6-17-2014

Visuomotor adaptation in older adults with and without cognitive impairment

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Visuomotor Adaptation in Older Adults with and without Cognitive Impairment

by

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Thesis

Submitted to the Department of Psychology

Eastern Michigan University

in partial fulfillment of the requirements

for the degree of

MASTER OF SCIENCE

in

General Clinical Psychology

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June 17, 2014

Ypsilanti, Michigan

Abstract

Even in early stages, dementia can cause motor declines, hindering the ability to carry out tasks encountered in daily living. Error-driven learning processes are believed to be central to visuomotor adaptation. Research has shown that increasing error feedback may enhance adaptation in neurologically damaged participants. Some literature on dementia and motor learning has indicated that demented patients have a tendency to rely more on sensory feedback for movement control. This study examined augmentation of error feedback in elderly controls and cognitively impaired individuals. A center-out visuomotor adaptation task assessed motor learning in two experimental conditions: normal and enlarged error feedback. It was hypothesized that the cognitively impaired would benefit from the enlarged feedback. Results indicated no differences in adaptation between groups in the normal condition. The enlarged condition revealed an interaction the after-effects of spatial deviation under movement paths, suggesting that cognitively impaired elderly may benefit from increasing visual error-feedback.

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Introduction

The acquisition of motor skills is an imperative developmental phase of an individual's life. The process of motor skill acquisition, or motor learning, can be defined as a set of processes in which practice or experience leads to relatively permanent changes in respondent capabilities (Schmidt & Wrisberg, 2008). Literature has identified motor learning deficits in the elderly (Bock, 2005; Cressman, Salomonczyk, & Henriques, 2010; Heur & Hegele, 2008a; Seidler, 2006; Szafran, 1951; Yan, Thomas, & Stelmach, 1998). Fine motor skills, gait and balance, movement accuracy, and movement speed are some examples of motor loss in the elderly (Seidler et al., 2009). Preservation of motor abilities could be a particularly vital step in maintaining independent living for the aging person.

The elderly population is increasing at a high rate. By 2030, it is expected that 20% of the world's population will be 65 and older (Thies & Bleiler, 2012). Increasing long-term care costs in the elderly make this growing population especially concerning. The national average annual nursing home cost escalated to over $83,000 in 2013 (Genworth Financial, 2013). Given these statistics, providing ways in which the elderly can maintain independent living is not only ethically important, but economically important as well. An increase in the research on motor learning in the elderly, especially those who are at risk for placement in assisted living facilities, should occur. Among the limited research on demented individuals, general motor learning deficits have been observed. However, it has been found that mildly demented individuals can maintain the capacity to learn some new motor skills (Gabrieli, Corkin, Mickel, & Growdon, 1993; Rouleau, Salmon, & David, 2002). But unfortunately, the conditions in which motor skills can be preserved or enhanced in the demented are not fully understood and have not been adequately studied.

Studies have revealed that increased sensory error feedback could enhance motor learning of stroke patients (Patton, Stoykov, Kovic, & Mussa-Ivaldi, 2006). Error feedback is the information received when the movement is deviating from the planned (feed-forward) movement (Wolpert, Diedrichsen, & Flanagan, 2011). Motor learning models have indicated sensory feedback as an important factor that drives motor learning (Shadmehr, Smith, & Krakauer, 2010; Wolpert et al., 2011). Increasing error feedback could have practical implications in the dementia population, and this study will attempt to address this knowledge gap in the literature.

The following sections will first review the prevalence, cost, types, symptoms, etiology, and neuropsychological function in demented individuals. Then, various motor learning models will be discussed to provide a framework of motor learning throughout the lifespan and to address the role of sensory error feedback in motor learning. Next, a discussion has been included on visuomotor learning in the elderly as well as in the demented. Finally, based upon the empirical studies and the proposed models, the specification of research questions and hypotheses are provided.

Literature Review

Dementia and Alzheimer's Disease

Prevalence and cost. Dementia is an incapacitating disorder that is becoming an epidemic. The DSM-IV-TR defines dementia as "characterized by multiple cognitive deficits (including memory impairment) that are due to the direct physiological effects of a general medical condition, to the persisting effects of a substance, or to multiple etiologies" (APA, 2000, p.147). The most common disease that causes dementia, Alzheimer's disease (AD) is defined by the Alzheimer's Association as a neurological disease state that causes problems with memory, thinking, and behavior (Thies & Bleiler, 2012). Recently, new criteria have been adopted to diagnose AD in 2011, stating that the disease begins much sooner than clinical presentation of symptoms, sometimes called Mild Cognitive Impairment (MCI) (Thies & Bleiler, 2012). The estimated cost of AD and other dementias in 2012 was $200 billion in the U.S and is projected to increase to $1.1 trillion in 2050 (Thies & Bleiler, 2012). This is not including the 15 million unpaid caregivers caring for a person with AD. Currently in the U.S., one in eight people have dementia, totaling 5.4 million people. As the baby boomer generations age, the prevalence of AD and other dementias will surge; by 2050, there will be 21 million Americans 85 years and older. There is no doubt that the prevalence of dementia will skyrocket as by age 85, individuals have a 50% chance of developing dementia. The estimated prevalence of dementia by 2050 is 13.2 million people (Thies & Bleiler, 2012). This statistic may yet be very conservative as researchers have indicated an under diagnosis of AD by almost 50% (Thies & Bleiler, 2012). The increase in prevalence is not only concerning because of the cost of dementia, but the mortality as well.

Mortality of dementia. Dementia is the sixth leading cause of death in the U.S. Dementia-related deaths have continued to rise while other leading causes of death, such as heart disease, have declined. From 2000 to 2008, deaths from dementia have risen 61% while heart disease has declined 13% (Thies & Bleiler, 2012). Even greater mortality is associated with early-onset dementia or the onset of dementia before age 65 (Barclay, Zemcov, Blass, & McDowell, 1985; Koedam et al., 2008). With dementia's worldwide increasing prevalence, rising costs, and serious mortality rate, dementia is undoubtedly a worldwide concern.

Symptoms and types of dementia. Onset of AD induced dementia symptoms are usually insidious in nature and involves degradation in a multitude of cognitive functions. The central feature of AD is memory loss (APA, 2000). Both memory loss of past events (retrograde amnesia) and inability to lay down new memories (anterograde amnesia) are common. This cognitive decline must be beyond what is considered normal for the aging mind. For example, as you age, it is normal to forget where you put your keys; however, it is not normal for you to forget what a key is or how to use one. Common features besides amnesia are aphasia (loss of expressive and receptive language), agnosia (inability to correctly interpret sensory information), and apraxia (inability to carry out motor tasks). Other features include delusions, hallucinations, depression, and personality changes (APA, 2000; Thies & Bleiler, 2012).

There are various types of dementia that have slightly different etiologies and symptoms. Vascular dementia (formerly known as multi-infarct dementia) consists of the above symptoms but also requires evidence of cerebrovascular disease or focal neurological signs and symptoms such as gait abnormalities, weakness of an extremity, and exaggerated deep tendon reflexes. There are also types of Dementia that occur due to other general medical conditions such as dementia due to: HIV disease, head trauma, Parkinson's disease, Huntington's Disease, Pick's disease, Creutzfeldt-Jakob Disease and other general medical conditions. However, dementia of the Alzheimer's type is by far the most common (APA, 2000; Thies & Bleiler, 2012).

Etiology of AD. The causes of AD have been researched for a century. In 1906, Alois Alzheimer documenting neurofibrillary plaques and tangles in autopsied brains (Hodges, 2006). The presence of plaques and tangles in the brain has been linked to cognitive decline (Kidd, 1964). Continuing on with this research were seminal breakthroughs from three different labs discussing the protein, Tau, and its involvement in the buildup of plaques and tangles (Grundke-Iqbal, Iqbal, Tung, Quinlan, & Wisniewski, 1986; Kosik, Joachim, & Selkoe, 1986; Wood, Mirra, Pollock, & Lester, 1986). Genetic links were established, the most pivotal of which may have been Sherrington et al.'s (1995) work on identifying the presenilin one gene located on chromosome 14 and its influence on early-onset AD. Although the exact etiology of the disease is complex, because of work like Sherrington et al.'s (1995) and others, researchers have derived the amyloid-cascade hypothesis.

Amyloid-cascade hypothesis. This hypothesis states that clumps of Amyloid-beta (A-beta) lead to neuronal cell death, leading to dementia. A-beta is a short peptide formed from the improper cleavage of Amyloid precursor protein (APP) by two enzymes (Sisodia & St George-Hyslop, 2002). The three genetic mutations that can cause the harmful APP to develop are the APP Swedish mutation, presenilin one, and presenilin two. Furthermore, apolipoprotein E4 (ApoE4) is another genetically mutated protein that leads to the clumping of these fragments. Normally, ApoE2 and ApoE3 can clear A-beta from the extracellular space, but ApoE4 doesn't effectively clear the A-beta. This results in formed plaques, which ultimately results in neuronal death (Sisodia & St George-Hyslop, 2002). Although these genetic mutations are present in about one percent of AD cases (usually early-onset), this information can prove vital to an eventual cure (APA, 2000).

Neurofibrillary tangles made of Tau lead to cytokine responses which also results in cell death. Less is known about the effects of A-beta aggregates on Tau but research has discovered proteins called kinases phosphorylate Tau in excess, causing the Tau to detach from the microtubule and form twists that prevent the neuron from functioning (Wolfe, 2006). The cell death resulting from plaques and tangles cause brain matter degradation, symptoms, and neuropsychological dysfunction in AD.

Neuronal loss and neuropsychological functioning in dementia. There are many cognitive declines occurring in dementia patients, some coming at the pre-clinical stages of the disease (Bidzan & Bidzan, 2002; Morris et al., 2001). Furthermore, attempts have been made to understand the cognitive decline before the diagnosis of dementia is met, called Mild Cognitive Impairment or MCI (Amieva et al., 2005). Neuropsychological deficits of AD include but are not limited to: executive functioning (planning, shifting, updating, attention, working memory, etc.), episodic memory, declarative memory, and motor functioning (Forstl et al., 1992; Morris & Kopelman, 1986; Swanberg, Tractenberg, Mohs, Thal, & Cummings, 2004). These deficits can be explained by loss of brain matter in various cortical areas, the cerebellum, and the neuropsychological functioning associated with these areas.

There are several brain regions that degrade during a progressive dementia. Loss of both grey and white matter has been observed in magnetic resonance imaging or MRI (Jernigan et al., 1991). As this shrinking occurs, there are increases in the sulci and gyri spaces of the cerebral cortex. Specific regions of the cerebral cortex are targeted in AD such as the medial temporal lobe and the frontal lobe (Braak & Braak, 1991).

The medial temporal lobe contains the hippocampus and amygdala which are vital for memory functions, particularly episodic and declarative memory. Episodic memory is encoding, storage, and retrieval of temporally and spatially defined events. Declarative memory is an explicit memory that is sometimes referred to as recalling facts, or declarations (Morris & Kopelman, 1986). These deficits can be found before full blown Alzheimer's has taken place or at the pre-clinical phase of the disease (Morris et al., 2001). The frontal lobe has also been linked to age-related memory decline, suggesting its involvement with temporal lobes in memory processes (Moscovitch & Winocour, 1995). Such evidence explains why memory loss is so profound in AD patients. Decreases in executive functioning are also prevalent in AD patients.

In addition to memory loss, the frontal lobe has been traditionally associated with executive functioning. AD patients have had plaques and tangles presented in the frontal lobe, explaining the reduction in executive functioning (Van Hoesen et al., 2000). However, the frontal lobe is not the only area involved in carrying out executive functioning tasks; other necessary areas that have simultaneous involvement are the posterior, parietal, and cerebral areas, which have also been indicated to decline in AD (Alverez & Emory, 2006; Morris, 1994; Morris, 1996). Some parts of executive functioning, specifically spatial working memory have been related to visuomotor adaptation and visuomotor learning; which has typically involved cerebellar and basal ganglia activity (Anguera, Reuter-Lorenz, Willingham, & Seidler, 2011; Krakauer et al., 2004).

The cerebellum (traditionally thought to be relatively unaffected in AD) has recently been associated with atrophy in AD as well. Thomman and colleagues (2007) have found that the posterior cerebellar lobe in AD patients is significantly smaller than in normal controls, but more so in the advanced stages of the disease. The cerebellum is crucial in some aspects of motor learning as evidenced by various empirical studies (Bernard & Seidler, 201; Doyon, Penhune, & Ungerleider, 2003; Seidler & Noll, 2008). Particularly, the cerebellum and basal ganglia have been thought to play a role in visuomotor adaptation (Ghilardi et al., 2000; Inoue et al., 1997; Krakauer et al., 2004). Interestingly, despite the degradation of the cerebellum in AD, some motor learning seems to be retained in AD, MCI, and certain dementias (Paulson, Butters, Salmon, Heindel, & Swenson, 1993).

Visuomotor Adaptation and Aging

Although there are multiple ways to measure motor learning (e.g., error-based learning, reinforcement learning, and use-dependent learning in Wolpertet al. [2011]), the current study focuses on sensorimotor adaptation, which evaluates how to adjust movements in response to sensory information. Examples of visuomotor adaptation include: driving a new car, doing tasks in front of a mirror, or playing a new video game (Seidler, 2006; Doyon et al., 2003; Willingham, 1998). To explain this further, in order to operate a vehicle, persons must be able to connect the visual feedback (the road, obstacles, stop signs) with the motor movements (steering wheel and pedals). If the vehicle has not been driven before, the person must be able to adapt to the new car based on visual feedback. When the steering wheel is tighter or looser than their previous experiences, the person must adapt their steering based upon their visual feedback in order to avoid a collision. The role of sensory feedback in motor learning is discussed in many empirical studies and models of motor learning.

