

**ASSESSMENT OF MOVEMENT SKILLS AND PERCEPTUAL JUDGMENT IN
ATYPICAL AGING**

A DISSERTATION

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Abstract

This study investigated if individuals with either mild cognitive impairment (MCI) or early-stage Alzheimer's disease (AD) exhibit higher levels of postural motion when engaged in a perceptually demanding visual task, compared to a similar group of typically aging individuals.

Participants were well-characterized patients currently enrolled in the Minneapolis Veteran Affairs Medical Center's, existing protocols for patients (Protocol-Cognitive Changes in Older Adults: A Minneapolis VA Medical Center Database [the GRECC Memory Loss Clinic database]) and normal controls (Protocol-Normative Changes in Older Adults). Fifty-nine volunteer participants enrolled from these protocols. Groups were assigned according to a consensus diagnosis of AD, MCI, and Normal. Twenty-five AD, 19 MCI and 15 Normal participated in the study. Participants completed a visual task comprising two conditions: a control condition (Inspection) - looking only within the perimeter of the blank (white board) target; and an experimental condition (Search) – which required counting the frequency of a designated letter within a text block of randomly presented alphabet letters. Postural motion was recorded as center of pressure (COP) in centimeters, in both the medial-lateral (ML) and anterior-posterior (AP) planes of motion, using a stable motion detecting platform.

Results indicate that the AD group was less able to modulate postural motion in the ML plane (postural motion increased when switching from the Inspection task to the Search task); both the MCI and Normal group decreased their postural motion when switching from the Inspection task to the Search task. All groups, in the AP plane, were able to modulate their postural motion when engaged in the more demanding Search task, but the

AD recorded significantly higher postural motion than the Normal group. There was no significant difference between the Normal and MCI group; or between the AD and MCI group in the AP plane.

When groups were reclassified according to their current Mini-Mental State Exam (MMSE) scores, there was a significant difference between the “Low” MMSE group and the “High” MMSE group, in which the Low group increased their postural motion in the ML plane when engaged in the more demanding Search task. Consistent with the previous analysis, in the AP, all groups were able to reduce their postural motion when engaged in the more demanding Search task. However, both the “Low” and “Middle” MMSE groups, who recorded higher postural motion, differed significantly from the “High” MMSE group.

The results extend previous findings with respect to the strength of the perception-action link in aging individuals who experience cognitive change. Deficits in cognitive function related to postural motion, indicate an ‘embodied’ relationship that may be a sensitive measure to early-stage dementia.

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CHAPTER I

INTRODUCTION

Across the lifespan, postural control is essential for an individual to successfully interact in his/her environment. Early in development, postural stability is a critical achievement as a precursor to locomotion, and as we mature into older adulthood, postural control becomes less stable and a constraint on safe locomotion. Research has shown that older adults with increased postural variability are at a higher risk for falls (Maki, Holliday, & Topper, 1994), which is a major health concern. For an individual to successfully interact in its environment, the ability to maintain upright postural stability is very important. Research indicates a critical connection of postural stability to vision and the impact of optical flow (Wade, Lindquist, Treat-Johnson, & Taylor, 1995); attention and dual-task performance (Woollacott & Shumway-Cook, 2002); and suprapostural task performance (Stoffregen, Pagulayan, Bardy, & Hettinger, 2000).

COGNITIVE DEFICITS IN AGING OLDER ADULTS

In addition to changes in postural stability, advancing age brings cognitive and perceptual changes as well. A modest level of forgetting maybe deemed ‘normal’ as we age; but more serious memory deficits take on their own pathology. For example, dementia is a clinical condition defined as a decline in cognitive functioning severe enough to interfere with activities of daily living and social relationships. Dementia is not a disease in itself, but can be caused by various pathologies that affect the nervous system, including cardiovascular disorders, a number of neurologically based disorders, and abnormalities in other bodily systems (Whitborne, 2008).

