Effects of Aging in Pointing to Visible and Remembered Targets

By

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Abstract:

Most studies that have compared pointing to visible versus remembered targets have involved situations when both the limb and target are present (closed loop-target present), or when both the limb and target are occluded (open loop-target absent). This comparison confounds vision of the target with vision of the hand. In order to dissociate these two sources of visual information in pointing, it is necessary to examine conditions in which only one of these sources of information is occluded, that is, when only vision of the hand (open loop-target present) or vision of the target (closed loop-target absent) is occluded. Some studies have compared subsets of these four conditions to examine, for example, the role of vision of the hand in pointing where the target is present throughout the movement but vision of the hand is occluded (open loop) or not (closed loop). Very few studies to date have compared all of these conditions to examine the relative contribution of these two sources of information in pointing. The purpose of this study was to make these comparisons and to examine whether aging had an effect on how these sources of information were used in pointing. To address this, we asked young (N=10, mean age = 21.8 years, 6 females, 4 males) and older (N=9, mean age = 73.8 years, 4 females, 5 males) right-handed adults to point to each of three targets: one situated at the midline and one each at 45 degrees to the left (contralateral) and right (ipsilateral) of the midline, while manipulating whether participants had vision of their pointing limb, the target, or both. In target-absent trials, the time between target occlusion and movement initiation was also manipulated (movement initiation immediately after occlusion or following a delay of 2 seconds) to examine the time course of the representation of target information in memory. All conditions were randomized between each participant. Results showed vision of the limb significantly affects the movement in a positive manner, such that endpoint error and variability were less than conditions in which the limb was not available during movement. This was true for both target present and absent actions, suggesting limb vision provides crucial visual and proprioceptive information to result in a much more precise and consistent movement to targets. This information may also be more important to

the participant than target presence, in terms of accuracy and variability, as there tended to be little differences between target present and target absence trials. Where target presence made a difference was during the decelerative phase of movement time (after peak velocity has been reached), where relatively more time was allotted in this period when the target was visible throughout the movement. Because this time is indicative of online feedback processing, this suggests that vision of the target was contributing some type of information to the movement. Interestingly, there was no significant main effect of age group in this study. However, age did play a role in the way participants moved to the targets. In the directional (x) axis, young adults were more likely to aim to targets that were biased further from their body, whereas elderly adult participants displayed the opposite bias: their accuracy data show they tend to aim closer to their body.

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1. Introduction:

Aging is a combination of inevitable processes that involve every aspect of the human body. Gradually, most cognitive and motor functions will exhibit some decrement over time, albeit at differing rates. One approach to investigating the effects of aging is to compare young and elderly adults in performing movements that require precision and mental representation of a goal such as a target location in space (Roy et al., 1999). Our particular interest was in a task where participants must reach to targets under four conditions: when a target was present or absent (often referred to as memory-dependent reaching) and when vision of the hand was present (often termed "closed loop") or absent (often termed "open loop") during the course of the movement to the target. The overall purpose of this study, then, was to determine the effects of aging on the combination of these four conditions: 1) closed loop reaching with the target present, 2) open loop reaching with the target present, 3) open loop reaching with the target absent, and 4) closed loop reaching with the target absent. Most of the work on aging has focused on the first and third conditions. All of these four conditions have been compared in young adults (Heath, 2005) but no one to date has examined the effects of aging comparing these conditions. A study (Skakum, Roy and Lau, 2007) we recently completed examining the effects of aging in conditions one and four was the impetus for the present investigation.

To address these questions, this thesis will begin with an analysis of previous work on pointing under the four conditions alluded to above. We will first look at the conditions in which the target is present throughout the movement, comparing what is known about how these movements are controlled when vision of the hand is present or absent. We will then review literature on memory-dependent pointing in which vision of the target is removed at or near the initiation of the pointing movement (immediate memory condition) or following a delay prior to movement initiation (delayed memory condition). We will review the time course of memory for target location as reflected in changes in accuracy as a function delay, and examine how this memory function is affected by the presence or absence of vision of the limb during the course of the pointing movement. We will then look at how aging influences movement control, particularly in the two target-present conditions, and how aging affects memory for target location when reaching to remembered targets. Lastly, we end with a description of the study we conducted that was designed to examine how aging affects movement control and memory for target location.

1.1 Target Present Condition

1.1.1 Closed loop-Target Present Condition

To clarify, this particular condition consists of pointing tasks where vision of the limb and target are in full view throughout the course of the pointing actions. This condition has been extensively studied in most pointing and reaching literature. Before the effects of vision and memory are considered, the fundamental factors that underlie the control in a pointing/reaching action in full vision must be identified. These types of precise movements utilize two different types of information, as established by multiple studies. By employing both visual information (namely the information about the target and the seen limb) and "somatosensory," or proprioceptive, input (e.g. Gregoriou & Savaki, 2003; Sarlegna et al., 2003; Admiraal et al., 2003; Blangero et al., 2005), the movement is effectively produced. The performer, at different points during the movement, can extract both types of information, and with different frames of reference (Admiraal et al., 2003; Lateiner & Sainburg, 2003; Sober & Sabes, 2003). It has also been observed that before movement onset, pointing is impacted by visual information about the pointing limb (Blangero et al., 2005). Both young and old participants usually plan movements based on visual information regarding the initial place of their acting limb and the target position, but are able to redesign their initial movement plan to adjust for the actual position of their limb to accurately reach to the target. Proprioception is used here, then, to utilize non-visual information to readjust the motor plan (Sarlegna & Sainburg, 2007). Proprioception can also assist in movement control while taking into account an alteration in the environment (Milner et al., 1999; Goodale, 1986). As demonstrated by numerous studies, vision tends to supply information chiefly to planning the direction of the movement. Proprioception, however, is more likely to lend information to plan for the distance the limb must move to reach the target. Because of the plethora of information that vision of the goal position can supply, full vision movements are more accurate than target absent ones solely because the continuous stream of target position information in concert with information about hand position helps to guide the movement throughout the entire task—a form of control known as a feedback mode of control (Pelisson et al., 1986). Feedback modes of control during a reaching and pointing task may use the proprioceptive system to assist in optimal and efficient movement. Proprioception supplies additional details to the motor system pertaining to the constantly changing movement properties of the limb (Khan et al., 2003). However, it should be noted that, conversely, it has been proposed that whenever the target and vision of the limb is present throughout the entire movement, the visual information processing takes precedence over processing of all other sensory information. That is, other sensory information, such as proprioception, may not prove to be useful to the task at hand, and processing may indeed even be attenuated (Posner, Nissen & Klein, 1976).

Many studies examining limb visible movements with the target available have suggested that these types of movements do not require "central planning processes" (processes that preplan the movement accurately) that tend to occur before movement onset in target absent tasks (e.g. Heath, Westwood & Binsted, 2004; Schmidt & Lee, 2005; Blouin et al., 1993). These studies have shown that the percentage of time after peak velocity (deceleration time) is longer in movements with limb and target vision than in tasks where the target and the environment are occluded. This decelerative phase of movement is usually utilized to process visual information from the environment and proprioceptive information obtained from the movement to allow for a more accurate movement to the target.

In typical "full vision" conditions, movement times tend to be longer and peak velocities tend to be lower than other conditions, simply because of the presence of both the pointing limb and target giving the performer much more visual information to utilize throughout the trial on top of the existing proprioceptive information. This finding has been repeated in a multitude of studies. As well, more time is usually spent in the deceleration portion of movement (that is, there tends to be longer time after peak velocity) in this condition. This is due to the processing of visual information to adjust the trajectory of the pointing limb after peak velocity (Carson et al., 1993; Chua & Elliot, 1993; see Khan et al., 2003). Factors such as distance to a target (target amplitude) and size of the target affect time spent in deceleration, as well as other kinematic measures. According to Fitts' Law (1954), the time it takes to move to a target depends on the distance to the target and the size of the target. Both influence the difficulty of the action (Fitts, 1954). Therefore, it is reasonable that movements with a larger amplitude (moving to targets further away) will result in longer movement times, reach higher peak velocities and require longer time in the decelerative phase of movement. The same trends are expected regarding target sizes. Larger targets are generally easier to "aim" towards, and thus require less precision in the form of online control. This causes the decelerative phase of movements to be less with larger target sizes when compared to smaller target sizes. Peak velocity also increases with target size (Roy et al., 1999; Messier & Kaslaska, 1999).

As well, during the beginning of these movements with limb and target visible, the first submovement has been seen to consistently underestimate the distance to the target. This undershooting is to allow corrections to be made to the movements in the same directional path to the target (Heath, Westwood & Binsted, 2004).

Initiation of a pointing movement with limb and target vision available necessitates a two-stage process, as suggested by multiple studies (e.g. Sober & Sabes, 2003; Sarlegna & Sainberg, 2007).

Firstly, information about the target must be acquired and incorporated with the starting position of the pointing limb to generate a plan to reach the goal target. Once this is done, the central nervous system produces transformations to allow this plan to be implemented. Specifically, it transforms the appropriate movement vector into a “joint-based motor command” (Sober & Sabes, 2003). This propagates a motor program to allow the task to physically occur because of the brain choosing a unique blend of sensory inputs based on what the body expects as a movement output (Sober & Sabes, 2003; Sarlegna & Sainburg, 2007; Sarlegna et al., 2003).

An important factor here is target position. Ipsilateral target positions (targets on the same side as the pointing limb) seem to exhibit advantages in terms of movement time and peak velocity, and proportionate time after peak velocity when compared to targets placed at midline or contralateral to the pointing limb. Movement times are generally shorter, and peak velocity higher (Kazennikov et al., 1999; Cisek, Crammond & Kalaska, 2003).

Target position differences are explained broadly by two theories. Firstly, target information in ipsilateral target tasks are processed within the same brain hemisphere controlling the pointing limb. Specifically, the visual input of the target and the motor output (the programming of the muscles to reach) are all executed in the hemisphere contralateral to the target and pointing limb. With contralateral targets, the visual input and motor output are instead processed in different hemispheres. The information must be passed between the two hemispheres through a callosal pathway that may be specific for aiming (Velay & Benoit-Dubrocard, 1999; Hodges et al., 1997). Being that processing within the same hemisphere has been thought to be more efficient than cross-hemisphere processing, this may account for the advantages seen in ipsilateral pointing tasks.

However, many researchers believe that ipsilateral advantages cannot only be explained by this “within-hemisphere” explanation. A second theory has examined biomechanical properties, and how these properties provide distinct advantages during movements towards ipsilateral target positions. Ipsilateral movements appear to exert less inertial force on the arm and hand (Gordon et al., 1994). Specifically, Gordon and colleagues have suggested that if the "long axis" of the upper arm is perpendicular to the path of the hand (such as in contralateral movements), longer movement times and lower peak velocities appear to arise, when compared to movements that are more parallel to the upper arm's long axis, which is what transpires in ipsilateral tasks (Gordan et al., 1994).

Physically, ipsilateral movements require less muscle activation proximally when compared with contralateral movements, and this fact may benefit performance. As well, typical ipsilateral target movements require less rotation about the shoulder in contrast to the distance- comparable contralaterally placed target, Increased shoulder rotation may have a direct relationship on movement time, such that movement time is increased as shoulder rotation is increased. (Jeannerod, 1988). Carey et al. (1996) have also corroborated this theory of biomechanical differences between reaching to targets at different positions. Their participants were asked to make movements to point directly to a target, or what they thought would be the mirror image of the intended target (termed "anti-pointing"), in order to differentiate neuronal and biomechanical factors. Specifically, participants saw a fixation light, and then a target of a particular angle from the fixation light. They were either asked to make a movement as quickly and as accurately as possible to the target (pointing), or to make a movement opposite of the fixation light with the same angle as the target seen (antipointing). In pointing performance, the results were what were expected: ipsilateral target movements were advantageous in terms of accuracy and kinematic measures. However, during anti-pointing movements, this target position advantage was not seen—and in fact, the opposite was seen. That is, in antipointing movements, contralateral targets were seen to exhibit the target position advantages seen in the ipsilateral movement trials of the pointing condition. This can be described as an innate position advantage for ipsilateral movements, despite target position. Their findings suggest that the demands of intra and interhemispheric processing cannot fully explain the differences seen when pointing or reaching to different target locations. Instead, they propose that "complex biomechanical demands" are at the heart of ipsilateral positional advantages (Carey et al., 1996).

Furthermore, Carey and Otto-de Haart (2001) have recently discovered if target positions demanded an adductive movement (movement made toward the body), the action was more efficiently carried out, even if the target was located at a contralateral position. This finding is currently undergoing further exploration, since the central nervous system's control of both proximal and distal muscles may be affecting these results (Carey & Otto-de Haart, 2001). Because of the conflicting nature of these findings, further research is warranted to clearly understand the advantages of ipsilateral target positions over the others in closed loop-target present conditions. Furthermore, it will be advantageous to see if these effects of target position carry over to target absent situations with both closed and open loop feedback.

1.1.2 Open loop-Target Present Condition

These particular pointing tasks involve movements in which the target is continuously present but vision of the limb is occluded. Such open loop movements have been extensively studied, however, most of this literature has focused on obliterating both vision of the limb and vision of the target, which confounds loss of visual information about the hand with loss of visual information about the target. For example, Elliott and Madalena (1987) noticed that when comparing target absent and target present conditions with no limb vision available, there was much greater endpoint accuracy in the latter condition suggesting that, despite no information about limb position, pointing accuracy was much greater when the performer could see the target. These findings suggest in order to clearly understand the role of vision in the control of movement one must isolate the effects of vision of the hand from the effects of vision of the target. This dissociation will be examined further below.

Simply possessing vision of the pointing limb during a movement evokes noticeable differences in both the underlying controlling mechanisms and endpoint accuracy and variability of a movement to a target. Having both the target and pointing limb visually available allows the participant to extract crucial pieces of information that have a significant effect on the variable and constant errors of pointing (Admiraal et al., 2003; Sarlegna et al, 2003; Carlton, 1981; Heath, 2005). Subjects tend to obtain higher accuracy in limb present trials, when compared to limb absent trials. The underlying mechanisms controlling the movement differ drastically with or without visual feedback of the limb, which is evident in kinematic analysis (Sarlegna et al., 2003; Carlton, 1981). In open loop movements, movement times may take less time than their closed loop counterparts. The lack of limb vision appears to generate a more feed forward mode of control involving a larger "initial force specification" which, although speeding up the movement, also leads to more endpoint error and endpoint variability (Heath, 2005). However, it has been shown that subjects can correct their arm position during the movement trajectory without having vision of their pointing limb (OL) while having vision of the target. For instance, Prablanc and colleagues (1986) showed endpoint accuracy increased almost three fold in their participants when performing target present trials, when compared to target absent trials when limb vision was occluded (Prablanc et al., 1986). As well, some studies have documented that when there is no feedback of the hand to utilize, having vision of the target can help in pointing performance by improving endpoint accuracy. This indicates that the CNS is able to adjust and change movements during a pointing task without limb vision input.

Open loop reaches tend to rely heavily on proprioceptive feedback (Admiraal et al., 2003, Prablanc et al., 1986). Jeannerod and colleagues have suggested an explanation. They propose that visual information (for example, of the target), may act as a substitute for the lack of "position sense" that open loop reaching brings. This can be explained by a theory proposed by Jeannerod and Prablanc (1983), which they term the "visual-proprioception loop." Vision may be able to calibrate "position sense" so that the proprioceptive "map" is matched to what is actually seen—the visual "map" (Jeannerod & Prablanc, 1983; Jeannerod, 1988).

Further investigation is warranted to confirm these results.

Work by Khan and colleagues suggest that visual feedback of the target can invoke both offline and online processing when performing tasks in which only the target is present. Khan et al. (2003) examined the spatial variability of the limb trajectory at peak acceleration, peak velocity, peak deceleration, and at the end of movement. They asked participants to perform aiming movements with vision of the limb and target and movements with only the target visible under four set movement times (225, 300, 375 and 450 ms). The researchers noticed that as expected, the trials with vision of the limb produced less limb variability than the ones that did not. However, for the two shorter movement times (225 and 300 ms movements), there was no difference in variability from peak deceleration to the end of movement for the movements without limb vision, and that the ratio in spatial variability in this particular condition did not differ in these movement times as well, when compared to movements made with limb vision. This suggests that offline processing was utilized for faster movements, since there seemed to be little effect of visual feedback of the limb in the variability profiles of these movement times between target present movements with and without limb vision. The researchers suggest that visual feedback in faster movements impacts vision such that there are differences in variability between the different limb feedback conditions, but this difference in information is processed after the movement performance to enhance subsequent trials.