Motor learning models. There are numerous models that employ feedback and feed forward mechanisms to explain visuomotor adaptation. One proposed model involving these two mechanisms is a stochastic sub-optimized model (Meyer, Abrams, Kornblum, Wright, & Smith, 1988). This model involves a primary feed forward mechanism that is corrected by a secondary feed-back mechanism. It is optimized by reducing the average movement time and maintaining accuracy of movement. With this model, it is evident that physical action involves a feed-back mechanism dependent on environmental changes and links movement, sensation, and cognition together (Meyer et al., 1988). Alternatively, Shadmehr, Smith, and Krakauer (2010) discussed a forward model that relies on an adaptive internal model that is used to make sensory prediction errors that help us guide our movements. Both Meyer's et al. (1988) and Shadmehr's et al. models argue that feedback error is important in the motor learning process. However, the importance and function of feedback differs between the two models.

Meyer's et al. (1988) model involves both feed-forward and feedback phases. The first phase of the model is the feed-forward phase which is without sensory feedback. This phase uses an internal model in which there is a central execution of motor movement (Meyer et al., 1988; Seidler, Noll, & Thiers, 2004). Thus, to make an accurate movement with a feed-forward mechanism, this internal model must be accurate as well. The second phase uses feedback to make optimal adjustments very quickly that maintains both speed and accuracy. The feedback phase relies on the ability to make corrections from sensory receptors, but optimal movement control most likely relies on both feed-forward and feedback mechanisms (Meyer et al., 1988; Seidler et al., 2004). More recently, a similar model has been proposed by Shadmehr et al. (2010). In this model, motor learning is still largely dependent on feedback mechanisms as the model argues that the initial movement (feed-forward) relies on movement correction predictions because of the delay in sensory motor feedback. The feedback will allow for calibration of these predictions throughout life, making it an extremely important component of motor movement and motor learning (Shadmehr et al., 2010). Overall, both models (Meyer et al., 1988; Shadmehr et al., 2010) agree that feedback is a very important part of motor learning. Based on these models, multiple experimental paradigms have been used to study the role of feedback in visuomotor adaptation.

Paradigms of visuomotor adaptation. There are multiple paradigms that have been used to study visuomotor adaptation. One of these is known as a prism adaptation. In a prism adaptation task, participants don a pair of glasses that distort the visual field by laterally displacing vision (Fernandez-Ruiz, Hall, Vergera, & Diaz, 2000; Paulson et al., 1993; Roller, Cohen, Kimball, & Bloomberg, 2002; Weiner, Hallett, & Funkenstein, 1983). Another commonly used paradigm is a mirror tracing task in which participants are instructed to trace one image and then trace another image using mirror induced visual feedback (Rouleau et al., 2002).

Perhaps the most frequently used paradigm is a center-out visuomotor rotation paradigm. In this paradigm, participants sit in front of a computer screen with a mouse or joystick and are asked to move the cursor from a center stimulus to various targets around the screen. In each trial, the participant returns to the center. A rotation will occur that will move the cursor a certain number of degrees to the left or right. For example: if a target were to be straight up from the center stimulus (0^{o}) and a clock wise rotation of 45^{o} were present, if the participant moved the cursor straight up (by pressing forward) the cursor would then angle 45^{o} to the right. In this paradigm, adaptation is measured by comparing the ideal target line to the participant’s generated movement line. Motor learning is measured via after effects. After effects refer to movement in the opposite direction of the rotation or displacement after the distortion has ended; suggesting that the participants have learned to compensate for the distortion (Buch, Young, & Contrares-Vidal, 2003; Cressman et al., 2010; Heur & Hegele, 2008a; Heur & Hegele, 2008b). Researchers have generally found adaptation deficits in the elderly but some research has demonstrated certain learning conditions in which adaptation deficits are not present (Cressman et al., 2010; Heur & Hegele, 2008a; Heur & Hegele, 2008b; Roller et al., 2002).

Visuomotor adaptation declines with aging. Studies have found adaptation losses in aging across paradigms. In a prism adaptation task, Fernandez-Ruiz et al. (2000) found slower adaptation in elderly participants versus younger participants. The aged group (50-78 years old) and younger controls (18-24 years old) were instructed to throw clay balls at a target before and after donning the glasses. Before donning the glasses, the older group showed larger hit variance, suggesting motor control impairment increases. They also showed slower adaptation after donning the glasses, taking more trials to adapt to the prisms than the younger group, suggesting decreased adaptation. A mirror tracing task conducted by Rodrigue, Kennedy, & Raz (2005) found similar declines in adaptation. The results indicated a presence of a main effect of age on mirror tracing ability. The loss of visuomotor adaptation across multiple paradigms strengthens the support for visuomotor adaptation loss with age.

In center-out rotation tasks, general deficits of visuomotor adaptation have been found in the elderly (Buch et al., 2003; Cressman et al., 2010; Heur & Hegele, 2008a; Heur & Hegele, 2008b; Seidler, 2006). However, the exact staging and magnitude of visuomotor loss with age vary across studies. Knowledge of the degradation process would be important information for understanding the aging brain. Some studies have data to support the decline of visuomotor adaptation ability, the magnitude of the loss, and the timeline of deterioration (Heur & Hegele, 2008a; Seidler, 2006) while other studies do not.

A particular study conducted in 2006 by Seidler showed that visuomotor adaptation and rotation after effects degrade with age. Older adults (M = 73.3 and M = 76.8) were exposed to two rotation conditions of 30^o and 45^o. She found decreased adaptation for both 30^o and 45^o rotations compared to normal controls as well as decreased after effects, suggesting a hindering of visuomotor adaptation capability and motor learning for these relatively small rotations. These results are unfortunate, considering the ability to retain motor skills is a critical aspect of independent living. Moreover, there have been multiple studies that have found similar results that strengthen the conclusion that visuomotor adaptation declines with age (Buch et al., 2003; Fernandez-Ruiz et al., 2000; Heur and Hegele, 2008a; Heur and Hegele, 2008b).

Heur and Hegele (2008a) used pre-retirement aged participants (ages 51-65) in a visuomotor adaptation study. Age-related differences were found in the adaptation stage of the paradigm (when the visuomotor rotation was present). After reducing the rotations to 30^{o}, the researchers found no age-related adaptation deficits, suggesting that the magnitude of the rotation at pre-retirement age is an interacting variable that affects visuomotor declines. Such results suggest that there is a gradually changed adaptation deficit with age. In a previous study with older participants, a deficit for 30^{o} rotation was found (Seidler, 2006). This pre-retirement age study was important for at least two reasons. First, it showed that adaptation deficits appear before retirement age. Second, it provided evidence that visuomotor adaptation declines are a gradual process that onsets before 65.

Visuomotor variables that affect decline. Numerous studies have shown age-related visuomotor adaptation deficits but certain conditions in the paradigms may facilitate compensation processes (Buch et al., 2003; Cressman et al., 2010; Heur & Hegele, 2008b). These conditions include the magnitude of the rotation, the administration of rotation in gradual or non-gradual increments, the learning strategy engaged by participants, and the age of the participants.

As mentioned before, deficits in adaptation are a gradual process, suggesting that the specific ages of the participant population is an important variable to consider. In pre-retirement aged participants, deficits in visuomotor adaptation were not found in 30^{o} rotations (Heur &

Hegele, 2008a). However, deficits in these rotations were found in older participants aged 65 and older (Seidler, 2006). Both of these studies have found adaptation deficits of 45^{o,} suggesting a gradual, but progressive decline in visuomotor ability. In order to further examine the relationship between the size of the rotation and the magnitude of visuomotor decline, other studies have examined visuomotor rotations in gradual increments.

Buch et al. (2003) examined the effect of gradual versus sudden distortion in elderly participants. The design consisted of two experimental groups (young and elderly participants) exposed to two different conditions (gradual versus sudden rotation). The gradual rotation was introduced in 11.25^{o} increments after 45 trials, reaching 90^{o}, while the sudden rotation instituted a 90^{o} rotation from the onset of exposure. Importantly, this study found no age-related differences in the gradual condition, suggesting that bigger rotations versus smaller rotations are more difficult for elderly participants. These findings are in agreement with the aforementioned studies suggesting that decline is a gradual process with advancing age (Heur & Hegele, 2008a; Seidler, 2006). These results can be cautiously interpreted as a linear relationship between aging and decline. However, these findings can also be understood by means of explicit versus implicit strategy.

Some research has demonstrated that motor learning in implicit activities is retained in older participants while motor learning in more explicit activities deteriorates. In the previous research by Buch et al. (2003), the gradual increase of rotation does not involve the use of an explicit cognitive strategy, but an implicit one because of the subject's unawareness of the rotation. The sudden rotation contains more of an explicit strategy because of the immediate awareness of distortion. These results suggest the preservation of motor learning ability with implicit strategy but not explicit. Other studies have found similar results using older participants (Cressman et al., 2010; Heur & Hegele, 2008).

In summary, there are multiple studies that have shown that visuomotor adaptation declines during aging, albeit with mixed results. Buch et al. (2003) discovered that if rotation was instituted in gradual increments, there were no significant age-related declines. Furthermore, studies investigating explicit versus implicit strategies have found that explicit strategies are more declined in elderly subjects than implicit ones (Cressman et al., 2010; Heur & Hegele, 2008a; Seidler, 2006). An additional study by Heur and Hegele (2008b) found that age-related deficits in adaptation are met only when certain conditions are met such as age, direction of rotation, degree of rotation, and explicit strategy. The results finding situational declines are understandable given that visuomotor adaptation research on the elderly has had mixed results. Overall, it is logical to assume age related declines in visuomotor adaptation are present but dependent on multiple factors.

After effects of visuomotor adaptation in the elderly. After effect is traditionally thought of as a key measure of motor learning. As mentioned before, it is defined as the remaining effect of the adaptation condition (rotation or displacement) after the condition has ceased. There are multiple studies suggesting that elderly participants have retained the ability to learn motor tasks based on after effects of the adaptation condition (Bock, 2005; Fernandez-Ruiz et al., 2000; Heur & Hegele, 2008a; Heur & Hegele, 2008b). In prism adaptation paradigms, the after effects are measured by trials it takes to return to baseline accuracy of throwing objects. In at least two different studies, age related declines in after effects were not found in the elderly participants, suggesting that older adults retain the ability to learn new motor movements via adaptation to new environmental stimuli (Fernandez-Ruiz et al., 2000; Roller et al., 2002).

Similar results have been found in a tracking paradigm (Bock, 2005) as well as in computer rotation paradigms, strengthening the support for the absence of differences in age-related after effects in the elderly (Heur & Hegele, 2008a; Heur & Hegele, 2008b).

The literature has identified deficits in visuomotor adaptation in elderly participants and pre-retirement age participants, indicating age related declines. On the contrary, age related declines in after effects have not been consistently found. These results collectively suggest that even though elderly individuals have slower adaptation, they are able to learn motor skills as well as younger participants if the right conditions are met, suggesting that the capacity to learn motor skills remains relatively intact in normal aging.

Dementia and Motor Learning

Some studies have found that participants who have mild AD can have some capacity to learn certain motor tasks (Bondi & Kaszniak, 1991; Dick, Nielson, Beth, Shankle, & Cotman, 1995; Dick et al., 1996; Eslinger & Damasio, 1986; Heindel, Butters, & Salmon, 1988; Heindel, Salmon, Shults, Walicke, & Butters, 1989, Rouleau et al., 2002). But the progressive effect of AD on the aging brain’s ability to learn new motor tasks is not fully understood and there is a lack of research on visuomotor adaptation in dementia. Possible links can be established among the neuropathology of AD, the neuropsychological functioning of AD patients, and the motor learning of AD patients.

Neuropathology of AD and neural correlates of motor learning. Neuroimaging studies have revealed that brain areas associated with motor learning and adaptation include the motor cortex, basal ganglia, cerebellum, and parietal regions (Inoue et al., 1997; Krakaueret al., 2004; Seidler, 2006; Seidler & Noll, 2007). Although the detailed functions for each of the areas still need to be verified, in brief, it can be argued that parietal areas and parieto-frontal connections are involved in a series process of sensory motor transformation (Burnodet al., 1999; Snyder, 2000). Prefrontal areas are preferentially activated in tasks based on internally driven selection, retrieval efforts, attention, working memory and higher cognitive demands. The cerebellum is engaged in the creation and storage of a long-term representation of learned movements. The visuomotor losses of older adults can be explained by the structural degeneration with age (Seidler et al., 2009). In AD, parietal regions are among the most prominent brain regions lost (Braak & Braak, 1991; Duyckaerts, Delatour, & Potier, 2009; Greene & Killiany, 2010; Jernigan et al., 1991). Based upon the neuropathology of AD and the older age of onset of AD, visuomotor capacity should be compromised in AD.

Tippet and Sergio (2006) conducted a study in which the effects of AD on visuomotor transformation were observed. The study required probable AD participants to slide their finger from a center position to various targets. AD patients were then exposed to rotations with age-matched controls. The study found more task-related errors even in patients with mild memory impairments, suggesting visuomotor deficits at the early stages of AD. This study provides in-direct evidence linking the neuropathology of AD, even at the early stages, to declines in visuomotor adaptation. Specifically, the researchers hypothesized that the posterior parietal cortex degradation leads to losses in visuomotor integration (Tippet & Sergio, 2006). This region, among others, integrates the motor cortex and occipital lobe. Specifically, one of its functions involves action planning and movement (Anderson & Buneou, 2002). At least one of the two areas associated with visuomotor adaptation (posterior parietal area and cerebellum) are compromised with the pathology of AD.

The cerebellum is also an area affected by pathology in AD. Until recently, the general consensus was that the cerebellum was spared in AD, but newer research has demonstrated plaques and tangles in regions of the cerebellum that are more prominent in the later stages of the disease (Li, Woodruff-Pak, & Trojanowski, 1994). A study examining AD compared to mild cognitive impairment (MCI) patients discovered lesions only in AD patients and not in MCI patients (Thomann et al., 2007). This information suggests that AD patients will have limited visuomotor capacity based on their cerebellar loss, but not in the pre-clinical stages of the disease (Amievaet al., 2005). This information helps explain results indicating that some motor learning abilities are retained in AD (Bondi & Kaszniak, 1991; Dick et al., 1995; Dick et al., 1996; Eslinger & Damasio, 1986; Heindel et al., 1988; Heindel et al., 1989, Paulsonet al., 1993; Rouleau et al., 2002).

