the time to execute the movement. Further details in the planning and control of reaching movements can also be examined during the course of the movement within the MT interval by using movement kinematics, which reflect the spatiotemporal characteristics of these reaching movements. One set of measures pertains to the planning and control of the arm as it points or reaches towards a target. The features of proximal limb control in bringing the arm toward the target are collectively referred to as the transport component of the movement and are usually measured by sensors or markers located on the wrist (Jeannerod, 1984; Jakobson & Goodale, 1991; Gentilucci, Chieffi, Scarpa, & Castiello, 1992; Chieffi & Gentilucci, 1993; Haggard & Wing, 1995;). By examining the trajectory formation of the movement, being the path taken by the hand when moving to a new location and the speed at which it moves along that path (Abend, Bizzi, & Morasso, 1982; Jeannerod, 1988), one can examine the two phases of the movement as defined by a key feature, peak velocity (PV), with the time before PV reflecting the time spent in acceleration and the time after PV being the time spent in deceleration.

In reach-to-grasp movements, there is an additional movement component compared to pointing movements, the grasp or manipulation component, reflecting the opening and closing of the hand as the arm approaches and the hand grasps the object. The features of the grasp component are typically measured by several sensors or markers placed near the tips of the thumb and index finger (Mason, Gomez, & Ebner, 2001; Jones & Lederman, 2006). Here one can examine features such as the peak aperture achieved between the thumb and index finger (PA), the relative timing of when PA occurs within the MT interval, and the relationship (coordination) between the PA of the grasp component and the PV of the transport component for such movements.

Part of the reason for the lack of consensus between studies regarding the underlying mechanisms responsible for motor slowing with age is that few studies have kinematically examined both the transport and grasp components in both younger and older adults, and furthermore, even fewer have examined these movements when the context of the task is changed, such as when the movement is performed in isolation compared to when it is embedded in a sequence. Therefore, the overall purpose of this study was to investigate how motor planning and control, as reflected by these kinematic movement features, is influenced by the effects of aging in reaching and grasp movements. Furthermore, another goal of this study was to examine how the planning and execution of a reach-to-grasp movement differs when it is performed as a single-movement task compared to when it is the first part of a two-movement sequence.

To address these issues, this thesis will begin with a review of the kinematics involved in the transport component, starting with an overview of how these movement features relate to facets of motor planning and control in general, followed by findings from studies on aging. Then, literature pertaining to reaching movements involving a grasp component will be reviewed. After reviewing the kinematic features of the manipulation component, research related to the influences of aging on these features in prehension will be discussed. This paper will then look at conditions in which a second movement task is required following the reaching movement and how the context of a subsequent task affects how the first movement is performed, with a review on what has been reported in research on aging to follow. Lastly, a description of the objectives, specific research questions, and hypotheses will conclude the introductory portion of this thesis.

1.2 Pointing & Aiming Movements (Transport Component)

1.2.1 Pointing & Aiming Movements- General Concepts

Most research on pointing and aiming movements posits that there are at least two distinct phases of a motor act when moving the arm toward a target (transport component) (Woodworth, 1899; Meyer, Abrams, Kornblum, Wright, & Smith, 1988; Elliott, Helsen, & Chua, 2001; Gravenhorst & Walter, 2007). The initial ballistic phase of reaching to a target, considered to be under open-loop (feed-forward) control, accounts for the first part of the movement trajectory (Woodworth referred to this phase as the "initial impulse phase"). It is believed to represent the motor program's efficiency for planning that action (Meyer et al, 1988). This is largely due to the fact that the movement as a whole is believed to be programmed as a function of PV, occurring within this initial phase (Meyer, et al., 1990; Bellgrove, Phillips, Bradshaw, Hall, Presnell, & Hecht, 1997). In a study examining the ability to modify a planned movement online, Heath, Roy, and Weir (1999) found that if properties of the target unexpectedly changed after movement initiation, the time-to-PV and PV are carried out to the original parameters (unmodified). Furthermore, PV is believed to be scaled as a function of the properties of the target, such as target size and distance (Jeannerod, 1984). This was also supported in the previously mentioned study such that as target size decreased, PV also decreased, yet the total time to complete the aiming movement (MT) increased. Jeannerod (1981) also supported this notion by showing increases in PV that correlated with increases in movement amplitude.

The final phase of the transport component, the movement correction phase (sometimes referred to as the “error-correction” or “current control” phase), relies predominantly on feedback control (closed-loop/online control) in order to make corrective adjustments for accuracy. Precision can be achieved by relaying and comparing sensory and proprioceptive information to internal models of action (Wolpert, Ghahramani, & Flanagan, 2001). By minimizing the disparity between actual and predicted performance (internal models of action) when narrowing in on the target, movements become more accurate (Wolpert et al., 2001). In other words, the focus of this movement correction phase is to decrease the apparent discrepancy between the current limb position and the movement goal (Abrams, Meyer, & Kornblum, 1990, p. 250). Online control is typically engaged at the end of the movement, in the deceleration phase [synonymous with “time-after-PV” in this thesis (Cooke, Brown, & Cunningham, 1989; Goggin & Stelmach, 1990; Goggin & Meeuwsen, 1992)], rather than at the beginning in order to allow for time to recognize errors from the initiation of the trajectory before it can be corrected for through feedback. When movements become more demanding or require more spatial precision (i.e. - smaller target size), there is typically an increase in the amount of time spent after PV relative to before PV (Langolf, Chaffin, & Foulke, 1976; Meyer et al., 1988). An increase in time spent in deceleration is believed to reflect a greater dependence on response-produced feedback for precision in target acquisition (Chua & Elliott, 1993; Heath et al., 1999; Thompson, McConnell, Slocum, & Bohan, 2007).

This last notion has been supported by a multitude of studies that have compared performance on pointing movements under conditions in which either the size of the target or the distance to the target (movement amplitude) are varied, finding that as the task became more difficult (i.e. - smaller target size or larger movement amplitude; see Fitts, 1954, for effects of task properties on the ‘index of difficulty’), a characteristic pattern of changes occurs to the movement profile, reflecting an increase in the time to plan and initiate the movement (RT), an increase in the time taken to execute the movement (MT), and a decrease in the peak speed of the movement (PV) (Fitts, 1954;Marteniuk, MacKenzie, Jeannerod, & Athenes, 1987). Other studies that have looked at the relative timing of the acceleration and deceleration phases (the pattern of the trajectory) have found that the increased MT is typically a function of spending proportionally greater time-after-PV (Marteniuk et al., 1987). Researchers have attributed the increased time-after-PV to the increased time required for the movement correction phase in order to ensure the accuracy demands of the movement task are met (Meyer et al., 1988; Chua & Elliott, 1993; Heath et al., 1999; Thompson et al., 2007). More specifically, when movements become more difficult, there is a greater dependence on response-produced feedback for precision in target acquisition and thus a greater proportion of the movement is dedicated to closed-loop control than to open-loop control (Heath et al., 1999). Heath and colleagues (1999) posit that such a change in the symmetry of the movement profile may reflect a shift in motor control strategy. In certain populations and/or circumstances, such modification in movement timing is thought to reflect cautious behaviour in an attempt to decrease associated risks in the movement context. For example, an older adult may spend more time in deceleration due to the risks associated with movement errors, such as fracturing a hip due to misjudging a step (Heath et al., 1999). Thus, the increased time spent in deceleration (time-after-PV) represents a shift towards feedback control to ensure that the movement is accurate. This form of control, although allowing for improved accuracy, is limited in its effectiveness for fast movements. In other words, when the overall MT is very short, the ability to process feedback information in this deceleration phase is limited. In order to achieve greater accuracy (or decrease inaccuracy), the movement is executed more slowly so that more time is dedicated to relaying and processing feedback during the movement correction phase (Woodworth, 1899; Keele, 1968; Gordon, Ghilardi, & Ghez, 1994; for a detailed and current review of speed-accuracy relations and models of limb control, see Elliott, Hansen, Grierson, Lyons, Bennett, & Hayes, 2010).

1.2.2 Pointing & Aiming Movements- Aging Studies

It is well established that motor processes and performance become slower with age. However, there have been a variety of inconsistent findings from studies that have compared the characteristics of movement planning and control in younger and older adults, and as such, a variety of interpretations regarding the underlying mechanisms responsible for the motor slowing with age. Most research on simple aiming movements has found that older adults generally show changes- at least to some degree- in the same features of the movement (i.e. - MT longer and PV lower for more demanding tasks) in response to changes in task demands as that found for younger adults (Stelmach, Goggin, & Amrhein, 1988; Heath et al., 1999). Roy, Weir, Desjardins-Denault, and Winchester (1999) found that although older adults performed movements more slowly in general, they revealed the same predicted task effects on PV (greater with target size and movement amplitude) and on time-after-PV (increased with decreasing target size and increased with increasing movement amplitude). Furthermore, in their study, they found no significant difference between the two age groups in the real or relative time spent in deceleration. This would suggest that both older and younger adults use similar movement patterns in the planning and execution of reaching movements. In other words, the age-related differences in aiming movements are attributed to changes that appear to impact all motor processes uniformly or equally- older adults simply just take longer to do it (Salthouse, 1985; Goggin & Meeuwsen, 1992).

Although some studies have supported this by showing no difference in the relative timing of motor processes between age groups (Haaland et al., 1993), many other studies have contrasted this notion, often showing that older adults spend a significantly greater proportion of MT in the deceleration phase than younger adults do (Cooke et al., 1989; Darling, Cooke, & Brown, 1989; Roy, Winchester, Weir, & Black, 1993; Bennett & Castiello, 1994; Pratt, Chasteen, & Abrams, 1994; Walker, Philbin, & Fisk, 1997; Seidler-Dobrin & Stelmach, 1998; Bellgrove, Phillips, Bradshaw, & Gallucci, 1998). The lengthened time spent in deceleration creates an asymmetrical movement profile for the older adults, suggesting a reliance on visually based feedback to help guide their movements to the target (Elliott, Chua, & Helsen, 2001; Grierson & Elliott, 2009).

Various explanations have been proposed to account for the greater time spent in feedback control for older adults. For example, the asymmetrical movement profile may be interpreted as an increased reliance on feedback control as a result of a more conservative movement strategy (Roy et al., 1999), or alternatively, it may be interpreted as a decreased ability to use feed-forward or open-loop processes, and as such, may be a result of relying more heavily on closed-loop control to compensate for the compromised planning and programming processes (Haaland et al., 1993; Lyons, Elliott, Swanson, & Chua, 1996; Ketcham, Seidler, Gemmert, & Stelmach, 2002). In Haaland, Harrington, and Grice's study (1993), they found that when visual feedback was unavailable, both younger and older adults' accuracy diminished in the deceleration phase of the movement. However, only the older adults' accuracy was negatively/differentially affected by increases in movement amplitude, suggesting that older adults rely more heavily upon visual feedback to modify the motor program in conditions requiring longer movement durations. They also found that older adults did not show the same degree of increases in PV as the younger adults did for movements with increasing amplitude or target size. Since movements are believed to be programmed as a function of PV, and older adults did not modulate PV according to the new parameters of the movement task, this also implies degradations in motor planning and programming. Studies by both Goggin and Stelmach (1990) and Roy et al. (1999) have also found that older adults did not show as great of an increase in PV between shorter and longer movements. Furthermore, when Roy and colleagues (1999) compared performance on pointing and aiming movements to reaching and grasping movements under the same task parameters for each condition, they found that even when the demands of the movement goal were lowered (i.e. - pointing compared to grasping task), older adults did not increase PV to the same degree as the younger adults, which suggested that open-loop processes may be compromised as a function of aging.

On the other hand, there are also studies that provide evidence that online and feedback processes are impaired, as depicted by slower, more fragmented, and less accurate movements during the movement correction phase in older adults (Teeken, Adam, Paas, van Boxtel, Houx, & Jolles, 1996; Chaput & Proteau, 1996; Sarlegna, 2006). Sarlegna (2006) found that when aiming to stationary targets, visual information improved accuracy for both younger and older adults. When the target was displaced after movement onset, however, older adults made significantly less accurate movement corrections than the younger adults (72% compared to 95%, respectively), modified their movements much later (538 ms compared to 339 ms after movement onset, respectively), and were more variable than the younger adults. Thus older adults took longer and were less efficient at processing visual feedback when movements needed to be updated and re-adjusted online, indicating degradations in feedback processes for monitoring movements online.

Taken together, there is a lack of consensus about the underlying mechanisms responsible for the motor slowing associated with aging. For example, some studies find no difference between age groups for MT (Murrell & Entwisle, 1960; Weir, MacDonald, Mallat, Leavitt, & Roy, 1998; Heath et al., 1999; Sarlegna, 2006), PV (Walker et al., 1997; Heath et al., 1999), and relative timing of PV in the movement profile (Haaland et al., 1993; Roy et al., 1999), while others have shown younger and older adults to be significantly different for these same measures [MT: Roy et al., 1999; PV: Ketcham et al., 2002; and relative timing of PV in the movement profile:

Walker et al., 1997; Seidler-Dobrin & Stelmach, 1998; Bellgrove et al., 1998; Heath et al., 1999). As such, a variety of interpretations have been proposed, some supporting generalized slowing of all motor processes (Salthouse, 1985; Goggin & Meeuwsen, 1992), some supporting differential impairments in feed-forward, planning processes (Goggin & Stelmach, 1990; Haaland et al., 1993; Ketcham et al., 2002), and others contending disproportional impairments for online, feedback corrective processing (Pratt et al., 1994; Chaput & Proteau, 1996; Teeken et al., 1996; Sarlegna, 2006). Although there have been a variety of inconsistent findings, it does appear that the degree to which task demands/parameters impact motor performance may be differentially affected with aging (Haaland et al., 1993; Roy et al., 1999; Ketcham et al., 2002; Sarlegna, 2006).

1.3 Reaching & Grasping Movements (Transport and Manipulation Components)

1.3.1 Reaching & Grasping Movements- General Concepts

The literature on pointing and aiming studies has allowed us to gain insight into the control of arm movements, but it does not tap into the complexity of manual and prehensile movements performed in everyday life (Weir et al., 1998). Compared to pointing and aiming movements, reaching and grasping movements have an added element, the opening and closing of the fingers, or the grasp/manipulation component.

In accordance with Jeannerod's (1981, 1984) "visuomotor channel hypothesis", there are two neural channels involved in a reaching and grasping action: a transport channel and a manipulation channel ("channels" is analogous to "components"). These two channels are thought to function together in parallel to achieve the higher-order goal of coordination (Jeannerod, 1984; Paulignan, MacKenzie, Marteniuk, & Jeannerod, 1991; Hoff & Arbib, 1993). The transport channel presumably extracts extrinsic information about the spatial location of the object in order for it to be transformed into a movement that brings the hand optimally towards the object. The manipulation channel is said to extract information pertaining to the intrinsic properties of the object (i.e. - object size) for the most appropriate grasp profile to be determined relative to that object. When he manipulated the size of the objects to be grasped, Jeannerod (1981) found participants to have increasing grip apertures (PA) for objects of greater sizes.

Furthermore, when object sizes were unexpectedly changed after participants had initiated the movement, corresponding changes in hand shaping were found. In both cases, features of the transport channel, such as PV of the wrist, remained unaltered when intrinsic properties of the target were varied. He also found that increases in movement amplitude correlated with increases in wrist PV. No significant changes in hand shaping were reported for this condition. This would suggest that if only extrinsic properties of the end-target are manipulated, such as target location, no changes would be expected in the grasp patterns.