1.2 Target Absent Conditions

1.2.1 Open Loop-Target Absent Condition

As important as "full vision" movements in everyday life may be, situations where pointing to a remembered target, and not having vision of your pointing limb, also arise frequently, and thus, are studied very often in memory dependent pointing and reaching literature. These tasks involve pointing to targets with no visual information throughout the movement. That is, both vision of the limb and target are unavailable to the participant while moving. In order for this to be possible, it has been proposed that a stored visual representation of the target must be accessible in memory. This theory has been corroborated by multiple studies. One of the first studies to provide support for a stored visual representation was reported by Elliott and Madalena (1987). Here, the researchers asked participants to move to either one of two potential targets. These movements were performed in either a "full vision" condition or a "no vision" condition where the delay period between target occlusion and movement onset varied from 0, 2, 5 or 10 seconds. Elliott and Madalena found that participants displayed a significant error increase only after a delay of two seconds. The researchers were able to replicate their findings using a between-subjects research design to counter the argument that the results obtained in the first within-subject experiment were due to "asymmetrical transfer effects." Based on these findings Elliott and Madalena argued for a very brief (~2 sec) visual representation of the target (Elliott & Madalena, 1987).

However, other work has suggested that this brief visual representation may degrade much quicker than the proposed two seconds. Westwood, Heath and Roy (2001) have recently demonstrated this. They asked participants to reach to single targets at amplitudes of 20, 25, 30, 35 and 40 centimetres along the midline under 6 different visual conditions. There were six conditions: a target present condition with limb vision available and 5 target absent conditions in which vision of both target and limb was extinguished at movement onset (which they termed open loop), or following 4 delays, where participants had to wait 500, 1000, 1500 or 2000 ms after target occlusion before initiating their movement. Westwood, and colleagues found that radial error at the movement endpoint increased significantly more in their "open loop" condition, and even more so in the delay conditions (which were not significantly different from one another) when compared to trials with both target and limb vision available. The researchers have suggested that there is a swift transition from online control of movement with visual information available, to an offline control based on a stored representation of the target. This transition occurred quickly (at least less than 500 ms) after the occlusion of the target (Westwood, Heath & Roy, 2001).

The same researchers, in 2003, devised another experiment to further their previous results. Here, they asked participants to reach to one of three potential targets located on the midline after hearing an auditory tone in four different visual conditions: occluding limb and target vision at movement onset (what they called the "open loop" condition), a "brief delay" condition (occluding vision coinciding with the auditory cue), and delay conditions of 500 and 2000 ms. In all of these visual conditions, the targets were shown for 2000 ms. Westwood et al. found that in these different movements without the availability of target or limb vision, endpoint variability increased as target occlusion time increased. More specifically, the endpoint variability was least in the "open loop" condition, increased in the "brief delay" condition, and increased again at the 2000 ms condition. The authors thus suggest that there was little evidence for an accurate stored representation of the environment (and target) for an "appreciable amount of time" after the target and limb are occluded because of the increasing endpoint variability, even at the “brief delay” stage (Westwood, Heath, & Roy, 2003).

These examples, and other work (e.g. Milner et al., 1999; Goodale & Humphrey, 1998; Westwood et al., 2000; Goodale et al., 1994) argue that there are actually two visual systems utilized for control of movement. The first is the visuomotor system, and is what is typically thought of when "vision" and "movement" are amalgamated and studied. The visuomotor system assists in immediate guidance of movements in space, and results in an accurate orientation of the movement to the position of the target (Grafton et al., 1996; Kawashima et al., 1996; Milner et al., 1999). Targets in this system are represented relative to the viewer, or a "perception" of the environment from the viewer's point of reference (Goodale & Humphrey, 1998; Westwood, Heath & Roy, 2003).

The second system proposed is beneficial for coding spatial relationships for movements that may be needed for long-lasting "cognitive and perceptual" purposes (Milner et al., 1999). This system stores a representation of the spatial arrangement of the environmental surrounding the target. Targets are represented here relative to things in the visual scene, rather than relative to the viewer (Goodale & Humphrey, 198; Westwood, Heath & Roy, 2003). This system is less accurate than the visuomotor system. It aims to simply direct the mover to the approximate area where the target is located to prepare for proprioception or online control later on to come into effect and assist it in movement guidance (Milner et al., 1999).

Findings from past neuropsychological studies have also suggested the utilization of two different visual and spatial representation systems for movement control. The activation of the visuomotor system has been suggested to be in and around the intraparietal sulcus and other parts of the parietal lobe, utilizing spatial information that has already been transformed into a motor plan (Grafton et al., 1996; Kawashima et al., 1996; Milner et al., 1999). Conversely, the second visual system receives information through the occipito-temporal visual areas, and houses activation in a separate area of the plan than the visuomotor system. Studies have speculated that activation predominately in the right hemisphere in a more inferior parieto-temporal brain area may be indicative of the second system at work.

When target and limb vision are occluded, it has been generally established that feedforward control is utilized in normal healthy populations (See Schmidt & Lee, 2005). With feedforward control, movement planning processes that take place before movement onset largely determine the pointing limb's goal position (Abram & Pratt, 1993; Heath, Westwood & Binsted, 2004). These "no-vision" tasks also tend to exhibit a "distance effect" where accuracy may be affected by the amplitude of the movement to the target position. More specifically, spatial error and variability have both been seen in multiple studies to increase with movement amplitude (Lemay & Proteau, 2002; Messier & Kalaska, 1997; Prablanc et al., 1986; Khoshnoodi et al., 2006). Misrepresenting the target location in conditions without vision of the limb and target may be due to distortion of the target location in memory. That is, participants may tend to memorize the location of farther targets closer to themselves than the targets truly are, due to an alteration of the mental spatial representation of the area the target is located in when kept in memory. This may be due to the visual representation degrading quickly, resulting in inaccurate performance despite short delay periods (Westwood, Roy & Heath, 2003; see also Sarlegna et al., 2003). Alternatively, the distance effect may also be a tactic used to counter hesitancy about the actual target location (Khoshnoodi et al., 2006; Westwood, Roy & Heath, 2003).

As well, systematic undershooting the target has been observed over many trials in "no-vision" conditions, when there is a delay between target occlusion and movement onset (Schneider et al., 1987; Romero et al., 2003). Schneider and colleagues (1987) have proposed that the constant lack of visual feedback leads to a diminution in "position sense" of the pointing limb. More specifically, this is a result from the adaptation of the sensory receptors due to the lack of visual feedback for an extended period of time. This adaptation is proposed to make it difficult for the CNS to take into account the pointing limb's initial position when planning for the movement. This has led to constant underestimation when reaching to targets in conditions with no limb or target vision available (Schneider et al., 1987; Romero et al., 2003). Although Schneider's work has focused mainly on those with Parkinson's disease, this systematic undershooting has also been found in normal healthy young and older adults (Heath, 2005; Romero et al., 2003).

1.2.2 Closed Loop-Target Absent Condition:

These tasks require the participant to remember where the intended target is, and reach to it at a later time while having vision of the aiming limb. This time can vary from immediately after the target is occluded (immediate memory) or some time afterwards (delayed recall).

In the past, most pointing and reaching literature focused on conditions that had vision of the target and limb or that had both variables occluded during memory trials. It has only been in the last twenty years that researchers have shown simply having vision of the limb even when vision of the target is not available serves to enhance pointing accuracy and variability. For instance, a study by Carlton (1981) asked participants to move to a target located 15.24 cm ahead of the body midline. Subjects pointed, using a stylus, under the following visual conditions: full vision, no vision, stylus only (essentially, limb vision only) and target only. The results indicated a significant decrease in endpoint accuracy in conditions that extinguished vision of the stylus, even if the target was present during the response (Carlton, 1981). This led Carlton to speculate that visual information about movement of the pointing limb (stylus) was crucial to pointing accuracy. Later, Heath and Westwood (2003) demonstrated a relationship between vision and proprioception that occurred only when participants could see their hand. The researchers manipulated the ratio of cursor movement to the movement of a computer mouse that participants used. Participants were to reach to a target in movements with both limb and target available or limb visible but target occluded movements with 0, 2000 or 5000 ms of delay between target occlusion and movement onset. The participants were always able to see their aiming limb. This variation to the expected 1:1 ratio resulted in an uncoupling of vision (the target's visual location, regardless if it was remembered or not) and proprioception (the target's felt location). Endpoint accuracy was decreased and endpoint variability increased as delay period became longer, suggesting visual information of the environment and target alone may not be enough to sustain an accurate representation of target location in conditions when the aiming limb is visually available. Heath and Westwood maintain that vision and proprioception must be integrated in order to retain the most stable representation of the target location in tasks with limb vision (Heath & Westwood, 2003).

Limb movement in the closed loop-target absent condition becomes slower, less accurate and slightly more variable when compared to tasks with limb and target vision available (e.g. Binsted, Rolheiser & Chua, 2006). However, participants may be able to utilize the proprioceptive system to aid in limb occluded and target absent actions. Recent research has proposed that the endpoint variability seen in these tasks may be due to the presence of feedback processing taking place, similar to the trials with vision of the limb and target (Heath, Westwood & Binsted, 2004; Heath

& Westwood, 2003), perhaps due to the visual presence of the limb. This has been illustrated in the limb's trajectory towards the latter half of a closed loop-target absent movement. Participants in a study by Heath (2005) demonstrated similar movements that were indicative of online control in conditions with limb vision but without target vision. It did not matter whether targets were extinguished at movement onset or with delay periods of 500, 1500 or 2000 ms. In fact, except for slightly more spatial variability, the latter half of the participants' movements in this condition resembled those that were made in full vision (Heath, 2005).

In terms of delay times (time between target occlusion and movement onset), healthy adults usually respond more accurately and less variably to immediate memory conditions rather than delay memory conditions. This finding has been replicated across multiple studies (e.g. Heath & Westwood, 2003; Skakum et al., in 2007), and indicated that the stability of the target representation may degrade with time, despite having visual access to the limb and utilizing a more feedback oriented mode of movement control. However, this effect is diminished with vision of the pointing limb.

1.3 Comparing the Four Conditions:

Recently, it has been suggested that there is dissociation in pointing performance between occluding only the vision of the limb, only the vision of the target, or both (Heath, 2005). Heath tested young adult participants, asking them to point to one of two potential targets located in ipsilateral space.

Subjects were tested in four conditions: limb and target visible, limb and target occluded, limb visible but target occluded and limb occluded but target visible. Heath presented ten targets and defined the target absent conditions by delay time between target offset and movement onset (target occluded at movement onset, 0, 500, 1500 and 2000 msec).

Heath noticed that regardless of vision of the target, trials with limb vision consistently displayed higher levels of endpoint accuracy, showed less variance at peak acceleration, peak velocity and peak deceleration landmarks during trajectory, and had lower endpoint variability levels. Furthermore, participants in trials with limb vision spend more time in deceleration (time after peak velocity) when compared to limb occluded trials. Because of these findings, Heath proposed that limb visible trials utilize a feedback-based online mode of control as well as an accurate and “temporally stable” representation of the target. This is contrasted with the limb occluded trials, which displayed higher levels of variability within trials at the later kinematic trajectory markers (peak velocity and peak deceleration). Combined with the higher levels of endpoint error and variability, Heath suggests that these results are indicative of an offline, feed forward mode of control that did not primarily enable online corrections to be made. Moreover, because of the higher levels of endpoint error, it was proposed that there was no utilization of an accurate and temporally stable stored target representation here (Heath, 2005).

This study indicates that there are significant differences between these types of control (limb occluded vs. limb visible) as they pertain to moving to remembered targets. Heath (2005) only examined ipsilateral targets. Thus, it would seem important to compare these open and closed loop conditions, with targets in ipsilateral, contralateral and midline positions. Moreover, we (Lau et al., 2007; Skakum et al., 2007) have found that older adults are able to retain an accurate representation of target location in memory dependent reaching under conditions when vision of the hand is available. We need to examine whether aging affects the ability to retain a representation of target location under limb occluded conditions. Certainly Heath (2005) showed in young adults that such a representation was poorly retained when vision of the hand was not available. Possibly the quality (accuracy) and stability (variability) will be further reduced with age. Before examining this question in our study we need to examine the effects of aging on the control of pointing movements and on the ability to retain a representation of target location in memory dependent pointing.

1.4. Aging and Movement Control:

Many studies in the aging literature have established that although some aspects of cognitive performance of healthy older adults is comparable to younger adults until past eighty years, task performance may be slower in speed (e.g. Teeken et al., 1996). Some work has suggested that there is a comparable decrease in movement speed of older adults, which may be as a results of a decrease in muscles size and function. However, the slowing of central processing of sensory inputs that may assist in preparing movements before onset (Morgan et al., 1994; Ebersole & Hess, 1998; Chaput & Proteau, 1996) produced by a slowing of neuronal conductive properties as aging occurs may also affect movement control (Vrtunski & Patterson, 1985; Morgan et al., 1994; Roy et al., 1999).

An explanation for slowing seen in older adults was the speed-accuracy trade-off (Welford, 1984). It was proposed that older adults favour accuracy, diminishing the speed at which they performed the movement. Indeed, Morgan et al. (1994) found in their study that older adults tend to be as accurate as younger participants when moving at slower speeds. Also, with the proper motivation, older adults could force themselves to move to targets as quickly as the younger adults, without many sacrifices to their accuracy (Morgan et al., 1994). However, older adults tend to display more coordination problems (for example, exhibiting more submovements) than their younger equivalents, even when both groups were matched in terms of movement time, suggesting more time is needed to process sensory information (Morgan et al., 1994, Skakum et al., 2007; Chaput & Proteau, 1996; Pratt et al., 1994). For example, older adults tend to exhibit more submovements in order to correct their trajectory to a target, especially in the decelerative phase of movement (Chaput & Proteau, 1996; Pratt et al., 1994). Therefore, strategic differences (e.g., a focus on accuracy at the cost of speed) may not be the primary reason older adults exhibit slower movements with less force, although differences in movement strategies likely play a prominent role (Amrhein et al., 1991; Labyt et al., 2003; Schiavetto et al., 2002).

Older adult movement is furthermore typically characterized by lower peak velocity (Roy et al., 1999; Goggin & Stelmach, 1990; Goggin & Meeuwsen, 1992), but not always (Skakum et al., 2007). Peak velocity may also be scaled less efficiently in older adults over varying movement amplitudes when compared to young adult performance (Roy et al., 1999; Goggin & Stelmach, 1990). This has been found in both pointing and grasping tasks (e.g. Roy et al., 1999). The ineffective scaling of velocity may be related to changes in the manipulation of force production possibly due to reduction in the size and functional efficiency of muscles in the elderly due to natural muscle atrophy (Vrtunski & Patterson, 1985; Morgan et al., 1994; Roy et al., 1999). Despite the lessened ability to scale velocity over short and long target amplitudes, aging does not seem to affect basic task effects on peak velocity; that is, both young and older adults show increased peak velocities with increased target amplitude and object size (Roy et al., 1999; Skakum, Roy & Lau, 2007). These findings suggest that although aging may affect the ability to efficiently respond to task demands (e.g., modulating peak velocity to movement amplitude), it does not affect the inherent ability to actually respond to task demands (e.g., peak velocity is modulated in response to movement amplitude). This is also true in aging studies that examine memory-dependent aiming and reaching movements.

1.5 Age and Movement to Remembered Targets:

In the aforementioned study, Skakum et al. (2007) compared young and older adults pointing to remembered targets in the closed loop condition. It was found that although endpoint accuracy was similar in both age groups, endpoint variability was significantly higher in the elderly adults, suggesting that although accuracy was not hindered, the stability of the target representation was weaker in the older participants, even when vision of the limb was present. Because of this, the authors proposed that aging does not directly affect limb visible pointing actions. Rather, aging renders the visual representation to be less stable so that movements are more variable. (Skakum et al., in 2007).

Work by Lemay and Proteau (2002) also investigated the effect of age when reaching to remembered targets. They examined limb occluded movements with the target occluded between two different age groups (young and old), while varying the delay period between target occlusion and movement initiation (0, 100, 1000, or 10 000 ms). Participants were required to point to one of nine possible targets (Lemay & Proteau, 2002). Lemay and Proteau found significant increases in variable error (but not constant error) for both age groups as delay periods increased. Moreover, the older participants moved to target locations as accurately as younger participants, suggesting age did not affect the way a stored representation of the target was utilized. Because of these findings, Lemay and Proteau suggest differences in the participants' performance across the different delay periods may not be affected by age. Rather, it may be due to distortion of the (allocentrically) stored representation of the target as delay times become prolonged, such that there is a decline in stable representation as a function of time as reflected in increased endpoint variability. Furthermore, Lemay and Proteau argue that the stability changes in the representation of the targets due to aging may only be evident in more challenging situations. They propose aging effects may be seen more clearly in tasks that require higher cognitive demands, such as forcing participants to keep multiple target locations in memory, such as those done in target perturbation tasks where target location are altered more than once (Lemay & Proteau, 2002). In cases where participants may need to remember locations of more than one target, it may be more advantageous to "code" these target locations relative to one another (allocentrically) rather than egocentrically (relative to one's body, which is typically used as a stable frame of reference when remembering where a single target in space is). This ability to allocentric code targets may decline with age (Lemay & Proteau, 2003).