Retention of motor learning in dementia. Like in the normal aging elderly, explicit learning mechanisms are degraded in AD, but the implicit learning mechanisms are retained (Kuzis et al., 1999; Sabe, Jason, Juejati, Leigarda, & Starkstein, 1995; Starkstein, Sabe, Cureva, Kuzis, & Leigarda, 1997; Taylor, 1998; Van Tilborg, Ilse, Scherder, & Hulstijn, 2007). This idea, although not directly related to visuomotor adaptation, provides more evidence that AD patients still have the ability to learn new motor skills. However, it has been difficult to integrate these findings into practical application. In one study, mildly demented AD participants were taught to use household appliances both explicitly and implicitly. The findings suggested no benefit for implicit learning (Van Tilborg, Kessels, & Hulstijn, 2011). These results indicate the need for more research to be conducted on motor learning conditions with practical application. The role of feedback in AD patients has also been indicated as a potentially important condition that affects the ability of AD patients to learn motor skills.

Dick et al. (2001) has particularly focused on the reliance of visual feedback in motor control for AD. The authors tested the role of visual feedback under restricted vision and nonrestricted vision conditions in a rotary pursuit task with three different experiments. In a rotary pursuit task, participants are asked to track a rotating block with a hand held pointer. In the restricted vision experiments, both the normal aging and AD participants had more difficulty in the task, although AD had significantly more difficulty. This evidence indicates that feedback is vital in motor learning like many of the proposed motor learning models have suggested (Meyer et al., 1988; Shadmehr et al., 2010). In the last experiment, both groups of participants (AD and normal aging controls) were not restricted in visual feedback and they found equivalent performance among groups. Given all three experiments, the conclusion can be drawn that visual feedback is important for motor learning across participants, but AD patients are more reliant on visual feedback. However, the feedback characteristics and cognitive faculties needed for optimal learning is still unknown.

Neurocognitive Measures and Motor Learning

There is a lack of research devoted to studying the relationship between cognitive measures and motor learning. Anguera et al. (2011) examined nine older adults and nine younger adults in a visuomotor adaptation task and in a mental rotation task designed to measure spatial working memory. The participants were also given several neuropsychological examinations. Overall, when examining just the early adaptation stages (the first four blocks), the spatial working memory scores (Corsi Block Tapping backwards, Thurston Card Rotation, and Thurston Cube Rotation) were not related to visuomotor adaption performance in older adults (as measured by DE) but was correlated in the younger adults. The older adults also showed a lower rate of learning in early visuomotor adaptation. In the visuomotor adaptation task, during the early blocks, young adults showed more activation in the right medial frontal gyrus (MFG) and right DLPFC among others. In late adaptation, no between group differences were observed.

More activation was discovered for the older adults than the younger adults in the mental rotation task, including the right DLPFC, right IPL, bilateral MFG, and cerebellum. The activation in the early adaptation task for older adults did not overlap with what was exhibited in the mental rotation task (spatial working memory). Conclusions that were drawn by the researchers included that the older adults failed to engage spatial working memory, which contributed to their declined visuomotor learning (Anguera et al., 2011).

Visual Feedback Augmentation

Studies have shown that augmenting feedback can improve motor learning (Patton et al., 2006; Wei, Bajaj, Scheidt, & Patton, 2005). One aspect of visual feedback is error feedback, or the information received when the movement is deviating from the planned (feed-forward) movement. This information contains two things. First, the information indicates that a deviation from the planned action has occurred. Second, the information indicates the direction of the deviation. Given this information it can be hypothesized that error feedback can drive motor learning (Wolpert et al., 2011). Increasing the amount of error feedback might accomplish at least two things. First, it may increase motor learning (Patton et al., 2006; Wei et al., 2005). Second, it may enhance the motivation for learning in individuals. This would be accomplished by manipulating the perception that smaller errors seem like larger errors which in turn, may improve the signal to noise ratio (Wei et al., 2005). Error augmentation is proposed in numerous models; specifically, the amount of error has been posited to be the essential drive for learning in artificial models (Gomi & Kawato, 1993; Rumelhart, Hinton, & Williams, 1986). At least two empirical studies have investigated error feedback in adaptation paradigms (Pattonet al., 2006; Wei et al., 2005).

Wei and colleagues (2005) investigated the role of error feedback in neurologically normal 22 to 30 year olds. The participants were randomly assigned to one of four conditions which varied in the amount of error received with gains ranging from one to three point one. The findings indicated that increasing the error feedback did facilitate motor learning for these participants. Furthermore, it provided evidence of the amount of gain that would optimize motor learning. A gain of two was found to be the most beneficial for learning. It was hypothesized that a gain of three point one resulted in participant discomfort because of the instability of the adaptation process. A gain of two was also reported to have positive effects on motor learning in a virtual reality setting (Sharp, Huang, & Patton, 2010).

Extending the work of error-driven learning to brain injured individuals, Patton and colleagues (2006) investigated the effects of error feedback on stroke patients. Hemiparetic stroke survivors were exposed to two conditions: an error-enhancing condition or an error-reduction condition. The stroke victims were instructed to make reaching movements towards a target and were provided with robotic force towards the target (error reduction) or away from the target (error enhancement). It was discovered that only in the error enhancement conditions did participants benefit from the robotic force. This provides evidence that neurologically injured individuals may use compensatory mechanisms that rely on error feedback to update their initial feed-forward action. It could be hypothesized that because AD patients rely more heavily on visual feedback (Dick et al., 2001) and increasing error feedback could increase motor learning, the AD population may benefit from augmented error in motor learning paradigms.

Study Aims and Hypotheses

Although some conflicting results exist in the literature, general declines on visuomotor adaptation have been found in normal aging (Buch et al., 2003; Heur and Hegele, 2008a; Heur and Hegele, 2008b; Fernandez-Ruiz et al., 2000; Seidler, 2006). There is an even greater decline of motor learning ability in dementia patients (Tippet & Sergio, 2006). It has found that dementia patients rely more on visual feedback when making motor movements (Dick et al., 2001), indicating possible compensational processes in adaptation. Increased error feedback can be an important variable to be studied since the importance of feedback has been proposed in many models (Gomi & Kawato, 1993; Meyer et al., 1988; Shadmehr et al., 2010; Wolpert et al., 2011). The research on augmented error and adaptation has not been thoroughly studied in empirical designs but some studies have indicated that augmented error can facilitate motor learning in young participants (Wei et al., 2005) and stroke patients (Patton et al., 2006). Therefore, the overall aim of the proposed study is to investigate the role of visual error feedback on visuomotor adaptation in individuals with and without mild dementia. The specific aims and hypotheses are outlined below.

Specific aim 1: To examine the ability of normally aging elderly participants (65-80 years old) and cognitively impaired participants to adapt to different error feedback conditions in a computerized center out adaptation task.

Hypothesis 1-1. Individuals with cognitive decline (cognitively impaired) will show worse visuomotor adaptation (i.e., slower improvement during adaptation and smaller after effect) than the normally aging controls.

Hypothesis 1-2. Both cognitively impaired participants and normally aging participants will have increased adaptability in the enlarged error feedback condition than in the normal feedback condition.

Hypothesis 1-3. Cognitively impaired participants will have a greater increase in adaptation than normal aging participants from the normal feedback condition to the enlarged error feedback condition.

Specific aim 2: To examine the relationship between cognitive assessments and visuomotor adaptation in a computerized center out adaptation task.

Hypothesis 2: The adaptability (measured by after-effect) in the regular visual feedback condition will be strongly influenced by cognitive scores while the adaptability in the enlarged visual feedback condition will not be affected.

The proposed project is aimed to investigate error augmentation in cognitively impaired participants. Such a study will be able to further investigate the role of error feedback in visuomotor learning as well as discover the relationship between dementia related cognitive decline and visuomotor adaptation. It also has the potential benefit of identifying augmenting error as a possible intervention technique for motor learning in dementia patients.

Research Design and Methodology

Participants

Twenty three elderly participants between the ages of 65 and 78 were recruited by fliers posted at senior apartment complexes and area senior centers. The sample included 19 Caucasians and four African-Americans. Sex of the sample included 19 females and four males. The average age of participants was 69.9 years old with 15.2 years of formal education.

Permission was obtained before placing fliers in Senior Living Communities and area Senior Centers. An explanation of the study's intent and procedure was explained face to face with the participants and informed consent was obtained from the subjects before participation.

Participants were excluded if they had a history of neurological disease or illness (besides dementia) such as: meningitis, stroke, traumatic brain injury, Parkinson's disease, Huntington's disease, multiple sclerosis, brain abscess, or other neurological injury. Overall, two participants were excluded because of guardianship, and four more because of previous neurological illness. Since a mild level of cognitive decline is the focus for the current study, any participant who had a score less than 19 on the Montreal Cognitive Assessment (MoCA) indicating a moderate to severe level of cognitive decline (Nasreddine et al., 2005), were excluded. Three participants were excluded for a MoCA score less than 19.

Procedure

After recruitment from senior living facilities, participants were asked to come to the cognitive neuroscience lab, room 352D in the Mark Jefferson Science Building at Eastern Michigan University in Ypsilanti, Michigan. However, for the majority of participants, the researchers traveled to area senior centers to circumvent driving restrictions placed upon participants. Before the study took place, participants had a face-to-face explanation of the intent and purposes of the experiment. Then, they were asked to read and sign the informed consent form (Appendix A). The participant was excluded if they had a legal guardian and could not consent under their own power. The principle investigator obtained the Institutional Review Board of Eastern Michigan University approval prior to the studies implementation.

After informed consent, participants were asked to complete a computer task that assessed visuomotor adaptation. All participants were exposed to both normal and enlarged feedback conditions. The order of conditions was counterbalanced via random assignment. The second condition was performed seven days (or one week) after the original testing session to avoid any carry over effects from the previously tested condition. For each testing day, and after the visuomotor assessment, participants were assessed using multiple neuropsychological assessments. The approximate time to completion for these assessments was 40 minutes each testing day (refer to Table 1 for a summary of the testing procedures).

After completion of each testing day, the participants were informed they had completed the task or will be scheduled for the next testing date. Any questions were answered and they were thanked for their participation. After each session, participants received a parking pass (if on EMU campus) and a $20 gift card to Target for compensation, totaling $40 for participation.

Measures

Questionnaire. Participants were first asked to complete a demographic and health history questionnaire before completing the neuropsychological assessments (See Appendix B). The questionnaire asked participants to provide information on dexterity, sex, race, education level, previous neurological injury or disease, vision deficiencies, and shoulder or wrist injuries. Current medication was not assessed as elderly participants may not know the names of all their current medication in addition to pharmacology being beyond the scope of the current study.

Visuomotor Adaptation Assessment. The visuomotor adaptation tasks were written in PRESENTATION and were completed by all participants. Participants were seated in front of a computer monitor that rested on a table. The participants were approximately 24 inches from the computer monitor. The participants were asked to hold a joystick with their pointer finger on the trigger and their offhand resting on the base of the joystick to prevent excess movement. The joystick was centered midline to the participant's body, approximately 15 inches from the participant. The joystick was used to collect the digitized data of the participants' hand movements in x/y coordinates at a 60Hz sampling rate. Visual feedback of the hand movements (displayed as a computer cursor) were provided in real-time on the computer monitor with two different experimental conditions, enlarged and regular visual feedback. This paradigm was adapted from Chi-Mei Lee's master's thesis (2012).

Participants were instructed to move a cursor from a home position to a target position presented on the computer screen. The home position was on the monitor as a picture of yellow smiling face located in the center of the screen. The target position was one of eight green smiling face pictures (diameter of 1 cm) appearing randomly in one of eight locations (0°, 45°, 90°, 135°, 180°, 225°, 270°, 315°) around the home position. The distance from the home position to the targets was 10 cm. The home position was visible throughout the duration of the testing session. The target disappeared as soon as the cursor entered the target picture. Participants were instructed to move the cursor as fast and as straight as possible from the home position to the target.

The task consisted of five phases: (A) baseline phase: 48 trials (six trials per angle, six blocks) with normal visual feedback of the hand movements; (B) first exposure phase: 32 trials (four trials per angle, four blocks) with the visual feedback of the hand movement rotated 30°

counterclockwise (the hand movement and visual effect on the screen do not match); (C) second exposure phase: 48 trials (six trials per angle, six blocks) with the visual feedback of the hand movement rotated 30° counterclockwise in the regular condition, or with the enlarged visual feedback which doubled the discrepancy between hand movement and ideal movement in the enlarged condition; (D) third exposure phase: 32 trials (four trials per angle, four blocks) with the visual feedback of the hand movement back to 30° rotation; (E) post-exposure phase: eight trials (one trial per angle, one block) with normal visual feedback of the hand movements to test for after-effects.

There were six catch trials in three exposure phases in order to track participants' learning curve progress. Each catch trial will be introduced after 16 exposure trials and ceased of any visuomotor transformation (back to zero rotation). There were two catch trials in the first exposure phase, three catch trials in the second exposure phase, and one catch trial in the third exposure phase.

Neuropsychological assessments. The neuropsychological assessments were conducted by this author, a fellow master's student, and an undergraduate research assistant. The majority of assessments were conducted by this author. The other testers were trained by this author to assure standardized testing. All neuropsychological testing was completed in a closed room on site or at EMU with minimal background noise.

Montreal Cognitive Assessment (MoCA). The MoCA was designed as a rapid screening instrument for mild cognitive dysfunction. It assesses the following cognitive domains: attention and concentration, executive functions, memory, language, visuoconstructional skills, conceptual thinking, calculations, and orientation. The total time of administration is approximately 10 minutes. The total possible score is 30 points; a score of 26 or above is considered normal and a score below 26 is considered having cognitive impairment (Nasreddine et al., 2005).