However, as both channels must function together to coordinate movement, an adjustment in the transport channel should inevitably result in an adjustment to the manipulation channel and vice versa. For example, PA has repeatedly been found to occur at approximately 60-70% of the total movement duration (Jakobson & Goodale, 1991; Chieffi & Gentilucci, 1993; Santello & Soechting, 1998; Jeannerod, 1981, 1986, 1999; Jones & Lederman, 2006). As such, the time at which PA occurs is during the deceleration phase (transport component) of the movement, often identified to occur at peak deceleration. In considering how PA is scaled to the size of the object to be grasped, yet its' occurrence is correlated with peak deceleration of the transport component, it seems reasonable to presume that a change in either component will inevitably result in a change in the other (Gentilucci et al., 1992). Indeed Paulignan and colleagues (1991a,b) found that if either the size or location of the object to be grasped is suddenly altered following movement initiation, adjustments occur in both the transport and manipulation components within 100 ms. Others have found similar results, supporting the notion that either intrinsic or extrinsic properties influence both components of reaching and grasping movements (Gentilucci et al., 1992; Haggard & Wing, 1995; Timmann et al., 1996; Castiello, Bennett, & Chambers, 1998). Furthermore, findings from other studies have shown that the two components are not only coupled temporally, but that they are also linked spatially (Wing, Turton, & Fraser, 1986; Haggard & Wing, 1998; Rand & Stelmach, 2005) and functionally (Marteniuk, Leavitt, MacKenzie, & Athenes, 1990) as well in order to produce an effective and successful reach-to-grasp action.

Research supports the notion that changes in PA size may reflect changes in control strategies. In studies manipulating the availability of visual feedback, PA has been found to increase when visual feedback is reduced (Wing et al., 1986; Berthier, Clifton, Gullapalli, McCall, & Robin, 1996). The grip is thought to open wider as a compensatory measure for the decrease in visual feedback by allowing for online correction of spatial errors (Schettino, Adamovich, & Poizner, 2003). Although the margin of (spatial) error increases with a larger PA, the margin of safety also increases, as the participant is more likely to have an adequately sized aperture to successfully grasp the object when vision is not available (Jakobson & Goodale, 1991). This is thought of as a more conservative strategy.

Similar to the effects of task demands on PV of the arm (transport component), several studies have shown a smaller aperture over-opening (margin of spatial error) for large compared to smaller objects (Meulenbroek, Rosenbaum, & Vaughan, 2001; Tretriluxana, Gordon, & Winstein, 2008). This supports the notion that PA not only can be scaled to such object properties, but can reflect changes in control strategies associated with task demands.

1.3.2 Reaching & Grasping Movements- Aging Studies

Most of the studies on aging have focused on changes in the movement patterns of the transport component, but far fewer have investigated the presence of such effects in the more distal and fine motor movements of the hand in grasping actions.

One of the first known studies to examine the kinematics of reach-to-grasp movements in older adults was reported by Bennett and Castiello in 1994. They found that not only were older adults able to scale PA according to changes in object size to the same degree as the younger adults, but they also showed a strong correlation between the temporal events of the transport and manipulation components. For example, the point at which PA occurred in the movement was temporally coupled with the point of peak deceleration of the arm for older adults, regardless of task or condition.

In the study by Roy et al. (1999) previously discussed with regards to their results in pointing performance, age-related changes in prehension were also reported. They found that both younger and older adults were able to scale the size of the grasp to the size of the object. That is, both groups increased PA as a function of increased object size and PA (unlike PV) was not affected by age or movement amplitude. Similar to their findings for time-to-PV in the transport component, the time to reach PA was longer for older adults, farther movements, and larger objects. However, the relative timing of PA was no different between age groups or movement amplitudes, but rather was only influenced by object size, with a greater proportion of time spent in the hand enclosing phase when grasping the smaller object. These findings are in concert with those reported by Bennett and Castiello (1994, 1995), being that the coordination between the transport and manipulation components are maintained with age (Bennett & Castiello, 1994, 1995).

Unfortunately, there have been relatively few studies that have kinematically compared features of the grasp component in healthy younger and older adults, and even fewer- if any- in the last decade. This is particularly surprising considering the, at least to some extent, incongruous effects of aging between the two visuomotor channels involved in prehension. For example, studies that have examined the influences of object size (Bennett & Castiello, 1994) and task goal/intention (Weir et al., 1998) have found no differences in the formation of the grasp between younger and older adults (Roy et al., 1999). These studies report that older adults are able to scale PA (manipulation component) in accordance with task demands to the same degree as younger adults, but are not able to modulate PV (transport component) to changes in task demands like younger adults do. Yet researchers contend that the coupling of the transport and manipulation components remains intact with age. If one of these components (transport) is found to be influenced by the effects of aging, this presumably would put into question the "inter-dependent" nature of these two components as explained by the visuomotor channel hypothesis.

1.4 Reaching Movements with a Subsequent Task

1.4.1 Intention for Reaching

Typically when one performs a motor action with an object or tool, there is a successive goal with or for the use of that object. Reaching for an object typically suggests a goal to take possession of that object on which a second motor act will be performed, such as throwing, bringing to the mouth, shifting position, etc (Gentilucci, Negrotti, & Gangitano, 1997). Therefore, it seems reasonable to presume that the characteristics of the successive motor act influence the movement control of the current motor act (Gentilucci et al., 1997; Haggard, 1998; Armbruster & Spijkers, 2006; Ansuini, Giosa, Turrella, Altoe, & Castiello, 2008).

1.4.2 Reaching Movements with a Subsequent Task- General Concepts

Henry and Rogers (1960) showed that the more complex the subsequent movement pattern to be performed was, the greater the demands placed on planning the movement as a whole. In particular, they found an increase in RT as movement complexity increased. These findings have since been replicated numerous times by researchers like Fischman (1984) and Christina (1992), showing RT to increase as the number of movement components increased, indicating that the second movement in the sequence is at least partially planned before initiating the first movement (for a detailed review, see Klapp, 2010).

Since Henry and Rogers' study (1960), a number of studies have looked at, not only differences in the time for planning and initiating movements (RT) of varying complexity, but also at the time required to actually execute these movements. One finding that has received much support is that MT is shorter for single-movements performed in isolation compared to when the same movement is performed as the first part of a sequence. This phenomenon has been termed the "one-target advantage" (OTA) (Adam, Nieuwenstein, Huys, Paas, Kingma, Willems, & Werry, 2000). There have been various explanations for the OTA, but most include, at least to some degree, the notion that A) in a two-movement sequence, the increased MT of the 1st movement is attributed to online processes required to plan the 2nd movement while the 1st movement is in progress (Chamberlin & McGill, 1989; Adam et al., 2000), and B) there is a temporal cost also related to the constraints of having to perform a more controlled 1st movement (Fischman & Reeve, 1992; Adam et al., 2000).

In contrast, other studies have found that the OTA does not apply under all contexts, but rather may be more dependent upon the specific demands of the task. For example, Lavrysen, Elliott, Helsen, and Adam (2002) found a OTA when the second movement was made in the same direction as the first, but not when the second movement was made in different (reverse) direction. Other studies have also shown the OTA to be dependent upon the properties/parameters of the task (i.e.- 'ID'), such as target size (Adam et al., 2000; Helsen, Adam, Elliott, & Buekers, 2001).

Although these studies are amongst some of the most influential and frequently cited in such peer-reviewed journals (i.e. - Henry and Rogers (1960) article is the most frequently cited in

Research Quarterly for Exercise and Sport), many of them have focused merely on basic measures like RT and MT, and furthermore, in the context of pointing and aiming movements[1].

Marteniuk et al. (1987) wanted to investigate the effects of movement complexity in the context of prehensile movements. More specifically, they wondered if and how, in a two-movement sequence task, the characteristics and demands of the second movement would affect performance on the first reach-to-grasp movement. In light of the work done on measures of RT and overall MT, Marteniuk and colleagues examined whether movement complexity would be reflected in the features and shape of the kinematic movement profile within the MT interval. In order to quantitatively test this aspect of motor planning capacity, they asked participants to reach and grasp a 4 cm-diameter disk placed in front of them and then to either move and place it into a tightly fitting receptacle or to toss it into a larger receptacle. They found that the intrinsic properties (target size) of the placement task did indeed affect the shape of the movement profile for the reach-to-grasp movement. More specifically, if a participant was required to place the disk in the smaller receptacle, the deceleration phase of the movement trajectory was disproportionately longer than when asked to pick up the same object, but to toss it in the larger box. This study showed that the intrinsic task requirements of the successive motor act affect the upper limb kinematics of the first motor act (Marteniuk et al., 1987).

However, this did not necessarily support the notion that the first motor task is planned according to the properties of the second motor task since changes occurred exclusively in the movement correction (feedback) phase. Thus, it can be argued that initially, the movement may have been planned according to features of the first motor task alone, since no significant changes in PV were found; properties of the second motor task may have only been incorporated in the movement following the initial ballistic phase (original planned motor program).

Gentilucci and colleagues (1997) were interested in determining if perhaps extrinsic, rather than intrinsic, properties of the second task target could be planned prior to initiating movement. Like Marteniuk and coworkers' study (1987), they had participants reaching and grasping an object

[1] It should be noted that some elements of Henry and Rogers' study (1960) involved a variety of other types of motor actions, such as lifting a finger off a key, reaching forward and "snatching" or grasping a tennis ball, reaching and striking another tennis ball with the back of the hand, changing directions and "slapping" or touching a push button, etc. (for a review, see Fischman, Christina, & Anson, 2008; Klapp, 2010). However, no measures of performance of the proximal or distal limb control were examined during the movement; only RT measures were reported.

(first motor act) and placing it on a second target (second motor act). However, they manipulated distance and position of the second target and were specifically interested in whether the initial ballistic phase of the first movement would be affected. They found PV and hand shaping (PA) in the reach-to-grasp task to vary as a function of target distance in the successive placing task. More specifically, PV and PA increased significantly for the farther placement target compared to the nearer second target. These findings reinforced three important concepts in the field of motor planning and control: (1) the notion that movement as a whole is programmed as a function of PV (Meyer, et al., 1990; Bellgrove et al., 1997), (2) PV is scaled as a function of the extrinsic properties of the target (Jeannerod, 1984), and (3) such properties of the final target in a two-step motor task are incorporated in planning the movement for first motor act.

Although these last two studies provide us with a better understanding of how the motor planning and control of prehensile movements are affected by the properties of the subsequent movement task, some elements/aspects remained unaddressed. In Marteniuk et al.'s (1987) study, they did not report any measures related to the manipulation component. As such, it is unknown whether or not the features of the grasp were modulated as a function of the second motor task's parameters. Also, neither of the studies by Marteniuk et al. (1987) nor Gentilucci et al. (1997) examined the influence of task complexity on the time to plan and prepare the movement prior to initiating it (RT measures). Furthermore, and perhaps more importantly, neither study included a single-movement condition to compare to the two-movement task condition.

By including a single-movement condition to compare to the first movement in a two-movement task, Roy, Rohr, and Weir (2004) were able to investigate the influence of movement context (single-movement vs. movement 1 in a two-movement sequence) and task demands (spatial precision) on performance. Although this study involved pointing and aiming movements rather than prehensile movements, the results they obtained led them to propose an alternate explanation for instances when the OTA is not seen. In their study, participants were instructed to move 100 mm for the single-movement task. For the dual-movement task, they were instructed to reach to the same target as they did for the single-movement task, but to subsequently move another 100 mm farther to a second target. The size of the second movement target was varied such that it was either the same size as the single-movement condition target (10 mm in diameter) or smaller (5 mm) or larger (15 mm) in diameter.

Interestingly, they found no difference in RT among the tasks, which implies that neither the number of movement components nor the relative precision demands of the second movement had an effect on this early stage of motor planning. They did, however, find a main effect of task for MT, such that the MT for the single-movement task took longer than the same movement when it was performed as the first movement in the two-movement sequence tasks. In addition to longer MT, analysis of the kinematic measures revealed longer time in deceleration and lower PV for the single-movement task than for movement 1 in the two-movement tasks.

Since no differences were found in endpoint accuracy (spatial variability or dispersion around target 1) between the single- or dual-movement tasks, Roy, Rohr, and Weir proposed an explanation for these results pertaining to differences in the requirements for movement termination. They proposed that in the case of the single-movement task, no further movements are planned and thus the termination of the movement involves stabilizing the arm to come to a complete stop at the first target position. In the case of movement 1 in a two-movement sequence, however, the addition of a subsequent movement involves more of a slowing down at the first target in preparing for the second movement. Therefore, if the movement plan involves stabilizing the arm at the first target (single-movement) as opposed to merely slowing it down, the constraint of achieving a stabile position imposes a greater demand, thus requiring the movement to be made more slowly. In other words, although both the single- and movement 1 movements were made to the same size target, only the single-movement required terminating the movement in terms of achieving a stable position on the first target. This ‘movement termination effect’ implies that movement planning is influenced by whether the movement is to be terminated or continued on to a subsequent target location.

1.4.3 Reaching Movements with a Subsequent Task- Aging Studies

Although there are a number of studies that have looked at the effects of aging in various sequential pointing tasks, relatively few have examined the effects of aging in prehensile movements under such two-movement task paradigms. One study that did, however, compared younger and older adults using a similar task paradigm as the one previously described by

Marteniuk and his colleagues (1987). In this study by Weir et al. (1998), participants were instructed to reach and grasp a disk (4.5 cm diameter, 1 cm thick, located 20 cm away from starting position) and then to either place it in a small well (5 cm diameter), place it in a larger box (20 cm high, 20 cm wide), or to throw it in the larger box. The distance to move and place the disk remained the same for all three conditions. Results for the transport component of the reach-to-grasp movement revealed no differences between the two age groups for MT, PV, or time-after-PV, regardless of task condition. When they examined the percentage of MT spent after PV, however, they found that older adults spent significantly longer relative time in deceleration than the younger adults. Interestingly, a similar pattern of results was found for the kinematics of the grasp component, reflecting no between-group differences for PA nor the absolute time at which it occurred, but a main effect of age was found for the relative timing measures of PA, with older adults spending a longer percentage of MT enclosing the grasp for the well-placement condition (greatest precision demands) than the younger adults did. Some researchers argue that the slower movements associated with aging may be a function of changes in force generation-muscular strength with age (referred to as "hardware limitation"; for a review, see Roy et al., 1999). In Weir et al.'s study (1998), however, no differences in MT or PV were found between age groups in the reaching and grasping movement. Furthermore, for both groups, the duration of the movement and relative timing were significantly greater for the place tasks than for the throw task. This suggests that the older adults were equally able to anticipate and adapt their movements in the first reach-to-grasp movement in accordance with the precision demands of the subsequent task as the younger adults were. However, the longer relative time spent in deceleration and in closing the grasp (time-after-PA) indicates that the strategies older and younger adults use for motor control differ, with older adults relying more heavily on online feedback control.

Similar to Marteniuk and colleagues' (1987) study, however, Weir et al. (1998) did not include a single-movement condition with which to compare performance on the reach-to-grasp movements in dual-task conditions. They also did not report any results pertaining to the time spent planning and preparing the movement prior to initiating it (RT). Thus, hypothetically, it could be argued that the longer MT and relative time in deceleration for the place task compared to the throw task could be because movement for the throw task may have been planned more effectively beforehand than movement for the place task. Furthermore, one potential confound in both Marteniuk et al.'s (1987) and Weir et al.'s (1998) studies pertains to the level of constraints used in their tasks. For example, in the former study, they manipulated movement extent (20 cm vs. 40 cm amplitude), accuracy (2 cm vs. 4 cm target size), and task goal/intention ("throw into a large box" vs. "place into a tight fitting well"). As such, results may be confounded by the level of representation these actions were described, being that "toss" and "fit" may be more representative of a cognitive or meaningful aspect of the action (Jeannerod, 1988). Since both "tossing" and "fitting" action commands were not examined across each of the other second movement task parameters (small, large, near, and far targets), it is difficult to distinguish whether, or to what degree, changes in the first movement performance were a function of the second task parameters or the second task intention. Therefore, it is unclear whether the reach-to-grasp movement was equally, differentially, or completely influenced by one or the other.