Alzheimer's disease. Alzheimer's disease (AD) is perhaps the most common and well known type of dementia and the greatest risk factor is advancing age (Katzman, 1986). The disease is progressive and irreversible, affecting memory, language, behavior, and judgment of the individual. The only clear diagnosis is a post-mortem autopsy showing plaques and tangles throughout the cortex of the brain. An estimated 5.4 million Americans have AD (Alzheimer's Association, 2012).

Genetic Factors. Two subtypes of AD are linked to genetic factors: early- and late-onset AD. Early-onset AD is characterized by symptoms that occur before the age of 65 years and is caused by a mutation in one of three inherited gene groups. This type of AD is rare; the Alzheimer's Association (2012) estimates that less than 4% of the U.S. population is living with early-onset AD.

The more common form of the disease is "late-onset" in which symptoms occur after the age of 65 years. The genetic risk factor linked to late-onset AD is Apolipoprotein E-e4 (APOE-e4). APOE-e4 is one of the three common forms of the APOE gene, which provides the blueprint for a protein that carries cholesterol in the bloodstream. Those who inherit one APOE-e4 gene have an increased risk of developing AD. Individuals who inherit two APOE-e4 genes have an even higher risk, but there is no certainty that they will develop Alzheimer's (Bertram, McQueen, Mullin, Blacker, & Tanzi, 2007; Alzheimer's Association, 2012).

Environmental Factors. In addition to genetic factors that predispose one to AD, an instance where the disease is non-inherited is called sporadic AD. Sporadic AD has been the focus of more research in recent years evaluating lifestyle factors as a risk factor.

A healthy lifestyle includes several elements and strongly affects the risk of several chronic diseases. Recent research shows evidence that AD shares some of the same risk factors (National Institute on Aging, 2007). For example, a lack of quality sleep has been found to have a negative effect on cognitive functioning at any age (Blackwell, Yaffe, Ancoli-Israel, & Schneider, 2006); prolonged psychological distress/stress (Wilson, Arnold, Schneider & Kelly, 2006); social disengagement (Bennett, Schneider, Tang, & Arnold, 2006); unhealthy diet, and obesity (Weil, 2005). Interest in physical activity and exercise and its effects on cognitive functioning has increased. Research has found that cognitive decline can be delayed when individuals engage in 15 minutes of physical exercise three or more times per week (Kramer, Erickson, & Colcombe, 2006; Larson, Wang, Bowen, & McCormick, 2006). There is also evidence that moderate to severe head injuries sustained early in adulthood are an additional risk factor for AD (Anderson, Jorm, Korten, Creasey, & McCusker, 1992; Plassman, Harlik, Steffens, Helms & Newman, 2000). These lifestyle risk factors should be taken into consideration when assessing individuals with AD.

How is Alzheimer's disease Diagnosed/Assessed? Currently, no single test will detect Alzheimer's. Instead, a series of diagnostic tests and clinical assessments are used to diagnose (See Table 1 [Appendix A] for example). Tests include mental status and neuropsychological assessments to determine which thinking and memory functions are affected and to what degree. An example of this type of test is the Standard Mini-Mental State Examination (MMSE) (Psychological Assessment Resources, 2005), which is a brief quantitative measure of cognitive status, cognitive changes over time, and severity in adults. It tests for dementia by evaluating six areas of cognitive functioning:

orientation, attention, recall, immediate recall, short-term recall, language, and the ability to follow simple commands. Out of 30 possible points, a score 24-30 is considered normal, 20-23 is possible early stage/mild AD, 10-19 is middle-stage/moderate AD, and 0-9 is late-stage/severe AD (Folstein, M., Folstein, S., & McHugh, 1975). A second edition (MMSE-2, 2011) of the MMSE allows for more flexibility, encompassing the standard version, a brief version for rapid assessment and an expanded version to detect milder forms of cognitive impairment with aging (Folstein, M., Folstein, S., White, & Messer, 2011).