Dementia Rating Scale – 2 (DRS-2). The DRS-2 is an enhanced version of the original DRS designed to assess levels of cognitive functioning for individuals 55-89 years of age with brain dysfunction. There are 36 task items and 32 stimulus cards. This instrument is individually administered. The DRS-2 has age corrected scales and percentile ranks that are sensitive to change in cognitive status for both total score and subscale scores. There are five subscales contained in the DRS-2: attention (eight items), initiation/perseveration (11 items), construction (six items), conceptualization (six items), and memory (five items). Stimulus items contain familiar material to the majority of individuals such as cubes, blocks, etc. The DRS-2 tasks are presented in a fixed order. Within each subscale the most difficult tasks are presented first. Generally, if the first one or two tasks in a subscale are performed well, subsequent tasks in the subscale are credited with a correct performance and the examiner proceeds to the next subscale. This procedure significantly shortens the total testing time for individuals with relatively intact cognitive functioning. Overall, the estimated completion time is 15 minutes for cognitively intact individuals while cognitively impaired individuals might take 45 minutes to complete the assessment. High scores indicate higher cognitive functioning with a range of zero to 144 points. The cutoff score for cognitive decline can be based upon the age corrected scores; however a total cutoff score of 132 can be used to determine mild cognitive impairment (Matteau et al., 2011).

Weschler Memory Scale- III (WMS-III): Spatial Span Board Task. The spatial span board task from the WMS-III will be used as a measure of visuospatial memory. As stated in the WMS-III Manual, “Spatial Span is a visual analogue to the familiar digit span test. The Spatial

Span Board features 10 cubes, with numbers one to 10 printed on the sides of the cubes facing the examiner. For Spatial Span Forward, the examiner taps the cubes in a specified sequence and asks the examinee to tap the same sequence. For Spatial Span Backward, the examiner taps the cubes in a specified sequence and asks the examinee to tap them in reverse order. Two trials for each sequence length are administered. As with digit span tests, sequences of increasing length are administered in both forward and backward conditions. Both trials of an item are administered even if the examinee passes the first trial. Only if the participant taps all of the blocks in the correct sequence, either forward or backward, is one point awarded. Zero points are awarded and deemed incorrect if the participant deviates from the required sequence. Raw scores for both Forward and Backward Spatial Span tasks are zero to 16 points. Raw scores may be converted to scaled scores which range from one to 19. WMS-III Spatial Span requires approximately five to 10 minutes for administration to both clinical and control samples (Weschler, 1997).

Weschler Adult Intelligence Scale Fourth Edition (WAIS-IV): Digit Span Tasks. The digit span tasks from the WAIS-IV are designed to measure working memory, attention, and concentration. There are three subtasks that synthesize the Digit Span Subtest from the WAIS-IV, Digit Span Forward, Digit Span Backwards, and Digit Span Sequencing. Much like the Spatial Span task, participants are asked to repeat numbers from the examiner forwards, backwards, and in sequence. Two trials of each length are conducted and the discontinue criterion is met after failure of two successive within trial spans. The scoring is the same as the Spatial Span task, one point for every correctly recalled span and zero points for any deviation from that span. The raw score possible for each subtask is 16 points. These raw scores, as well as the longest digit spans recalled for each subtest can be normed by approximate age. (Weschler, 2008).

WAIS-IV: Arithmetic Subtest. The WAIS-IV Arithmetic subtest is a 26-item task that measures the mathematical and working memory abilities of adults. For each item, the examiner reads an arithmetic problem to the participant. The participant is allowed 30 seconds to give the correct response, and the correct response within the time limit is scored one point, allowing a maximum of 26 points for this subtest. The participant is not allowed any aid such as paper or pencil and each item must be completed mentally. Each item increases in difficulty and the discontinue criterion is met after three consecutive failures. Each arithmetic problem requires several successive, simple mathematical steps that have to be represented in working memory to complete. Raw scores are then converted to scale scores and can be normed according to approximate age. The combination of this score, and of the Digit Span Subtest can produce a Working Memory Index (WMI) that will be helpful in determining the overall working memory ability of the participant (Weschler, 2008).

WAIS-IV: Coding Subtest. The coding subtest from the WAIS-IV is a measure of processing speed. The participant is asked to look at a key on the top of the task and then match that key with a series of numbers. Each number is associated with its own special mark. Down the page are a series of numbers without the special marks under them, the participant is asked to fill in the marks that correspond with the number according to the key. The participant is given 120 seconds to complete as many items as possible. The number of correct items is scored one point, with a maximum of 135 points, and can be converted to a scaled score and be normed with the approximate age (Weschler, 2008).

WAIS-IV: Symbol Search Subtest. The Symbol Search subtest from the WAIS-IV is very similar to the Coding subtest and is designed to measure processing speed. Unlike Coding, the participant is shown *two* target symbols and is asked to identify a matching symbol to the target symbol. If the matching symbol is not present, the participant is asked to mark a “NO” box. The participant is given 120 seconds to complete as many items as possible. The raw score is derived by totaling the correct items and subtracting the incorrect items. The maximum raw score is out of 60 points and can be converted to a scaled score to be normed by age. The Symbol Search subtest and the Coding subtest from the WAIS-IV can be combined to give a Processing Speed Index (PSI) that will be helpful in determining the overall visual processing ability of the participant (Weschler, 2008).

Grooved Pegboard Test. The Grooved Pegboard is a manipulative dexterity test. This test contains 25 holes with randomly positioned slots. The participant is asked to insert pegs into these holes. The pegs have a key on one side and must be rotated to match the hole before the can be inserted. This test requires more complex visual-motor coordination than most pegboards and will be used for our purposes in measuring visual-motor coordination. The examiner is to score the time in seconds, the number of pegs correctly placed, and the number of drops. The task takes approximately five minutes to administer (Lafayette Instruments, 2002).

Thurston’s Card and Cube Rotation Tasks. This assessment measures the spatial working memory and visual-spatial abilities of the participant (Ekstrome, French, & Harmon, 1976). The card and cube rotations are very similar. Each item represents a base image and a rotated image. Participants are asked to rotate the base image in their mind and indicate whether the rotated image on the task matches the base image. For the card rotation task, participants are asked to indicate whether the rotation of the image requires a mirror flipping. For the cube rotation task, participants are asked to indicate whether the rotation is possible (Ekstrome et al., 1976). Participants are asked to complete as many items as possible in three minutes. The amount of incorrect answers is subtracted from the amount of correct answers to give a raw score.

The Stroop Color-Word Test. The Stroop Color-Word Test is an executive functioning measure designed to assess processing speed, selective attention, concentration, and inhibitory functioning of individuals (Golden, 1978). The Stroop is relatively easy to administer and is very quick, taking approximately five minutes to administer. The task consists of three stages. In the first stage, the participant is asked to read a card that consists of 100 words (RED, GREEN, and BLUE) printed in black ink on a white sheet and arranged randomly with no work allowed to follow itself in a column. The participant is asked to read the words as fast as possible in 45 seconds. The second portion of the Stroop consists of 100 colors (written as XXXX) printed in either red, green, or blue on a white sheet with no color allowed to follow itself in a column or match the corresponding word on card one. The participant is asked to read the words as fast as possible in 45 seconds. The third stage of the Stroop contains a card that consists of 100 colored-words on a white sheet. On this card the order of the words from card one are printed in the order of the colors from card two. For example, the first word on card one is printed in color on card two to produce the first color-word on card three. Using this procedure, no word for a color matches that particular color. Participants are asked to read as many words as possible in 45 seconds. For each card, the participant is asked to say the correct response before continuing. The experimenter simply counts the number of correct responses for each card. The Word Score (W) and Color Score (C) and the Color-Word Score (CW) are normed by age and years of education. The predicted score based upon age and education is subtracted from the raw score to obtain a residual which can be converted into *t*-scores to assess level of impairment. Furthermore, an interference score can be obtained that subtracts the predicted CW score from the CW score that can also be converted into *t*-scores to assess level of impairment (Golden, 1978) This task is especially pertinent to the dementia population considering the pronounced degradation of the prefrontal cortex in dementia, an area that contains inhibitory functioning.

Mood assessments. ***Beck Depression Inventory-II (BDI-II).*** The BDI-II is a 21-item screening measure for depression symptoms (Beck, Steer, & Brown, 1996). The BDI-II is scored by summing the ratings for the 21 items. Each item is rated on a four point scale ranging from zero to three. Scores can range from zero to 63 with higher scores indicating more severe depression. The cutoff scores for the BDI-II are as follows: zero to13 indicates minimal depression, 14–19 indicates mild depression, 20–28 indicates moderate depression, and 29–63 indicates severe depression. Thus, higher total scores indicate more severe depressive symptoms. If a higher rated option is chosen by the respondent, the presence of an increase or decrease in either symptom should be clinically noted for diagnostic purposes. The BDI-II takes roughly five minutes to complete (Becket al. 1996). For this study, the BDI-II was used to prevent a potential spurious relationship between motor learning and cognitive scores. A cut-off score of 29 was used, i.e. if any participants scored 29 or higher, they were excluded from the study due to screening at a severe depression level.

Data Analysis

All neuropsychological and self-reported data collected by this study was entered, coded, and double checked for errors. All the hard copies were kept for data checking and the entered data was transferred to the SPSS software version 18.0 (SPSS Inc., Chicago, III) to perform data analyses.

The analyses of the data collected by the visuomotor adaptation tasks was performed in MATLAB. In order to reduce noise in the data, the velocity time series was subjected to a dual-pass eighth order Butterworth filter with a cutoff frequency of 10Hz. Customized MATLAB scripts searched the velocity time series and marked the starting points for each movement when the velocity exceeds 20% of the peak velocity. In cases which the algorithm fails to mark the onset, the experimenter manually adjusted the markers. After all the movements were verified, the dependent variables were calculated.

The following dependent variables were retrieved in the visuomotor adaptation tasks: (a) directional error (DE, in degrees), defined as the directional deviation of the actual movement direction from the ideal movement direction at the peak of the tangential velocity profile (not likely to be under the influence of feedback processes); (b) movement total distance (DIST, in millimeters), defined as the total movement length traveled by the joystick for each trial; (c) movement time (MT, in milliseconds), defined as the time moving from the home position to the target position; (d) reaction time (RT, in milliseconds), defined as the time from when the target appears and when the participant starts to move; and (e) root mean square error (RMSE, in millimeters), defined as the average point-to point spatial deviation of the actual movement trajectory from the ideal vector between home and target position (Contreras-Vidal, 2006; Contreras-Vidal, Bo, Boudreau, & Clark, 2005).

Three methods were used in the present study to assess adaptability (learning effect) based on the above mentioned dependent variables.

Method 1: The changes of means across blocks in the three exposure phases were one way to estimate participants’ learning. The first method will assess the differences of block means between exposure phase on all dependent variables.

Method 2: The second method will analyze the performance of six catch trials in the three exposure phases. Participants' performance on each catch trial will be compared with the baseline performance.

Method 3: The third method will compare the after-effects. To assess after-effects, the mean of the first block after rotation had ceased (block 27) was calculated for each variable, and then compared to a mean of the sixth and last block in the baseline.

Specific aim 1: To examine the ability of normally aging elderly participants (65-80 years old) and cognitively impaired participants to adapt to different error feedback conditions in a computerized center out adaptation task.

To assess general differences between cognitively impaired participants and normal aging older adults, a score of 25 on the MoCA and 132 on the DRS-2 were used as cutoff points to dichotomize cognitively impaired from normally aging participants. Demographic homogeneity of the two groups (cognitively impaired and normal aging controls) was assessed using chi-square tests for discrete variables. Any demographic differences between the two groups were used as a covariate in the subsequent MANOVAs to control for any potential confounds.

Hypothesis 1-1: Individuals with cognitive decline (cognitively impaired) will show worse visuomotor adaptation (i.e., slower improvement during adaptation and smaller after effect) than the normally aging controls in the regular feedback condition.

Within the regular condition: Method 1: A general linear model repeated-measures MANOVA was conducted. Groups (cognitively impaired versus normal aging controls) were the between-subjects factor and mean scores on the blocks was the within-subjects factor. In the three exposure phases, the 112 trials were divided into 14 blocks of 8 trials (four blocks in the first exposure phase, six blocks in the second, and four blocks in the third). The mean differences between each block and baseline were calculated with the Bonferroni method being used to prevent inflated type-I error among groups, blocks, and a group by block interaction in the post-hoc analysis.

Within the regular condition: Method 2: The six introduced catch trials were treated as a within-subjects factor for the repeated-measures MANOVA analysis using the Bonferroni method to prevent inflated alpha levels.

Within the regular condition: Method 3: Independent *t* tests were used to compare the after-effect differences between groups. The Bonferroni method was implemented to prevent inflated alpha levels.

Hypothesis 1-2 and 1-3.

1-2: Both cognitively impaired participants and normally aging participants will have increased adaptability in the enlarged error feedback condition than in the normal feedback condition.

1-3: Cognitively impaired participants will have a greater increase in adaptation than normal aging participants from the normal feedback condition to the enlarged error feedback condition.

For Method 1: Three-way general linear model repeated-measures MANOVA was performed with the group (cognitively impaired vs. normally aging controls) as a between-subjects factor, and the condition (regular vs. enlarged) and blocks (14 exposure blocks) as the within-subjects factors. The main effects tested hypothesis 1-2 and the interaction tested hypothesis 1-3. The Bonferroni method was used to adjust p values for the comparisons among the groups, conditions, blocks, and their interactions in the post-hoc analysis.

For Method 2: The six catch trials were treated as a within-subjects factor for the three-way MANOVA analysis and the group will be treated as a between subjects factor. The main effects will test hypothesis 1-2 and the interaction will test hypothesis 1-3.

For Method 3: Hypothesis 1-2 was assessed via paired samples *t*-tests comparing the baseline block against block 27 for all dependent variables. For hypothesis 1-3, a two-way general linear model repeated-measures MANOVA was performed with the group (cognitively impaired vs. controls) as a between-subjects factor and the condition (regular vs. enlarged) as a within-subjects factor on after-effects (block 27).

Specific aim 2: To examine the relationship between cognitive assessments and visuomotor adaptation in a computerized center out adaptation task.

Hypothesis 2: The adaptability in the regular visual feedback condition will be strongly influenced by cognitive scores while the adaptability in the enlarged visual feedback condition will not be affected.