The only known studies to compare one- and two-movement task performances in older adults have used pointing and aiming paradigms. Interestingly, these studies show that MTs for older adults are much more affected by discrete (single movement to one target) versus reciprocal (moving back and forth between two targets) movement tasks. Moreover, in Teeken et al.'s (1996) study, as younger adults (25-year old age group) revealed the expected performance in response to discrete versus reciprocal movements, being faster MT for the former than the latter (supporting the OTA), the opposite was found for the older adult groups. In fact, with increasing age, the differences in MT for the discrete compared to the reciprocal movements became increasingly larger, with substantially longer MTs for the single-movement task than the reciprocal aiming task (supporting the movement termination effect). It should be noted, however, that more errors (representing each time the participant missed the target) were made in the reciprocal aiming task than in the discrete task (2.2% and 0.94%, respectively). Also, this study did not examine the kinematic features within the MT interval.

1.5 Thesis Purpose, Questions, & Hypotheses

1.5.1 General Purpose of the Study

The purpose of this study was to investigate the movement profiles of both younger and older healthy adults on a single reach-to-grasp task as well as on a two-step motor task, requiring them to reach and grasp the object (like the single-movement task) and then to move and place it on either a closer or farther target location. By first adding a second motor task, and then by manipulating the extrinsic properties of the second task target, this will not only determine if older adults are able to plan the first motor task movement in anticipation of performing a subsequent task, but also whether or not they are able to plan, execute, and modify that movement in accordance with the properties of subsequent task target.

Unlike Weir et al.'s (1998) study, a single-movement condition was included in the present study as a true control condition measure of prehensile performance for younger and older adults. Also, to avoid any potential confounds related to intentions of the second movement task (i.e. - toss vs. fit), it was ensured that the same movement instructions were used for both dual-task conditions ("move and place" for both near and far second movement conditions). Thus the paradigm used in this study was similar to that used in Roy and colleagues' (2004) study, but with a different population (older adults), movement context (prehension opposed to pointing and aiming), and second task parameter (amplitude rather than target size). The ultimate goal of the study was to quantitatively assess the areas of motor programming and control that may be differentially affected by aging.

1.5.2 Research Questions & Hypotheses

There were three specific research questions this study aimed to address. The first pertains to how aging affects performance in a single reach-to-grasp movement. It was predicted that older adults would have slower movements and take longer to initiate and perform the reach-to-grasp movement than the younger adults for all conditions, confirming what has been reported in the bulk of the literature on aging and motor performance. The velocity profile of the younger adults were expected to depict a symmetrical bell-shaped curve for the first reach-to-grasp condition; indicating a relatively equal portion of time spent in feed-forward and feedback control. For the older adults, however, it was predicted that the temporal symmetry of the velocity profile would be slightly skewed, indicating a longer period of time spent in deceleration, or the movement correction phase. This is based on findings from kinematic studies on healthy aging showing similar characteristic changes in motor processes associated with aspects of both motor planning [in accordance with the notion that the proportion of movement in the ballistic phase is thought to reflect the efficiency of motor planning (Meyer et al., 1988; Walker et al., 1997; Yan, Thomas, Stelmach, & Thomas, 2000)] in conjunction with a greater reliance on online feedback control (Walker et al., 1997; Seidler-Dobrin & Stelmach, 1998; Bellgrove et al., 1998; Heath et al., 1999). In accordance with findings from these and other studies, older adults were also expected to produce greater RTs, longer MTs, and lower PVs than younger adults. With regards to the manipulation component, it was hypothesized that the two groups would not differ in the formation of the grasp when making a single reach-to-grasp movement. More specifically, both groups were expected to show the same scaling of PA in terms of size as well as its relative timing in the movement. That is to say that, although older adults would likely take longer absolute time reaching PA and absolute time after PA, this would merely be due to them taking longer to perform the movement overall, and therefore, the relative movement pattern of the manipulation component would be the same as that for younger adults. This is supported by studies showing the physical and temporal formation of the grasp- as well as its coordination with the transport component- to be maintained with age (Bennett & Castiello, 1994, 1995; Roy et al., 1999).

The second research question pertains to how movement context affects performance on the movement to reach and grasp the object when it is performed alone or as the first movement in a two-movement sequence. In other words, is the movement termination effect seen by Roy et al. (2004) for aiming movements observed when the task involves a reaching and grasping movement; and furthermore, would this movement termination effect be comparable between the younger and older adults.

In contrast to the OTA predictions, and in concert with the findings from Roy et al.'s (2004) study, which, although was an aiming task, more closely resembles the paradigm used in this study, longer MT and lower PV were expected for the single-movement task than the dual-movement tasks for both groups. These predictions for older adults are also in concert with the MT results from Teeken et al.'s (1996) study for discrete and reciprocal aiming tasks. For the transport component, it was hypothesized that the relative timing of PV (shape of the movement profile) would again show older adults spending a greater proportion of time-after-PV than the younger adults for the dual-task conditions, but that the difference would be even greater than for the single-movement condition. The rationale for this is that, even though the reach-to-grasp MT was predicted to be shorter in the dual-movement conditions based on the movement termination effect (Teeken et al. 1996), it is also known that older adults rely more heavily on feedback control when movements increase in complexity, duration, and/or amplitude, such as when adding a second movement task (Haaland et al., 1993; Weir et al., 1998; Ketcham et al., 2002). For the manipulation component, it was hypothesized that both groups would have larger PAs for the dual-movement tasks than the single-movement task. However, based on the literature indicating that when motor tasks become more demanding or increase in complexity, older adults tend to shift toward a more cautious motor control strategy, it was expected that this would be reflected by PA being greater in size and also occurring sooner in the movement profile when the subsequent placing motor task is added to the motor action goal (compared to the younger adults). The prolongation of grip closure time ensures a successful grasp, especially when motor tasks become more demanding (Gentilucci et al., 1997). The relative timing of PA for the manipulation component, however, was hypothesized to mirror the relative timing patterns of the transport component that was predicted for each group.

The third research question pertains to whether or not younger and/or older adults are able to modify the first movement according to the extrinsic properties (near vs. far target) of the second movement task. By changing the parameters of the second movement task, one can verify whether features of the second task movement are incorporated in the planning and control of the first movement. In other words, by comparing the reach-to-grasp movement when the subsequent movement is made to a near target compared to when the subsequent movement is made to a far target, one can determine whether the changes in the first reach-to-grasp movement are actually due to planning the second movement or due to terminating the first movement (which would be depicted by no differences between near- and far- dual-task conditions).

It was predicted that for the two-movement tasks, younger adults would have longer MTs, lower PVs, greater time after-PV, and lower PA values for the reaching-to-grasp task when the second movement is made to the near target compared to the far target; whilst older adults were expected to show no differences between near or far placement conditions. It was hypothesized that older adults would be insensitive to the parameters of the second movement task while planning and controlling the first movement. This prediction is made based on studies showing limitations in motor planning ability with age- particularly for longer movements, as discussed in the predictions for the previous research question. Further support for this comes from studies that have shown that younger adults modify their movements to a greater degree than older adults in order to optimize their performance across varying task conditions (Goggin & Stelmach, 1990; Haaland et al., 1993; Roy et al., 1999).

2. METHODS

2.1 Participants:

Two groups of healthy adults participated in the study. Twenty participants were recruited for the younger adult (YA) group (19-25 years; mean age= 20.8 (±1.4), 11 females and 9 males) and fourteen participants for the older adult (OA) group (65-84 years; mean age= 74.7 (±6.3), 11 females and 3 males). Participants from the YA group were undergraduate students recruited from the Psychology Participant Pool in the Psychology Department at the University of Waterloo, a university-organized participant pool. Participants from the OA group were recruited from the Waterloo Research in Aging Participant Pool, a volunteer-based research pool. All participants were paid. Only right-handed participants were included in the study. Furthermore, exclusion criteria included any prior diagnoses of neurodegenerative, cognitive, or motor impairments, vision problems that cannot be corrected for, depression, and other medical conditions that may affect performance on the motor task (i.e. - moderate-to-severe arthritis, recent injury to upper limbs, etc.). All participants provided informed consent to participate and all procedures in the study were conducted in accordance with ethical requirements set forth by the Human Research Ethics Committee at the University of Waterloo.

In order to ensure that the findings from the study were truly due to the effects of healthy aging and that the participant samples for each group were a true representation of their participant group population, all participants completed a cognitive test (Modified Mini Mental Status Examination) and a speeded motor task (grooved peg board task), both of which are widely used measures in clinical settings. The Modified Mini Mental Status Examination (3MS) was used to ensure that all of the participants were within the normal range for their age for cognitive-related measures. Moreover, since this test is also a clinical tool used to detect signs of dementia, it also served as an additional means to ensure that none of the participants in the OA group fell below the normalized cut-off score (80/100). The grooved peg board task (GP) is a uni-manual task that measures the time it takes a person to pick up and place pegs in each hole on the board (see appendices for GP task protocol). Scores from each group were compared to the normative data for their respective age groups.

2.2 Apparatus:

The reaching task apparatus used in the study consisted of a flat, rectangular wooden tablet that was placed on the table in front of the seated participant. Flat metal plates (raised above the surface of the testing area by only 0.02cm) that were built into the surface of the tablet were used to represent the start position (SP) (10 X 10 cm) and 3 circular target locations (5.6 cm diameter). The center of the SP was located 14 cm away from the edge of the table where the participant was sitting and positioned along the participant's midline. On the 1st target plate, located 20 cm directly ahead of the SP, rested a cylinder (4 cm diameter X 3 cm height), representing the object to be grasped on each trial. Directly to the right of this 1st target (object location) were the two other target plates, one located 15 cm to the right of the cylinder (near target; condition 2) and the other located 30 cm to the right of the cylinder (far target; condition 3). Therefore, the object to be grasped was aligned along the participant's midline and the other two targets directly to the right of the object. The change in direction from moving forward in the first reach-to-grasp movement to moving right-ward in the second movement, which involved placing the object on one of the two targets, was used to ensure that participants made two distinct movements. Also, since all participants were right-handed and used their right hand in this task, the second 'place' movements were always directed toward targets in the ipsilateral plane to avoid any confounds associated with making contralateral movements to targets in the second and third conditions.

A light-emitting diode (LED) was located behind each of the 3 target locations, which indicated the target for each trial. The LED representing the target for the upcoming trial was illuminated for 2 – 5 seconds before the go-signal and remained illuminated throughout the entire trial for all conditions. In order to eliminate temporal anticipatory effects, the duration of this foreperiod/warning signal (time between LED lighting up and go-signal) was randomized between 2 – 5 seconds. The target 1 LED (representing the object to be grasped) was illuminated for every trial in every condition; for the dual-movement conditions, the second movement target LED (either target 2 or 3) simultaneously illuminated with the target 1 LED prior to the go-signal. The rationale for this was that, although there was only one target option for the single-movement task condition, it was illuminated during this condition nonetheless to ensure that the visual cues associated with movement termination was consistent in all conditions to avoid any possible confounds related to sensory information differences for ending movements to targets in the single- or dual-movement task conditions. In line with this notion, for the dual-movement task conditions, it was decided to keep the target 1 LED illuminated in addition to the LED for the second placement target (2 or 3) to allow for as valid a comparison between the reach-to-grasp movement in the dual-movement conditions (first movement in the sequence) and the reach-to-grasp movement in the single-movement condition (only movement in the sequence).

Vision of the limb and cylinder was available for all conditions. The total time for the testing session was approximately 1.5 to 2 hours, including time for optional breaks if the participant desired to take one. Two of the three conditions were counter-balanced (single-movement task was always performed first, reflecting the baseline task) to reduce practice effects for the more complex movements. For reasons cited in other literature relating to order of presentation of task difficulty as a deterrent for participants in certain age groups (i.e. - such as when the more complex task is administered first) (Yan et al., 2000), the relatively simple movement task was performed first (condition 1) and the more complex movement tasks (conditions 2 and 3) were performed in a semi-randomized order later.

2.3 Procedures:

Condition 1: Single-Movement Task

Before beginning the trial, the participant positioned the hypothenar edge of his/her right hand on the SP with the index finger and thumb in a tip pinch position. Upon hearing the go-signal, the participant was instructed to reach and grasp the cylinder as quickly and as accurately as possible. Note that in this case, accuracy represented a successful cylinder grasp without bumping or knocking it off of its target plate location. Each trial was recorded for a total of 10 seconds to ensure that the entire movement was recorded in the collection. Also, in order to ensure that the condition 1 movement task was truly a single reach-to-grasp movement (and that participants were not planning their return movement back to the SP to prepare for the next trial during the execution of the reach-to-grasp movement), they were asked to remain at the target (grasping the object) until the end of the recording time for each trial (Roy et al., 2004). Participants performed this single reach-to-grasp task for a total of 30 trials.

Conditions 2 (near target) and 3 (far target): Two-Movement Tasks

In conditions 2 and 3, participants were again instructed to reach and grasp the cylinder at target 1 (same as condition 1), however, after grasping the cylinder, they were to subsequently move and place it on one of the other two targets to the right. Participants were again instructed to perform this two-movement sequence as quickly and as accurately as possible. Again, in order to ensure that the participants were not confounding the movement task by incorporating a third movement (return to SP movement) at the end of the dual-movement conditions, they were asked to remain on the end placement target until the end of the recording time for each trial. To reduce the effects of practicing the same movement over a block of trials, the second-movement target for each trial was selected semi-randomly (random order, but ensuring 15 trials for the near and 15 trials for the far target locations) for a total of 30 trials. The same order of randomization of conditions 2 and 3 was used for all participants.

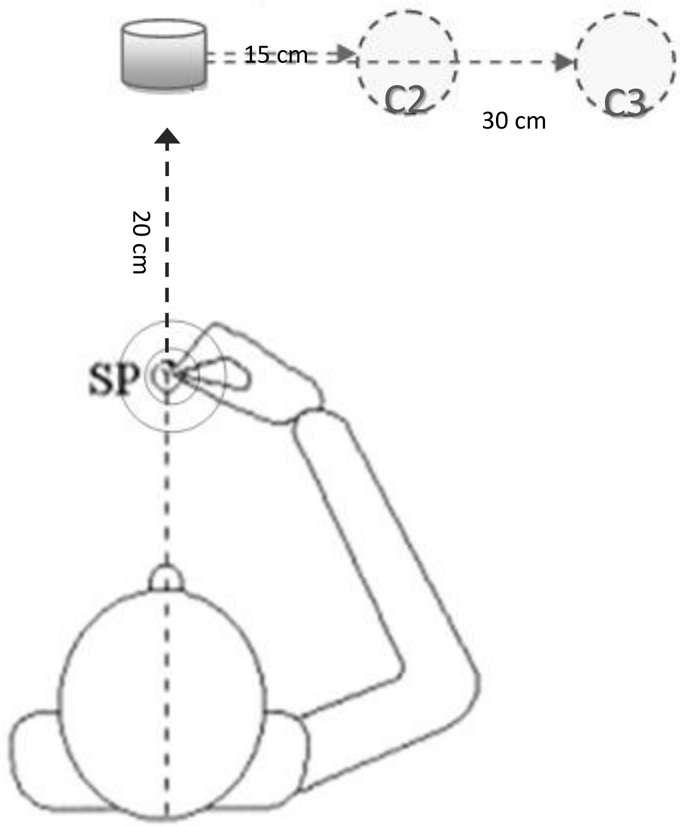

Figure 1: Reaching and grasping paradigm. Placement target locations for condition 2 (C2) and condition 3 (C3).