An assessment of the patient also includes an interview with a care provider regarding the emotional state of the patient, day-to-day routines, and any personality and behavioral changes. In addition, psychiatric assessments are used to detect any mental illnesses; blood tests to identify any infections or deficiencies that may cause memory loss, and brain scans to help rule out possible strokes, tumors or other conditions that may affect the brain function (Mayo Clinic, 2009).

Mild Cognitive Impairment. Mild cognitive impairment (MCI) is considered a subtle level of cognitive impairment; beyond the normal memory loss that occurs with typical aging but prior to the more advanced symptoms of dementia. This level of cognitive decline does not interfere with activities of daily living. The prevalence of MCI is estimated between 3 – 19% with an incidence of 8 – 58 per 1000 persons per year, and a risk of MCI developing into dementia at 11 – 33% over 2 years in older adults over 65 years (Ritchie, 2004). Approximately half the individuals with MCI progress into the harsher stages of dementia, such as AD, while others maintain a stable form of MCI or return to normal (Ganguli, Dodge, Shen, & DeKosky, 2004).

EMBODIED COGNITION

Consistent in research is the notion that cognition has an impact on motor skill and vice versa. This supports the emerging viewpoint of embodied cognition which proposes that perception, cognition, and motor function are inseparable; and that cognitive processes are deeply rooted in the body's interactions with the world (Gibson, 1966; Wilson, 2002). Thus, for example, just as vision facilitates postural control, postural control facilitates vision. Indeed, studies have demonstrated fundamentally different postural responses to secondary tasks, which are dependent upon task demands.

Decrements in cognitive function have been shown to have a negative effect on motor skills. Research show an increase in postural instability and fall risk in the AD population, as well as decrements in both fine and gross motor skills, which is discussed in Chapter 2: Literature Review.

Posture, Gait & Fall Risk. It has been shown that AD is associated with several gait abnormalities; decreased walking speed, step length, stepping frequency (Nakamura, Meguro, & Sasaki, 1996) and increased step-to-step variability, double support ratio, and sway path (Alexander, Mollo, & Giordani, 1995). In addition, individuals with dementia show significant difficulties in coordination and performing quick postural adjustments (Elble & Leffler, 2000).

It is now well established that subjects with dementia and particularly AD have a greater risk of falls compared to non-demented elderly people (Horikawa, Matsui, Arai, & Seki, 2005); furthermore falls are more serious in individuals suffering from AD, than in non-demented elderly people, with traumatic consequences including hip fractures (Buchner & Larson, 1987). This reflects a decrease in their compensatory techniques of

the postural control system and insufficient motor control which likely increases the frequency of falls.

POSTURAL CONTROL

For an individual, effective postural stability is needed for normal daily activities. Massion (1994) noted that to maintain posture involves interactions between external forces, the mechanical properties of the body and the neuromuscular forces.

How is posture measured? Many investigators measure posture, and observe indicators of postural instability by recording center of pressure (COP) using a force platform (Manckoundia, Pfitzenmeyer, d'Athis, Dubost, & Mourey, 2006; Melzer, Benjuya, Kaplanski, & 2004). The individual stands on the force platform as the strain gauges embedded in the platform records the movements and changes of ground reaction forces. The motion of the individual is computed into a measure of postural sway, or COP. COP is the vertical component ('Z') of the two directions of motion; medial/lateral (x) and anterior/posterior (y) (see Figure 1). COP is thus a computed indirect measure of postural sway and postural instability (Wade et al., 1995).

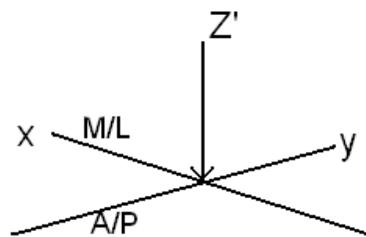


Figure 1: Center of Pressure (COP) represented at the vertical component (Z) in the X (medial/lateral) and Y (anterior/posterior)

Other investigators have used a magnetic tracking device (Flock of Birds, Ascension Technologies, Burlington, VT; and Polhemus FASTRAK, Polhemus, Colchester, VT) to record posture sway and instability. Both systems use information from sensors placed on the subject within the magnetic field. The sensors provide real time 6 Degrees of Freedom, or tracking feedback on the subject's position (X, Y, & Z Cartesian coordinates) and orientation (azimuth, elevation, and roll) to a reference point in the environment.