The findings proposed by Lemay and Proteau are in line with recent work by Sarlegna (2006). He examined young and old adults performing "single step" (limb occluded reaching to a target) or "double step" (limb occluded reaching with forced modification to trajectory when target locations were suddenly perturbed or occluded) conditions. Sarlegna found little difference in accuracy between the 2 age groups in single step trials. However, in double step conditions, elderly participants became significantly slower to start trajectory readjustment when responding to a location perturbation, and displayed less corrective submovements (Sarlega, 2006). This is consistent with Lemay and Proteau's claim that only tasks that require more demand, cognitively, will be affected significantly with age. Otherwise, their accuracy, and subsequently, the egocentrically stored visual representation of targets in target absent trials, is similar to younger adults.

However, aging differences may be present when targets are encoded in an allocentric frame of reference. Lemay and Proteau (2003) investigated the effects that aging has on remembering targets encoded in allocentric space. The experimenters asked young and elderly participants to move a pointer to one of four potential targets from a predetermined starting position. All four targets were present for 1000 ms before they were all occluded from sight. A delay period of 10 000ms followed before three of the four targets materialized in the same arrangement, but in different colours and situated at a different place on the computer screen. The participant was to move to where they believed the fourth target was placed. This set-up established that participants were able to remember targets from an allocentric point of view, where any one target must be remembered relative to the other targets it was presented alongside. Results of this study indicated that the older participants were statistically more variable when pointing to the remembered targets, both in terms of direction and extent. As well, although both groups heavily undershot remembered targets (more so than visible targets) and displayed more undershooting when targets were placed in ipsilateral hemispace, these errors were much larger among the older participants. Kinematically, while both groups exhibited longer movement times to remembered compared to visible targets, the older participants had longer movement times to remembered targets when compared to the younger participants. Because of these results, Lemay and Proteau have suggested the processes that may aid in remembering targets in allocentric space may be slowed with age (Lemay & Proteau, 2003).

Aging evidently affects multiple aspects of a pointing and reaching task in terms of efficiently responding to these types of movements, and particularly with allocentrically stored targets. Little work, however, has compared how young and older healthy adults reach to targets in both closed and open loop conditions.

1.6 Objectives and Hypotheses:

The general purpose of this study, as stated at the beginning of the introduction, was to determine how healthy young and old adults differ in performance of precise pointing movements. However, this broad purpose can be broken down into the specific objectives stated below.

1.6.1 Role of Vision and Aging in Movement Control

1.6.1.i. Aging and movement control:

The first objective was to examine the effects aging has on movement control. We hypothesize that young adults will exhibit shorter movement times, have higher peak velocities and require less time in the decelerative phase of movement when compared to the older participants. As well, past work in our lab has indicated that in terms of target position, the elderly tend to show an advantage for making ipsilateral movements (Lau, Roy & Skakum, 2007). In this study, younger participants displayed shorter movement times and greater peak velocities when reaching for ipsilateral and midline targets than for contralateral targets in near conditions. However, for targets further away, contralateral and midline reaches appeared to be equivalent in terms of movement time, with ipsilateral targets being significantly shorter than the other two. In contrast, elderly participants displayed this latter pattern for both near and far targets. This suggests that elderly adults may be more proficient in ipsilateral movements, perhaps due to an increased preference to perform ipsilateral movements as they grow older. Thus, we expect in our proposed study that older participants will exhibit similar movement trends in that their ipsilateral movements will be relatively more efficiently performed when compared to the ipsilateral movements to the younger participants.

1.6.1.ii. Role of vision of the limb in visually guided aiming movements:

The second objective was to investigate the effects that vision of the pointing limb had on aiming movements. We hypothesize that with vision of the limb, participants will exhibit greater endpoint accuracy and less endpoint variability than when vision is not available. This difference may arise because vision of the limb provides an egocentric frame of reference that may enhance the ability to make movement corrections, allowing for greater endpoint accuracy (Heath, 2005; Heath & Westwood, 2003; McIntyre et al., 1998). If this explanation is correct, we expect to find movements with vision of the limb to take longer because of the time required to process limb feedback information, particularly during the deceleration phase of the movement (Heath, 2005). These effects of the availability of limb vision should be most pronounced in the condition where the target is present throughout the movement.

1.6.1.iii. Aging and vision of the limb in aiming movements:

The third objective involves examining the differences in performance between age groups when performing aiming movements with and without vision of the pointing limb. To our knowledge, there has not been any work done comparing the different age groups while performing these movements and manipulating vision of the limb. However, we hypothesize that both age groups will exhibit less endpoint variability, greater endpoint accuracy and longer movement time and time in deceleration when vision of the hand is available, but that this difference between closed- and open-loop movements may be larger for the older participants. This difference in movement time and time in deceleration will likely arise from the older adults taking longer to process feedback or exhibiting more corrective submovements.

This study also strived to examine movement to remembered targets.

1.6.2. Role of Vision in Moving to Remembered Targets:

1.6.2.i. The role of limb vision in memory for target location:

The fourth objective was to examine the role of vision of the limb when moving to remembered targets. Because of multiple studies suggesting the significance vision of the pointing limb has for preserving the accuracy to remembered targets (e.g. Carlton, 1981; McIntyre et al., 1998), we hypothesize that movements to remembered targets will exhibit greater endpoint accuracy and less variability at the movement endpoint when vision of the hand is available. Further based on Heath's work we expect to see less of an effect of memory delay in the CL condition.

The rationale here is that vision of the limb may enable participants to better use the visual representation of the target so they are more accurate and less variable overall, but also less affected by a memory delay.

1.6.2.ii. Aging and limb vision in memory for target location:

Another objective of this study was to examine how aging affects memory for targets in both closed and open loop trials. Previous work has proposed that aging does not have a significant effect on the integration of visual and proprioceptive cues, nor the way a stored representation of the target is utilized (e.g. Lemay & Proteau, 2002). However, aging effects may be seen in tasks that require more efficient usage of a visual representation of the target (for example, Lemay & Proteau's 2003 study utilizing allocentric targets, or in studies that require participants to make a movement under quick temporal restrictions). Vision of the hand allows a person to make better use of the visual representation of the target. We hypothesize that the use of the visual representation may be less effective for older adults due to natural cognitive slowing, which may lead to less of an improvement in endpoint accuracy when compared to younger participants.

However, in conditions where participants will have vision of their limb without target availability, we hypothesize that we will see smaller differences between age groups in endpoint accuracy and variability when compared to conditions without vision of the limb because of the extra visual information available.

Similarly, because retaining a representation of target locations for a longer period of time is more cognitively demanding in the conditions with no vision of the target and limb, we expect to see older adults exhibit more endpoint variability than in conditions with target occlusion but limb visibility, particularly in delayed recall trials, as predicted from results in studies our lab has done in the past, as well as multiple sources of literature.

2. Methods:

2.1 Participants:

Twenty healthy adults were asked to participate in this study: ten young (19-25 years, mean age: 21.8 years, 6 females and 4 males) and ten older (60 to 85 years, mean age: 73.8 years, 5 males, 5 females). The young group was recruited from university-organized participant pools, as well as undergraduate and graduate classes. Some received extra credit in their undergraduate classes. The 10 healthy elderly participants were recruited from the Waterloo Research in Aging Participant Pool, established by the University of Waterloo's Kinesiology and Psychology departments. All of the elderly participants were paid. Only people with no history of neurologic or psychiatric disorders or chronic conditions that may affect sensory or motor functions, have corrected to normal vision and are right-handed were selected for the study. All participants provided informed consent and were treated according to the established guidelines from the University of Waterloo's Office of Research Ethics. One elderly female participant was excluded from data analysis due to unforeseen medical ailments that indirectly affected results.

Furthermore, experience with using computers and computer mice were taken into account. This was done through verbal accounts of past computer experience asked before each participant is recruited. This was done in order to ensure that the elderly participants were not complete novices in computer related tasks.

2.2 Apparatus:

The apparatus was comprised of a graphics tablet (SummaSketch III), sampling at 122.3 hertz, a computer monitor, a small table and a custom built "pointing box." This box (55cm x 60cm x 120cm) was placed on the desk. The hollow interior of this wooden box was separated into two sections by a large mirror. The computer monitor was placed on the "roof" of the box, so that the monitor's image is reflected onto the mirror through a section cut from the top of the box. Below the mirror, the graphics tablet was placed on the table. This tablet was where the participants' movement took place using a mouse. With this setup, vision of the hand itself was occluded but movement of the hand was reflected in movement of a bright yellow coloured cursor on the screen that was controlled by movement of the mouse. Movements of the mouse were in a 1 to 1 ratio to movements of the cursor. The graphics tablet was connected to the serial port of a PC that runs a computer program in MS DOS that presented the targets and recorded movements of the cursor for later analysis. The entire structure was painted black to reduce allocentric environmental information as to target location. In order to account for eye movement (motion of the eyes may affect the way the visual representation is utilized), an ASL head mounted eyetracker was utilized. More eye movement may make it more difficult to keep the visual representation of environment in memory, which has been indicated in some sources of aging gaze literature. Although time constraints in this particular study restricted measuring exact points of foveation, the eyetracker noted whether the participants foveated on the target, or where the target was after occlusion, and the different gaze patterns seen between young and elderly age groups, which was useful for later analyses.

At the beginning of each task, the participant was asked to move the cursor to the start or home position located within an open circle (bright blue in colour) that is slightly larger than the cursor in diameter. The start position was located at the body midline near the middle, lower edge of the mirror. The participant held the cursor at the start position until an auditory tone signaled movement to one of the targets. The solid blue coloured targets appeared at 30 centimetres from the start position and was placed at the midline or 45 degrees to the left (contralateral target) or right (ipsilateral target) of the midline.

2.3 Procedure:

Total testing time was approximately 50 minutes, with breaks allowed for participants if they required them.

Participants first performed 9 practice trials, which exposed them to all the conditions in the study (target present control, immediate memory, and delayed memory), in both limb visible and limb occluded settings. Following these practice trials, the participants then performed the actual tasks, with their data being recorded for later analysis. Participants were told to hit the target as quickly and as accurately as possible.

For each condition, there was a 5 second "preparation" period before presentation of the target on each trial. During this time, participants moved the mouse back to the start position in preparation for the presentation of the target. In all conditions the target was presented for 1 second.

2.3.1 Limb Conditions:

i. Closed loop:

In this condition, participants always saw their pointing limb's movement depicted as a round yellow cursor on the screen.

ii. Open loop:

In this condition, participants did not see their hand (the cursor) moving to the target. However, they were able to see the yellow cursor at the "home" position at the beginning of each trial. Participants did not have any terminal feedback (the relative positions of the cursor and the target at the end of the movement).

2.3.2 Target Conditions:

i. TP conditions:

Following the target presentation time (1 second), an auditory cue sounded, signaling movement to the target. In these conditions, the target remained on throughout the movement

ii. TA conditions:

Following the target presentation time (1 second), the target was occluded. In the immediate memory condition (IMEM), the auditory cue signaling movement to the target sounded at the same time the target was occluded. In the delayed memory (DMEM) condition, the auditory cue sounded two seconds after the target was occluded. Thus, the participant did not start movement onset until two seconds after vision of the target disappeared.

The limb conditions were put together with the target conditions. In doing so, there became 6 blocks of experimental conditions. In condition 1, both vision of the pointing limb and target were present throughout the movement. In condition 2, the pointing limb was visible, but the target was occluded coinciding with the auditory cue to begin movement. In condition 3, the pointing limb was available throughout the movement duration, but the target was occluded two seconds before the auditory cue sounds. In condition 4, the target was always visible, but pointing limb vision was occluded, coinciding with the auditory cue to initiate movement. In condition 5, vision of the pointing limb and target was occluded when the auditory cue sounded. Lastly, in condition 6, vision of the target and limb was occluded 2 seconds before the auditory cue. Each of these conditions consisted of 18 trials to total 108 trials per participant. Target presentation in each block was randomized.

All participants were tested in all experiments conditions. Each participant received a random assignment of all of the conditions. All conditions consisted of three targets: one in the ipsilateral side of space, one on the midline, and one in the contralateral side of space.

2.4 Data analyses:

To examine kinematic data, information from each of the participants' trials was analyzed, taking the information from the SummaSketch III graphics tablet using the d-track program, and processed using the KinAnalysis program. A dual-pass Butterworth filter with a low-pass cutoff frequency of 6 hertz was used to filter the data.

Dependent variables included: movement time (time between movement initiation and movement end), peak velocity (maximum velocity reached during a trial), percent time after peak velocity (the percent of movement time spent after peak velocity), and endpoint error expressed as error perpendicular to the direction of movement, directional error (x), error in the direction of the movement, amplitude error (y), and the composite of these two errors termed radial error. Negative values for directional error (x) indicate errors made to the left of the target, and a positive value in the represents error made to the right of the target. Similarly, a negative value in amplitude error (y) indicates undershooting the target (that is, reaching below the target) and a positive value indicates overshooting the target (that is reaching beyond the target).

Eye Tracker Analysis:

Eye movements analyzed using DVD recordings of the eye and the environment in each trial. Movements were separated by limb feedback, target feedback and target position, so that there were 18 separate data categories (the aforementioned six experimental conditions, each of which were separated into the three target positions: contralateral, midline and ipsilateral). The data in each category was sorted into two groups. The first group consisted of trials where participants foveated on the target and kept their gaze on the area of the target while performing the movement. The second group consisted of trials where participants' gazes wavered. These trials consisted of any large amplitude eye movements that were not due to natural fluctuations in eye position during stable foveation. Trials sorted into the first group were given a value of 1. Those sorted in the second were given a value of 0. Frequencies of values were tallied, with a maximum value of 6 in each category. Using these frequency calculations, percentage values were computed.

All statistical analyses involved using SPSS version 16 at an alpha level of 0.05. When main effects for factors with more than two levels or interaction of factors were significant post hoc testing was done using Tukey's HSD statistic ($p < 0.05$).

3. Results:

A 4-way mixed ANOVA was performed with Age group (2) as the between subject factor and limb feedback (2), target feedback (3) and target position (3) as the within-subject factors. Any significant effects were followed up with Tukey's HSD post hoc tests ($p < 0.05$).

3.i. Kinematic Data

a. Movement Time:

Data analyses yielded a main effect of target feedback ($F(2,34) = 7.52$, $p < 0.05$) where movements made in the immediate memory condition required the least movement time (775 milliseconds). Delayed memory and target present condition yielded significantly longer movement times (853 and 835 milliseconds, respectively) but did not differ from each other. There was also a main effect of target position ($F(2,34) = 8.60$, $p < 0.05$). Movements made to the ipsilaterally placed target required the least time to complete (786 milliseconds). Movements to midline and contralateral targets were significantly longer (831 and 845 milliseconds, respectively), but did not differ from one another.

b. Peak Velocity:

Results yielded a main effect of target feedback ($F(2, 34) = 16.04$, $p < 0.05$), such that movements made in the immediate memory condition (315.88mm/s) exhibited significantly greater peak velocity than that in the delayed memory and target present control conditions (266.67 mm/sec and 283.69 mm/sec, respectively), which did not differ significantly.

There was also a main effect of target position ($F(2,34) = 17.90$, $p < 0.05$). Movements made to contralateral and midline placed targets did not differ in peak velocity (276.34 mm/sec and 279.76 mm/sec, respectively), but both exhibited significantly less peak velocity than movements made to ipsilateral targets (310.13 mm/sec).