2.4 Data Collection and Processing

Movements were recorded via an optoelectric analysis system (Optotrak, Northern Digital Inc., Waterloo, Ontario) which detected infrared markers (IREDS) at a sampling rate of 200 Hz. The Optotrak system is equipped with three digital cameras, allowing for processing and recording movements in 3-dimensional coordinates. Displacement data collected from the IREDs was processed by the KinAnalysis program, which filtered the data using a second-order low dual-pass Butterworth filter with a cut-off frequency of 10 Hz to reduce the noise in the signal.

The IREDs were placed on four specific locations. One marker was placed on the styloid process of the radius of the wrist and reflects movement of the arm which represents the transport component of the reach to grasp movement. Two IREDs were placed on the digits: one on the medial base of the nail of the thumb and the other on the lateral base of the nail of the index finger. Their positions relative to one another reflects the grasp or the manipulation component. In order to ensure that participants successfully moved the cylinder to the second target adequately and to verify they were made to the correct target, a final IRED was placed on the cylinder itself.

For the transport component (wrist IRED), the filtered displacement data was differentiated by using a central finite difference technique to obtain a velocity profile of the y-direction. After calculated comparisons, it was found that using the velocity profile of movements in the primary axis of movement (y-axis) was a more accurate representation of the reaching movement than using the resultant velocity since movements in the x and z axes were very small by comparison. To obtain information about grasp size for the manipulation component, however, the resultant was calculated for both the thumb and the index finger from the displacement data and then the (spatial) difference between each was used to obtain aperture size at each point in the movement to the cylinder. The kinematic variables of interest for both the transport and manipulation components (see below) were calculated using automatic algorithms.

A bank-timer was set to release a voltage switch/signal for the LED(s) and the buzzer (go-signal) in accordance with the foreperiod interval for each trial. The time at which these signals were released was recorded by an Optotrak Data Acquisition Unit (ODAU II) (Northern Digital Inc., Waterloo, Ontario), which allowed for the voltage data to be synchronized with the Optotrak kinematic data. This voltage switch measure also served as an additional means of verifying the temporal events captured by the kinematic data (IREDs). Small wire filaments were placed on the palm, thumb, and index finger of the participant as well as on the cylinder, SP plate, and target plates of the reaching task apparatus to signal when contacts or breaks in contact occurred. More specifically, it was used as an additional means to verify the point at which the participant lifted the palm from the SP (break in contact between palm wire and SP plate), ensure that the participant started each trial in the same pinched position (index and thumb wires in contact), that double contact on the object was attained for the grasp action (more than one finger wire contacting the object to grasp it), and that the cylinder was accurately placed on the second target plate for the dual-task conditions (contact signal required the cylinder to be lying flat on target plate, not unevenly).

Spatiotemporal Kinematic Variables of Interest

The dependent variables of interest in this study were RT, MT, PV, absolute time-to and time-after-PV, relative time-after-PV, PA, absolute time-to and time-after-PA, relative time-after-PA, and the difference in relative timing of PV and PA across age groups and conditions.

Reaction time (RT) was recorded for all trials and represents the difference in time between the go-signal (recorded by ODAU II) and the start of the movement. The first frame at which velocity exceeded 10 mm/sec for ten consecutive frames was used to define the start of the movement and the end of the movement was defined as the point at which the first of ten consecutive frames fell below 100 mm/sec (after the beginning of the movement). These cut-off values were determined to be the best measures for defining the start and end of the reach-to-grasp movement for all conditions[2]. Movement time (MT) was defined as the time between the start and end of the movement.

Peak velocity (PV) of the wrist (y-axis), peak aperture (PA) of the fingers, and the absolute time-to- and time-after each peak was calculated. The percentage of movement time spent after PV was calculated as a reflection of the relative timing of PV, and essentially, the shape (or pattern) of the velocity profile. This was calculated by dividing the real time-after-PV by MT and reflects the proportion of the entire movement (MT) spent in feedback control. The same method was used to calculate the relative timing of PA in the velocity profile.

[2]There are three viable reasons for choosing these measures to define the start and end of the reach-to-grasp movement: 1) when compared to other measures of defining the beginning and end of the movement, this means was found to be the most accurate and consistently viable representation of movement across participants; 2) it was the best measure that could be used to define the end of the movement for both single and dual-movement tasks (for example, people typically do not stop completely at the end of the 1st movement when it is part of a sequence, in other words, velocity would not reach 0 mm/sec for conditions 2 and 3), and the same definition must be used to define the end of the reach-to-grasp movement for all conditions in order to compare such timing variables; 3) it was the best measure that corroborated with the displacement data, but offered the consistency of using the same measures as the other kinematic variables examined; and 4) it has been used and is supported by the literature.

To assess the degree to which the transport and manipulation components are coupled in the planning of movement, the relative timing differences between PV and PA were calculated. For example, if PV occurred at 50% of the movement and PA occurred at 70% of the movement, the difference between the two would be 20%. Since these two variables are believed to be pre-programmed, it was of interest whether this value would differ between groups and also whether/how it would change as a function of changes in task demands.

In the interest of this thesis, analysis of these features will be examined exclusively on the reach-to-grasp movement with respect to performance in isolation (single-movement) or when it is the first-movement in a two-movement sequence (movement 1 in dual-movement conditions).

2.5 Statistical Analysis

Nine participants were eliminated from the analysis of the kinematic measures of the transport component and three more participants were discarded from the manipulation component data due to incomplete data records (see Appendix for table outlining the excluded participants for each group). Reasons for incomplete data records were due to movement errors, such as when the subject moved prematurely/before the go-signal, or the signal from the IREDs may not have been continuously received by the Optoelectric system's cameras throughout a trial (i.e. - brief occlusion of the line of sight between cameras and the IREDs during the movement). Therefore, participants who were missing data for more than half of the testing the trials or were missing data for any one condition were excluded from the analysis (i.e. - if only condition 2 trials were missing IRED data, but not condition 1 or 3, still excluded the participant altogether). Since the primary focus of this thesis pertains to investigating performance of reaching movements (transport component), the nine participants excluded from the analysis of the transport component were also removed from the rest of the analyses (i.e. - 3MS and GP). The first trial of the testing session (condition 1) was considered as a practice trial and was therefore excluded from the data analysis for all participants. Among the remaining trials, 9 percent of the trials for the transport component and 19 percent of the trials for the manipulation component were eliminated due to missing IREDS or movement anticipation errors.

Means and standard deviations were calculated for age, gender, and years of education for each group using SPSS version 18. Means and standard deviations were also calculated for scores on the 3MS and GP (average of two trials performed by each hand for both the place and replace tasks). These were further compared to the standardized normative values for each age group to ensure that they were representative of their participant group populations.

Averages for each of the dependent variables were calculated from all of the trials for each group and condition. A 2 (group- YA and OA) X 3 (condition- single-movement task, two-movement task to near target, and two-movement task to far target) mixed design analysis of variance was used to analyze the performance data, with repeated measures on the latter factor. The level of significance was set at 5%. Significant effects involving more than two values were further analyzed using the Tukey HSD test ($p < .05$).

3. RESULTS

3.1 Participant Characteristics

Descriptive statistics were used to compare the participant group characteristics and are summarized in Table 1. The groups did not differ in the number of years of education (t= -1.20, p= .243). Although there were more females than males who participated in the study, the male-to-female ratio was comparable between groups (OA: 3M/8F; YA: 4M/10F, respectively).

Table 1: Participant Characteristics

Variable	**Younger Adults (YA)**			**Older Adults (OA)**		
	M	**F**	**Total**	**M**	**F**	**Total**
N	4	10	14	3	8	11
Age	21.25(2.5)	20.50(.85)	20.71(1.4)	73.67(9.1)	75.63(6.9)	75.09(7.1)
Edu (yrs)	15.50(1.7)	14.55(.69)	14.82(1.1)	16.33(1.2)	15.63(3.3)	15.82(2.9)
3MS	98.86(1.2)			96.91(2.3)		
GP:						
RH Place	54.9(7.0)			81.55(20.3)		
LH Place	60.59(9.0)			91.43(16.6)		
RH Replace	17.57(2.2)			21.92(3.4)		
LH Replace	18.24(2.1)			23.57(3.4)		

3.1.1 3MS

All participants fell within the healthy normative-range on the 3MS, with scores ranging from 93 to 100 out of possible total score of 100.

3.1.2 Grooved Peg Board

While OAs took longer to perform this task of motor speed than the YAs, both OAs and YAs were found to be representative of their participant group population, as they fell within the expected range for their age from the norms. Also, both groups showed a significant difference between right and left hand performance on the GP place task, reflecting much faster times with the RH than the LH (YA: t= 4.03, p= .001; OA: t= 2.66, p= .026), thus showing similar dominant-hand advantages for both groups.

3.2 Kinematic Data

3.2.1 Reaction Time

Analyses of RT revealed a main effect of group [F(1,23)= 18.74, p= .0002] and condition [F(2,46)= 9.26, p= .0004], with OAs taking longer to initiate movements than YAs and RTs being longer for movements in the single-movement condition than the dual-movement conditions. Analyses also yielded a significant 'group x condition' interaction [F(2,46)= 4.74, p= .0134]. Tukey's HSD post hoc analyses indicated that the main effect of condition is driven by the OA group, as revealed by significant differences in RT between the single- and dual-movement conditions for the OAs, but no differences in RT were found between any of the conditions for the YAs. This suggests that the task condition has a greater impact on the pre-movement motor planning time in OAs than it does in YAs.

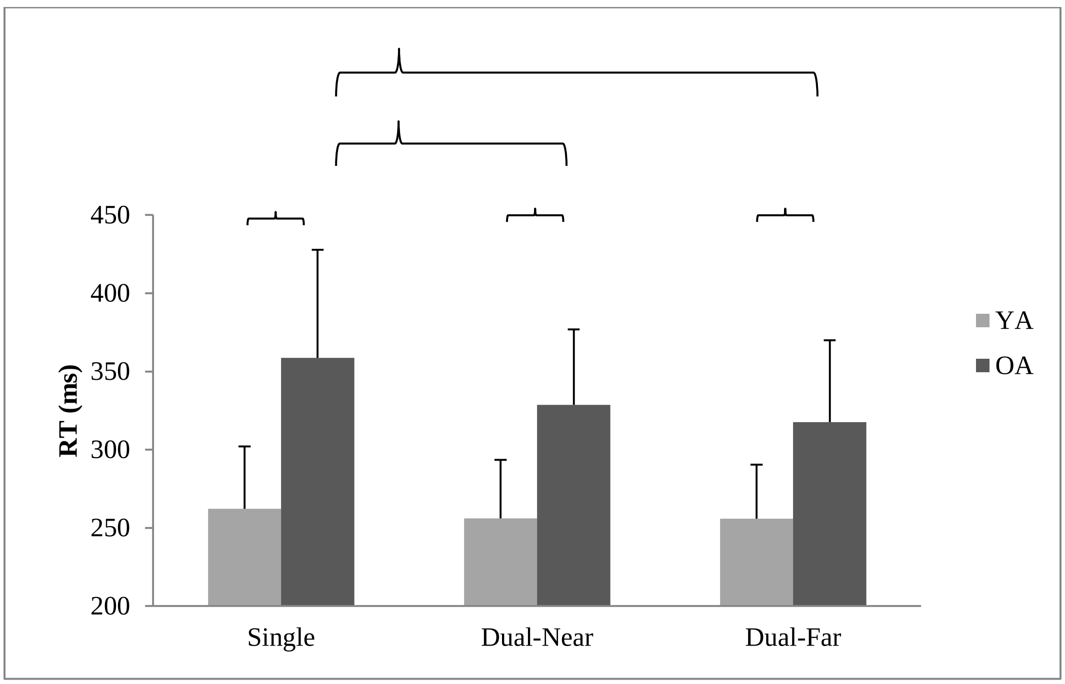

Figure 2: Reaction time (milliseconds) for each group for each condition.

3.2.2 Movement Time

Analyses of MT data revealed main effects of group [$F(1,23)= 37.92$, $p< .0001$] and condition [$F(2,46)= 17.47$, $p< .0001$], with OAs taking longer than YAs to perform the reach-to-grasp movement, regardless of condition, and with the reach-to-grasp movement taking longer in the single-movement condition than in the two-movement conditions. Also, a significant interaction was found [$F(2,46)= 4.60$, $p< .0151$], with the decreases in MT from single- to dual-movement conditions being disproportionately greater for the OA group than the YA group.

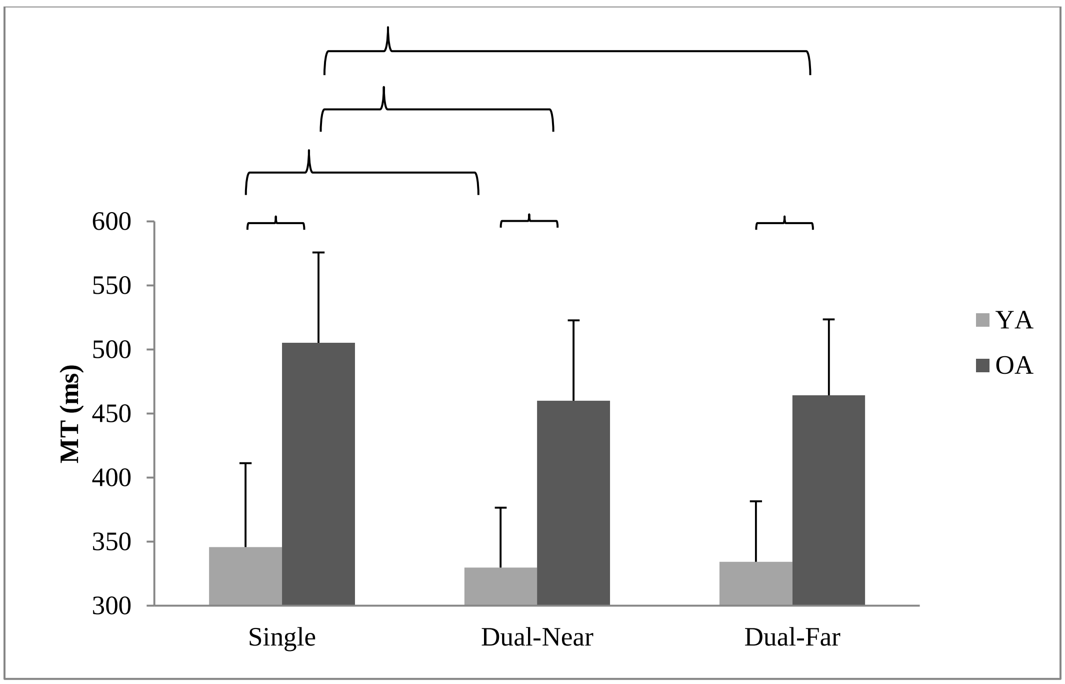

Figure 3: Movement time (milliseconds) for each group for each condition.

3.2.3 Peak Velocity

Analyses on PV revealed a main effect of group [$F(1,23)= 16.10$, $p= .0005$], with YAs reaching higher PVs than OAs across all conditions, and also a main effect of condition [$F(2,46)= 6.15$, $p= .0043$], with lower PVs for the single-movement condition than for the two-movement conditions. The lack of an interaction [$F(2,46)= 0.13$, $p= .8812$] indicates that the influence of task complexity on the peak speed of reaching movements affects both groups similarly or to the same degree.