For the current study, postural motion was recorded using the Wii Balance Board, a part of the popular video game WiiFit (Nintendo, Kyoto, Japan). The Wii Balance Board functioned as a stabilograph; and is comparable to the force platform, the "gold standard" tool to measure balance. The two are similar in that both contain four transducers which are used to assess force distribution. A recent study by Clark et al. (2010) examined the validity of the Wii Balance Board in comparison with the force platform using a combination of standing balance tests. Results found that the Wii Balance Board is a valid, inexpensive, and portable tool for assessing standing balance (Clark et al., 2010).

THE AIM AND PREVIEW OF THE PRESENT STUDY

The aim of the present study was to add to previous research showing that posture is not autonomous, as traditionally assumed, but part of a perception-action system (Stoffregen, et al., 2000; Prado, Stoffregen & Duarte, 2007). By the age of 10 years old, healthy children (Chen, Tsai, Stoffregen, & Wade, 2011), young adults (Stoffregen et al., 2000), and healthy older adults (Prado et al., 2007) are able to adaptively reduce their postural motion while actively engaged in performing a visual task. The proposed study

investigated the status of this perception-action system in typically aging older adults; especially those older adults with impaired cognitive functioning; (those labeled as AD and MCI). Of central interest was whether the underlying mechanisms involved in cognitive impairment weakened the link between perception and action while engaged in a suprapostural task.

STATEMENT OF THE PROBLEM AND HYPOTHESES

The present study addressed two research questions:

1. Does the magnitude of postural motion in groups of individuals diagnosed with cognitive deficits differ from the known effects on typically aging individuals?
2. Is postural support impacted by cognitive deficits when engaged in a suprapostural task?

Four hypotheses were developed around these two questions:

- H₁ Individuals with cognitive deficits will exhibit higher overall postural motion, than typically aging individuals, irrespective of task load.
- H₂ Individuals diagnosed as AD or MCI will exhibit a weaker perception-action link when engaged in a demanding suprapostural task.
- H₃ Performance scores (% correct) on the designated task will show superior performance by the typically aging group compared to those diagnosed with cognitive deficits.
- H₄ Correlations measuring the relationship between postural motion and task difficulty will be negative, supporting an 'embodied' relationship between posture and task engagement.

CHAPTER II

LITERATURE REVIEW

This review of literature discusses the cognitive and movement behavior changes relative to typical and atypical aging (i.e. AD and MCI). This discussion is followed by a review of the relationship between postural control and task performance (i.e. dual-task paradigm and suprapostural task).

NORMATIVE CHANGES IN COGNITION AND MOVEMENT BEHAVIOR IN AGING

As people age, there is a qualitatively “normal” decline of function. Cognitive and physical decline are the most concerning to the aging population. The following provides a brief overview of the normal functional decline as people age.

Cognition

The normal age-related decrease in cognition is not uniform across cognitive realms nor is the level of decrease consistent across individuals. On the other hand, this topic has been extensively studied, showing that older adults overall perform more poorly compared to a younger group. *Attention* and *memory* are the basic cognitive functions most affected by age; and previous research points to impairment of the executive function as a key contributor to these age-related declines (Glisky, 2007).

Attention. Research has shown a disadvantage in attention in older adults. For example, *selective* attention, or the ability to focus on the task at hand while disregarding another stimuli occurring simultaneously, is shown to have reaction time decrements. The Stroop task is a well-known for testing selective attention. Participants are asked to name the color of the ink in which an incongruent color word is printed, (e.g. the word “yellow” printed in blue ink) (Glisky, 2007). Overall, older adults are slower in

responding to the target words compared to younger adults, but maintain performance. Researchers attribute this response (i.e., increase in reaction time) largely to the decline of information processing speed within the aging nervous system (Salthouse, 1996).