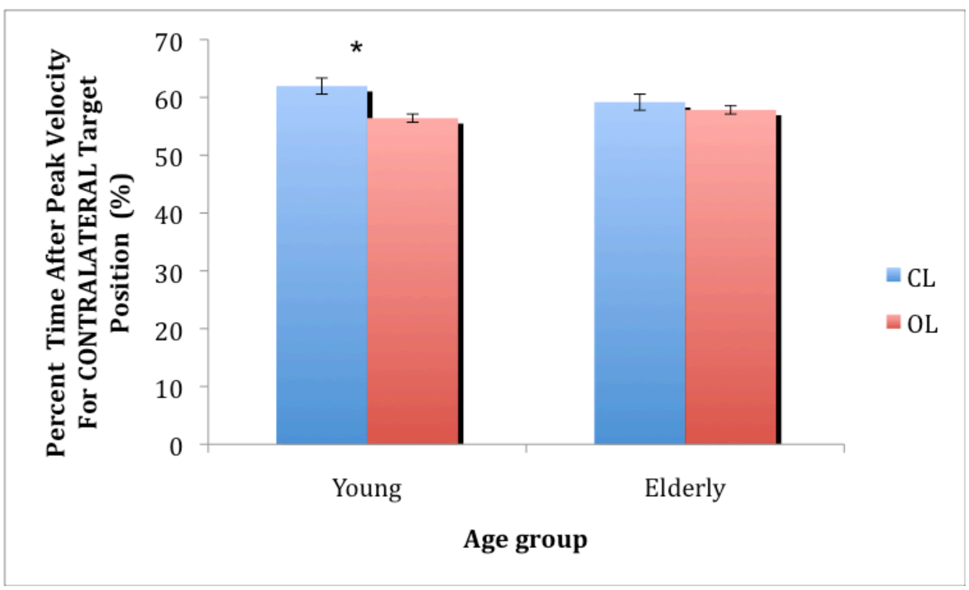
c. Percent Time After Peak Velocity:

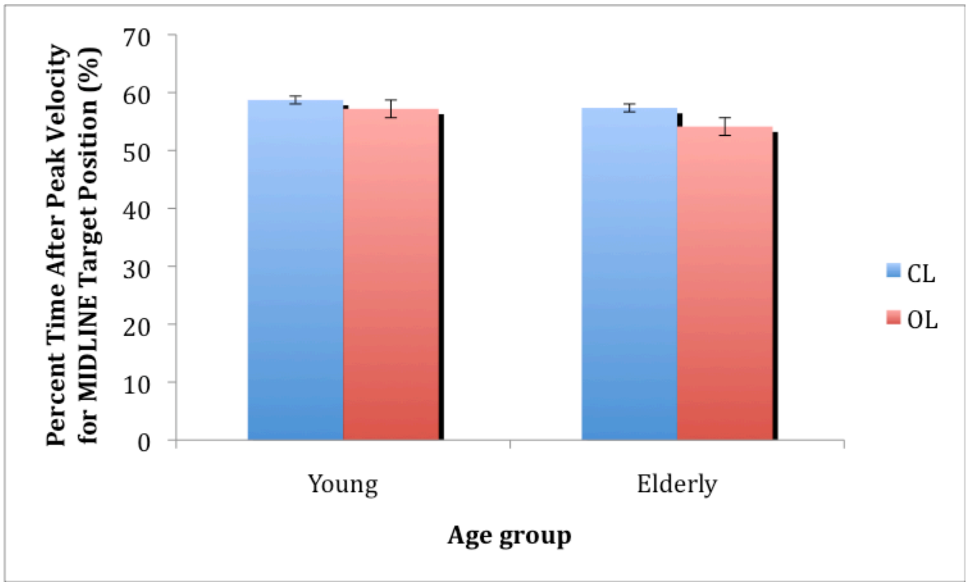
There was a main effect of limb feedback ($F(1,17) = 8.58$, $p < 0.05$), where closed loop movements demonstrated proportionately longer times during this phase of movement time (60.47%of movement time) than movements made in the open loop condition (56.69%).

There was also a main effect of target feedback ($F(2,34) = 5.84$, $p < 0.05$), where movements made in the target present condition required proportionately more time in this deceleration phase of movement (60.37%), when compared to movements made in the target absent conditions (immediate memory: 57.13%, delayed memory: 58.25%) which did not differ significantly.

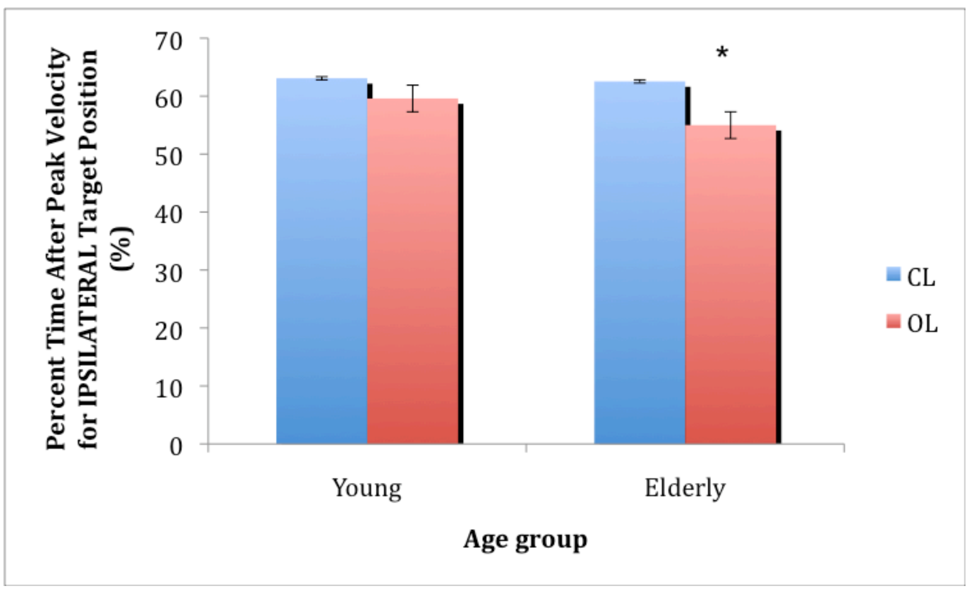
A main effect of target position was also found ($F(2,34) = 4.45$, $p < 0.05$) with movements made to the ipsilaterally placed target requiring proportionately more time after peak velocity (60.05%) than movements made to midline (56.846 %) or contralateral targets (58.85%) which did not differ significantly.

Lastly, analyses yielded a significant 3-way interaction: limb feedback x target position x age group ($F(2,34) = 3.49$, $p < 0.05$).

a. 



b.



c.

Figure 1.a. Contralateral Target Position: Percent Time After Peak Velocity vs. Age Group

Figure 1.b. Midline Target Position: Percent Time After Peak Velocity vs. Age Group

Figure 1.c. Ipsilateral Target Position: Percent Time After Peak Velocity vs. Age Group

Age group seemed to affect the time after peak velocity as well, when examining target position. The interactions between the differences in limb feedback and target positions with the two age groups were further examined using Tukey's post hoc test. These analyses revealed that the expected difference between the closed loop and open loop conditions, proportionately more time in deceleration in the closed loop condition, is seen only at one target position that differs for the two age groups. For the young group, this effect is seen only for movements to the contralateral target, while for the older adults this difference is seen only for movements to the ipsilateral target.

3.ii. Accuracy Data: Error Measures

Recall that the measures were examined in a composite measure of radial error, which was a combined value of x (directional) and y (amplitude) components. These components were individually examined as well.

a. Radial Error

Data analyses yielded a main effect of limb feedback ($F(1,17) = 53.80$, $p < 0.05$), where movements made to targets in the limb visible closed loop condition exhibited less radial error (4.12 mm) than movements made to targets in the limb occluded open loop condition (26.95 mm).

b. Directional Error

The directional error analyses yielded a significant interaction of target position x age ($F(2, 34) = 8.32$, $p < 0.05$). It should be noted that negative values indicate errors to the left of the target, and positive values indicate errors to the right of the target.

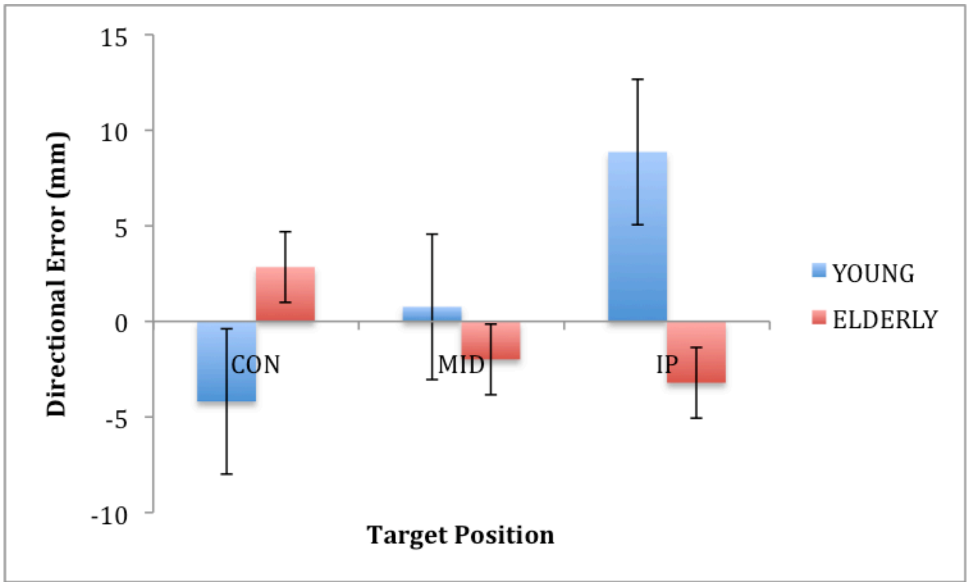
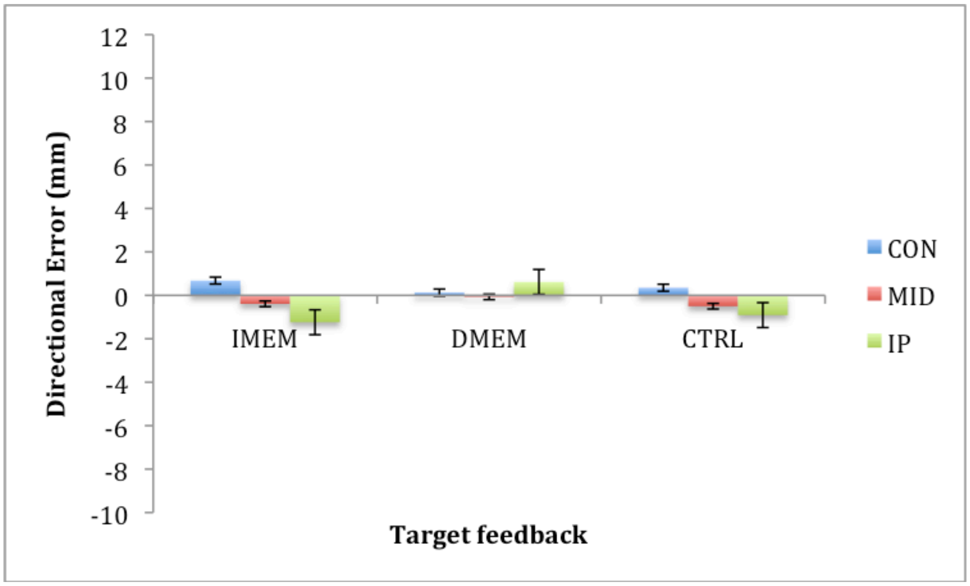


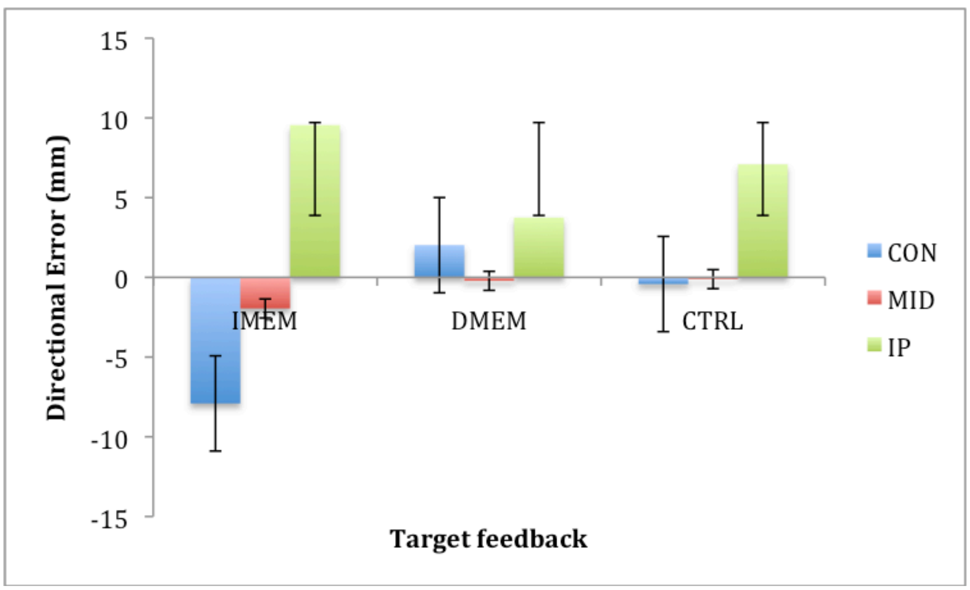
Figure 2: Directional Error vs. Target Position

Post hoc analyses of this interaction revealed that the young participants' movements to contralateral and ipsilaterally placed targets exhibit a significantly greater directional error than movements to targets placed along the midline with contralateral target movements being biased to the left and ipsilateral targets biased to the right of the target. For the elderly directional error did not differ across the three target positions. Further the difference between the young and elderly was significant only for movements to the ipsilateral target with movements for the elderly biased to the left and those for the young biased to the right of the target.

Results also yielded a significant three-way interaction: limb feedback x target feedback x target position ($F (4,68) = 5.77$, $p < 0.05$)



a.



b.

Figure 3.a. Closed loop: Directional Error vs. Target Feedback

Figure 3.b. Open loop: Directional Error vs. Target Feedback

Analyses of the target feedback condition by target position interaction for each limb feedback condition revealed no interaction in the closed loop condition showing no differences when movements are performed under limb visible, closed loop conditions ($F(4,68) = 1.35$, $p > 0.05$). However, the interaction was significant for the open loop condition. Tukey's post hoc analyses revealed movements made to all target positions in immediate memory in the open loop limb feedback condition were significantly different from one another ($F(4, 68) = 4.42$, $p < 0.05$). Movements to contralateral targets were biased to the left and movements to ipsilateral targets were biased to the right. In delayed memory and target present control conditions, ipsilateral targets showed the greatest directional error again showing a bias to the right of the target.

c. Amplitude Error

Recall that positive values indicate overshooting/overestimating the target position, and negative values indicated undershooting/underestimation of the target position.

Amplitude error analyses exhibited a main effect of target feedback ($F (2,34) = 6.90$, $p < 0.05$), where movements made in the immediate memory condition significantly overshot (4.17mm) the targets relative to movements in the delayed memory condition which were undershot (-2.60mm). Movements in the target present condition slightly undershot the target (-2.60) but were not significantly different from either of the other conditions.

Results also yielded a significant interaction of limb feedback by target feedback ($F (2,34) = 8.32$, $p < 0.05$).

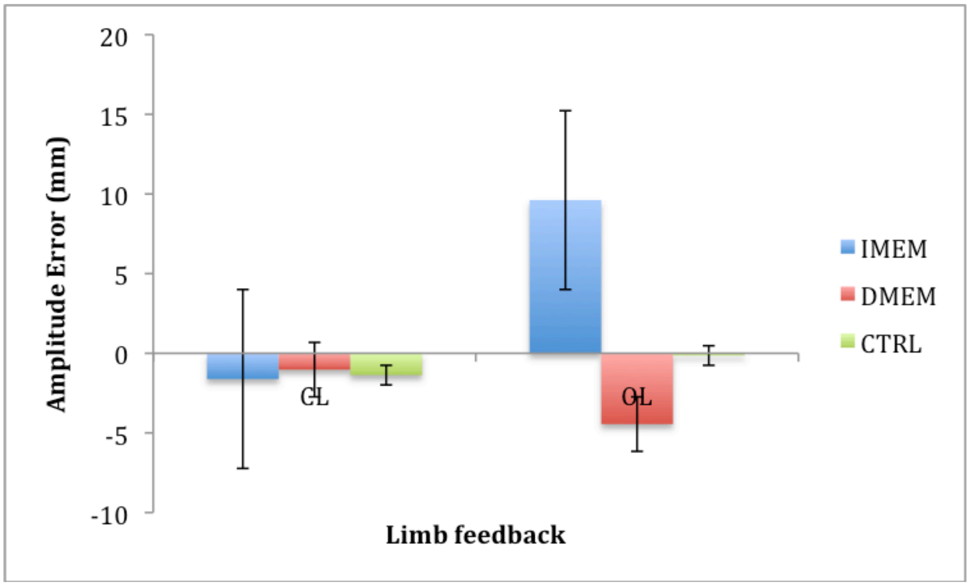
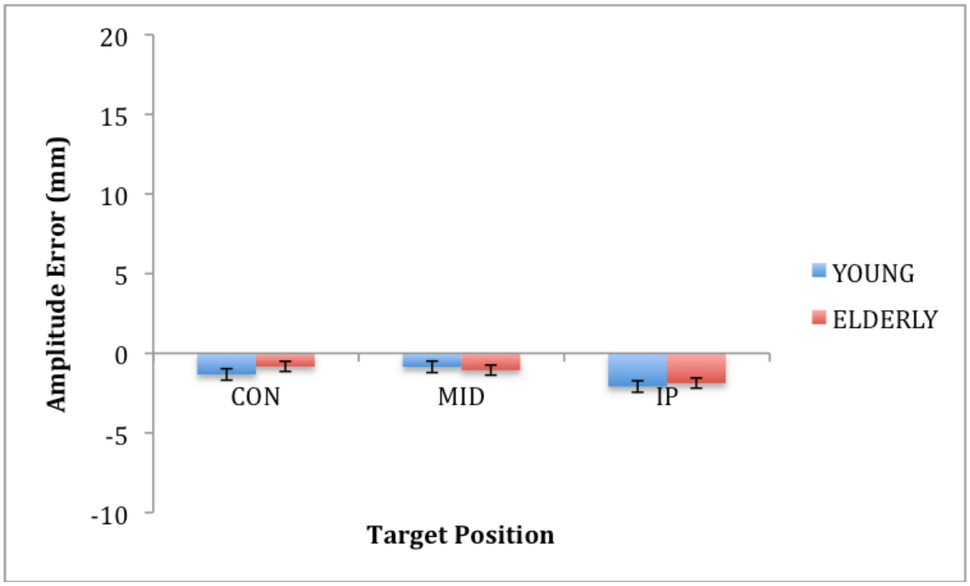


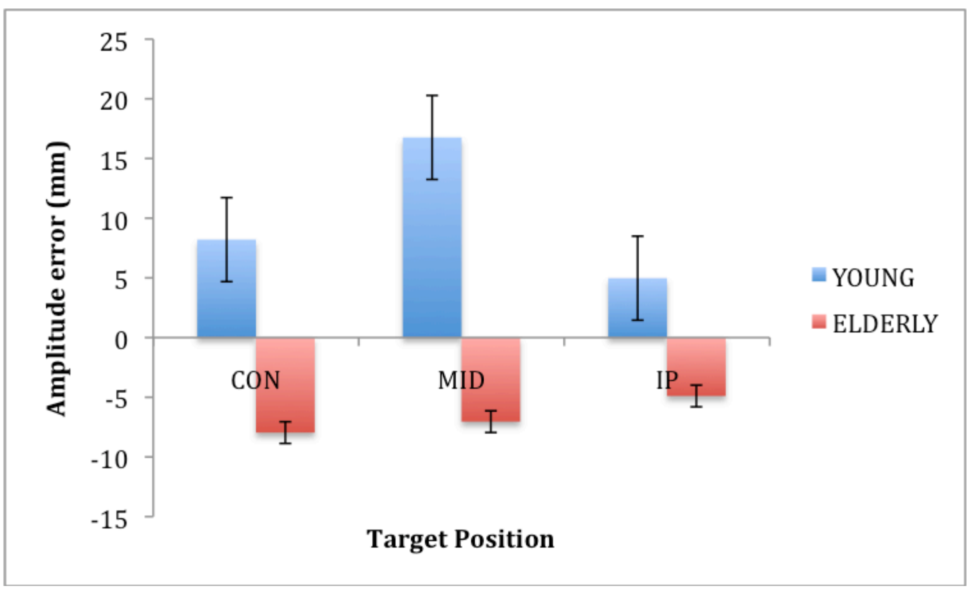
Figure 4: Amplitude Error vs. Target Feedback

There were no differences in closed loop movements between the target feedback conditions. Movements made in the limb occluded, open loop condition showed that immediate memory movements tended to overshoot the targets compared to the delayed memory and target present conditions that did not differ significantly.