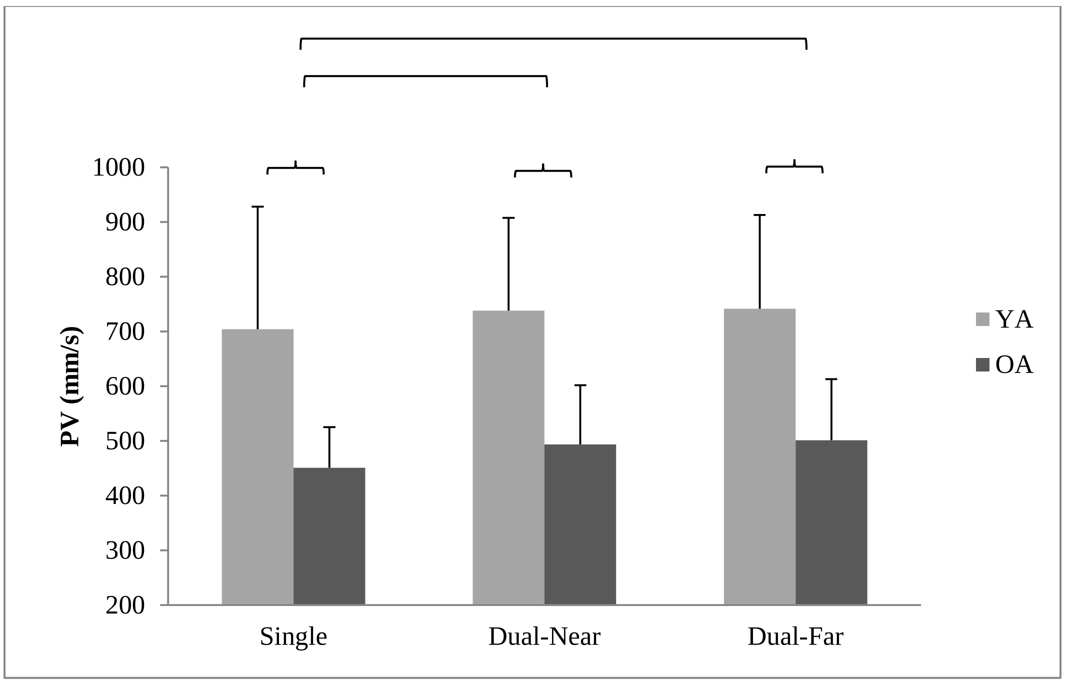

Figure 4: Peak velocity (millimetres/second) for each group for each condition.

3.2.4 Time-To-Peak Velocity

Data analyses yielded main effects of group [F(1,23)= 37.39, p< .0001] and condition [F(2,46)= 9.97, p= .0016] for time-to-PV, where OAs spent greater time reaching PV than YAs for all conditions and time-to-PV being longer in the single-movement condition than in either of the two-movement conditions. Analyses also yielded a significant interaction of ‘age x condition’ [F(2,46)= 7.41, p= .0016], with post hoc tests indicating that the task conditions had no effect on time-to-PV for YAs, whilst OAs took significantly more time to reach PV when the task required only a single movement.

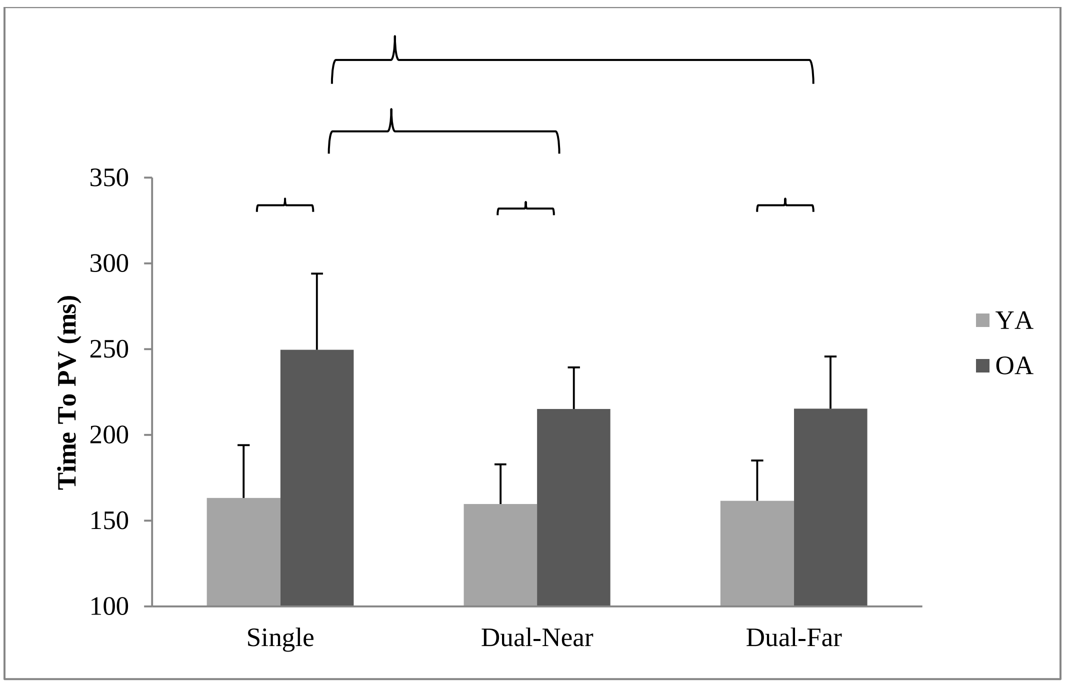

Figure 5: Time to peak velocity (milliseconds) for each group for each condition.

3.2.5 Time-After-Peak Velocity

For time-after-PV, the analyses revealed a main effect of group [$F(1,23)= 24.94$, $p< .0001$], with OAs spending more time-after-PV than YAs for all conditions. Although not reaching statistical significance, there was a near-significant main effect for condition [$F(2,46)= 3.16$, $p= .0517$], with a trend toward more time-after-PV for the single-movement condition than the dual-movement conditions. Unlike time-to-PV, the results did not yield a significant interaction [$F(2,46)= 0.04$, $p= .9574$], suggesting that both groups respond similarly, albeit not drastically different, to changes in task condition for the amount of absolute time they spend after PV.

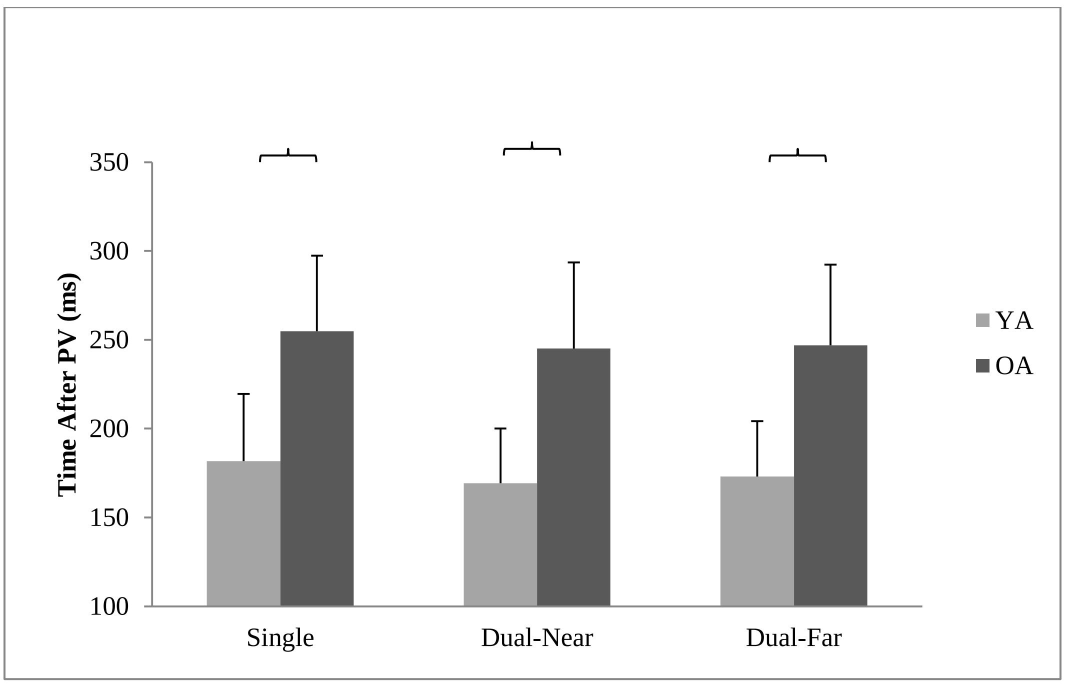

Figure 6: Time after peak velocity (milliseconds) for each group for each condition.

3.2.6 Percent Time-After-Peak Velocity (Relative Timing)

Results pertaining to the relative timing of PV revealed that the percentage of time spent after PV, as a proportion of the overall time taken to execute the movement, did not differ between groups [F(1,23)= 0.11, p= .7401] or between conditions [F(2,46)= 0.59, p= .5566]. There was, however, a significant interaction that revealed an interesting contrast in relative timing patterns between groups as a function of task demands [F(2,46)= 3.45, p= .0402]. This interaction showed that for the OAs the percent time-after-PV increased in the two-movement conditions compared to the single-movement condition, while the opposite pattern was found for the YAs; that is, the YAs spent proportionately less time-after-PV when a two-movement task was required than when they performed the single movement task. Post hoc analyses, however, revealed that this interaction is driven by the OAs, as there were no differences in the YAs' movement pattern between any of the conditions, but there were significant differences between the single-movement task (condition 1) and both the dual-movement tasks (conditions 2 and 3) for the OAs. This suggests that the OAs are more greatly influenced by task complexity when they program reach-to-grasp movements than are the YAs.

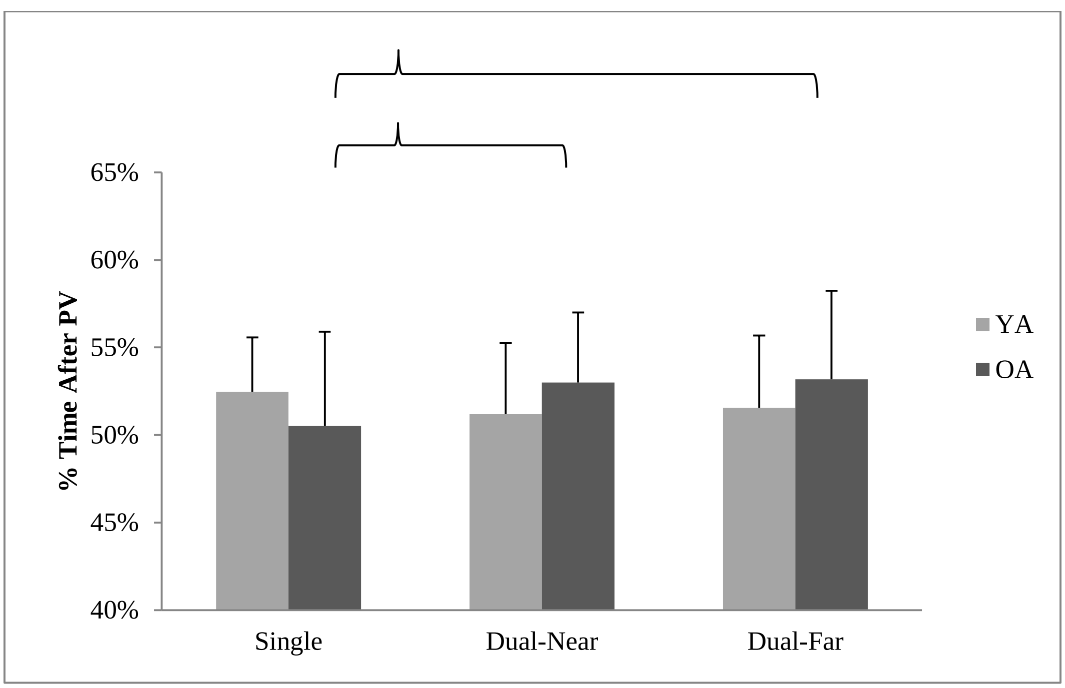

Figure 7: Percentage of movement spent after peak velocity (relative time) for each group for each condition.

3.2.7 *Peak Aperture*

Data analysis on the manipulation component revealed a main effect of condition for PA [F(2,40)= 7.62, p= .0016], with greater PA being achieved for conditions 2 and 3 than for condition 1. No other significant effects were found for PA. The lack of significant differences between groups as well as the lack of an interaction effect for PA [F(1,20)= 0.00, p= .9837] suggests that both groups use similar maximum grasp sizes in response to the task conditions for the manipulation component.

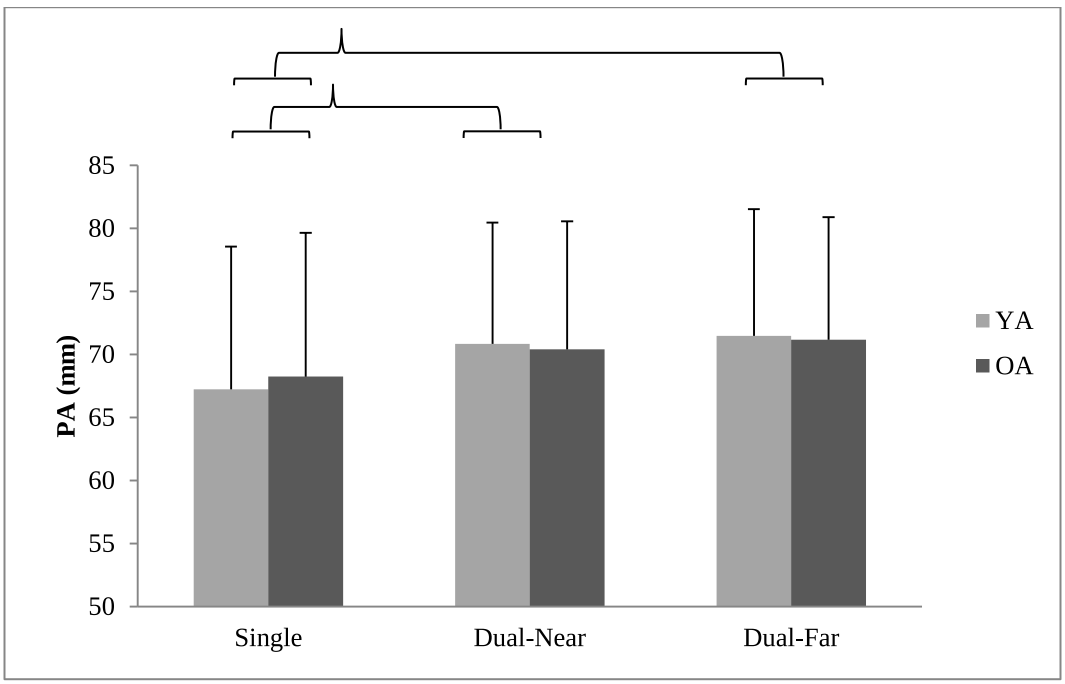

Figure 8: Peak aperture (millimetres) for each group for each condition.

3.2.8 Time-To-Peak Aperture

Analyses of time-to-PA yielded a main effect of group [F(1,20)= 23.15, p= .0001], with OAs spending more time to reach PA than YAs. A main effect of condition [F(2,40)= 16.57, p< .0001] was also found, reflecting greater time-to-PA for the single-movement condition than the two-movement conditions. There was also a near-significant interaction for ‘group x condition’ [F(2,40)= 3.14, p= .0542], with a trend depicting OAs being more greatly affected by task demands than YAs for time-to-PA. The greater decreases in the time-to-PA for the dual-movement conditions compared to the single-movement condition for OAs appears to mirror the OA’s pattern of decreases in MT for these conditions.