Significant age-related decline in performance have been reported during *divided* attention, in which there is a processing of two or more stimuli of information or dual-task (i.e., the performance of two or more task simultaneously). In general, results show that older adults are more affected by the division of attention than young adults, especially when the attentional demands of the two tasks are high. Traditionally, these findings are explained in terms of an age-related limitation in processing resources (Kahneman, 1973). What remains unimpaired with normal aging is *sustained* attention, or the ability to maintain concentration over an extended period of time (Glisky, 2007).

Memory. Many older adults complain of increased memory lapses as they age. A key focus in this field has been on distinguishing memory declines attributable to normal aging and those that are suggestive of pathological aging, such as AD.

Working memory is considered a multidimensional limited capacity system that involves the active handling of information that is presently being maintained in focal attention (Glisky, 2007). It is believed that working memory is really a divided attention task; the task being the maintenance of short-term memory information while simultaneously manipulating the information for an alternative purpose. As mentioned in the previous *attention* section, there appears to be a decrement in divided attention among older adults.

The most affected by normal aging is episodic memory, or the explicit recollection of events, the ‘what’, ‘where’, and ‘when’ of information storage (Brickman

& Stern, 2009). It is considered an extension of long-term memory, which requires retrieval of information that is no longer present or being maintained in an active state. Episodic memory is typically tested by having the person learn a list of words and then recall them after an interval period. Lastly, older adults have difficulty recalling the source in which information was acquired (Brickman et al., 2009).

Theories of working, episodic and source memory decrements mirrors those also mentioned in the attention section:

(1) *reduction of cognitive resources*, which reflects a reduction in mental energy.

Tasks with higher demands show impairments while lower demand tasks, that are relatively automatic, are mostly intact. Since working memory is considered a divided attention task, this type of memory “strains” the limited resources of older adults (Craik & Salthouse, 2000)

(2) *reduced speed of information processing*, in which speed is viewed as a resource. Salthouse (1995) suggests that deficits in working memory can be explained by the “slowing of fundamental cognitive processes”. On the other hand, it is argued that this is more of a descriptor of aging cognition rather than a theory of causation.

(3) *failure of inhibitory control* or failure to suppress irrelevant information in the working memory, which may reduce its capacity, denying access to relevant information. Hasher, Zacks, and (1999) proposed that this might account for cognitive deficits associated with aging. Data suggest that older adults experience more interference from irrelevant information under some conditions (Hedden & Park, 2001), but not all. Differences may be due to

different kinds of inhibition or that age-related effects are task- or paradigm-specific (Glisky, 2007).

While there are aging effects on working, long-term specifically episodic and source memory, there are other forms of memory that remain relatively unchanged by the aging process. Typically aging older adults are able to maintain information over a short period of time (short-term); store general knowledge such as facts, words, and concepts about the world (e.g. There are 50 states that compose the United States.) (semantic); remember one's personal past, where early childhood is the hardest to retrieve and the most recent events being the easiest (autobiographical); change behavior that occurs as a result of prior experience (implicit); maintain normal acquisition of the knowledge of skills and procedures in both motor and cognitive domains and retain them across the lifespan (e.g. riding a bicycle) (procedural); and remember to do things in the future, such as paying bills, with the use of external cues such as calendars (prospective) (Glisky, 2007).

Movement Behavior/Motor Skills

Movement behavior is similar to cognition, in that the level of decrease is not uniform across individuals. Major research findings demonstrate that older adults record increased reaction time and psychomotor speed (movement slowing), meaning these individual take longer to process, prepare, and execute a response to a stimulus compared to younger adults (Salthouse, 1993). In addition, older adults have decrements in coordination, balance, and gait (Wade et al., 1995).