Data analyses also yielded a significant three-way interaction in amplitude error data: limb feedback x target position x age group ($F(2,34) = 3.62$, $p < 0.05$)



a.



b.

Figure 5.a. Closed loop: Amplitude Error vs. Target Position

Figure 5.b. Open loop: Amplitude Error vs. Target Position

Analyses of the age group by target position interaction for each limb feedback condition revelaed no effect in the closed loop condition indicating no differences between young and elderly in this limb feedback condition ($F(2,34) = 0.111$, $p < 0.05$). This interaction was significant in the open loop condition (F?). Post hoc analyses revealed that the young adult participants tended to overshoot the targets, while the elderly undershot the targets. This age effect was greatest at the midline position compared to targets at the other two positions.

3.iii. Variability Measures

a. Radial Error Variability

Results yielded a main effect of limb feedback ($F(1,17) = 32.10$, $p < 0.05$), where movements made in the closed loop condition showed less variability than those made in open loop condition (6.64 mm and 15.57 mm, respectively).

There was also a main effect of target feedback ($F(2,34) = 4.45$, $p < 0.05$). Movements made in the immediate memory condition were significantly more variable (13.76mm) than those made in delayed (9.45 mm) and target-present control conditions (10.10 mm) which did not differ significantly.

A significant interaction between limb feedback x target feedback was also found ($F(2,34) = 7.73$, $p < 0.05$).

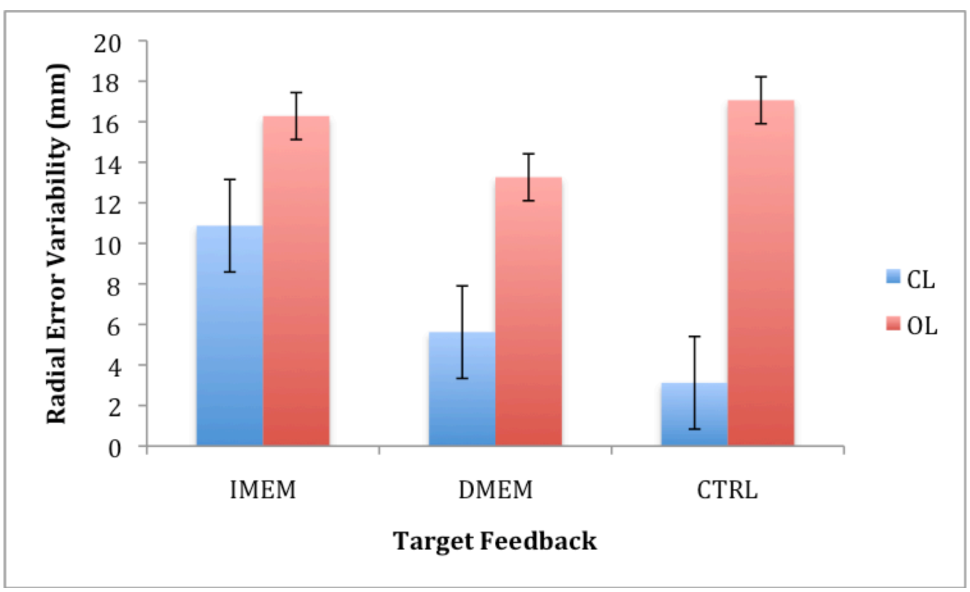


Figure 6: Radial Error Variability vs. Target Feedback

Post hoc analyses examining differences between the limb feedback conditions in each target feedback condition revealed that the open loop condition was significantly more variable than the closed loop condition only for movements made in the delayed memory and target present conditions. There was no difference between closed loop and open loop movements in the immediate memory condition, due to the increased variability in radial error in the closed loop limb feedback condition in this target feedback condition relative to the delayed memory and target present conditions.

b. Directional Error Variability:

Analsyse of variability in directional error indicated that there was a main effect of limb feedback ($F(1,17) = 18.08$, $p < 0.05$). Closed loop movements demonstrated less variability (3.87 mm) than movements made in the open loop limb feedback condition (9.18 mm).

There was also a main effect of target position ($F(2,34) = 14.68$, $p < 0.05$). Here, contralaterally placed targets exhibited the largest variability (8.23mm). Variability in directional error for movements to targets at this position was significantly greater than that for movements to the midline position (4.19mm). Movements to the ipsilateral target were also more variable than those to the midline target (7.12mm) but was not significantly different from the variability in movements to the contralateral target position.

c. Amplitude Error Variability:

There was a main effect of limb feedback ($F(1,17) = 30.36$, $p < 0.05$), where closed loop movements are less variable (5.09mm) than open loop movements (11.87 mm).

There was also a statistically significant main effect of target feedback ($F(2,34) = 3.52$, $p < 0.05$), where movements made in the immediate memory condition exhibited significantly more amplitude error variability (10.25 mm), when compared to movements made in delayed memory condition (7.355 mm) and target present control condition (7.83 mm) which did not differ significantly.

Results also yielded a main effect of target position ($F\ (2,34) = 3.52$, $p < 0.05$), where movements to the midline target exhibited the most amplitude error variability (9.52 mm). Variability at this target position was greater than that for movements to the contralaterally placed target (7.52 mm). Movements to ipsilateral target (8.395 mm) did not differ significantly from that observed at the other two target positions.

A significant 2-way interaction of limb feedback x target feedback was also found ($F\ (2,34 = 6.43$, $p < 0.05$).

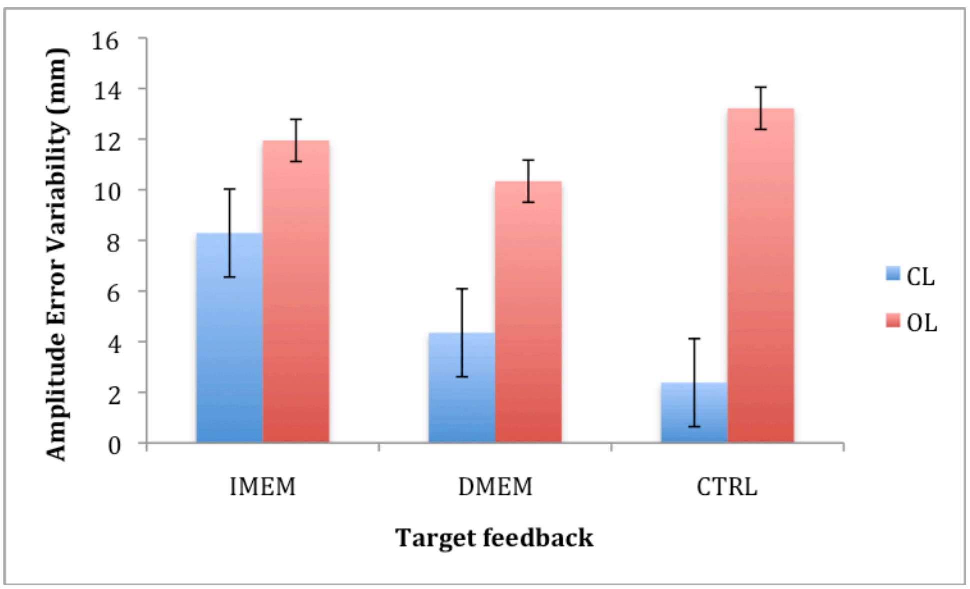


Figure 7: Amplitude Variability vs. Target feedback

Post hoc analyses examining differences between the limb feedback conditions in each target feedback condition revealed that the open loop condition was significantly more variable than the closed loop condition only for movements made in the delayed memory and target present conditions. There was no difference between closed loop and open loop movements in the immediate memory condition, due to the increased variability in amplitude error in the closed loop limb feedback condition in this target feedback condition relative to the delayed memory and target present conditions.

A second interaction was also seen during amplitude error variability analyses: Target feedback x target position ($F(4, 68) = 4.43$, $p < 0.05$).

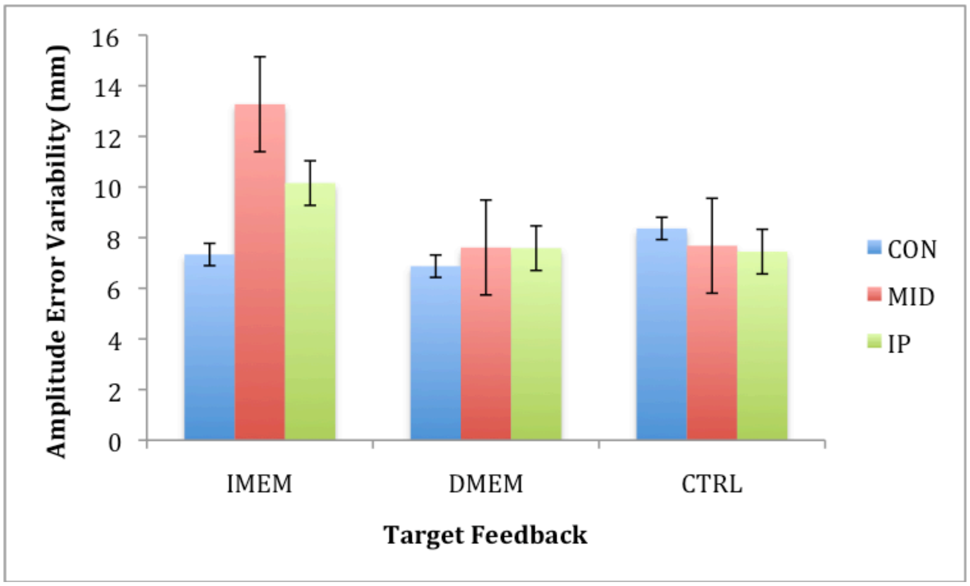


Figure 8: Amplitude Error Variability vs Target feedback.

Post hoc analyses revealed significant differences in amplitude error variability among movements to the three target positions only in the immediate memory condition with movements to the midline target exhibiting significantly greater variability than movements to the other two target positions which did not differ significantly. Further, movements to the midline target in this immediate memory condition were significantly more variable than movements to this position in either of the other target feedback conditions.

3.iv. Eye Movement Trends

A 4-way mixed ANOVA was performed with Age group (2) as the between subject factor and limb feedback (2), target feedback (3) and target position (3) as the within-subject factors. Any significant effects were followed up with Tukey's HSD post hoc tests ($p<.05$).

The measure being examined was whether stable foveation on the target occurred in all conditions. However, there were no significant main effects or interactions seen between age groups, limb feedback, target feedback or target position.

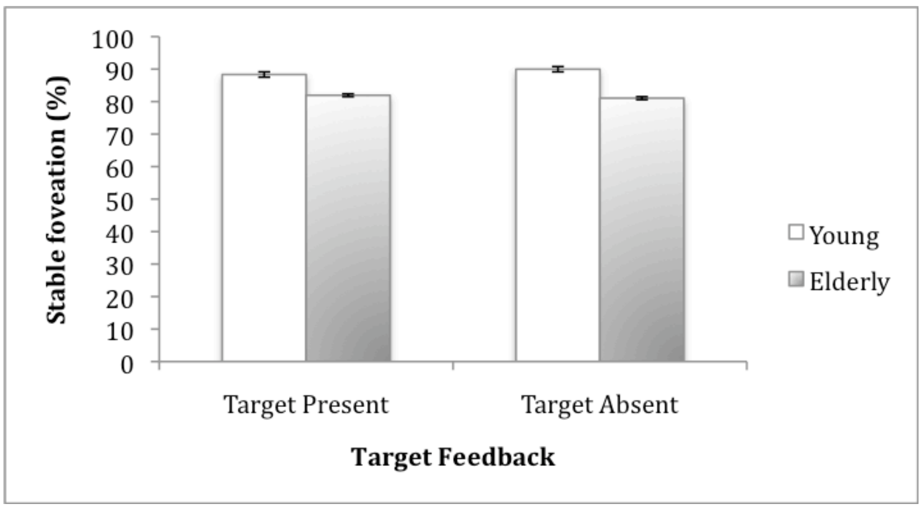


Figure 9: Percent Stable Foveations vs. Target Feedback

4. Discussion:

4.1 Aging and Movement Control

Our results show that there was no significant overall effect of age in any of the kinematic measures (movement time, peak velocity or percent time after peak velocity) even in the condition in which vision of the hand and the target was present throughout the movement. This is not in agreement with other work on aging, where it was found that older participants with no physical or mental ailments generally display longer movement times, lower peak velocities and spend proportionally longer in the time after peak velocity (e.g. Roy et al., 1999, Teeken et al., 1996, Goggin & Meeuwsen, 1992). It is important to note, however, that there has also been some literature also demonstrating little differences between young and elderly healthy adult participants (Skakum et al., 2007; Chaput & Proteau, 1996; Pratt et al., 1994). There may not be any main effects of age because age effects were modulated by the other factors in this study. This is shown in when the composite measure of radial error is broken down into its x (directional) and y (amplitude) components. In measures of directional error, our results indicated that age affected the way the participants moved to the various target positions. Recalling the experimental requirements, we know that all participants were right handed so that all contralaterally placed targets are located to the left of the midline, and those located ipsilaterally to the right of the midline. Directional errors for the young adults revealed a bias towards the left during movements to contralateral targets. That is, their movements tend to be such that the cursor ends further away from the body in the horizontal axis. This trend is also seen in ipsilaterally placed targets where movements are biased much more to the right: again, moving away from their body. The reverse trend is seen in elderly participants who appeared to favour economizing their movements, with their contralateral (left) targets are biased to the right and the ipsilateral (right) targets biased to the left; that is, the elderly movements were biased closer to their body.

The same trend was seen in the amplitude component of radial error. That is, the young adults tended overestimate target position such that the end position was away from the body, and the elderly seemed to underestimate their movements, biasing their movements closer to their body. However, this effect was also further modulated by vision availability and will be covered in detail later.

Percent time after deceleration data also show age effects modulated by limb vision as well. The young adult participants exhibited less time in deceleration when moving to midline targets only during trials with limb visibility. However, the young adults did not show differences in percent time after peak velocity when limb vision was not present. This suggests that when limb vision is occluded, all target positions are treated equally in young adults.

Elderly adult participants, however, did not display the trend found in the young. In closed loop conditions, with limb vision available, movements to ipsilateral targets exhibited significantly *more* time in this deceleration phase of movement. This suggests that significantly more time was allotted for online processing, suggesting that the elderly may require more time to process the extra visual information provided by the limb but only when moving to targets on the same side as their reaching limb.

4.2. Role of Vision of the Limb in Visually Guided Aiming Movements

A primary objective of this investigation was to examine the effects that vision of the pointing limb may have on aiming movements. Prior literature has shown that having vision of the pointing limb during movement enabled increased accuracy (decreased endpoint error) and decreased variability (e.g. Admiraal et al., 2003; Sarlegna et al., 2003; Carlton, 1981; Heath, 2005).