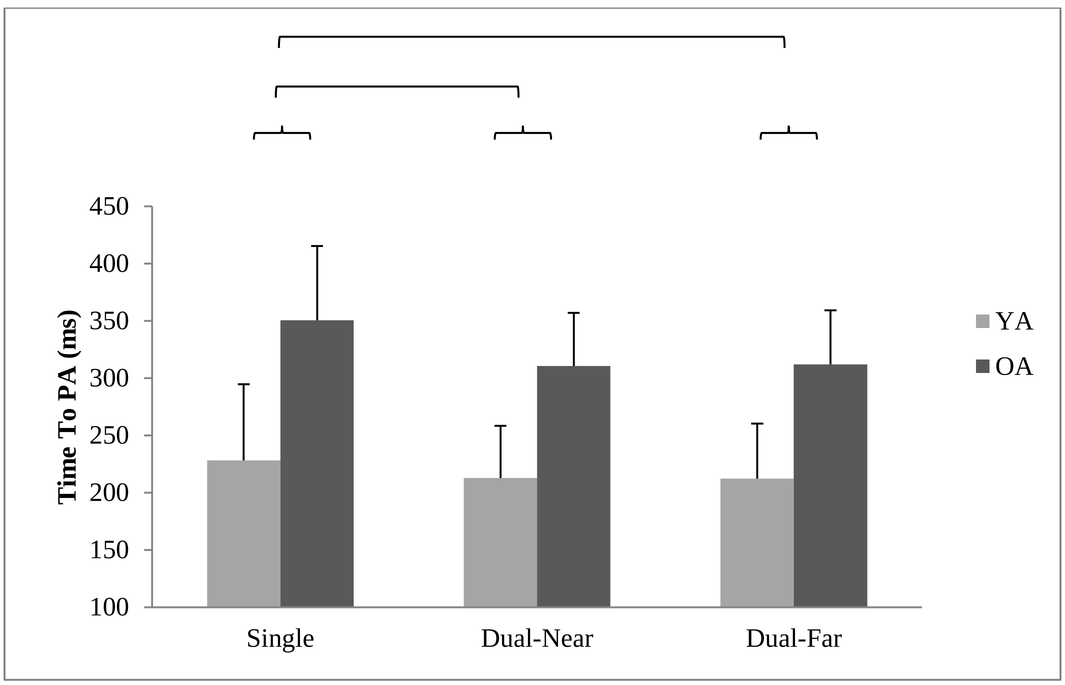

Figure 9: Time to peak aperture (milliseconds) for each group for each condition.

3.2.9 Time-After-Peak Aperture

Unlike time-to-PA, there were no main effects of group [$F(1,20) = 3.06$, $p = .0957$] or condition [$F(2,40) = 0.08$, $p = .9204$] for time-after-PA. No significant interaction was found either [$F(2,40) = 0.66$, $p = .5203$], indicating that both the older and younger adult groups spent similar amounts of time enclosing the hand and this enclosing time did not differ between conditions.

3.2.10 Percent Time-After-Peak Aperture (Relative Timing)

Interestingly, there was no difference between groups in the relative timing of PA [$F(1,20) = 2.88$, $p = .1054$]. Furthermore, the relative timing of PA was not significantly different between conditions [$F(2,40) = 2.23$, $p = .1211$], nor was there a significant interaction [$F(2,40) = 0.23$, $p = .7960$].

3.2.11 Coupling Between Relative Timing of Peak Velocity and Peak Aperture

Analyses on the relative timing differences between PV and PA revealed no main effects of group [$F(1,20) = 3.14$, $p = .0917$] or condition [$F(2,40) = 0.95$, $p = .3967$]. Furthermore, no interaction was found for this measure either [$F(2,40) = 1.69$, $p = .1974$].

4. DISCUSSION

The overall aim of this work was to investigate the effects of healthy aging on motor planning and control processes in reaching and grasping movements. More specifically, the aim of this study was to determine whether aging affects all processes equally or differentially by examining the kinematic features of prehensile movements of younger and older adults under different movement contexts.

4.1 First Research Question: How does aging affect performance on a single reach-to-grasp movement?

Older adults' overall performance showed the traditional motor slowing associated with aging, reflecting slower movements in general compared to the younger adults. With regards to the first research question, the findings obtained in this study replicated those from previous studies that have compared healthy younger and older adults on single reaching movements, with older adults consistently taking longer to both initiate and execute the reach-to-grasp movement than the younger adults. Analysis of the kinematic features also supported this notion, with older adults performing more slowly and taking more time before and after peak velocity than younger adults. Even though the older adults took longer both reaching peak velocity and decelerating after peak velocity than the younger adults in real time, it was of interest whether or not they spent the same percentage of time in the ballistic and movement correction phases as the younger adults. Although some studies have shown older adults spend a greater proportion of time in the deceleration phase than in the ballistic phase of the movement (Seidler-Dobrin & Stelmach, 1998; Heath et al., 1999), the findings from this study revealed that the relative time spent before or after PV when making a single reach-to-grasp movement did not differ between age groups. The fact that the relative proportion of the movement dedicated to the ballistic and movement correction phases was the same for both groups is in agreement with other studies that have found no differences in the movement patterns of younger and older healthy adults on discrete aiming movements (Haaland et al., 1993; Roy et al., 1999). Thus the temporal symmetry of the velocity profile was similar between younger and older adults, indicating that the relative portion of time dedicated to feed-forward and feedback control was comparable between groups on a single goal-directed reaching movement.

The findings for the manipulation component are also in concert with the literature, showing no differences in the size of maximum grip aperture, the relative timing of PA, nor the coupling of relative timing of the transport and manipulation components between groups (Bennett & Castiello, 1994; Roy et al., 1999). This suggests that older adults merely take longer and perform more slowly than younger adults when the task goal is to a make a single reach-to-grasp movement, implying that all motor processes are affected equally in healthy aging and the relative coupling between the transport and manipulation components in prehension remains intact with age (Salthouse, 1985; Goggin & Meeuwsen, 1992).

4.2 Second Research Question: Is the movement termination effect seen by Roy et al. (2004) for aiming movements observed when the task involves a reaching and grasping movement and is this effect on performance comparable between younger and older adults?

In examining reach-to-grasp performance in the single-movement task compared to when it is the first part of a two-movement sequence, findings from the current study were not only in concert with some studies and in contrast with others, but also provide an alternative explanation for the effects of movement context on performance as a function of age.

4.2.1 Reaction Time:

One interesting finding from the study revealed that the time to initiate movement was greater in the single-movement condition compared to the dual-movement conditions. In other words, when participants initiate a movement where they only have to grasp an object, they take longer than when they have to grasp the object, pick it up, and move it to a new location. This is in contrast with literature that contends that the more complex the motor task, or the greater the number of movement components in a motor task sequence, the longer it should take to plan (Henry & Rogers, 1960; Fischman, 1984; Christina, 1992), but is in concert with other literature pertaining to the movement termination effect (Roy et al., 2004). More specifically, the finding for RT can be explained by the movement termination effect such that if the movement plan involves stabilizing the arm at the first target (single-movement) as opposed to merely slowing it down to continue to a subsequent target location, the constraint of achieving a stabile position imposes a greater demand (Roy et al., 2004). Yet, in terms of pre-movement planning (RT) specifically, Roy and colleagues (2004) found no differences in RT between single- and dual-movement conditions. All participants in their study, however, consisted of younger adults. After looking more closely at the findings for RT, it is apparent that the greater RT for single-movements compared to two-movement sequences is driven by the older adults. That is to say that the time for planning a response prior to moving was not affected by any of the conditions for the younger adults in this study either, but older adults took longer to initiate movements performed in isolation compared to when they were embedded as the first part of a sequence. This indicates that terminating the movement must be occurring during the preparation for the older adults but not the younger adults. This also suggests that the demands for movement stability at the end of the movement have a greater effect for the older adults.

4.2.2 Movement Time:

In looking at the total time taken to execute the reach-to-grasp movement when performed in isolation compared to as the first part of a sequence, the classic movement termination effect is seen, such that reach-to-grasp MT is longer for the single- than for the dual-movement tasks. The resulting interaction, however, indicates that the movement termination effect has a greater impact on MT for older adults than younger adults, similar to what was found for RT.

The finding that the younger adults took longer to execute the movement (MT) in the single- than the dual-movement conditions, yet revealed no difference between these conditions in the time to prepare or initiate movements (RT), again implies that the younger adults only planned their movements online. For older adults, on the other hand, the planning occurs before movement initiation as well as online, as shown by changes in both RT and MT.

4.2.3 Components of the Movement in Real-Time (Transport Component):

Although the findings for RT and MT suggest that older adults are more sensitive to the movement termination effect than younger adults are, only by further examining the components of the movement would it be possible to determine whether certain features or phases of the movement are more affected than others. Analyses on the real-time components of MT show that the movement termination effect is reflected in the absolute time to reach PV, taking longer time-to-PV for the single- than the dual-movement tasks. Again, however, this effect is driven by the older adults, not the younger adults; movement context (making single- or sequence-movements) had no effect on the absolute time spent reaching PV for younger adults.

4.2.4 Relative Timing Components of the Movement (Transport Component):

Whether the time-to-PV is a merely a function of the overall greater MTs for older adults compared to younger adults or whether it is due to older adults spending proportionally more of the movement in the ballistic phase, under feed-forward control, was an integral piece to interpreting which motor processes may be differentially influenced under such task conditions with age. In particular, since the results yielded differences in the time-to-PV but not in the time-after-PV, it was therefore necessary to examine the relative timing of the velocity profile. Indeed, findings revealed that, compared to the younger adults, the older adults were spending disproportionately more time to reach PV for the single- than the dual-movement tasks. This implies that the reason older adults take longer to execute single-movements compared to sequenced-movements is because they spend relatively more time in the ballistic phase of the movement.

The notion that the movement termination effect found in MT is a result of changes in both the real and relative time spent reaching PV is inconsistent with findings from Roy and colleagues' (2004) study, which found the movement termination effect to be reflected in the time-after-PV. Also inconsistent with Roy et al.'s (2004) study is that this was only seen in the older adults, as the younger adults in this study revealed no differences in real or relative time-to- or after- PV, or RT as a function of movement context- only MT was affected. Thus it appears as though the movement termination effect is not as strong for the younger adults as it is for the older adults, and moreover, for the older adults, the increased MT appears to be driven by the time spent in the initial ballistic phase of the movement, rather than the deceleration phase.

In looking at the flip side of this relative timing relationship, it can conversely be viewed as older adults spending proportionally less time after PV for the single- than the dual-movement tasks; that is, they spend more relative time in deceleration when they have to make a subsequent movement following the first movement. These findings for the relative timing changes in the velocity profiles of older adults would appear to provide support for the OTA. More specifically, the shift in the velocity profile between single- and two-movement tasks for older adults can be interpreted as a variation of the previously coined term "length effect". This effect is based on studies that have examined performance on movement sequences, which have shown that RT of the first movement increases with the length or the number of movement components involved in the motor action. The increases in RT are attributed to the greater time needed for planning more complex motor sequences (Henry & Rogers, 1960). Since an increase in pre-movement planning time (RT) for conditions with an added movement component was not found, then there must be an increase in the proportion of time dedicated to online planning of the second movement during the deceleration phase of the first movement in order for the principles of the OTA to hold true. The notion here is that the greater demands placed on planning a two-movement sequence compared to a single isolated movement would be reflected in the form of either an advance programming strategy, whereby the plan is defined before the start of movement (increases in RT), or an online programming strategy, whereby planning continues during the movement (increases in time spent in deceleration) (Adam et al., 2000; Vindras & Vivianni, 2005; Khan, Franks, Elliott, Lawrence, Chua, Bernier, Hansen, & Weeks, 2006; Mirabella et al., 2008).This is indeed what was found, with older adults showing a greater proportion of time spent after PV for the sequence conditions compared to the single condition. This appears to provide support for the length effect (OTA) in the form of increased relative time required for online planning as opposed to pre-movement planning.

An alternate interpretation of this finding relates to research that shows when the movement as a whole takes longer to perform or when the total amplitude of the movement increases, older adults rely more heavily on online feedback control. This has been supported by previous studies on healthy aging showing older adults to be more reliant on feedback control than younger adults for longer movements (Phillips, Bruce, Newton, & Woledge, 1992; Haaland et al., 1993; Roy et al., 1999). Furthermore, research has shown that the online control for the first movement in a two-movement sequence has more to do with terminating and finishing the first movement successfully than with preparing the second movement in certain circumstances (Lavrysen et al., 2002).

4.2.5 Features of the Manipulation Component:

Although the movement termination effect could be a plausible explanation for the effects on motor performance between single and dual-movement task conditions for the transport component, the results for the manipulation component seem equivocal.

Unlike the transport component, the findings for the manipulation component revealed that older adults were able to scale the size and relative timing of their grasps to the context of the movement (single- versus two-movement tasks) like younger adults. Although older adults took more real-time reaching PA, both groups responded similarly in accordance with movement context, such that the time-to-PA was greater for the single-movement compared to the dual-movement tasks. Furthermore, the greater time spent reaching PA for the older adults is attributed to the fact they took longer to execute the movements in general, as the relative timing of the manipulation component did not differ between groups or conditions. This suggests that the motor programming and control processes involved in the manipulation component, as well as its coupling with the transport component, remains relatively unaltered with age.

4.3 Third Research Question: Do younger and older adults modify the first reach-to-grasp movement in accordance with the extrinsic properties (amplitude) of the subsequent motor task?

The third research question provided insight as to whether the increased proportion of time spent in decelerating the arm for the two-movement conditions compared to the single-movement condition for older adults was due to online planning of the second movement during the execution of the first (supporting the OTA), or whether it was due to online feedback control for terminating the first movement (in agreement with the movement termination effect). If that effect is due to the OTA, then one would expect to see a difference between conditions 2 and 3, since the increased relative time after PV for the dual-movement conditions compared to the single-movement condition is predominantly based on, or attributed to, online planning of the second movement. In other words, if this time was dedicated to online planning of the second movement as opposed to feedback control for ending the first movement, then one would expect to see differences in the proportion of time spent after PV between conditions where the second movement is made to a near target compared to a far target. This is based on a variety of studies that show movement amplitude affecting the time to plan movements- and moreover, findings from studies on healthy aging which indicate that older adults are particularly sensitive to changes in movement amplitude and/or duration. However, no differences were found between conditions 2 and 3 on relative timing measures. The fact that there were no differences in the relative time spent after PV for moving to the near- versus far-target in the two-movement conditions supports the notion of older adults spending proportionately more time for feedback control in terminating the first movement rather than for online planning of the second movement. Moreover, no differences between two-movement sequences when the second movement was made to a near compared to a far target were found for any of the measures.

4.4 Limitations and Future Directions

In the interest of this thesis, the influence of movement context (single- versus dual-movements) on the programming and execution of the first (or only) reach-to-grasp movement was the primary focus of this investigation. The findings from this study are in concert with those reported by Roy, Rohr, and Weir (2004), in that the reach-to-grasp MT was longer for the single-movement task than the two-movement task. Older adults, however, appear to be more affected by the act of ending a motor action, whether it is a single movement or the first movement in a sequence, than younger adults. In order to ensure that these effects are in fact due to the movement termination effect, future work should involve comparing performance on movements made in isolation to movements made as the last segment in a sequence.

Also, for the dual-movement tasks, the fact that changes in the amplitude of the second movement target did not affect the reach-to-grasp performance for either group suggests that the planning and control of the first movement is invariant to the extrinsic properties of the second movement. In order to confirm that the parameters of the second movement tasks do indeed elicit different motor performances, the movement profiles of the second motor tasks should be analyzed and compared as part of future work.

Another point that should be noted pertains to the order the conditions were presented in the study. The single-movement task was performed first and the two-movement sequence conditions were performed after to account for concerns raised by other studies, being that certain age groups, like young children or elderly persons, might have difficulty if the more complex movement tasks were presented first- before the relatively simple, baseline task (single-movement condition) is introduced, which may affect the effort put forth by the participants (Yan et al., 2000). Furthermore, the future direction for this research study involves examining reaching and grasping performance in people with Alzheimer's disease in order to compare the effects of healthy aging (current study) to aging with Alzheimer's disease (future study) on the motor planning and control of prehension. Since one of the signs of Alzheimer's disease relates to impairments in the ability to follow two-step commands, starting with the relatively simple single-movement task before the more complex two-step movement tasks would be important- perhaps even necessary- in testing such populations (Lezak, 2004; Lin, Winstein, Sullivan, & Wu, 2005). Although it is necessary to use the same task paradigm for comparing the effects of healthy aging (current study) and aging with Alzheimer's disease (future study), one of the downfalls is that performance results, specifically, the movement termination effect found in the study, may have been confounded by the effect of practicing the same reach-to-grasp movement overtime. One consideration for the future is to divide each participant group in half, with half the participants using the current paradigm and half using a paradigm where the order of the conditions are completely randomized.