To further evaluate the relationship between motor learning and cognitive decline, the current study used bivariate correlations as an alternative approach to examine the relationship between cognition and adaptability. Group differences were observed via Fisher's Z. The MoCA total scores, DRS-II total scores, and the other cognitive measures was compared to transformed after-effect variables (block 27 minus block six).

Results

All participants were able to successfully complete the adaptation tasks and neuropsychological assessments within three hours (about one and half hours in the two testing days). The neuropsychological assessments were scored first, and the scorer was blind to visuomotor data. For the computer adaptations tasks, visual inspection and manual adjustment of velocity onset and offset were successfully completed in MATLAB. Due to some participants not returning to the start position on some trials, some block means had to be excluded. There were a total of 25 missing block means of 6,670 total block means. These 25 missing block means were filled using a modified "hot deck" imputation technique in which participant's missing means were estimated based on similar participant's cognitive skills. At baseline, the movement paths were relatively straight from the home position to the target in both conditions. As the visual feedback rotation was introduced in the exposure phases, participants began to approach the target at different angles, which resulted in curved movement paths. Upon return to normal visual feedback in the post-exposure phase, the curvature of the movement paths were similar to the early exposure trials, indicating after-effects.

Group Characteristics

Overall, 23 elderly participants between the ages of 65 and 78 were recruited by fliers posted at senior apartment complexes and area senior centers. In the sample, there were 19 females and four males, and 19 Caucasians and 4 African-Americans. Only one of the participants was left-handed. The average age of participants was 69.9 years old with 15.2 years of formal education. The sample's average MoCA score was 24.7, indicating a majority of participants falling *below* the MCI cutoff score. To equate cell sizes in between group comparison, a cut-off score of 25 was used, which placed 11 participants in the control group and

12 participants in the cognitively impaired group. It has been suggested in the literature that score below 26 is considered having cognitive impairment (Nasreddine et al., 2005). The median split of our current sample is consistent with the literature. Interestingly, the DRS-2 data revealed that only one participant fell below a score of 132. Thus, only the more psychometrically sensitive MoCA was used to place participants in testing groups. Please refer to Table 2 for cognitive and mood characteristics of the sample.

To determine homogeneity between groups, independent sample t-tests and chi-square analyses were conducted. Between group comparison t-tests revealed that groups did not significantly differ in age. Chi-square analyses revealed that groups did not differ significantly in race or sex (Fischer's Exact Test, $p = 0.671$), indicating that homogeneity between groups was maintained.

Visuomotor Adaptation

To assess equal baselines between groups, independent sample t-tests were performed on the last block of the baseline (block six) before the introduction of any visuomotor rotation. Analysis revealed no significant differences between groups in DE, DIST, MT, RT, or RMSE (all $p > .05$), confirming equal starting points before the introduction of exposure trials.

Specific aim 1: To examine the ability of normally aging elderly participants (65-80 years old) and cognitively impaired participants to adapt to different error feedback conditions in a computerized center out adaptation task.

Hypothesis 1-1: Individuals with cognitive decline (cognitively impaired) will show worse visuomotor adaptation (i.e., slower improvement during adaptation and smaller after effect) than the normally aging controls in the regular feedback condition.

In the regular condition, paired samples t-tests performed comparing the first exposure block (block seven) to the last exposure block (block 26) on all participants revealed overall learning effects in DE (t = 3.910, p < .001), DIST (t = 2.834, p < .01), MT (t = 2.317, p < .05), and RMSE (t = 7.061, p < .001). No overall learning effect was observed in RT.

Using the general linear model, a repeated measures multivariate analysis of variance (MANOVA) was conducted on the regular blocks. Machuly's Test of Sphericity rejected the null hypothesis that the variances of the differences were equal. Epsilon values were less than 0.75, thus the Greenhouse-Geisser statistic was used to correct the degrees of freedom and reduce the Type-I error rate. Overall, statistical differences were found in the main effects of blocks specifically in DE (F = 2.172, p < .05), DIST (F = 6.164, p < .01), MT (F = 4.496, p < .05), and RMSE (F = 14.595, p < .001). The main effects of group and the group x block interactions were not found on any of the dependent variables (DE, DIST, MT, RT, and RMSE). Independent t-tests were conducted on the last exposure block (block 26) to evaluate whether two groups reach the same level of learning throughout the exposure blocks. No differences were found in any of the variables (DE, DIST, MT, RT, or RMSE).

To track participant's learning over-time, a repeated measures MANOVA was conducted on all catch trials in the regular condition. No significant differences on any of the dependent variables were observed in the main effects (catch-trials) or interactions (catch-trials x group). A follow up t-test between groups comparing only the last exposure catch trial (block 26) also showed no effect.

To compare after effects between groups, paired sample t-tests were conducted comparing the baseline block (block six) and the first block *after* all of the exposure trials with the absence of any visuomotor rotation (block 27). Paired sample t-tests in the control group only revealed DE to have significant after-effect (T = 2.613, $p < .05$). Paired sample t-tests of impaired group discovered significant differences in DE (T = 5.018, $p < .001$) as well as MT (T = -2.621, $p < .05$). The increased MT in the after-effect block suggests that cognitively impaired participants became more efficient in movement across exposures and the absence of rotation increased MT once again. Overall, though the data suggests that both cognitively impaired and control participants learned across trials. Evaluation of after-effects using independent samples t-tests on block 27 between groups revealed no significant differences in DE, DIST, MT, RT, or RMSE. This further supports that the regular condition had a similar effect on both groups.

Hypothesis 1-2: Both cognitively impaired participants and normally aging participants will have increased adaptability in the enlarged error feedback condition than in the normal feedback condition.

First, a repeated measures MANOVA was conducted only on the enlarged blocks with the 14 exposure blocks treated as the within subjects factor and group as the between subjects factor. An overall main effect of learning in the exposure blocks was observed ($F = 4.799$, $p < 0.001$). Evaluating each variable individually revealed effects for all dependent variables: DE ($F = 4.591$, $p < 0.001$), DIST ($F = 5.854$, $p < 0.001$), MT ($F = 9.252$, $p < 0.001$), RT ($F = 2.479$, $p < 0.05$), and RMSE ($F = 14.919$, $p < 0.001$).

A three-way repeated measures MANOVA of the 14 exposure blocks was used to evaluate the main effect of condition on participant's visuomotor learning. Overall, the main effect of condition was significant ($F = 4.751$, $p < .001$). Specifically, the enlarged condition increased MT ($F = 11.981$, $p < .001$), RT ($F = 6.467$, $p < .05$), and DIST ($F = 4.932$, $p < .05$), suggesting that enlarging error feedback slowed the overall speed and perhaps efficiency of motor movement during the exposure trials. These statistical differences make sense overall.

During the enlarged condition, participants are required to move further and take longer periods of time to adjust for the increased error.

To track participant learning over the exposure trials, a three-way repeated measures MANOVA was conducted on the six catch trials. No significant overall effect of condition was observed. Evaluating each variable individually, RT was shown to have a significant difference between conditions ($F = 4.632$, $p < .05$), with lower RT in the regular condition. This was similar to the exposure trials. The increased reaction time could be due to the realization they were getting "messier" feedback and indicates longer planning, i.e. feed-forward movement.

To compare after-effects of the enlarged condition independent of group, paired sample t-tests were conducted comparing baseline blocks (block 6) to the first block after the last exposure trial (block 27) on all dependent variables. Results are shown in Table 3.

The results displayed in Table 3 suggest that both conditions had significant learning. However, the enlarged condition displayed significant after-effects for MT and RMSE in addition to DE. In other words, the enlarged condition led to increased learning in MT and RMSE, something the regular condition failed to do. However, paired sample t-tests were also run on the after-effect block (block 27) in both conditions, which revealed no significant differences between conditions. Overall, this data suggest that the enlarged condition may not have beneficial effects on motor learning. The data indicates, though, that different strategies may have been used in the different conditions. In the enlarged condition, MT and RMSE (feedback variable) had significant after-effects, indicating more reliance on visual feedback throughout the trial.

Hypothesis 1-3: Cognitively impaired participants will have a greater increase in adaptation than normal aging participants from the normal feedback condition to the enlarged error feedback condition.

Using a MANOVA, exposure blocks were treated as one within subjects factor and condition another within subjects factor. Group was treated as the between subjects factor.

Overall, comparing an interaction between the condition and level of impairment, no significant effects were found. However, MT was discovered to have a significant interaction between condition and level of impairment ($F = 4.722$, $p < 0.05$) in the hypothesized direction (i.e. movement time was reduced for cognitively impaired group in the enlarged condition while the regular group's movement time remained stable). No other variable (DE, DIST, RT, or RMSE) showed significant interaction.

To assess the catch-trials, a three-way repeated measures MANOVA was conducted on only the catch trials throughout the exposure phases. Like the exposure trials, an overall interaction between condition and level of impairment was found not to be significant.

Comparing after-effects for hypothesis 1-3 was completed by using a MANOVA on the after-effect block (27) with condition as the within subjects factor and level of impairment as the between subjects factor. An overall significant interaction was discovered between level of impairment and condition ($F = 7.019$, $p < 0.001$). Looking at univariate effects specifically, RT approached significance ($F = 3.380$, $p = 0.08$) and RMSE was significant ($F = 11.657$, $p < 0.001$). This significant interaction for RMSE was in the hypothesized direction. The cognitively impaired group had lower RMSE after-effect in the regular condition than the control group and benefited (i.e. larger after-effect) in the enlarged condition. The control group benefited more from the regular condition (larger after-effect) than the cognitively impaired group. Figure 1 shows this important interaction.

Cognition and Visuomotor Adaptation

Specific aim 2: To examine the relationship between cognitive assessments and visuomotor adaptation in a computerized center out adaptation task.

Hypothesis 2: The adaptability in the regular visual feedback condition will be strongly influenced by cognitive scores while the adaptability in the enlarged visual feedback condition will not be affected.

As an alternative to group comparison, the relationship between cognitive scores and visuomotor adaptation was explored using bivariate correlations. Bivariate correlations were used to determine which variables relate(s) to adaptation. After-effect was determined for correlations using a transformed variable (block 27 minus block six). Cognitive scores are compared to each after-effect block in Table 4 and Table 5

In the healthy controls (Table 4.), there were significant negative correlations in the regular condition and significant positive correlations in the enlarged condition. Overall, global cognitive scores (MoCA and DRS-2) positively correlated with learning. Both auditory (digit span) and visual working memory (spatial span) had negative relationships with learning.

In the cognitively impaired population (Table 5), the relationships appeared reversed compared to the normal controls. There were five significant positive relationships with learning, with four coming in the enlarged condition. Only one significant negative relationship was observed, coming in the regular condition. Unlike the normal controls, the cognitively impaired visual and auditory working memory scores had a positive relationship with learning.

To compare the differences between groups, the significant correlations that were found within groups were compared using Fisher's *Z.* The significant results are reported in Table 6.

Between group comparison revealed significant differences in Regular MT, Enlarged DIST, RT, and RMSE. The majority of significant differences (seven of eight) were in the enlarged condition. All of the significant results were in measures of global cognitive decline (MoCA), simple auditory attention (Digit Span Forward), auditory working memory (Digit Span Backwards, Digit Span Sequencing), and processing speed (Processing Speed Index, Coding). These correlations will be discussed further in the discussion section under "Hypothesis 2."

Discussion

In the field of motor learning, very few studies have examined the effects of cognitive decline in the elderly on visuomotor adaptation. Most studies instead have focused on the general aging effects on visuomotor adaptation and excluded both age related cognitive decline and dementia pathology from their research questions. Based on these studies, it is known that general aging has a detrimental effect on visuomotor adaptation, in both the feed-forward planning aspect of motor movement and the feedback mechanism to correct “noisy” sensorimotor systems. Error augmented feedback has been proposed to improve visuomotor adaptation in various models but has been not adequately studied with empirical methods. Only two studies have concluded the beneficial effects of increasing visual error-augmented feedback in visuomotor adaptation in heimparetic stroke survivors (Patton et al., 2006) and young adults (Wei et al., 2005). Until now, these effects were yet to be explored in elderly participants.

Numerous neuroanatomical changes in the aging brain can effect motor movement, visual perception, and cognitive processes. These cognitive changes are sometimes caused by MCI that has a high probability to progress to Alzheimer’s induced dementia. Unfortunately, most visuomotor adaptation studies ignore cognitive data and only a small number of studies have examined cognitive processes in visuomotor adaptation in the elderly (Anguera et al. 2011). Overall, these studies have found general visuomotor impairments that go beyond normal aging, suggesting cognitive processes have some effect on motor learning. Some studies have identified motor skills that have been retained in demented subjects (Fernandez-Ruiz et al. 2000; Rouleau et al., 2002). A particular compensation process that was explored was the increased reliance on visual feedback in AD subjects (Dick et al., 2001). With this potential compensation technique, increasing and augmenting visual error feedback in cognitively impaired elderly may have beneficial effects for motor learning. The goals of the current exploratory study were to:

a) discover a link between age-related cognitive impairment and declining visuomotor adaptation skill and;

b) explore a potential intervention technique for elderly individuals with motor impairments, i.e. visual error augmented feedback.

These issues were discussed in the following section in the order of the proposed specific hypotheses.

Hypothesis 1-1

Individuals with cognitive decline (cognitively impaired) will show worse visuomotor adaptation (i.e., slower improvement during adaptation and smaller after effect) than the normally aging controls in the regular feedback condition. Previous research has demonstrated decreased learning in cognitively impaired participants in visuomotor learning paradigms (Dick et al., 2001; Fernandez-Ruiz et al., 2001; Tippet & Sergio, 2006). It was expected that individuals in the cognitively impaired group would show decreased learning in the regular, thirty-degree rotation, condition. In other words, the control group would perform *better* than the cognitively impaired group in the regular condition.

The main findings revealed overall learning effects for the regular condition regardless of group. Each dependent variable, with the exception of RT, showed improved learning across all the exposure blocks (MANOVA) and the first and last exposure block (paired sample t-test). This confirms the paradigm design was adequate to detect visuomotor changes in elderly participants and is consistent with other studies using 30^{o} rotation (Seidler, 2006).