Analyses of endpoint accuracy reflected in the composite measure (radial error) revealed that movements in the open loop condition yielded more radial endpoint error than movements in the closed loop condition when vision of the limb was available. These radial error findings concur with the literature (e.g. Carlton, 1981), and further the argument that limb vision provides crucial information to make an accurate movement.

This difference in limb feedback is also true of the radial variability measures where open loop movements displayed significantly more variability; however, this effect of limb feedback was modulated by target feedback, such that there were only significant differences between closed loop and open loop feedback in the target-present control condition and the delayed memory condition. In other words, movements made in the immediate memory condition showed no difference between closed and open loop feedback, due to the significant increase in variability seen when vision of the hand is available. This finding points to some disruption in movement planning in this immediate memory condition when participants must initiate their aiming movement at the same time as when vision of the target was occluded. It appears that participants were unable to take advantage of the availability of vision of their hand in order to reduce their variability in pointing at the target as was seen in the delayed memory and target present conditions.

Turning now to the components of this composite measure of endpoint accuracy and variability, we will first examine directional errors. Analyses of directional error revealed a target feedback by target position interaction that was modulated by vision of the limb. When vision of the limb was available, pointing errors were minimal across all target positions and target feedback conditions. However, this changed dramatically when participants did not have vision of their pointing limb. Here, we notice three trends. Firstly, directional error is greatest for movements to ipsilateral targets. This trend is not consistent with other research showing that movements to ipsilateral targets exhibit the least error. As movement time was shortest for ipsilateral target movements, there may have been a type of speed accuracy tradeoff occurring in movements to targets located in this target position.

Secondly, directional error was greatest when moving to remembered targets, but only in the immediate memory condition. This finding is contrary to that of others who found error to be greatest in the delayed memory condition. This discrepancy will be addressed in the next section dealing with pointing to remembered targets.

Thirdly, midline targets exhibited the least directional error. This advantage for midline targets may reflect the fact that participants may be able to use their body as a reference for localizing the target, thereby enabling them to point with equal accuracy to the target whether it was present during the reaching movement or not. It is interesting to note that this advantage for midline targets in directional error is only seen when vision of the hand is not available, suggesting that this body referent is most powerful when participants are not able to see their limb when pointing. This advantage for the midline target is also seen for variability in directional error where variability is smallest for the midline target, suggesting that the body referent for the midline target enables participants to point to this target with much greater consistency. Notably, vision of the limb plays no role in this measure in that variability for the midline target is least compared to that for the other targets regardless of whether the participant is able to see their hand. However, this midline advantage may also stem from the fact that the midline target may be the easiest target to process and reach to, as there are no orthogonal components to take into consideration, unlike the contralateral and ipsilateral target positions.

While the availability of vision of the hand played no role in the advantage for midline targets with regard to directional variability, it was clear that movements, when vision of the hand was available, were significantly less variable in direction than when vision was not available. This finding supports other work (e.g. Carlton, 1981. Sarlegna et al., 2003. Health, 2005) and indicates the importance of vision of the hand in pointing movements.

Looking now at the other component of radial error, amplitude error, we see that the availability of vision of the limb also affects amplitude error with error being smaller when vision of the hand is available. This effect, though, was mediated by target feedback condition such that the availability of vision had no effect on amplitude error when the target was present throughout the movement. When pointing at remembered targets, however, movements made with vision of the hand were significantly more accurate, suggesting that the availability of vision enhances the ability to remember target location. We will address this role of vision of the hand in memory for target location later in the discussion.

This effect of limb vision was also mediated by target position and age. We will examine these effects later in the discussion. At this point though, it is interesting to note that the advantage for the midline target when vision of the hand was not available seen for directional error was not seen for amplitude error. This finding suggests that participants may be using the body midline as a referent for pointing for the horizontal direction of movement to the target, but not for movement amplitude, the distance of the target from the body. However, further research is warranted to confirm and strengthen this argument. This effect may due to the midline target being easier to reach to because of the lack of orthogonal properties to consider. As well, movement to the midline target Inter-limb coordination is much less complex than movements to ipsilateral and contralateral targets. The movement to midline target mainly incorporated movements at the elbow joint, whereas movement to the other targets also encompasses movement not only at the elbow, but at the shoulder as well.

Turning to the variability of amplitude error we see that movements made with vision of the hand were much less variable, supporting what was seen for variability in directional and radial error and indicating the importance of vision in aiming movements. This effect of vision of the hand, though, was mediated by the target feedback condition, which is as we saw for radial error variability. That is, the availability of vision of the hand had an effect only in the target-present control condition and the delayed memory condition. Movements made in the immediate memory condition when vision of the hand was available did not differ from those when vision was not available. This lack of a difference arose due to the significant increase in variability when vision of the hand was available, suggesting again that in this target condition participants were unable to take advantage of the availability of vision of their hand in order to reduce their variability in pointing at the targets.

While having vision of the hand during pointing affected the accuracy and variability of aiming movements, vision of the hand also affected how the movements were controlled. When vision of the hand was available, participants spent proportionately more time in deceleration. This finding concurs with much other research (Khan et al., 2003) and indicates that processing visual information about the hand movement places demands on the time spent in deceleration.

4.3 Aging and Vision of the Limb in Aiming Movements

We have predicted that the effect of the availability of vision on the accuracy and variability of aiming movements and on movement kinematics would be greater for the elderly.

Analyses of endpoint error and variability provided mixed support for this prediction. Movements with vision of the hand exhibited significantly less radial and amplitude error and less variability for both of these measures and this effect was comparable for the two age groups. Age, however, did affect the bias to undershoot or overshoot targets as reflected in amplitude error. When vision of the hand was available there was virtually no bias to overshoot or undershoot the targets. However, when vision was not available, the tendency to undershoot or overshoot the targets increased significantly, with the young biased toward overshooting the targets and the elderly biased toward undershooting. This age difference in bias would appear to reflect a tendency for the young adults to bias their movements away from the body, while the elderly biased their movements toward the body.

Analyses of directional error revealed age differences that seemed to concur with the tendency in amplitude error to bias movements toward the body. As we noted above in our discussion of the overall effects of age, the young biased their movements away from the body and overestimating target position, while movements for the elderly were biased toward the body and underestimating target position.

Analyses of the proportion of time after peak velocity also provided mixed support for this prediction. Movements with vision of the hand exhibited significantly more time in deceleration. This effect was seen for both age groups, but the magnitude of this effect differed as a function of age and target position. For the young, the effect of having vision of the hand was most pronounced for the contralateral target, while for the elderly, this effect was largest for ipsilateral target. Although it is unclear why this effect of vision of the hand varies with age as a function of target position, it could be that the demands for processing visual feedback information in the online control of movement is greater for the young when pointing to the contralateral target but is greater for the elderly when pointing at the ipsilateral target. While the effect of the availability of vision varies as a function of target position for each age group, directly comparing the two age groups reveals that they differ in time spent in deceleration when vision of the hand is not available and when moving to the ipsilateral target. The elderly actually spend less time in deceleration than the young, suggesting that the demands of processing non-visual feedback during online control of movements to the ipsilateral target are less for the elderly as there were no differences in accuracy between the two age groups in the target position. This apparent advantage for the elderly in processing non-visual feedback information such as proprioception may arise from the increased practice the elderly have had in reaching for objects with the preferred right hand in right hemispace.

4.4 The Role of Limb Vision in Memory for Target Location

We predicted that movements made in the closed loop condition where vision of the limb is available would exhibit greater accuracy and less variability even when pointing to remembered targets. Further we predicted that when pointing to remembered targets the availability of vision of the limb would reduce the effect of memory delay on the endpoint accuracy and variability as Heath (2005) had found. Analyses of radial error supported the first prediction in that error was smaller when vision of the limb was available, even when pointing to remembered targets. While variability in radial error was also smaller with vision of the hand, this advantage for movements when vision of the hand was available was significantly smaller in the immediate than the delayed memory target condition. This difference in the advantage for movements with vision of the hand was also seen for variability in amplitude error. These findings suggest that in the immediate memory condition, participants do not seem as able to take advantage of the visual feedback in controlling their hand movement. That is when they move to the remembered target location with vision of the hand the variability at the movement endpoint was comparable to that when vision of the hand was not available. Performance in this immediate memory condition contrasts dramatically with that seen in the delayed memory condition where movements made with vision of the hand are significantly less variable than those where vision is not available.

The main difference between these conditions pertains to when the hand movement is initiated relative to occlusion of the target. In the delayed condition the hand movement begins 2 seconds after target occlusion while in the immediate condition the hand movement is initiated at the same time as target occlusion. It would appear that the temporal coincidence of these two events may have affected the planning and subsequent online control of the hand to the remembered target location. There would appear to be two effects on movement control here. Firstly, movements in this immediate memory condition would appear to be controlled much more using non-visual, likely proprioceptive, information since the advantage of having vision of the hand was significantly smaller in this condition than in the delayed memory condition. Secondly, there would appear to be a disruption in the planning and online control of the pointing movement in that the endpoint variability for both radial and amplitude error was significantly greater in this immediate memory condition than in the delayed memory condition.

What might be the source of this disruption to planning and control in the immediate memory condition? One possibility is that the variability in the hand movement arose from variability in eye movements at the remembered target location. While we did not measure eye movements with the precision needed to examine this variability, we did find that the success in accurately localizing the targets with the eyes did not differ between the immediate and delayed memory condition. The other possible source for this disruption in planning and control is the information used to control the movement. It appears that movements in the immediate memory condition may have relied much more on proprioceptive information than was the case in the delayed memory condition.

Analyses of amplitude error provides mixed support for this first prediction regarding the effect of vision of the hand on aiming movements, in that the effect of having vision depended on whether the target was present throughout the movement. In the target present control condition, participants were equally accurate whether or not vision of the hand was available. This finding suggests that participants were able to use proprioceptive information to accurately point to the targets since pointing without vision of the hand when only proprioception could be used was as accurate as when vision was available. While the accuracy data suggests that proprioception can be used to point to the visible targets, the variability of amplitude error questions this proposal: variability is significantly greater when vision of the hand is occluded and primarily proprioception is used to control the pointing movement. Taken together, these observations suggest that vision and proprioception may play different roles in controlling movements to visible targets, as far as the amplitude of the movement is concerned. Proprioception may be sufficient to accurately direct the hand to the targets. Having vision of the hand does not substantially increase the accuracy of pointing. Movements without vision of the hand, however, are much more variable with regard to movement amplitude, suggesting that vision is necessary to enable the consistency of the aiming movements in terms of movement amplitude.

While the presence of vision of the hand had little effect on accuracy in movement amplitude when the target was present throughout the movement, when pointing to remembered targets, accuracy was significantly reduced when vision of the hand was occluded. It is interesting to note that the magnitude of the error in movement amplitude is greater in the immediate than the delayed memory condition. This trend does not make sense with regard to the nature of the memory representation of target location; that is, one might predict that the magnitude of the error should be greater in the delayed memory condition since the time delay might reduce the quality of this representation. Rather, this finding with regard to the immediate memory condition seems to support the idea that initiating the hand movement coincident with target occlusion may disrupt the planning and online control of the aiming movement hence leading to greater amplitude error.

Looking at the sign of the amplitude error seems to shed some further light on how this planning/control process may have been disrupted. Movements in the delayed memory condition tended to be undershot in amplitude. This trend is consistent with what has been reported in the literature (Schneider et al., 1987; Romero et al., 2003). Movements in the immediate memory condition were overshot. Why might this inefficient approach to the aiming movement have been adopted in this condition? Examination of movement time and peak velocity provide a clue. Movements in this immediate memory condition overall exhibited significantly shorter movement time and greater peak velocity. This increase in the speed of movement may have resulted in this tendency to overshoot the targets. It is interesting to note that this apparent speed accuracy tradeoff is only seen when vision of the hand is occluded. When vision of the hand is available, the amplitude error is minimal and significantly less than when vision is occluded. Vision of the hand then appears to enable the participant to offset the effect of increased movement speed on movement accuracy when pointing to the remembered target locations. These findings suggest that as for pointing to visible targets, the accuracy of pointing to remembered targets in this immediate memory condition are enhanced.

Analyses of directional error also provide mixed support for the first prediction that vision of the hand would increase accuracy in pointing to remembered targets. For both memory conditions directional error was significantly smaller when vision of the hand was available, although again it was the immediate memory condition which showed the greater increase in error when vision was not available. Similar to amplitude error, this greater directional error could be due to the faster movements in this condition. Turning to the second prediction, it was clear that movements to remembered targets whether in the immediate or delayed condition were more accurate in both direction and amplitude when vision of the hand was available. This finding concurs with the work of Heath (2005) and suggests that having vision of the hand appears to enable the participant to better utilize the representation of target location when pointing to the remembered target locations. While vision of the hand facilitated movement accuracy, movement variability did not reveal this trend. One would have predicted that the increase in variability in the delay condition would be significantly smaller when vision of the hand is available. In fact, variability in both amplitude and radial error was greater in the immediate memory condition, an effect that we ascribed to a disruption in the planning and control of the aiming movement. This disruption in movement planning and control makes it difficult to interpret any differences between these two memory conditions in the context of the relative integrity of the memory representation over time. There was actually no evidence to support the prediction that the availability of vision of the hand would reduce the effect of memory delay on pointing accuracy or variability. Rather, the opposite trend was seen where the immediate memory condition exhibited less accuracy and greater variability.

4.5 Aging and Limb Vision in Memory for Target Location

From the multiple sources of aging literature, we predicted that the elderly would be unable to make as effective use of the representation of target location. In essence the increase in endpoint error when pointing to remembered targets as opposed to visible targets should be greater for the elderly and the effect of memory delay on accuracy and variability should be greater. We also predicted that removing vision of the limb when pointing at remembered targets should be greater for the elderly.

There was no evidence to support these predictions. For both the young and the elderly when vision was available aiming movements were very accurate and there were no differences in accuracy between movements to visible and remembered targets. When movements were made without vision of the limb accuracy decreased in all measures, that is, radial, directional and amplitude errors all increased. This pattern was seen for both age groups. When vision of the limb was not available the two age groups experience an equivalent decline in accuracy when pointing to remembered targets. These findings for error are mirrored in variability in that without vision of the limb both young and elderly experienced an increase in both radial and amplitude error variability. Together, these findings suggest that when vision of the limb is available, the healthy young and elderly participants in this study are equally able to use the representation of target location when pointing to remembered targets. When vision of the limb is not available, both age groups appear equally compromised in using the representation of target location with the greatest effect seen in the immediate memory condition. However, as we noted above performance in this condition may be ascribed more to a disruption in the planning and online control of the aiming movement than to impairments in the ability to maintain a representation of the target location. Interestingly this disruption in planning and online control appears to be comparable in the two age groups. That is, the requirement to initiate the pointing movement at the same time the target was occluded did not affect the elderly more than the young adults.

4.6 Eye Movement Trends

There were no significant main effects or interactions seen between age groups, limb feedback, target feedback or target position.

The eye movements seen while participants were performing the different tasks provided some insight into the accuracy and variability results.

When comparing all conditions (closed loop, open loop, in immediate memory, delayed memory and target present control conditions), there were no significant main differences in accuracy measures between age groups; that is, radial error, directional error or amplitude error was never significantly different between young adult and elderly participants. Inspecting the DVD recordings of elderly eye movements, elderly adults tend to switch their gaze between the target and the cursor representing their limb, or, in target absent conditions, tend to follow where their limb would hypothetically be to the remembered/present target location. Together, these qualitative observations and quantitative statistics suggest that these untypical gaze patterns may be a strategic gaze tactic in order to compensate for some type of decrement that occurred as a function of age.

5. Conclusions:

This study, although able to replicate and, therefore, provide strength to certain principles governing visuo-motor movements, has also unearthed some findings that, to date and our knowledge, have not been reported previously. These include the hypothesized disruption in planning processes during our immediate memory condition and the contrasting movement biases seen between young and elderly participants.

Vision of the Hand in Aiming Movements:

The availability of vision of the limb played an important role in aiming movements. When the target was visible throughout the movement, vision of the hand enabled more accurate and less variable movements. As well movements with vision of the limb available involved a greater proportion of time in deceleration.

Vision of the limb also played a role when pointing to remembered targets. Again movements with vision were more accurate and less variable. Further, as Heath (2005) found vision of the limb enabled the participant to maintain a more accurate representation of target location than if vision of the limb was not available.

Effects of Aging:

There were no overall age effects on any of the accuracy or endpoint kinematic measures. When pointing to visible targets there were no age differences in movement time, peak velocity or the proportion of time spent in deceleration, suggesting older adults proved to be as able to integrate visual and proprioceptive information from the movements as the younger adults. There were also no age differences in the ability to point to remembered targets. When vision of the limb was available the young and elderly appeared equally able to use the representation of target location when pointing to remembered targets. When vision of the limb was not available, both age groups appear equally compromised in using the representation of target location.