One argument against the movement termination effect that has been raised in pointing and aiming studies is that participants may have been more accurate in the single-movement condition as opposed to the dual-movement condition, and therefore performance may have been influenced by the speed-accuracy trade-off for achieving a higher degree of accuracy. This could justify the longer MT and lower PV that was found for single- compared to dual-movement conditions. However, unlike pointing and aiming movements, prehensile movements have an implicit requirement for the movement to be accurate in order to successfully complete the task of grasping the object; in other words, succeeding in the goal of grasping an object is contingent upon making movements accurately. Therefore, the argument against the movement termination effect that has been raised in pointing studies does not appear to be supported- or possibly even apply to this study. Furthermore, in Roy, Rohr, and Weir's (1999) study, they also found that there were no differences in end-point accuracy between the single- and dual-task (movement 1) conditions for pointing and aiming movements made to targets on a digitized tablet.

Although the findings from this study replicate those reported in previous studies in showing that older adults spend a greater proportion of time dedicated to online feedback control for longer movements (two- compared to one-movement segments), it is difficult to confidently ascertain whether these findings for aging are a function of degradations in feed-forward control, impairments in feedback control, or the result of implementing of a different motor control strategy due to the fact that all participants knew where they were supposed to move to in advance (before each trial). In light of the findings revealed in this study, the next step in this line of research is to develop a study with a similar reaching and grasping paradigm as the one used here, but with conditions that limit the ability to plan movements in advance as well as conditions that require movements to be re-adjusted online in accordance with unexpected changes in properties of the task goal during movement execution, such as size, location, or number of targets presented. With the added element of this type of perturbation condition, it would allow for a better determination of whether the motor processes affected with aging are a result of degradations in motor planning, inefficient use of feedback control, or using of a different control strategy altogether. This may even provide insight into whether a different strategy is used under certain conditions (such as conditions requiring longer movements to be made, for example) as a means to compensate for aspects of motor planning and control that may be more impaired than others with age.

Lastly, analysis of the spatial coupling of the transport and manipulation components (i.e. - distance travelled when PV and PA occurred) with age should be assessed in future work.

4.5 Applicable Purpose of Study (Why do we care?):

By knowing the effects of healthy aging on motor control processes, this can be used to delineate differences between healthy aging and abnormal aging (deviations of the norm), which could apply to patient populations in clinical assessment settings. Furthermore, by examining distal limb control in addition to proximal limb control, one may be able to tap into health-conditions that are not apparent in features of the reaching arm alone; in other words, it allows us to dig deeper for better coverage of the transport component (reaching), the manipulation component (using multiple digits for grasping), and the coordination/coupling of the two in order to succeed in the act of grasping and object.

4.6 Conclusion

The overall aim of this work was to investigate the effects of healthy aging on motor planning and control processes on goal-directed aiming movements as reported in previous studies and whether these effects would also be revealed in the kinematic performances of individuals in the present study. There were several fundamental differences in the methodologies between this study and previous studies. First, this study investigated reaching movements in a prehensile context, rather than merely pointing and aiming movements (Sarlegna, 2006), allowing one to examine features of the grasp and whether the two components involved in prehension remain relatively coupled with age. Second, this is the first known study that has directly investigated the effects of healthy aging on prehension using a paradigm that includes a single-movement condition to compare with the first movement in the two-movement task conditions. Also, this is the first known study on aging that has manipulated the extrinsic properties of the second-movement task (amplitude) rather than the intrinsic properties (size) (Weir et al., 1998).

The findings from this study are in concert with those reported by Roy, Rohr, and Weir (1999), in that the reach and grasping movement time was longer for the single-movement task than the two-movement tasks for both younger and older adults. Also, PV was lower when the movement was performed in isolation as opposed to when it was embedded as the first movement in a sequence. This would support the notion of a movement termination effect and furthermore, its persistence with age, since both groups showed this effect.

In conclusion, the findings from this study show that age has an overall effect on MT, but the task demands/movement context is also influenced by age. One of the possible reasons for this may be, at least in part, explained by the "movement termination effect" (Roy et al., 2004). That is, that older adults are more affected by the act of ending a motor action, whether it is a single movement or the first movement in a sequence, than younger adults and this movement termination effect has a stronger influence on performance than the extrinsic characteristics (movement amplitude) of the parameters of the second task. The data also shows that, for older adults, the movement termination effect on MT is reflected in greater real and relative time spent in the ballistic phase of the movement for reach-to-grasp movements performed in isolation compared to when they are embedded as the first part of a two-movement sequence. Finally, the findings indicate that the greater proportion of time spent in deceleration for the older adults in the two-movement task compared to the single-movement task has more to do with online feedback control processes for ending the first movement than online planning of the second-movement, since no differences were found in the reach to the first target as a function of the extrinsic properties of the second movement. One consideration for future research would be to further investigate this relationship in both younger and older adults by examining in more detail the extrinsic (movement amplitude) properties of the second movement.

REFERENCES

Abend, W., Bizzi, E., & Morasso, P. (1982). Human arm trajectory formation. *Brain, 105*, 331-348.

Abrams, R. A., Meyer, D. E., & Kornblum, S. (1990). Eye-hand coordination: Oculomotor control in rapid aimed limb movements. *Journal of Experimental Psychology: Human Perception and Performance, 16*(2), 248-267.

Adam, J. J., Nieuwenstein, J. H., Huys, R., Paas, F. G. W. C., Kingma, H., Willems, P., & Werry, M. (2000). Control of rapid aimed hand movements: The One-target advantage. *Journal of Experimental Psychology: Human Perception and Performance, 25*(1), 295-312.

Aggarwal, N. T., Wilson, R. S., Bech, T. L., Bienias, J. L., & Bennett, D. A. (2006). Motor dysfunction in mild cognitive impairment and the risk of incident Alzheimer disease. *Archives of Neurology, 63*(12), 1763-1769.

Ambruster, C. & Spijkers, W. (2006). Movement planning in prehension: Do intended actions influence the initial reach and grasp movement? *Motor Control*, *10*, 311-329.

Ansuini, C., Giosa, L., Turella, L., Altoe, G., & Castiello, U. (2008). An object for an action, the same object for other actions: Effects on hand shaping. *Experimental Brain Research, 185*, 111-119.

Bellgrove, M. A., Phillips, J. G., Bradshaw, J. L., Hall, K. A., Presnell, I., & Hecht, H. (1997). Response programming in dementia of the Alzheimer type: A kinematic analysis. *Neuropsychologia*, *35*, 229-240.

Bellgrove, M. A., Phillips, J. G., Bradshaw, J. L., & Gallucci, R. M. (1998). Response (re-) programming in aging: A kinematic analysis. *Journal of Gerontology: Medical Sciences, 53A*, M222-M227.

Bennett, K. M. B. & Castiello, U. (1994). Reach to grasp: Changes with age. *Journal of Gerontology: Psychological Sciences, 49*, P1-P7.

Bennett, K. M. B. & Castiello, U. (1995). Reorganization of prehension components following perturbation of object size. *Psychology and Aging*, ach to grasp: Changes with age. *Psychology and* Aging, *10*, 204-214.

Bernstein, N. A. (1967). The coordination and regulation of movements. London: Pergamon Press.

Berthier, N. E., Clifton, R. K., Gullapalli, V., McCall, D. D., & Robin, D. J. (1996). Visual information and object size in the control of reaching. *Journal of Motor Behavior, 28*, 187-197.

Buxbaum, L. J., Johnson-Frey, S. H., & Bartlett-Williams, M. (2005). Deficient internal models for planning hand-object interactions in apraxia. *Neuropsychologia*, *43*, 917-929.

Caselli, R. J., Stelmach, G. E., Caviness, J. N., Timmann, D., Royer, T., Boeve, B. F., & Parisi, J. E. (1999). A kinematic study of progressive apraxia with and without dementia. *Movement Disorders, 14*(2), 276-287.

Castiello, U., Bennett, K., & Chambers, H. (1998). Reach to grasp: The response to a stimulus perturbation of object position and size. *Experimental Brain Research, 120,* 31-40.

Chamberlin, C. J. & McGill, R. A. (1989). Preparation and control of rapid, multisegmented responses in simple and choice environments. *Research Quarterly for Exercise and Sport, 60*, 256-267.

Chaput, S. & Proteau, L. (1996). Aging and motor control. *The Journals of Gerontology: Psychological Sciences,51*, 346-355.

Chieffi, S. & Gentilucci, M. (1993). Coordination between the transport and the grasp components during prehension movements. *Experimental Brain Research, 94*, 471-477.

Christina, R. W. (1992). The 1991 C. H. McCloy research lecture: Unraveling the mystery of the response complexity effect in skilled movements. *Research Quarterly for Exercise and Sport, 63,* 218-230.

Chua, R. & Elliott, D. (1993). Visual regulation of manual aiming. *Human Movement Science*, *12*, 365-401.

Churchill, A., Hopkins, B., Ronnqvist, L., & Vogt, S. (2000). Vision of the hand and environmental context of human prehension. *Experimental Brain Research, 134,* 81-89.

Cooke, J. D., Brown, S. H., & Cunningham, D. A. (1989). Kinematics of arm movements in elderly humans. *Neurobiology of Aging, 10,*159-165.

Darling, W. G., Cooke, J. D., & Brown, S. H. (1989). Control of simple arm movements in elderly humans. *Neurobiology of Aging*, *10,* 141-157.

Elliott, D., Helsen, W. F. & Chua, R. (2001). A century later: Woodworth's (1899) two-component model of goal-directed aiming. *Psychological Bulletin*, *127*, 342-357.

Elliott, D., Hansen, S., Grierson, L. E. M., Lyons, J., Bennett, S. J. & Hayes, S. J. (2010). Goal-directed aiming: Two components but multiple processes. *Psychological Bulletin*, Advance online publication. Doi: 10.1037/a0020958.

Fernandez, L. & Bootsma, R. J. (2004). Effects of biomechanical and task constraints on the organization of movement in precision aiming. *Experimental Brain Research, 159*, 458-466.

Fischman, M. G. (1984). Programming time as a function of number of movement parts and changes in movement direction. *Journal of Motor Behavior, 16*, 405-423.

Fischman, M. G. & Reeve, T. G. (1992). Slower movement times may not necessarily imply on-line programming. *Journal of Human Movement Studies, 22,* 131-144.

Fitts, P. M. (1954). The information capacity of the human motor system in controlling the amplitude of movement. *Journal of Experimental Psychology*, *47*, 381-391.

Gentilucci, M., Negrotti, A., & Gangitano, M. (1997). Planning an action. *Experimental Brain Research, 115,* 116-128.

Gentilucci, M., Chieffi, S., Scarpa, M., & Castiello, U. (1992). Temporal coupling between transport and grasp components during prehension movements: Effects of visual perturbation. *Behavioural Brain Research, 47,* 71-82.

Goggin, N. L. & Meeuwsen, H. J. (1992). Age-related differences in the control of spatial aiming movements. *Research Quarterly for Exercise and Sport*, *63*, 366-372.

Goggin, N. L. & Stelmach, G. E. (1990). Age-related differences in cognitive-motor skills. In E. A. Lovelave (Ed.). *Aging and Cognition: Mental proesses, self awareness, and interventions* (pp.135-155). Amsterdam: North-Holland.

Goodale, M. A., Jakobson, L. S., & Keillor, J. M. (1994). Differences in the visual control of pantomimed and natural grasping movements. *Neuropsychologia*, *32*(10), 1159-1178.

Gordon, J., Ghilardi, M. F., & Ghez, C. (1994). Accuracy of planar reaching movements: I. Independence of direction and extent variability. *Experimental Brain Research*, *99*(1), 97-111.

Grierson, L. E. M. & Elliott, D. (2009). Goal-directed aiming and the relative contribution of two online control processes. *American Journal of Psychology*. *122*(3), 309-324.

Haggard, P. (1998). Planning of action sequences. *Acta Psychologica*, *99*, 201-215.

Haggard, P. & Wing, A. M. (1995). Coordinated responses following mechanical perturbation of the arm during prehension. *Experimental Brain Research, 102,* 483-494.

Haggard, P. & Wing, A. M. (1998). Coordination of hand aperture with the spatial path of hand transport. *Experimental Brain Research, 118,* 286-292.

Haaland, K. Y., Harrington, D. L., & Grice, J. W. (1993). Effects of aging on planning and implementing arm movements. *Psychology and Aging*. *8*(4), 617-632.

Heath, M., Roy, E. A., & Weir, P. L. (1999). Visual-motor integration of unexpected sensory events in young and older participants: A kinematic analysis. *Developmental Neuropsychology*, *16*(2), 197-211.

Heilman, K. M. & Rothi, L. J. (1993). Apraxia. (3rd ed.) *Clinical Neuropsychology* (pp. 141-160), New York: University Press.

Helsen, W. F., Adam, J. J., Elliott, D., & Buekers, M. J. (2001). The one-target advantage: A test of the movement integration hypothesis. *Human Movement Science, 20,* 643-674.

Henry, F. M., & Rogers, D. E. (1960). Increased response latency for complicated movements and a ‘‘memory drum’’ theory of neuromotor reaction. *Research Quarterly, 31***,** 448-458.

Hoff, B. & Arbib, M. A. (1993). Models of trajectory formation and temporal interaction of reach and grasp. *Journal of Motor Behavior, 25,* 175-192.

Hogan, N. (1985). The mechanics of multi-joint posture and movement control. *Biological Cybernetics*, 52(*5*), 315-331.

Hughes, C. P., Berg, L., Danziger, W. L., Coben, L. A., & Martin, R. L. (1982). A new clinical scale for the staging of dementia. *British Journal of Psychiatry*, *140,* 566-572.

Jakobson, L. S. & Goodale, M. A. (1991). Factors affecting higher-order movement planning: A kinematic analysis of human prehension. *Experimental Brain Research, 86,* 199-208.

Jeannerod, M. (1981). Intersegmental coordination during reaching at natural visual objects. In J. Long & A. Baddeley, *Attention and Performance IX: Information Processing* (pp. 153-169). Hillsdale, NJ: Lawrence Erlbaum Associates.

Jeannerod, M. (1984). The timing of a natural prehension movement. *Journal of Motor Behavior*, 26, 235-254.

Jeannerod, M. (1988). The neural and behavioural organization of goal-directed movements. Clarendon Press, Oxford England.

Jeannerod, M. (1999). Visuomotor channels: Their integration in goal-directed prehension. *Human Movement Science, 18,* 201-218,

Jones, L. A. & Lederman, S. J. (2006). Human Hand Function. New York: Oxford University Press.

Keele, S. W. (1968). Movement control in skilled performance. *Psychological Bulletin*, *70*, 387-403.

Keele, S. W. & Posner, M. I. (1968). Processing of visual feedback in rapid movements. *Journal cf Experimental Psychology, 77*, 155-158.

Ketcham, C. J., Seidler, R. D., Van Gemmert, A. W., & Stelmach, G. E. (2002). Age-related kinematic differences as influenced by task difficulty, target size, and movement amplitude. *Journal of Gerontology: Psychological Sciences, 57,* 54-64.

Klapp, S. T. (2010). Comments on the classic Henry and Rogers (1960) paper on ts 50th anniversary: resolving the issue of simple versus choice reaction time. *Research Quarterly for Exercise and Sport, 81*(1), 108-112.