There are two explanations that could account for the lack of differences between groups in the regular condition found in this study. First, the methods used for group separation could be arbitrary. The range in MoCA score was only 21-30 points with a standard deviation of two point one points. More extreme group selection may have achieved different results. In the normative data empirical study of the MoCA, the range of MCI patients was 19.0 to 25.2 with an average MoCA score of 22.1; this led researchers to determine a cutoff score of 26 because it would capture *all* MCI patients in their sample (Nasreddine et al., 2005). The sample in the current study had an average MoCA score of 24.7, much higher than 22.1. This current sample may not have been "impaired" enough. Alternatively, it is also possible that the MoCA, which is a very sensitive instrument, created some false positives in the cognitively impaired group.

The increased sensitivity explanation of the MoCA is supported by divergent findings in the DRS-2, where only one participant fell below the MCI cutoff score. The MoCA has a reported sensitivity of 90% in detection of MCI (Nasresddine et al., 2005) while the DRS-2 has only a 71% sensitivity (Springate, Tremont, Papandonatos, & Ott, 2014). The specificity of these assessments are 87% (Nasreddine et al., 2005) and 86% (Springate et al., 2014) respectively, showing no difference. Although sensitivity is described as a "true positive rate," some false positives may have entered into the cognitively impaired group, thus diluting a true impaired group. This is difficult to conclude with certainty for the simple reason that the MoCA *is* more sensitive and the differences in scores found between the DRS-2 and the MoCA could indeed be a "true positive rate." A different explanation may be more likely.

A second explanation for the findings on hypothesis 1-1 could be due to the fact that the cognitively impaired group learned in a similar fashion to the healthy controls. There are a number of studies that have supported retention of learning in cognitively impaired participants.

In a particular study, 12 AD participants were compared to 12 healthy controls in a mirror-tracing paradigm in which visuomotor adaptation was required (Rouleau et al., 2002). It was discovered that AD participants who were *initially* able to complete the task (i.e. no different than healthy controls at baseline) showed no differences in the learning and retention throughout the study. AD participants that were not able to perform the task at baseline had decreased learning and retention. In the present study, groups were found to have no significant differences at baseline (block six), indicating that *all* participants were able to perform the task.

The similar learning between groups in the regular condition of the current study could be explained by the lack of differences at baseline (no differences were discovered between groups in DE, DIST, MT, RT, or RMSE in block six). It is possible that the cognitively impaired participants in this study did not have enough decreased visuomotor skills entering the task. Indeed in AD pathology, the cerebellum, a crucial component of visuomotor adaptation, does not necessarily show atrophy and cell death in the pre-clinical stages of the disease (i.e. MCI) (Thomman et al., 2007). Frontal functions, such as executive functions, are also known to be involved in visuomotor adaptation (Koziol, Budding, & Chidekel, 2012; Seidler, 2006). This current study did not use prominent executive functioning measures such as the Wisconsin Card Sorting Test (WCST) or the Word Context Test from the Delis-Kaplan Executive Functioning System (DKEFS).

Another interesting finding in Rouleau's et al. (2002) study was that participants who had difficulty with the task had impairments in several neuropsychological measures that measured complex problem solving and executive functioning skills (Wisconsin Card Sorting Test, Trails B), but no differences were found in global cognitive decline measures, such as the Mini-Mental State Examination (MMSE) or DRS-2 (Rouleau et al., 2002). In the current study, it was discovered that there were no differences in the regular condition when separated by the MoCA. Perhaps if this study used visual executive functioning measures (like the Wisconsin Card Sorting Test and Trails B) to separate groups, between group differences in the regular condition may have been significant. In the future, evaluation of executive functioning using these assessments would prove worthwhile based upon Rouleau's et al. (2002) findings.

Another study in 1995 conducted by Dick and colleagues discovered that participants with AD benefited from practice with an optimum practice effect at 40 trials in a rotary pursuit task. This current studies paradigm used five blocks (40 trials) of practice before using the baseline block (block six) for comparison. Independent *t*-tests at block one (no practice) revealed significant differences in feedback variables MT (t = 2.270, p < 0,05) and DIST (t = 2.931, p < 0.05). These differences disappeared at block six, after 40 trials. It is possible that this studies optimized 40 practice trials influenced the participants overall motor learning abilities throughout the paradigm. Looking forward, perhaps using only one block of no rotation before the introduction of 30^{o} rotation would create different results.

Hypothesis 1-2

Both cognitively impaired participants and normally aging participants will have increased adaptability in the enlarged error feedback condition than in the normal feedback condition. Motor-movement is a complex multi-system human behavior. The execution of a motor movement involves the initial planning phase (feed-forward) and adjustment of the planned phase based upon sensory information (feedback). Multiple models have hypothesized that *both* these processes are important for motor movement (Meyer et al., 1988; Shadmeur et al., 2010). Some models, however, have argued that feedback is more important for optimal motor movement (Wolpert et al., 2011). More specifically, some models have argued that augmenting error-feedback (or the deviance between planned and actual movement) can drive motor learning (Gomi & Kawato, 1985; Rumelhart et al., 1986). Based upon these models, Wei and colleagues (2005) demonstrated that visual feedback error augmentation with a gain of two increased motor learning in healthy young participants. Therefore, it was hypothesized that employing a gain of two to double visual error feedback in elderly participants would improve their motor learning.

After running a MANOVA on only the enlarged exposure blocks, significant learning was achieved in all variables. However, when comparing the enlarged condition's exposure blocks to the regular condition's exposure blocks, it was discovered that the enlarged condition increased MT, RT, and DIST. These differences are not surprising given that the participants are forced to travel further and longer when introducing doubled error feedback. The increased RT found in the exposure blocks and in the catch trials was probably due to the participant's realization that they were getting "messier" feedback, forcing them to slow down and develop a strategy (i.e. feed-forward mechanism). Although learning took place in the enlarged condition, there were no significant findings that supported increased learning in the enlarged condition versus the regular condition. This was not consistent with Wei's (2005) data in which error augmentation with a gain of two increased the rate of learning across blocks. One explanation for this discrepancy may be due to the sudden introduction of the exposure condition.

Several studies have examined the effects of introducing perturbations in a gradual versus a sudden fashion. Kagerer, Contrares-Vidal, and Stelmach (1997) conducted a study on younger participants and revealed that participants had less spatial error and larger after-effects if introduced to perturbation in a gradual manner. One condition had participants reach 90^o rotation in 10^o gradual increments and another condition had participants exposed to a sudden 90^o

rotation. The condition in which the distortion was introduced gradually allowed for more complete adaptation with less spatial error. In this current study, a sudden introduction of the enlarged condition may mimic an introduction of a large distortion, causing participants to not improve across the exposure trials.

Another study conducted by Buch et al. (2003) revealed similar results to Kagerer's et al. (1997) study using aging participants (mean age of elderly participants was 73.3). In their experiment, participants were introduced to a sudden 45^{o} rotation or 11.25^{o} rotations in gradual increments. This type of experiment is related to the implicit verses explicit learning in older adults, with gradual introductions of rotation using a more implicit strategy (i.e. participants are unaware of the gradual introduction of trials). Explicit strategy has been observed to be more impaired while implicit learning seems relatively spared in older adults (Kuzis et al., 1999; Sabe et al., 1995; Starkstein et al., 1997; Taylor, 1998; Van Tilborg et al., 2007). During the exposure blocks in Buch et al.'s 2003 study, elderly participants showed decreased learning compared to young participants in the sudden exposure (explicit) condition. After-effects between participants in this condition, however, were similar (showed little difference). The results were incongruent in the gradual condition with elderly and young participants showing similar adaptation levels but less after-effect in the elderly participants. The sudden exposure in the enlarged condition may have had a similar effect, like Buch et al.'s sudden 45^{o} rotation. It's possible the explicit nature of the enlarged feedback in the current study influenced the learning across the exposure blocks.

No overall differences were discovered in the learning between the groups as measured by after-effects. However, after-effects revealed the enlarged condition had overall learning effects in DE, MT, and RMSE. The regular condition only showed significant after-effects in

DE. Thus, the enlarged condition revealed feedback learning measured in MT and RMSE that the regular condition did not. In other words, the enlarged condition helped participants shorten their movement time and reduce their spatial deviation over the exposure trials and when the exposure trials ceased, the participants showed their adaptive strategy, increasing their movement time and spatial deviation. This indicates that participants used a different strategy in the enlarged condition, relying more on visual feedback than in the regular condition, in which participants relied more on feed-forward planning. Additionally, the finding of increased RT in the enlarged condition exposure trials and the lack of difference found in after-effects indicates that participants initially were forced to slow down and plan their movements, but then returned to their primary learning strategy, using their visual feedback (as indicated by RMSE and MT). The differing strategies used in the enlarged versus regular conditions did not result in significant differences in visuomotor learning in the entire sample. The results differed slightly though, when examining between group differences.

Hypothesis 1-3

Cognitively impaired participants will have a greater increase in adaptation than normal aging participants from the normal feedback condition to the enlarged error feedback condition. Improving motor learning via augmenting error-feedback has been researched in individuals with neurologic disease. Patton et al. (2006) introduced a haptic error augmented feedback task to hemi-paretic stroke survivors. His findings indicated that augmenting error sensory feedback increased motor learning in these neurologically damaged individuals. Patients with Alzheimer's dementia have also shown that they still have motor learning capabilities, although only in some special conditions. One of these conditions involved restricting visual feedback in a rotary pursuit task. Dick et al. (2001) examined 18 healthy controls and 18 Alzheimer’s dementia participants in different visual restriction conditions. It was discovered that both groups were able to learn the task equally when vision was not restricted. Once vision was restricted however, both groups showed decline with AD participants showing significantly larger decline. This indicates that individuals dementia show increased reliance on visual feedback, possibly as a compensation strategy due to declining motor skills. Given the studies finding that augmented error feedback drives motor learning (Patton et al., 2006; Wei et al., 2005) and Dick et al.’s work on increased visual feedback, it was hypothesized that cognitively impaired participants in this study would have increased learning in the enlarged visual error feedback condition.

A significant interaction was found for the feedback variable MT. It showed that cognitively impaired group in the enlarged condition had less MT overall in the enlarged condition’s exposure blocks than the control group. This data suggests that the enlarged condition may have made the visual feedback more salient for the cognitively impaired participants in which to adjust their movements. At the same time, the enlarged condition may have been excessive for the normal controls. Similar findings were observed by Seidler in 2006. She discovered that gain adaption of one point five (i.e. enhancing visual feedback) in normally aging elderly subjects was not as beneficial as 30^{o} rotation. It’s possible the enlarged condition in the current study was not optimal for feedback in the normally aging participants, increasing their overall movement time across trials.

The enlarged condition did not help cognitively impaired participants improve in feed forward movement planning (DE, RT) or in other visual feedback variables (DIST, RMSE) across the *exposure* blocks. In the feed forward variables, the lack of significance is not surprising, considering that cognitively impaired participants may rely more on visual feedback rather than rely on their "noisy" sensorimotor planning systems. It was expected however, that the increased feedback would help adjust the "noisy" sensorimotor system in an optimized fashion, much like the Meyer et al. (1988) model suggests, which would show improvement in DE and RT across trials.

While the cause of the lack of significant findings in exposure trials is not entirely clear, it may have been the length of time needed to adjust to the exposure. When visually observing (Figure 2) the RMSE data across exposure blocks, both normally aging controls and cognitively impaired participants decreased RMSE from the initial exposure phase (30^{o} rotation) to the second exposure phase (double error feedback). Once the introduction of the enlarged feedback occurred, normal aging participants increased the RMSE substantially (not as much as the cognitively impaired participants) and decreased over the enlarged exposure blocks. Once the second exposure ceased and participants went back to 30^{o} rotation (block 22), the cognitively impaired participants achieved *lower* (albeit not statistically significant, p = 0.093) RMSE scores than the regular controls. It's possible that cognitively impaired participants may have continued to decrease learning if the second exposure trials continued. Given the visual trend in the right direction (enlarged condition benefited the cognitively impaired participants more than the healthy controls), it's possible the small sample size or the length of the exposure trials may have prevented statistical significance. The dependent variable DIST revealed very similar trends. These trends most likely resulted in the significant after-effects discovered that supported hypothesis 1-3.

After-effects are often considered the primary measure for learning in visuomotor adaptation (Fernandz-Ruiz et al., 2000). Evaluating *only* block 27, it was discovered that the cognitively impaired exhibited larger after-effects than the regular controls in the enlarged condition while the controls exhibited larger after-effects than the cognitively impaired in the regular condition for the feedback variable RMSE (see Figure 1). The other dependent variables (DE, DIST, MT, RT) did not show significant interactions (albeit RT approached significance, $p = 0.08$). This suggests that the enlarged condition increased the RMSE learning for only the cognitively impaired group (supporting hypothesis 1-3) but had a negative effect on the healthy controls.

The increased learning for the cognitively impaired participants in the enlarged condition suggests that participants were learning throughout the exposure trials (i.e. they were using the enlarged feedback to reduce spatial deviations in their motor movement, when the exposure ceased, the adaptive strategy remained, causing increased after-effect). Specifically, RT approaching significance may indicate that the participants became more efficient with their planning (feed-forward movement). It is possible, like Meyer's et al. (1988) model suggested, that the feedback (RMSE) increased the effectiveness of the feed-forward movement. Although possible, DE would also have shown increased after-effects if the feed-forward planning had been optimized. Further study of this matter is required before any definite conclusions are drawn.

The increased RMSE after-effect for the cognitively impaired participants in the enlarged condition suggests improvement in the feedback aspect of visuomotor adaptation. Already documented in this paper are the effects of increasing error to drive motor learning (Patton et al., 2006; Wei et al., 2005). The explanation for this finding may be indeed the increased reliance on visual feedback (Dick et al., 2001) for the cognitively impaired participants coupled with the increased augmented error feedback that enhanced their motor learning. However, it was not expected that the controls would have *reduced* after-effect in the enlarged condition.