This lack of an overall age effect may have been due to the task being too cognitively simple. There are not multiple targets, perturbations or long delay periods, which generally tax cognitive processes. Because it has been argued that motor processing deterioration does not show between age groups of healthy adults unless they are exposed to cognitively demanding situations, this task may have not evoked aging effects as clearly as more difficult tasks (Lemay & Proteau, 2002; Sarlegna, 2006).

While there were no overall effects of age, age did have an effect on some aspects of performance. Age did have an effect on movement control when vision of the limb was unavailable throughout the movement. The elderly spent less time during the deceleration period of the movement when pointing to ipsilateral targets when vision of the hand was not available. This apparent advantage for the older adults in processing non-visual information (e.g. proprioception) when pointing to ipsilateral targets may have come from the increased practice the elderly have in reaching for objects with the preferred right hand in right hemispace area.

There were also age effects when examining directional and amplitude error when pointing to targets without vision. Data analyses of directional error showed the elderly participants consistently biased their movements toward their body aiming more to the right in contralateral (left) targets, and more to the left when reaching to ipsilateral (right) targets. Similarly, for amplitude error, their movements were biased toward their body in that they consistently undershot targets. These findings indicate that when they were unable to see their limb the elderly appeared to use their body as a referent more than did the young adults.

Disruption to Planning and Control of Movement in the Immediate Memory Condition:

Our results pointed to a disruption of planning and online control of movement in the immediate memory condition when vision of the limb was not available. Compared to the delayed memory condition, movements in the immediate memory condition exhibited greater directional and amplitude error. This difference was unexpected in that error should have been greater in the delayed memory condition with the magnitude of this difference depending on the ability to retain the representation of target location over the memory delay. The larger error in the immediate memory condition was thought due to the temporal coincidence between movement initiation and target occlusion in this condition compared to the delayed memory condition where there was a 2 second interval between these events. This temporal coincidence was thought to cause a disruption in the planning and online control of the reaching movement resulting in the increased error. Interestingly, this disruption was seen only when vision of the limb was not available suggesting some disruption in the use of non-visual information when pointing to the remembered target location.

Further insight into this disruption in planning was seen when comparing movements with and without vision of the limb on endpoint variability. In the delayed memory condition endpoint variability was significantly less when vision of the limb was available. In contrast in the immediate memory condition the advantage for movements with vision of the limb in terms of reduced endpoint variability was dramatically smaller, suggesting that participants were much less able to take advantage of the availability of vision of their hand in order to reduce their variability in pointing at the remembered target location.

6. Recommendations for Further Research:

In our study, the results indicated that a brief processing period between target occlusion and movement onset when moving to remembered targets may be required to allow for a more accurate and less variable movement. This was postulated because there were more errors made in our immediate memory condition, where movement onset was forced to occur simultaneously with target occlusion. Thus, in future studies, a new condition that allows for target occlusion to occur when the participant begins movement onset might allow for more insight into how delay times might affect movements to remembered targets in terms of accuracy and variability measures, as well as examine the notion of a time-sensitive representation of the target in memory.

Another direction that this research can take is one involving the eyetracker apparatus. In this current study, due to time constraints, the eyetracker was strictly used to see whether participants focused on the target location before and during movement. We examined this by taking the percentage of stable eye movement that remained on targets during the target pointing. Studies found in literature have suggested that there may a common neural site that incorporates the eye movement information with the motor movement output, leading to equal amounts of hand movement amplitude changes regardless of moving to visible or remembered targets. However, the timing between the onset and offsets of the eye movement saccades and hand movement differs between visual and remembered target movements (Van Donkelaar & Staub, 2000).

As well, there may actually be more than one reference frame when pointing only to remembered targets. The direction of the movement appears to be coded in a frame of reference that is more linked to the moving limb, whereas the amplitude of the movement is seem to be more reliant on a frame of reference that is central to the eye (Lemay & Stelmach, 2005).

Future research can employ the eyetracker to find out the exact coordinates of where the eye is looking throughout the entire movement, and put together this information with the kinematic, accuracy and variability measures to discover the role of eye movements and frame of references used during both visually guided and memory dependent pointing movements.

There were no significant age differences seen between any of the conditions in terms of accuracy measures, suggesting that older adults are able to integrate the visual and proprioceptive information of the target and limb, and use it just as well as the young adult participants. Another future direction that can further probe this hypothesis is by increasing the complexity of this study, perhaps by perturbing the target or adding multiple targets into the protocol to be remembered. Whether the natural aging motor and cognitive deteriorations show between age groups will be interesting to examine.

In terms of analysis, it would be a useful addition to perform a regression analyses, similar to Heath's methods in his 2005 study. He used this technique in order to investigate the variable proportion at three points in the movement: peak acceleration, peak velocity, and peak deceleration. Analyzing the variability in these particular spatial location during movement allows for insight into what corrective movements may have been made in each phase of movement, which again may allow researchers to more thoroughly comprehend the different natures of open loop and closed loop task, as well as the how target presence and position influences movement kinematics.

As well, in future studies, incorporation of reaction time may be advantageous to allow for differences between the age groups to become more apparent. Elderly adults have been shown to require longer reaction times (e.g. Poston et al, 2008) and elicit greater variability between reaction times, indicating this measurement may be important in terms of indicating the level of cognitive aging and functioning (Hultsch, MacDonald & Dixon, 2002). Regression analysis may also be helpful to use with this measure of reaction time; studies have indicated, using this method of analysis, that mental processing in non-demented elderly adults slows additively, but not proportionately (e.g. Bashore, Osman & Heffley, 1989).

Future research in this area can also start to incorporate neuroimaging techniques. There has been literature suggesting that parts of the posterior parietal lobe and intraparietal areas are activated during pointing movements. These are linked to the premotor areas in order to subserve visual and proprioceptive control. Gregoriou and Savaki (2003), in a functional imaging study involving monkeys, had their primate participants reach to targets in both lit environments (with a plethora of information, akin to our closed loop-target present condition) and in darkened environments, similar to our open loop-target absent condition. They found there were specific "circumscribed regions in the intraparietal cortex” that were activated under these particular reaching conditions. These areas belong to a “parietal-premotor circuit” that attends to the various sources of information from the environment in order to guide the arm to make the most accurate movement possible. Reaching in the darkened environments relies on proprioceptive information and uses the stored representation of the target location; using neuroimaging, the researchers have found two “largely segregated neuronal ensembles” that assist in controlling the visual and proprioceptive/nonvisual components of aiming and reaching to targets within this parieto-premotor circuit (Gregoriou & Savaki, 2003; Milner et al., 1999). It would be interesting to see what types of areas are activated in conditions in which the environment in which the limb is occluded but the target is present, or when the target is occluded but the limb is still present.

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Appendices

Appendix A

Waterloo Research in Aging Pool (WRAP): Participant Screening Questionnaire

WRAP
Participant Information Booklet

Participant Name:

____

Recruited from which Source?

____

Date Contacted:

____

Questionnaire Completed By:

____

Data Entered (Date):

____

Participant Identification Code:

____

GENERAL INFORMATION

Name:
____

Address: ____

____

____

Telephone:
____

Email:
____

Gender:
____

D.O.B.:
____

First Language (if not English, how old were you when you learned English?)
____

Total Education (in years):
____

Handedness:
____

If UW staff/faculty member, please indicate which department you work/worked in:

____

MEDICAL INFORMATION

1. *Please describe your general health.*

____
____
____

2. *Have you ever had any neurological problems (i.e. strokes, seizures)?*

Yes No

If yes, please describe:

____
____
____

3. *Have you ever been unconscious for any length of time (i.e. head injury, black-outs)?*

Yes No

If yes, please describe:

____
____
____

4. *Have you ever been diagnosed with any medical conditions or illnesses?*

Yes No

If yes, please describe:

____
____
____

5. *Have you ever had any surgeries?*

Yes No

If yes, please describe:

____
____
____

6. *Do you drink alcohol?*

Yes No

If yes: How many times per week/month?
How many drinks would you consume on the average occasion?
Preference: Beer Wine Liquor
Has it ever been a problem for you?
If yes: Did you receive treatment?

If no, did you ever drink? Yes No
How many times per week/month?
How many drinks would you consume on the average occasion?
Preference: Beer Wine Liquor
Has it ever been a problem for you?
If yes: Did you receive treatment?

7. *Do you, or have you used recreational drugs including marijuana?*

Yes No

If yes: Are you currently or was it in the past?
How often per week or per month?
Which drug or drugs?
How long have you been/were you using this drug for?
Did you ever receive treatment for it?

8. *Have you ever been treated for anxiety, depression, or any other psychological problem?*

Yes No

If yes: What were you treated for?
When did you begin receiving treatment?
How long did the treatment last?
What type of treatment did you receive?
Were you ever prescribed any medication?
What were you prescribed to take?
How long did you take that medication for?
Were you ever hospitalized?

9. *Are you currently taking any medications?*
Yes No

Drug	Dosage	Reason
1.		
2.		
3.		
4.		
5.		

10. *Is your current weight over 200 lbs?*

Yes No

What is your height? _________

11. *Do you wear glasses or contact lenses?*

Yes No

If yes: For reading or distance?

12. *Do you have any difficulty with your hearing?*

Yes No

If yes: Do you wear a hearing aid?

13. *Have you ever had a stroke or a T.I.A? (Transient Ischemic Attack)?*

Yes No

14. *Have you been seen by a neurologist or a neurosurgeon?*

Yes No

If yes: Was this for a back or neck problem?
If yes: Was this for a tension headache?

15. *Have you had cancer other than skin cancer diagnosed within the last three years?*

Yes No

16. *Do you have shortness of breath when sitting?*

Yes No

17. *Do you use home oxygen?*

Yes No

18. *Do you have difficulty understanding conversations because of your hearing even if you wear a hearing aid?*

Yes No

19. *Do you have trouble with your vision that prevents you from reading ordinary print even if you have glasses on?*

Yes No

20. *Have you had heart surgery?*

Yes No

21. *Have you ever been resuscitated?*

Yes No

22. *Do you have diabetes that requires insulin to control?*

Yes No

23. *Do you have hypertension that is not well controlled?*

Yes No

24. *Have you had a head injury with loss of consciousness greater than five minutes?*

Yes No

25. *Have you ever been unconscious for more than one hour other than during surgery?*

Yes No

26. *Have you ever required overnight hospitalization because of a head injury?*

Yes No

27. *Have you had encephalitis or meningitis?*

Yes No

28. *Have you ever had a heart attack?*

Yes No

If yes: Did you have any change in your memory, ability to talk or solve problems 24 hours after your heart attack?

29. *Are you currently taking medications for mental or emotional problems?*

Yes No

30. *Have you been hospitalized for mental or emotional problems in the past five years?*

Yes No

31. *Have you ever had seizures?*

Yes No

32. Do you have Parkinson's disease?

Yes No

33. Have you ever had brain surgery?

Yes No

34. Have you ever undergone surgery to clear arteries to the brain?

Yes No

35. Have you ever had any illness that caused a permanent decrease in memory or other mental functions?

Yes No

36. Have you ever received electroshock therapy?

Yes No

37. Have you ever been diagnosed as learning disabled?

Yes No

38. Were you placed in special classes in school because of learning problems?

Yes No

39. Have you ever been diagnosed as having a brain tumour?

Yes No

40. Do you have difficulty using your hands?

Yes No

41. Have you ever had major surgery with anaesthesia?

Yes No

If yes: Did you have any change in your memory, ability to talk or solve problems one week after surgery?

42. Do you have multiple sclerosis, cerebral palsy, or Huntington's disease?

Yes No

43. Are you receiving kidney dialysis?

Yes No

44. Do you have liver disease?

Yes No

45. Do you have lupus?

Yes No

Request for Participants Summary

New Request? _____ Request for Additional Participants? _____ - project #________

Name of Project: Contact email: ______________________________

____

Principal Investigator (please indicate if you are a student):

____

Collaborators (if you are a student, please indicate your supervisor):

____

Number of participants required: Anticipated duration of study (minutes):

_______________________________ _____________________________________

Inclusion criteria:

____

Exclusion criteria:

____

ORE Approval number: Type of study (i.e. memory, cognitive, etc.):

________________________________ _____________________________________

Testing requirements (time, number of sessions, type of testing, location of testing, etc.):

____

For WRAP - Project completed? (Date): ___________________________

I agree to hold any personal information about potential participants in the strictest confidence. I agree to contact these participants for the purposes of the study described above, and I agree to notify the WRAP Coordinator as soon as I no longer require these participants for the purposes of this study. I will not contact potential participants that I know personally, or whose names are familiar to me – instead, I will notify the WRAP Coordinator of this conflict of interest immediately, and additional names will be provided to me in order to replace the ones that I recognize. I agree to provide the WRAP Coordinator with a one-page summary of this study upon request, to facilitate publication of the WRAP Participant Newsletter. I HAVE READ AND AGREE TO ABIDE BY THE POLICIES AND PROCEDURES ASSOCIATED WITH WRAP.

Signed: _________________________________ *Date:* ________________________

Appendix B

Information, Consent and Feedback Forms

INFORMATION LETTER

Title of Project: Effects of Aging in Pointing to Visible and Remembered Targets

Faculty Advisor: Dr. Eric Roy
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This study is being conducted to investigate how hand movements to various targets are controlled and remembered, and the consequences that aging has on these processes. Relatively little is known about how aging affects memory for and control of movements to targets in space.

As a participant in this study, you will be asked to move a cursor on a computer monitor using a mouse. After you hear an auditory tone, you are to initiate movement and slide the cursor on the screen to the target via the mouse. An eye tracker device will be placed on your head to account for eye movements. This technology consists of a crown-like apparatus worn on your head. There are two cameras attached on this crown: one fixated at your where your eye moves, and one is aimed at where you are looking in the environment. The eye tracker device is there to detect eye movements and is not intrusive whatsoever.

The procedure will take about 60 minutes to complete.

You will first perform 9 practice trials, which will expose you to all the conditions in our study: control, immediate recall, and delayed recall in both open loop (pointing limb occluded) and closed loop (pointing limb visible) settings. These will be described below. Following these practice trials, you will then be asked to perform the actual tasks, with your data being recorded for later analysis. **You should try to hit the target as quickly and as accurately as you possibly can.**

For each condition, there is a 5 second "preparation" period before presentation of the target on each trial. During this time you should move the mouse back to the start position in preparation for the presentation of the target. In all conditions the target will be presented for 1 second.

Visual conditions you will be exposed to:

1. Target Present (TP) conditions:
Following the target presentation time an auditory cue will sound signalling movement to the target. In these conditions, the target will remain on throughout the movement

2. Target Absent (TA) conditions:
Following the target presentation time the target will be occluded. In the *immediate recall* condition, the auditory cue signalling movement to the target will sound at the same time the target is occluded. In the *delay recall* condition, the auditory cue will sound two seconds after the target is occluded.

Limb Conditions you will be exposed to:

1. Closed loop (CL):
In this condition, you will always see your pointing limb's movement depicted as a yellow cursor on the screen.

2. Open loop (OL):
In this condition, you will not be able to see yourself moving to the target. However, you will be able to see the yellow cursor at the "home" position at the beginning of each trial.

The limb conditions will be put together with the visual conditions. In doing so, there becomes 6 blocks of trials (CL-TP, CL-TA-Immediate, CL-TA-Delayed, OL-TP, OL-TA-Immediate, OL-TA-Delayed), each consisting of 18 trials to total 108 trials. Target presentation in each block will be randomized and order of blocks will be randomized.

Some of you may not benefit personally from your participation in this study. However, you may learn about your own motor capabilities within the visual aiming domain. Also, you will have first hand experience in a psychomotor laboratory setting, which may be of interest to them in the future. Some of you may earn a credit towards your classes. Lastly, older individuals recruited from the Waterloo Research in Aging Participant Pool will earn $10.

We want you to be aware of the possible risks associated with participation in this research. There are no known risks for healthy participants. However, some participants may become anxious when performing the tasks, due to the hurried nature of the tasks. As well, because there are multiple trials that will be performed, some participants may feel tired. If this occurs, a break can be requested. As a researcher, I will be monitoring for any signs of distress or fatigue and I will suggest a break if it seems appropriate.

All information collected from participants in this study will be collectively combined. Thus, your name will not appear in any report, publication or presentation resulting from this study. The data, with identifying information removed, will be retained indefinitely and will be securely stored in a locked room in Burt Matthews Hall or kept with myself on my computer, which is password protected.

If you have any questions about participation in this study, please feel free to ask the researchers. If you have additional questions at a later date, please contact Dr. Eric Roy at the University of Waterloo (519-888-4567, ext. 33536) on any weekday between 8:30 A.M. and 4:30 P.M, or email myself at kkwlau@uwaterloo.ca.You are under no obligation to participate and may withdraw from the study at any time by advising the researcher of this decision. In no way will this impact your relationship with the university, or the researchers.

I would like to assure you that this study has been reviewed and received ethics clearance through the Office of Research Ethics. However, the final decision about participation is yours. If you have any comments or concerns resulting from your participation in this study, you may contact Susan Sykes, Director of the Office of Research Ethics at (519) 888-4567 ext. 36005, or by email at ssykes@uwaterloo.ca.