Khan, M. A., Franks, I. M., Elliott, D, Lawrence, G. P., Chua, R., Bernier, P-M, Hansen, S., Weeks, D. J. (2006). Inferring online and offline processing of visual feedback in target-directed movements from kinematic data. *Neuroscience and Biobehavioral Reviews 30,* 1106-1121.

Kluger, A., Gianutsos, J. G., Golomb, J., Ferris, S. H., & Reisberg, B. (1997). Motor/psychomotor dysfunction in normal aging, mild cognitive decline, and early Alzheimer’s disease: Diagnostic and differential diagnostic features. *International Psychogeriatrics*, 9 (S1), 307-316.

Langolf, G. D., Chaffin, D. B., & Foulke, J. A. (1976). An investigation of Fitts’ law using a wide range of movement amplitudes. *Journal of Motor Behavior*, 8, 113-128.

Lavrysen, A., Helsen, W. F., Elliott, D., & Adam, J. J. (2002). The one-target advantage: Advanced preparation or online processing?. *Motor Control, 6,* 230-245.

Lezak, M. D. (2004). Neuropsychological assessment. (4th ed). New York: Oxford University Press.

Lin, C., Winstein, C. J., Sullivan, K. J., & Wu, A. D. (2005). Effects of random and blocked order practice on motor learning in individuals with Parkinson's disease. *Journal of Neurologic Physical Therapy, 29*(4), 200-201.

Lyons, J., Elliott, D., Swanson, L. R., & Chua, R. (1996). The use of vision in manual aiming by younger and older adults, *Journal of Aging Physical Activity, 4*, 165-178.

Mason, C. R., Gomez, J. E., & Ebner, T. J. (2001). Hand synergies during reach-to-grasp. *Journal of Neurophysiology, 86*, 2896-2910.

Marteniuk, R. G., Leavitt, J. L., MacKenzie, C. L., & Athenes, S. (1990). Functional relationships between grasp and transport components in a prehension task. *Human Movement Science, 9,* 149-176.

Marteniuk, R. G., MacKenzie, C. L., Jeannerod, M., Athenes, S., & Dugas, C. (1987). Constraints on human arm movement trajectories. *Canadian Journal of Psychology, 41*(3), 365-378.

Meulenbroek, R. G., Rosenbaum, D. A., & Vaughan, J. (2001), Planning reaching and grasping movements: Simulating reduced movement capabilities in spastic hemiparesis. *Motor Control, 5,* 136-150.

Meyer, D. E., Abrams, R. A., Kornblum, S., Wright, C. E., & Smith, J. E. K. (1988). Optimality in human motor performance: Ideal control of rapid aimed movements. *Psychological Review*, 95, 340-370.

Meyer, D. E., Smith, J. E. K., Kornblum, S., Abrams, R. A. & Wright, C. E. (1990). Speed-accuracy tradeoffs in aimed movements: Toward a theory of rapid voluntary action. In M. Jeannerod, *Attention and Performance XIII: Motor Representation and Control* (pp. 173-226). Hillside, NJ: Lawrence Erlbaum Associates.

Mirabella, G., Pani, P., & Ferraina, S. (2008). Context influences on the preparation and execution of reaching movements. *Cognitive Neuropsychology, 25*(7-8), 996-1010.

Morasso, P. (1981). Spatial control of movements. *Experimental Brain Research, 42,* 223-227.

Morgan, M., Phillips, J. G., Bradshaw, J. L., & Mittingly, J. B. (1994). Age-related motor slowness: Simply strategic? *Journals of Gerontology, 49*(3), M133-M139.

Murrell, K., F., H. & Entwistle, D. G. (1960). Age differences in movement pattern. *Nature, 185,* 948-949.

Nagasaki, H. (1989). Asymmetric velocity and acceleration profiles of human arm movements. *Experimental Brain Research, 74,* 319-26.

Novak, K. E., Miller, L. E., & Houk, J. C. (2002). The use of overlapping submovements in the control of rapid hand movements. *Experimental Brain Research, 144,* 351-364.

Paulignan, Y., Frak, V. G., Toni, I., & Jeannerod, M. (1997). Influence of object position and size on human prehension movements. *Experimental Brain Research, 114,* 226-234.

Paulignan, Y., Jeannerod, M., MacKenzie, C. L., & Marteniuk, R. G. (1991). Selective perturbation of visual input during prehension movements: I. The effects of changing object size. *Experimental Brain Research, 87,* 407-420.

Paulignan, Y., MacKenzie, C. L., Marteniuk, R. G., & Jeannerod, M. (1991). Selective perturbation of visual input during prehension movements: I. The effects of changing object position. *Experimental Brain Research, 83,* 502-512.

Pennathur, A., Contreras, L. R., Arcuate, K., & Dowling, W. (2003). *International Journal of Industrial Ergonomics, 32*, 419-431.

Phillips, S. K., Bruce, S. H., Newton, D., & Woledge, R. C. (1992). The weakness of old ages not due to failure of muscle activation. *Journal of Gerontology: Medical Sciences, 47,* M45-M49.

Plamondon, R. & Alimi, A. M. (1997). Speed/accuracy trade-offs in target-directed movements. *Behavioral and Brain Sciences. 20,* 279-349.

Pratt, J., Chasteen, A.L., & Abrams, R. A. (1994). Rapid aimed movements: Age differences and practice effects in component submovements. *Psychology and Aging, 9*(2), 325- 334.

Rand, M. K. & Stelmach, G. E. (2005). Effect of orienting the finger opposition space on the control of reach-to-grasp movements. *Journal of Motor Behaviour, 37,* 65-78.

Roy, E. A., Rohr, L. E., & Weir, P. L. (2004). Effect of movement termination in single- and dual-phase pointing tasks. *Motor Control, 8,* 121-138.

Roy, E.A., Weir, P.L., Desjardins-Denault, S., & Winchester, T. (1999). Pointing versus grasping in young and older adults. *Developmental Neuropsychology*, *16,* 19-27.

Roy, E. A., Winchester, T., Weir, P., & Black, S. (1993). Age differences in the control of visually aimed movements. *Journal of Human Movement Studies, 24,* 71-81.

Salthouse, T. A. (1985). Speed of behavior and its implications for cognition. In J. E. Bairren & K. W. Schaie (Eds.). *Handbook of the Psychology of Aging* (pp. 400-426). New York: Van Nostrand Reinhold.

Santello, M. & Soechting, J. F. (1998). Gradual molding of the hand to object contours. *Journal of Neurophysiology*, *79,* 1307-1320.

Sarlegna, F. (2006). Impairment of online control of reaching movements with aging: A double-step study. *Neuroscience Letters, 403*(3), 309-314.

Schettino, L. F., Adamovich, S. V., & Poizner, H. (2003). Effects of object shape and visual feedback on hand configuration during grasping. *Experimental Brain Research, 151,* 158-166.

Schmidt, R. A., Zelaznik, H. N., Hawkins, B., Frank, J. S., & Quinn, J. T. Jr., (1979). Motor output variability: A theory for the accuracy of rapid motor acts. *Psychological Review, 86*, 415-451.

Seidler-Dobrin, R. D. & Stelmach, G. E. (1998). Persistence in visual feedback control. *Experimental Brain Research, 119,* 467-474.

Stelmach, G. E., Goggin, N. L., & Amrhein, P. C. (1988). Aging and reprogramming: The restructuring of planned movements. *Psychology and Aging*, *3*, 151-157.

Teeken, J. C., Adam, J. J., Paas, F. G. W. C., van Boxtel, M. P. J., Houx, P. J., & Jolles, J. (1996). Effects of age and gender on discrete and reciprocal aiming movements.

Timmann, D., Stelmach, G. E., & Bloedel, J. R. (1996). Grasping component alterations and limb transport. *Experimental Brain Research*, *108,* 486-492.

Thompson, S. G., McConnel, D.S., Slocum, J. S., & Bohan, M. (2007). Kinematic analysis of multiple constraints on a pointing task. *Human Movement Science, 26,* 16.

Tretriluxana, J., Gordon, J., & Winstein, C. J. (2008). Manual asymmetries in grasp pre-shaping and transport-grasp coordination. *Experimental Brain Research, 188,* 305-315.

Vindras, P. & Vivianni, P. (2005). Planning short pointing sequences. *Experimental Brain Research, 160,* 141-153.

Walker, N., Philbin, D. A., & Fisk, A. D. (1997). Age-related differences in movement control: Adjusting submovement structure to optimize performance. *Journal of Gerontology: Psychological Science, 52B,* 40-52.

Weir, P.L., MacDonald, J. R., Mallat, B. J., Leavitt, J. L., & Roy, E. A. (1998). Age-related differences in prehension: The Influence of Task Goals. *Journal of Motor Behaviour, 30*(1), 79-89.

Wing, A. M., Turton, A., & Fraser, C. (1986). Grasp size and accuracy of approach in reaching. *Journal of Motor Behavior, 18,* 245-260.

Wolpert, D. M., Ghahramani, Z., & Flanagan, J. (2001). Perspectives and problems in motor learning. *Trends in Cognitive Sciences, 5*(11), 487-494.

Woodworth, R. S. (1899). The accuracy of voluntary movement. *Psychological Review, 3,* 1-119.

Yan, J. H., Thomas, J. R., Stelmach, G. E., & Thomas, K. T. (2000). Developmental features of rapid aiming arm movements across the lifespan. *Journal of Motor Behaviour, 32,* 121-140.

APPENDIX A: Participants' Data Comprised in Analysis

Table I: Participants' Data Comprised in Analysis

Subject	Group	Gender	Participants' Data Comprised In Analysis
1.	YA	M	Excluded for all data.
2.	OA	F	Excluded for all data.
3.	YA	M	Excluded for all data.
4.	YA	M	Excluded for all data.
5.	OA	F	Excluded for all data.
6.	YA	M	Excluded for manipulation component only.
7.	YA	F	
8.	OA	F	
9.	YA	F	Excluded for all data.
10.	YA	M	Excluded for manipulation component only.
11.	YA	F	
12.	YA	M	Excluded for all data.
13.	YA	F	
14.	YA	F	
15.	YA	F	
16.	YA	F	
17.	YA	M	Excluded for all data.
18.	YA	M	
19.	OA	F	
20.	OA	F	
21.	OA	F	
22.	OA	F	
23.	YA	F	
24.	YA	F	
25.	OA	M	
26.	OA	F	
27.	OA	F	Excluded for all data.
28.	OA	M	
29.	OA	M	
30.	YA	M	
31.	YA	F	
32.	OA	F	Excluded for manipulation component only.
33.	YA	F	
34.	OA	F	

APPENDIX B: Test Form for the Administration of the 3MS Test

3MS Examination Date ____________________ Examiner ______________________

Non-AD or AD ______________________ Age ______ Edu ______ M F Score _____/100

____/5 **DATE AND PLACE OF BIRTH**
Date: year _____ month ______ day _____
Place: town _______________ province _____

____/3 **REGISTRATION** (No. of presentations ____)
SHIRT, BROWN, HONESTY
(or: SHOES, BLACK, MODESTY)
(or: SOCKS, BLUE, CHARITY)

____/7 **MENTAL REVERSAL**

5 to 1	
Accurate	2
1 or 2 errors/misses	0 1
DLROW	0 1 2 3 4 5

____/9 **FIRST RECALL**

Spontaneous recall	3
After "Something to wear"	2
"SHOES, SHIRT, SOCKS"	0 1
Spontaneous recall	3
After "A colour"	2
"BLUE, BLACK, BROWN"	0 1
Spontaneous recall	3
After "A good personal quality"	2
"HONESTY, CHARITY, MODESTY"	0 1

____/15 **TEMPORAL ORIENTATION**

Year	
Accurate	8
Missed by 1 year	4
Missed by 2-5 years	0 2
Season	
Accurate or within one month	0 1
Month	
Accurate or within 5 days	2
Missed by 1 month	0 1
Day of month	
Accurate	3
Missed by 1 or 2 days	2
Missed 3-5 days	0 1
Day of week	
Accurate	0 1

____/5 **SPATIAL ORIENTATION**

Province	0 2
County	0 1
City (town)	0 1
Hospital/Office Building/Home?	0 1

____/5 **NAMING** (Pencil: ____, Watch: ____)
Forehead ____, Chin ____, Shoulder ____,
Elbow ____, Knuckle ____.

____/10 **FOUR-LEGGED ANIMALS**
(30 seconds) 1 point each

____/6 **SIMILARITIES**

Arm-Leg	
Body Part; Limb; etc.	2
Less correct answer	0 1
Laughing-Crying	
Feeling; emotion	2
Less correct answer	0 1
Eating-Sleeping	
Essential for life	2
Other correct answer	0 1

____/5 **REPETITION**

"I WOULD LIKE TO GO OUT"	2
1 or 2 missed/wrong words	0 1
"NO IFS ___ ANDS ___ OR BUTS ___"	

____/3 **READ AND OBEY** "CLOSE YOUR EYES"

Obeys without prompting	3
Obeys after prompting	2
Reads aloud only	0 1

____/5 **WRITING** (1 minute)
(I) WOULD LIKE TO GO OUT.

____/10 **COPYING TWO PENTAGONS** (1 minute)

	Each Pentagon	
5 approximately equal sides	4	4
5 unequal (> 2:1) sides	3	3
Other enclosed figure	2	2
2 or more lines	0 1	0 1
	Intersection	
4 corners		2
Not 4-corner enclosure		0 1

____/3 **THREE-STAGE COMMAND**
___ TAKE THIS PAPER WITH YOUR LEFT/RIGHT HAND
___ FOLD IT IN HALF, AND
___ HAND IT BACK TO ME

____/9 **SECOND RECALL**

(Something to wear)	0 1 2 3
(Colour)	0 1 2 3
(Good personal quality)	0 1 2 3

APPENDIX C: Test Form for the Administration of Grooved Peg Board Test

The Grooved Peg Board Test is used to assess fine motor skills. The method of the placement of the pegs into the grooves is considered as well as the time it takes to completely fill the board.

Protocol:

The participant will be sitting directly in front of the board with the receptacle end closest to them. It is best to start with the person's dominant hand. When using the right hand, the order of peg placement from the receptacle to the board should be from left to right beginning with the top row, filling the board from the left each time and ending with the bottom row. When the left hand is used, it is important to proceed from the right to the left from top to bottom and filling from the right each time.

"**I want to see how quickly you can pick up one peg at a time and place it in the groove until the board is filled. You will start at the top of the board each time and fill from right to left when you are using your left hand and from left to right when you are using your right hand. I would like you to do this as quickly as you can without sacrificing accuracy for speed. I will be timing your performance. Do you understand? Are you ready to begin?"**

Once the procedure is explained to the participant, the stopwatch is started when they have lifted the first peg from the receptacle. The stopwatch is stopped when the participant has inserted a peg in the last remaining hole. The time shall be recorded on the record sheet in seconds.

The number of errors a participant makes on each hand will also be recorded for each trial and then averaged. An error occurs when the participant drops a peg when moving it from the receptacle toward a hole or when placing a peg in a hole.

The time units will be in seconds to properly compare it to the norms.

"Good. Now I would like you to remove the pegs from the board one by one and place them in the receptacle. Please use the same hand you just used to place the pegs in the grooves. I will be timing you again so please do this as quickly as you can without sacrificing accuracy for speed. You may begin when you are ready."

The participant will then be timed on removing the pegs from the board. The pegs should be removed in the reverse order they were placed in, according to what hand is used.

The time to remove the pegs, in seconds, as well as the number of errors made, shall be recorded on the record sheet. This procedure will be used twice for each hand, alternating between the dominant and non-dominant hands.

Grooved Peg Board Record Form

Trial	Left Hand (sec)		Right Hand (sec)	
	Place Time	Remove Time	Place Time	Remove Time
1				
2				
Average				

Figure Reference: http://www.allegromedical.com/diagnostic-products-c521/grooved-pegboard-