It's possible that because of the general timeline of decline, the regular controls have not yet acquired the reliance on increased visual feedback and remained rigid in their learning strategy. In other words, the normally aging controls feedback (RMSE) was not enhanced because they have not acquired reliance on visual feedback as a strategy, and did not use the feedback for correction. The increased error feedback perhaps disrupted the strategies of the normally aging controls that was not as productive as the regular 30^{o} rotation, similar to what Seidler (2006) found in normally aging participants. Although error has been hypothesized to drive motor learning, it does not appear based on this study, that it affects all older adults equally. Perhaps the size and method of error introduction played a role.

Some studies have shown that introducing error in smaller, gradual perturbations is more effective in older participants (Buch et al. 2003). The neural basis for the differences has been studied in a 2009 force field adaptation study by Cricismagna, Bastian, and Shadmehr. It was discovered that in patients with cerebellar damage, their ability to adapt to smaller perturbations was much more intact than in large perturbations. This would suggest that in the current cognitively impaired sample, cerebellar functions have remained relatively spared. This is also supported by findings that suggest that the cerebellum is spared in the *early stages* of AD and MCI (Thomman et al., 2007). This neural explanation, though, does not explain why the normal controls had increased difficulty with RMSE in the enlarged condition, as one would assume that their cerebellums are more intact than the cognitively impaired participants. Additional studies need to take place to understand the effects of augmenting visual error feedback in older adults with and without cognitive impairment.

The lack of significant interactions in after-effect for the other variables (DE, DIST, and MT) is interesting. The lack of DE after-effect suggests that the enlarged condition did not fully readjust the cognitively impaired participant's "noisy" sensorimotor system. They may have been slower in their planning but the enlarged condition did not significantly affect the participant's accuracy of movement. The explanation for DIST and MT may be simpler. DIST and MT are closely related feedback variables and it would stand to reason that the more distance traveled the more total movement time the participants endorsed. Indeed these variables approached a significant correlation in block 27 (r = 0.366, p = 0.086). The enlarged condition fundamentally requires more distance traveled and more time to complete. When examining the introduction of MT and DIST across all of the exposure blocks, it was observed that the enlarged condition increased MT and DIST regardless of group. The lack of after-effect simply means that participants did not become faster. Bock (2005) found similar results, seeing that overall speed of older participants did not improve across trials in a visuomotor rotation task. It appears that introducing enlarged visual error feedback does not improve speed of movement nor total distance traveled but may improve spatial deviation (RMSE) for the cognitively impaired.

Hypothesis 2

The adaptability in the regular visual feedback condition will be strongly influenced by cognitive scores while the adaptability in the enlarged visual feedback condition will not be affected. There have not been many studies that have examined neurocognitive data in relation to visuomotor adaptation. One important study examined the effect of visuospatial working memory on motor learning in older adults (Anguera et al., 2011). Researchers concluded overall, that the older adults fail to engage spatial working memory during visuomotor adaptation, which led to decreased learning. Researchers discovered that older adults had increased brain activation in a mental rotation task. Increased activation in older adults have been observed in this task before (Reuter-Lorenz et al., 2000). The older adults increased activation in this mental rotation task did not lead to improved performance. It's possible that the generalized decline of older adults led to de-differentiation in brain structures, i.e. the aging brain increases activation of surrounding structures but it does not help behavioral performance (Li & Lindenberger, 1999).

This current study hypothesized that the cognitive abilities of the regular condition would be strongly influenced by scores (because the cognitively impaired participants would not benefit from the regular condition) and the enlarged would not (because the cognitively impaired participants would benefit from the enlarged condition, reducing the relationship). The discussion of cognitive relationships will be explained by neurocognitive domains.

Global Cognitive Measures. In the enlarged condition, RMSE after-effect was positively associated with the MoCA score for the controls but not for the cognitively impaired participants (Fisher's Z = 2.29, $p < 0.05$). In other words, as MoCA scores for the normal controls decreased, so did the learning in the enlarged condition RMSE. This relationship was not found for the cognitively impaired participants. These results are consistent with the interaction observed in the enlarged RMSE after-effect. This particular finding is supportive of hypothesis 1-3, it was expected that the MoCA scores of the cognitively impaired participants would have no relationship with their learning in the enlarged condition. Similar findings were discovered in the enlarged DIST and the DRS-2, as the between group differences approached significance (Fisher's Z = 1.7, $p = 0.080$). In addition, DIST after-effect was not associated with DRS-2 scores in the impaired group, but positively correlated in the controls.

These data support the idea that the enlarged condition has different effects on the cognitively impaired elderly. Particularly, these variables (DIST, RMSE) are more indicative of learning through visual feedback versus feed-forward planning. The cognitively impaired participant's global cognition didn't have a relationship with their learning, suggesting they used a different strategy (feedback) than the normal controls. The normal controls may not have relied on feedback, which resulted in a positive relationship with their cognitive scores and visuomotor learning in predominantly feedback variables. Ultimately though, these results will need to be replicated in further studies with a larger sample size before any definite conclusions are drawn.

Working Memory. In the domain of auditory attention/working memory, specifically sequential auditory attention/working memory (Digit Span), significant differences were discovered between groups in both the regular and enlarged condition. In the regular condition, healthy controls had a negative relationship between MT and Digit Span backwards, meaning as their auditory attention skills decreased, their visuomotor learning increased. This relationship was significantly different than in the cognitively impaired, which did not show a significant relationship in regular MT. In the enlarged condition, positive relationships were found in the cognitively impaired group between RMSE and Digit Span forward and sequencing. This was significantly different than the controls, which had no significant relationship between enlarged RMSE and auditory working memory. Together these results suggest that auditory working memory abilities helped cognitively impaired participants learn in the enlarged condition but the same was not true in the regular condition (in which normal controls had a negative relationship). These results were not expected but could potentially be explained by compensation theory.

The compensation theory suggests that as individual's age, they must recruit from other brain areas to compensate for their functional decline (Cabeza, 2002). There have been numerous studies that show bilateral activation in areas such as the prefrontal cortex (for a review, see Cabeza, 2002). It may be that the cognitively impaired participants are showing compensatory effects, recruiting from the left-hemisphere. It's possible that participants in this current sample are doing the same. Digit Span tasks have been argued by some to be a primarily left-hemisphere task while spatial working memory is a predominantly right hemisphere task (Smith & Koeppe, 1996). Others have argued Digit Span is a bilateral task involving both frontal lobes (Rypman & D'Esposito, 2000). If the cognitively impaired participants are using areas such as the left-frontal lobe (auditory working memory) for compensatory strategies, it could explain the positive correlation between Digit Span and visuomotor learning. However, this is a speculative hypothesis and future studies needs to be conducted.

Spatial working memory (as measured by the Spatial Span task) had significant relational differences between groups as well. The controls had a significantly negative relationship between visuospatial working memory and enlarged RT (feed-forward planning variable). The cognitively impaired did not show this relationship. That is to say, as normal controls increased their visuospatial working memory, their feed-forward planning time (RT) decreased and vice versa. This finding is not consistent with Anguera et al. (2011) who found no significant correlation between spatial working memory and learning (measured by the rate of early adaptation). One explanation is that participants with cognitive impairments may not rely on the feed-forward mechanisms during learning. The other possible explanation is that this study is using different measures to evaluate learning. The current study is analyzing after-effects where Anguera et al. (2011) analyzed the exposure adaptation blocks.

Significant differences in visuospatial working memory may further indicate different learning strategies used by the two groups. Earlier it was mentioned that enlarged RT after-effects showed a near significant interaction ($F = 3.380$, $p = 0.08$) in the hypothesized direction. It's possible that the normal controls were not able to utilize or activate visuospatial working memory (similar to Anguera's (2011) findings) in the enlarged condition because they weren't as reliant on visual feedback as the cognitively impaired. This reliance on feedback helped recalibrate the cognitively impaired's "noisy" sensorimotor map. In other words, the cognitively impaired were able to utilize their visuospatial working memory capabilities to help plan their movements while the normal controls could not. This is further supported by the fact that the Spatial Span tasks were not significantly lower in the cognitively impaired group (Spatial Span Total, $p = 0.577$), which suggests that different strategies may have occurred with similar visuospatial working memory capabilities but global cognitive decline differences. This explanation is interesting, but needs to be replicated on a larger scale and examined more closely before comprehensive conclusions are made.

Visual Processing Speed. Processing speed has been argued to be a mediator between working memory capabilities and performance (Flanagan & Harrison, 2005). It's suggested that increased processing speed can reduce the demands of the limited capacity working memory system, allowing increased working memory function. In the current study, it was observed that the relationship between Processing Speed Index (aggregate score of Coding and Symbol Search subtests) and enlarged DIST was significantly different between groups. The normal controls had a large positive correlation between processing speed and enlarged DIST while the cognitively impaired did not. In the normal controls, there was a significant positive relationship between visuospatial working memory scores (Spatial Span) and enlarged DIST in addition to Coding and enlarged DIST. However, there was not a significant difference in the relationships of visuospatial working memory and enlarged DIST between groups. This may suggest that visual processing speed mediated the visuospatial working memory for the normal controls but not for the cognitively impaired in the enlarged condition. This could explain why there was no difference in learning between groups in enlarged DIST, that is, the cognitively impaired's visuospatial working memory was not enhanced by their visual processing speed, which did not allow them to improve their DIST in the enlarged condition.

General Summary and Conclusions

Visuomotor adaptation has been shown to degrade with age (Buch et al., 2003; Bock, 2005; Heur & Hegele 2008; Seidler, 2006) Even more difficulty with motor learning has been observed in demented participants (Dick et al., 2001; Tippet & Sergio, 2006). However, some abilities have been preserved in both older adults (Bock, 2005; Ruiz, 2000) and demented participants (Kuzis et al., 1999; Sabe et al., 1995; Starksteinet al., 1997; Taylor, 1998; Van Tilborg et al., 2007). Some have speculated that visual feedback when making motor movements is especially important for individuals with dementia (Dick et al., 2001). Additionally there have been models that postulate that error-driven learning processes may enhance visuomotor learning (Meyer et al., 1988; Shadmeur et al., 2010). It has been found that increasing error feedback can enhance adaptation in both normal aging participants (Wei et al., 2005) and brain damaged individuals with stroke (Patton et al., 2006). Spatial working memory ability has been suggested to have a significant effect on visuomotor adaptation ability. Thus, the purpose of this study was to examine the role of error feedback on visuomotor adaptation in the normal aging elderly and cognitively impaired individuals as well as determine the neurocognitive domains that may relate to these error-driven learning processes. It was hypothesized that individuals with cognitive decline (cognitively impaired) would show worse visuomotor adaptation (i.e., slower improvement during adaptation and smaller after effects) than the normally aging controls in the normal feedback condition. It was expected that little group differences in the enlarged feedback condition were to be found, suggesting individuals with cognitive decline rely more on their sensory feedback during adaptation.

Results from the adaptation tasks indicated that there were no real differences between groups in the normal feedback condition. This was not expected and may have been due to practice effects, arbitrary group separation, or the true lack of differences between groups, suggesting that cognitively impaired participants can learn just as well. It was also discovered that the enlarged condition did not improve overall learning. However, the enlarged condition had different impacts on the groups, revealing an interaction in the spatial deviation under the movement paths, suggesting that cognitively impaired elderly may benefit from increasing visual error-feedback. This difference may have been attributed to the increased reliance on visual error-feedback. To put it simply, the cognitively impaired used a different strategy in the enlarged condition.

From a cognitive standpoint, global cognition measures, visual processing speed, visuospatial working memory, and auditory working memory all revealed significantly different relationships with the visuomotor variables between groups. These differences again suggest differing strategies between groups, indicating that certain cognitive domains may be more important to adaptation to enlarged visual error-feedback. Overall though, the cognitive data is correlational and needs to be replicated via a larger sample and regression analysis to determine true predictions.

Further studies are needed to examine augmented error feedback on the elderly population. The current study at least partially supported the hypothesis that enlarging error-feedback may increase motor learning in the cognitively impaired elderly. This is an important finding that needs to repeated in a larger sample. If replicated, augmenting error-feedback to increase visuomotor adaptation may not only be able to help cognitively impaired elderly suffering from Alzheimer's Disease, but also other neurologic disease with cognitive impairments like Parkinson’s, Huntington’s, Multiple Sclerosis, or even Traumatic Brain Injury. This study’s findings could be used as a guide to explore the link between aging, cognition, visuomotor adaptation, error-driven learning.

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APPENDICES

APPENDIX A

Informed Consent

Project Title: Visuomotor adaptation in older adults

Principal Investigators: Rebecca Neill B.S. & Jeffery Schaffert B.A, Department of Psychology, Eastern Michigan University

Purpose of the Study: The purpose of this study is to 1) examine the relationships between cognitive functioning and visuomotor adaptation in aging; and 2) examine the adaptability differences between physically active and sedentary older adults. Visuomotor adaptation is being able to physically adapt to changes in your visual experience, like reaching for a drink when the drink has been moved.

Participant: You have been invited to participate in this research study because you are 65-80 years old and in the population needed for the study. Please do not participate in this study if you have severe wrist or shoulder pain, are color blind, or are unable to legally consent. If you find you are color blind during participation, you will still receive $10 compensation but cannot participate in the experiment.

Procedure: The experiment will take a total of 2.5 hours to complete, split into two equal length testing days separated by approximately 1 week. The study will all be completed at Eastern Michigan University in the Mark Jefferson Science Building, Room 352 D or at your Senior Facility. You will be asked to complete a series of questionnaires related to your personal health history including, fitness level, medications, current and past health issues, and dementia and depression screening measures. All of the information collected for this research study will be kept confidential and locked in a file cabinet. This assessment portion will take one hour to complete.

The computerized portion of the task will involve a number of different trials. In each trial you will be asked to use a computer and a joystick. You will be instructed on how to operate the equipment at the time of the start of the task. You will be asked to use the joystick to move the cursor from the start point to a number of different targets on the screen. This portion of the experiment will take about one half-hour each for the two testing days.

Voluntary Participation: Participation in this study is completely voluntary. You may choose not to participate or you may withdraw at any time without negative consequences.

Withdrawing from participation before 30 minutes will result in loss of compensation. If withdrawing after thirty minutes but before completion, compensation will drop from $20 to $10. If you score below a cutoff score on a screening measure we will not be able to participate in the study. If this does occur, you will be compensated $10 for participation.