Consent of Participant

I have read the information presented in the information letter about a study being conducted by Karen Lau, and Dr. Eric Roy of the Department of Kinesiology at the University of Waterloo. I have had the opportunity to ask any questions related to this study, to receive satisfactory answers to my questions, and any additional details I wanted. I am aware that I may withdraw from the study without penalty at any time by advising the researchers of this decision.

This project has been reviewed by, and received ethics clearance through, the Office of Research Ethics at the University of Waterloo. I was informed that if I have any comments or concerns resulting from my participation in this study, I may contact the Susan Sykes, Director, Office of Research Ethics at (519) 888-4567 ext. 6005.

With full knowledge of all foregoing, I agree, of my own free will, to participate in this study.

____

Print Name

____

Signature of Participant

____

Dated at Waterloo, Ontario

____

Witnessed

FEEDBACK LETTER

Title of Project: Effects of Aging in Pointing to Visible and Remembered Targets

Faculty Advisor: Dr. Eric Roy
University of Waterloo, Department of Kinesiology
(519) 888-4567 Ext. 33536 or by email at eroy@uwaterloo.ca

Student Investigator: Karen Lau, BSc. Kin (Hons)
University of Waterloo, Department of Kinesiology
(519) 888-4567 Ext 33865 or by email at kkwlau@uwaterloo.ca

I would like to thank you for your participation in this study. Aging is a combination of inevitable processes that involves e very aspect of the human body. A method of investigating the effects of aging is to have both young and elderly adults perform movements that require precision and mental representation of a goal (Roy, Weir, Winchester & Desjardins-Denault, 1999). A suggested method to execute these movements is to carry out a pointing and reaching task (a movement which requires some precision), in situations that call for participants to reach to targets both in full vision and memory conditions. These categories of action are termed, "visually guided" and "target memory dependent" (also known as, "goal reproducing") movements, respectively. As a reminder, the objective of the proposed study, then, is to determine how normal, healthy individuals of 2 different age groups differ in performance of precise pointing movements.

This study required participants of different ages in order to compare various characteristics of movement, including pointing accuracy, as measured by radial error, reaction time (the time it takes to initiate movement), movement time (the time it takes to complete a movement), as well as other measurements, such as velocity, acceleration and deceleration. The movement distance to the targets and the spatial position of the targets varied in order to examine the effects of these variables on the accuracy of your movement to the target location. For example, it is expected that targets further from the home position will be less accurate (larger radial error), although there should not be a significant difference between young and older healthy people.

The information obtained from this research may lead to furthering knowledge in the psychomotor behaviour field within Kinesiology. Data collected may also lead to useful knowledge regarding how aging effects the motor and cognitive system in terms of fine motor control and memory. Lastly, participation may aid in further studies that may establish normative data useful for research with special populations.

Please remember that any data pertaining to you as an individual participant will be kept confidential. If you are interested in receiving more information regarding the results of this study, or if you have any questions or concerns, please feel free to contact my project supervisor, Dr. Eric Roy, at the University of Waterloo (519-888-4567, ext. 33536) on any weekday between 8:30 A.M. and 4:30 P.M. If you would like a summary of the results, please let me know now by providing me with your resident address, telephone number, or email address. When the study is completed, Dr. Roy and I will send the information to you. The expected date of study completion is by late 2008.

As with all University of Waterloo projects involving human participants, this project was reviewed by, and received ethics clearance through, the Office of Research Ethics at the University of Waterloo. Should you have any comments or concerns resulting from your participation in this study, please contact Dr. Susan Sykes in the Office of Research Ethics at 519-888-4567, Ext., 36005.

Karen Ka Wing Lau, BSc. Kin (Hons)
MSc. Candidate
Department of Kinesiology
Psychomotor Behaviour Lab
University of Waterloo

The following reference is provided in case you might like to read further in this area of research:

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.

Appendix C

Mean Tables

Kinematic Data:

Table 1: Movement Time

Age Group	Limb Feedback	Target Feedback	Target Position	Movement Time (secs)
Young	CL	IMEM	CON	0.689 (0.065)
			MID	0.648 (0.07)
			IP	0.642 (0.059)
		DMEM	CON	0.78 (0.081)
			MID	0.758 (0.072)
			IP	0.762 (0.086)
		CTRL	CON	0.725 (0.083)
			MID	0.720 (0.079)
			IP	0.661 (0.081)
	OL	IMEM	CON	0.736 (0.089)
			MID	0.794 (0.105)
			IP	0.661 (0.081)
		DMEM	CON	0.799 (0.123)
			MID	0.813 (0.119)
			IP	0.777 (0.121)
		CTRL	CON	0.847 (0.107)
			MID	0.824 (0.094)
			IP	0.785 (0.112)
Elderly	CL	IMEM	CON	0.910 (0.069)
			MID	0.887 (0.074)
			IP	0.801 (0.063)
		DMEM	CON	0.962 (0.086)
			MID	0.910 (0.076)
			IP	0.919 (0.090)
		CTRL	CON	0.967 (0.087)
			MID	0.914 (0.084)
			IP	0.905 (0.085)
	OL	IMEM	CON	0.865 (0.094)
			MID	0.854 (0.111)
			IP	0.781 (0.095)
		DMEM	CON	0.938 (0.129)
			MID	0.930 (0.125)
			IP	0.888 (0.128)
		CTRL	CON	0.922 (0.113)
			MID	0.928 (0.099)
			IP	0.818 (0.118)

Table 2: Peak Velocity:

Age Group	Limb Feedback	Target Feedback	Target Position	Peak Velocity (mm/s)
Young	CL	IMEM	CON	335.217 (32.732)
			MID	333.610 (33.09)
			IP	369.447 (37.554)
		DMEM	CON	292.281 (29.246)
			MID	290.833 (30.492)
			IP	300.037 (36.036)
		CTRL	CON	328.03 (32.294)
			MID	323.692 (32.16)
			IP	379.131 (43.349)
	OL	IMEM	CON	372.812 (41.965)
			MID	368.414 (43.364)
			IP	406.364 (46.54)
		DMEM	CON	301.504 (35.708)
			MID	312.104 (37.216)
			IP	345.893 (40.766)
		CTRL	CON	319.371 (38.668)
			MID	312.370 (39.658)
			IP	357.548 (47.82)
Elderly	CL	IMEM	CON	249.143 (34.502)
			MID	256.217 (34.88)
			IP	287.041 (39.585)
		DMEM	CON	217.929 (30.828)
			MID	229.904 (32.141)
			IP	250.504 (37.986)
		CTRL	CON	233.524 (34.041)
			MID	245.701 (33.900)
			IP	258.208 (45.694)
	OL	IMEM	CON	257.295 (44.235)
			MID	259.777 (45.710)
			IP	295.265 (49.058)
		DMEM	CON	207.47 (37.639)
			MID	217.430 (39.229)
			IP	234.103 (42.972)
		CTRL	CON	201.490 (40.760)
			MID	207.135 (41.804)
			IP	238.064 (50.406)

Table 3: Percent Time After Peak Velocity

Age Group	Limb Feedback	Target Feedback	Target Position	Time After PV (%)
Young	CL	IMEM	CON	61.583 (2.162)
			MID	56.436 (1.755)
			IP	58.221 (2.894)
		DMEM	CON	61.080 (1.986)
			MID	59.147 (2.583)
			IP	65.3111 (3.101)
		CTRL	CON	63.222 (2.032)
			MID	60.565 (1.563)
			IP	65.311 (3.101)
	OL	IMEM	CON	54.200 (2.530)
			MID	56.872 (2.653)
			IP	57.634 (2.708)
		DMEM	CON	55.739 (3.372)
			MID	55.059 (2.984)
			IP	59.834 (2.970)
		CTRL	CON	59.292 (2.913)
			MID	59.632 (2.702)
			IP	61.319 (3.473)
Elderly	CL	IMEM	CON	60.204 (2.278)
			MID	54.734 (1.850)
			IP	60.915 (3.051)
		DMEM	CON	56.594 (2.093)
			MID	59.039 (2.723)
			IP	62.065 (3.026)
		CTRL	CON	60.627 (2.142)
			MID	59.284 (1.648)
			IP	64.641 (3.269)
	OL	IMEM	CON	56.528 (2.667)
			MID	54.255 (2.797)
			IP	54.929 (2.854)
		DMEM	CON	58.956 (3.555)
			MID	52.436 (3.145)
			IP	53.259 (3.131)
		CTRL	CON	58.022 (3.071)
			MID	55.695 (2.848)
			IP	56.799 (3.661)

Accuracy:

Table 1: Radial Error Means of Young Adult Participants

	Contralateral (mm)	Midline (mm)	Ipsilateral (mm)
CL-IMEM	4.10 (5.45)	3.26 (5.50)	3.60 (5.40)
CL-DMEM	5.17 (6.20)	2.96 (5.34)	4.16 (4.44)
CL-CTRL	2.21 (2.83)	2.28 (3.19)	2.21 (4.52)
OL-IMEM	25.75 (13.87)	26.58 (15.80)	24.20 (14.99)
OL-DMEM	15.38 (10.12)	19.64 (14.05)	17.88 (15.24)
OL-CTRL	23.77 (18.73)	26.85 (11.95)	27.02 (19.59)

Table 2: Radial Error Means of Elderly Participants

	Contralateral (mm)	Midline (mm)	Ipsilateral (mm)
CL-IMEM	8.09 (0.30)	6.89 (3.04)	5.36 (3.03)
CL-DMEM	7.52 (-0.96)	4.61 (1.83)	4.09 (1.49)
CL-CTRL	2.79 (1.81)	2.56 (1.96)	3.00 (1.09)
OL-IMEM	39.18 (4.70)	37.19 (3.97)	33.24 (1.84)
OL-DMEM	30.80 (15.02)	28.76 (8.78)	29.41 (7.94)
OL-CTRL	18.73 (13.56)	11.95 (16.31)	19.59 (8.57)

Table 3: Directional (X) Error Means of Young Adult Participants

	Contralateral (mm)	Midline (mm)	Ipsilateral (mm)
CL-IMEM	-1.26 (1.83)	-0.28 (1.65)	0.81 (3.34)
CL-DMEM	-0.11 (3.34)	-0.44 (2.12)	1.31 (2.96)
CL-CTRL	-0.31 (1.76)	-0.511 (1.19)	0.36 (1.72)
OL-IMEM	-12.79 (15.57)	0.62 (6.55)	17.67 (13.88)
OL-DMEM	-3.54 (11.82)	3.72 (9.41)	13.43 (10.54)
OL-CTRL	-7.12 (18.69)	1.45 (5.79)	19.58 (12.58)

Table 4: Directional (X) Error Means of Elderly Participants:

	Contralateral (mm)	Midline (mm)	Ipsilateral (mm)
CL-IMEM	2.84 (9.51)	-0.52 (1.17)	-3.53 (10.01)
CL-DMEM	0.4 (6.39)	0.35 (1.78)	-0.15 (3.97)
CL-CTRL	1.09 (1.56)	-0.49 (1.22)	-2.32 (3.35)
OL-IMEM	-2.48 (27.34)	-4.8 (5.81)	0.53 (23.54)
OL-DMEM	8.19 (19.38)	-4.6 (2.80)	-7.01 (18.34)
OL-CTRL	7.01 (17.75)	-1.85 (5.41)	-6.78 (18.26)

Table 5: Amplitude (Y) Error Means of Young Adult Participants:

	Contralateral (mm)	Midline (mm)	Ipsilateral (mm)
CL-IMEM	-1.09 (4.26)	-0.20 (3.48)	-2.63 (3.43)
CL-DMEM	-1.97 (4.33)	-1.06 (2.37)	-2.51 (2.69)
CL-CTRL	-0.93 (1.86)	-1.29 (2.04)	-1.12 (2.24)
OL-IMEM	14.55 (16.92)	22.94 (24.09)	9.68 (20.28)
OL-DMEM	-1.14 (14.17)	8.82 (21.06)	-2.61 (11.51)
OL-CTRL	11.2 (22.81)	18.53 (27.27)	7.86 (17.42)

Table 6: Amplitude (Y) Error Means of Elderly Participants:

	Contralateral (mm)	Midline (mm)	Ipsilateral (mm)
CL-IMEM	0.30 (7.81)	-3.04 (9.38)	-3.03 (11.53)
CL-DMEM	-0.96 (7.68)	1.83 (5.33)	-1.49 (2.78)
CL-CTRL	-1.82 (2.46)	-1.96 (1.78)	-1.09 (1.39)
OL-IMEM	4.70 (36.47)	3.97 (43.75)	1.84 (26.89)
OL-DMEM	-15.02 (26.99)	-8.78 (36.53)	-7.95 (26.89)
OL-CTRL	-13.56 (25.85)	-16.32 (29.41)	-8.57 (21.40)

Standard Deviation:

Table 1: Standard Deviation for Radial Mean Error: Young Adults Participants

	Contralateral (mm)	Midline (mm)	Ipsilateral(mm)
	5.45	5.50	5.40
CL-IMEM	(3.14)	(2.56)	(2.53)
	6.20	5.34	4.44
CL-DMEM	(2.35)	(1.77)	(1.69)
	2.83	3.19	4.52
CL-CTRL	(1.12)	(1.27)	(4.65)
	13.87	15.80	14.99
OL-IMEM	(3.69)	(5.34)	(5.32)
	10.12	14.05	15.24
OL-DMEM	(3.39)	(5.50)	(6.41)
	18.73	11.95	19.59
OL-CTRL	(5.73)	(3.86)	(8.93)

Table 2: Standard Deviation for Radial Mean Error: Elderly Participants

	Contralateral (mm)	Midline (mm)	Ipsilateral (mm)
	15.48	18.87	16.30
CL-IMEM	(24.42)	(22.62)	(23.40)
	6.55	4.35	6.93
CL-DMEM	(2.93)	(2.17)	(4.83)
	3.32	3.06	3.18
CL-CTRL	(1.07)	(1.26)	(1.01)
	20.62	17.80	15.03
OL-IMEM	(18.74)	(9.27)	(8.63)
	14.73	10.49	14.97
OL-DMEM	(5.67)	(4.36)	(6.91)
	19.55	15.88	17.51
OL-CTRL	(7.57)	(5.75)	(9.43)

Table 3: Standard Deviation for Directional (X) Error Means: Young Adult Participants

	Contralateral (mm)	Midline (mm)	Ipsilateral (mm)
	3.42	3.34	3.69
CL-IMEM	(1.73)	(1.24)	(1.85)
	4.27	2.07	3.02
CL-DMEM	(2.65)	(1.29)	(1.55)
	1.83	1.43	1.82
CL-CTRL	(0.69)	(1.13)	(1.60)
	10.66	5.33	9.85
OL-IMEM	(2.75)	(3.00)	(3.96)
	6.86	4.74	10.48
OL-DMEM	(2.85)	(1.37)	(4.83)
	15.85	11.40	13.79
OL-CTRL	(15.21)	(19.59)	(11.77)

Table 4: Standard Deviation for Directional (X) Error Means: Elderly Participants

	Contralateral (mm)	Midline (mm)	Ipsilateral (mm)
CL-IMEM	12.76 (22.48)	5.45 (10.49)	11.43 (16.86)
CL-DMEM	3.93 (1.60)	1.94 (1.38)	4.12 (2.86)
CL-CTRL	1.63 (0.94)	1.32 (0.54)	2.21 (0.95)
OL-IMEM	17.57 (18.52)	4.99 (2.33)	8.98 (6.28)
OL-DMEM	9.17 (2.38)	4.79 (2.13)	9.40 (2.90)
OL-CTRL	11.55 (3.50)	3.16 (2.22)	6.59 (12.72)

Table 5: Standard Deviation for Amplitude (Y) Error Means: Young Adult Participants:

	Contralateral (mm)	Midline (mm)	Ipsilateral (mm)
CL-IMEM	3.96 (3.06)	4.27 (2.44)	3.82 (2.02)
CL-DMEM	4.14 (1.37)	4.79 (1.68)	3.07 (1.29)
CL-CTRL	1.99 (1.04)	2.69 (1.18)	1.98 (0.72)
OL-IMEM	9.41 (3.48)	13.43 (3.96)	11.29 (4.29)
OL-DMEM	7.05 (3.11)	13.04 (5.80)	10.61 (5.33)
OL-CTRL	13.29 (7.10)	10.87 (4.70)	12.41 (6.70)

Table 6: Standard Deviation for Amplitude (Y) Error Means: Elderly Participants

	Contralateral (mm)	Midline (mm)	Ipsilateral (mm)
CL-IMEM	6.55 (11.49)	18.57 (22.80	13.98 (20.68)
CL-DMEM	5.09 (2.79)	3.61 (2.26)	5.50 (4.00)
CL-CTRL	2.78 (1.00)	2.68 (1.33)	2.19 (0.78)
OL-IMEM	9.41 (6.30)	16.80 (9.57)	11.53 (6.99)
OL-DMEM	11.21 (5.89)	8.99 (4.64)	11.15 (7.23)
OL-CTRL	15.39 (7.78)	14.48 (6.56)	13.21 (8.51)