Confidentiality: Your responses will be completely confidential. All consent forms, questionnaires, and data collected will be stored in a locked file cabinet or in a password protected electronic format. Signed consent forms are stored separately from completed questionnaires. Only a code number will identify your data. At no time will the name be associated with the response.

Dissemination and Results: The results of this study will be used for scholarly purposes only and may be shared with Eastern Michigan University representatives, presented at research meetings, conferences, published in scholarly journals and used as the basis for a Masters' Thesis. Results will be presented in group form only. No names or individually identifying information will be revealed.

Risks and Benefits: The risks of participating in this study are minimal. All measures are noninvasive. There is a minor risk of some wrist soreness. You are allowed to discontinue if so felt and will receive $10 if after thirty minutes into the experiment. You may take a break at any time. Another possible risk is your frustration over your performance on the test. They are designed to be difficult and you will not answer every question correctly or finish every test item. Also, please keep in mind that we are not licensed psychologists and the assessments are for research purposes only. For this reason, we will not be giving out the assessment results. This study has the potential benefit of expanding the current knowledge of dementia and physical fitness on visuomotor learning.

Compensation: You will be given $20 for each completed testing day in exchange for your time and participation in this research study. Thus, you will receive a total of $40 for the two testing days.

Questions: If you have any questions about this study, contact the principal investigators, Rebecca Neill at rneill@emich.edu or Jeffrey Schaffert at jschaff8@emich.edu. You can also contact their supervisor Dr. Jin Bo at jbo@emich.edu.

This research protocol and informed consent document has been reviewed and approved by the Eastern Michigan University Human Subjects Review Committee for use

from 01/01/2013 to 01/01/2014. If you have questions about the approval process, please contact UHSRC administrative co-chair at human.subjects@emich.edu or call 734-487-0042.

Consent to Participate: I am legally capable of giving consent and I voluntarily take part in this study.

My name is ______________________________

Signature________________________________

Date________________________

APPENDIX B

Health and Demographics Questionnaire

Please answer or fill in the requested information below

Age________ Race_______ Gender_____________

Years of formal education_________

Have you ever had a stroke? Y or N

Have you ever suffered from alcoholism, been diagnosed with alcohol abuse or withdrawal? Y or N

Do you suffer from arthritis? Y or N

If yes, where do you suffer arthritis? _________________________

Do you currently have any shoulder pain or problems? Y or N

Do you currently have any wrist pain or problems? Y or N

If yes please describe ____

Do you currently have any vision deficiencies? Y or N

If yes please describe ____

Have you ever suffered from any neurological disease? (Parkinson's, Huntington's, Traumatic Brain Injury, Multiple Sclerosis, Brain Abscess, Multiple Concussions, etc…)

Y or N

If yes please note the disease: _______________________

Please provide a list of your current medications below:

I confirm that I have answered these questions truthfully or to the best of my knowledge.

X____

Date _____________________

Participant number_____________ (for experimenter to fill out)

Table 1.

Summary of Experimental Testing Procedures

Day 1	Day 2
Visuomotor paradigm, condition 1 or 2	Visuomotor paradigm, condition 1 or 2
Montreal Cognitive Assessment (MoCA)	Dementia Rating Scale-2 (DRS-2)
Health History Questionnaire	Stroop Color-Word Assosciation
Grooved Pegboard Test	Digit Span Subtest from WAIS-IV
Coding Subtest from WAIS-IV	Arithmetic Subtest from WAIS-IV
Symbol Search Subtest from WAIS-IV	BDI-II (one week follow up)
Becks Depression Inventory-II (BDI-II)	Spatial Span Task from WMS-III
Thurston's Card Rotation Task	Thurston's Cube Rotation Task

Note. MoCA and Health History Questionnaire were given before the visuomotor paradigm to assess for exclusionary criteria.

Table 2.

Descriptive Statistics, Assessment Data

Assessment (Raw Scores)	*Range*	*Mean*	*Median*	*SD*
MoCA Total	21-30	24	24	2.18
DRS-2 Total Raw	123-143	138	138	4.39
Card Rotation	7-57	32.52	32	15.78
Cube Rotation	-4-9	2.39	2	3.69
Beck's Depression Inventory	0-28	7.27	4	8.59
Assessment (Percentiles)				
Spatial Span Total	5-98	61.17	63	29.82
Spatial Span Forward	5-98	60.57	60.57	31.65
Spatial Span Backwards	9-100	61.43	63	25.97
Stroop Word	1-69	22	17.50	19.46
Stroop Color	0-55	12.23	8	16.12
Stroop Color-Word	0-86	24.36	14	25.56
Stroop Color-Word Interference	2-88	35.32	27	28.97
Working Memory Index	9-87	44.87	42	22.46
Processing Speed Index	5-99	52.39	50	27.81
Digit Span Total	25-95	54	50	23.25
Digit Span Forward	16-99.9	60.34	63	24.65
Digit Span Backward	5-95	46.61	37	29.29
Digit Span Sequence	25-84	49.04	50	18.89
Arithmetic	5-91	43.22	37	29.28
Coding	5-95	52.87	63	27.18
Symbol Search	1-99.9	50.60	50	27.22
Grooved Peg Dominant Hand	0-75	19.77	7.50	23.45
Grooved Peg Non-Dominant Hand	0-97	25.78	21	25.47

Table 3.

Visuomotor After-effect (Baseline x Block 27)

Visuomotor after-effect	N	df	*t*-score
Regular DE	23	22	4.929**
Regular DIST	23	22	0.663
Regular MT	23	22	-1.775
Regular RT	23	22	0.453
Regular RMSE	23	22	-1.105
Enlarged DE	23	22	2.286*
Enlarged DIST	23	22	-1.977
Enlarged MT	23	22	-3.840**
Enlarged RT	23	22	-0.704
Enlarged RMSE	23	22	-3.719**

*$p < 0.05$
**$p < 0.001$

Table 4.

Significant Bivariate Correlations: Controls

Visuomotor Score	Neurocognitive Score	Pearson's *r*	Significance (*p*)
Regular DE	Digit Span Total	-0.585	0.058
	Digit Span Backwards	-0.578	0.062
	Digit Span Sequence	-0.657	0.028*
Regular DIST	DRS-2 Total	-0.701	0.024*
Regular MT	Digit Span Backwards	-0.680	0.021*
Regular RT	Stroop CW Interference	-0.743	0.035*
	Digit Span Forward	-0.660	0.053
	Coding	0.738	0.023*
Enlarged DIST	DRS-2 Total	0.638	0.064
	Spatial Span Total	0.815	0.007**
	Spatial Span Forward	0.815	0.008**
	Spatial Span Backwards	0.695	0.038*
	Processing Speed Index	0.915	0.001**
	Coding	0.949	0.0001**
	Symbol Search	0.718	0.038*
Enlarged MT	Spatial Span Backwards	0.576	0.083
	Stroop CW Interference	-0.641	0.046*
Enlarged RT	Spatial Span Total	-0.646	0.032*
	Spatial Span Forward	-0.786	0.004*
Enlarged RMSE	MoCA Total	0.681	0.021*
	Grooved Peg-Board	0.563	0.071

*$p < 0.05$
**$p < 0.01$

Table 5.

Significant Bivariate Correlations: Cognitively Impaired

Visuomotor Score	Neurocognitive Score	Pearson's *r*	Significance (*p*)
Regular DIST	Spatial Span Total	0.577	0.063
	Spatial Span Forward	0.625	0.040*
Enlarged DE	Processing Speed Index	0.663	0.026*
	Symbol Search	0.754	0.007**
Enlarged DIST	Stroop CW Interference	-0.584	0.046*
	Digit Span Total	0.599	0.040*
	Digit Span Sequence	0.775	0.003**
Enlarged RT	Spatial Span Backwards	0.650	0.042*
	Digit Span Forwards	0.684	0.029*
Enlarged RMSE	Spatial Span Total	0.571	0.052
	Spatial Span Forward	0.582	0.047*
	Digit Span Total	0.691	0.013*
	Digit Span Forward	0.743	0.006**
	Digit Span Sequence	0.607	0.036*

*$p < 0.05$

**$p < 0.01$

Table 6.

Significant Bivariate Correlations: Between Groups

Visuomotor Score	Neurocognitive Score	Fisher's Z	Significance (*p*)
Regular RT	Stroop CW Interference	-1.81	0.070
Regular MT	Digit Span Backwards	-2.16	0.030*
Enlarged DIST	DRS-2 Total	1.70	0.080
	Processing Speed Index	2.29	0.022*
	Coding	3.66	0.001**
Enlarged RT	Spatial Span Forward	-2.43	0.015*
	Spatial Span Backward	-2.33	0.019*
Enlarged RMSE	MoCA	2.29	0.022*
	Digit Span Total	-1.92	0.055
	Digit Span Forward	-2.19	0.029*
	Digit Span Sequence	-2.40	0.016*

*$p < 0.05$
**$p < 0.01$

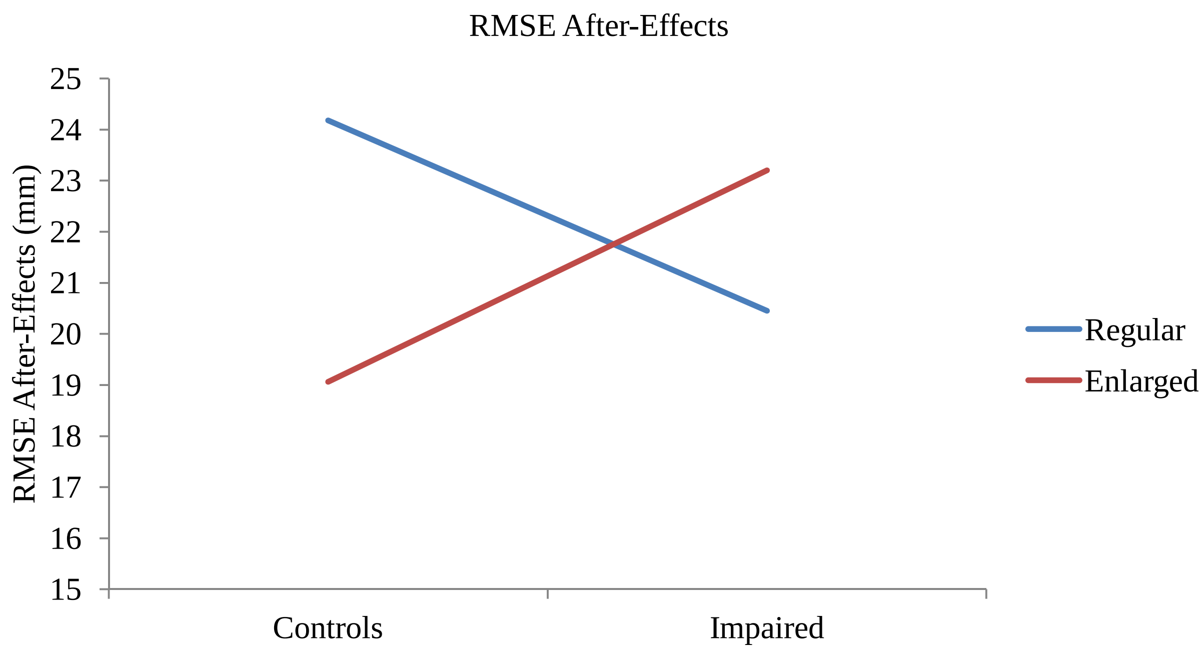

Figure 1. RMSE after-effects (block 27) by group membership deterimined by MoCA score of less than 25. RMSE is expressed as millimeters. Conditions differ by color, regular in blue and enlarged in red.

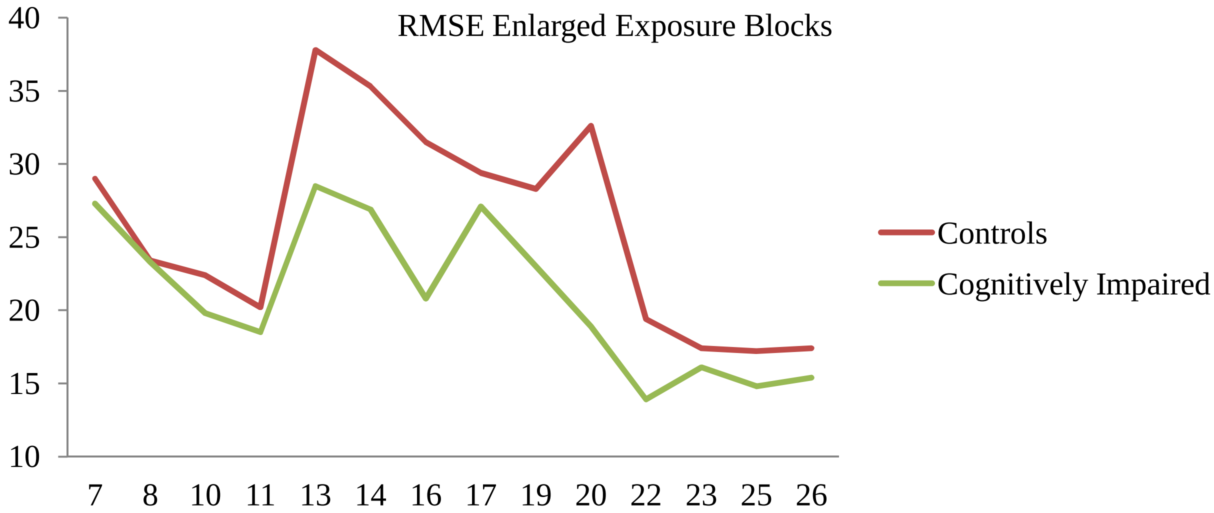

Figure 2. RMSE enlarged exposure block means x RMSE displayed in millimeters. Groups are represented by color, controls in red and cognitively impaired in green. Blocks 7-11 = 1st exposure phase with 30° rotation. Blocks 13-20 = 2nd exposure phase with doubled error feedback. Blocks 22-26 = 2nd exposure phase with 30° rotation.