Welford (1982) states, from an information processing viewpoint, that in order to explain the functional components and process, motor processes alone are not sufficient

to account for changes in motor skill, but must include the sensory, central, *and* motor mechanisms. Age-related changes in the movement based integrated sensory systems of vision; vestibular; and somatosensory are reviewed below:

Vision. Vision is a large component of successful motor skill performance. It determines how clearly a person can see objects. Visual acuity, or the ability to see details at a distance, decreases as a person age. The visual acuity of an 85 year old is 80% less than that of a person in their 40s (Whitborne, 2008). Researchers suggest that the loss of visual acuity affects the quality of visual information that reaches the central nervous system resulting in a negative impact on performance of motor behavior and skills (Welford, 1982).

Vestibular. The vestibular system provides information about spatial orientation and assists in the control of balance (equilibrium). As individuals age there is a decrease in this function by showing an increase in variability, making it difficult for older adults to detect their body position in space (Contreras-Vidal, Teulings, & Stelmach, 1998). Adults that are over 70 years of age have a 40% reduction in sensory cells within the vestibular system (Woollacott, 1993).

Somatosensory. The somatosensory system provides information about body contact and position. In addition, the system translates information about pressure, temperature, pain, and proprioception. Older adults have an impaired detection of the motion of limbs, especially at slow speeds due to slower motor nerve conduction velocity and slower muscle activation (Shaffer & Harrison, 2007). In addition there is a decrease in touch and pressure-sensitive nerves (Wickremaratchi & Llewelyn, 2006). These decrements affect the individual's quality of movement skills in the environment.

As mentioned previously, sensory, central, and motor mechanisms are needed to understand motor behavior/skill. The functional changes in the motor system in aging individuals have been linked to degeneration of the neurons in the *basal ganglia*, which contributes to the slowing of movements; the *cerebellum*, which is involved in complex movement coordination, timing, and contributes to the maintenance of muscle tone, stretch reflexes, gait, postural control, sensory integration and motor learning; and the *motor cortex* leading to weakness deficits in motor function (Ketcham & Stelmach, 2001).

These age-related changes in these mechanisms have been shown to effect movement patterns, such as walking, coordination, balance, and gait. An increase in movement duration has been seen on a variety of tasks in aging individuals. With age, movements slow by as much as 15-30% compared to younger adults, which researchers report is a strategy that older adults use emphasizing movement accuracy at the cost of movement speed (Diggles-Buckles, 1993; Seidler-Dobrin & Stelmach, 1998). Salthouse (1993) suggests that the age-related slowing of information processing affects motor performance in a nonspecific fashion.

Coordination of both bimanual and multi-joint movement also show deficits with aging. Seidler, Alberts, and Stelmach (2002) showed that when older adults move their shoulder and elbow joints simultaneously as opposed to performing single joint actions, movements become slower and less smooth. Age-related changes in the cerebellum and the proprioceptive systems are reported to have an impact on the coordination problems.

Postural sway in older adults has been extensively studied as it relates to fall risks, a major health concern in this vulnerable population. Research has shown that older

adults show increased postural sway in steady stance; an inability to execute effective stepping responses, and difficulty controlling displacements of the center of mass and center of pressure relative to their limits of stability (Maki & McIlroy, 1999; Tang & Wollacott, 1996) when compared to young adults.

ATYPICAL COGNITIVE DEFICITS IN AGING

Alzheimer's Disease - Cognitive Pathology

AD is the sixth leading cause of death among adults in the United States (Alzheimer's Association, 2012). It accounts for 60 to 80% of dementia cases (Alzheimer's Association, 2012). Dementia of the AD type is characterized according to the Diagnostic and Statistical Manual of Mental Disorders-IV-TR (DSM-IV-TR) by multiple cognitive deficits that include impairment in memory (American Psychiatric Association, 2000). For a diagnosis to be given for dementia of the AD type, cognitive deficits must be severe enough to cause impairment in occupational or social functioning (e.g., working, shopping, going to school, handling finances, and other activities of daily living) and must represent a decline from a previously higher level of functioning.

The DSM-IV-TR (2000) diagnostic features consist of the following four criteria:

Memory impairment (Criterion A). Deterioration of language function (aphasia) such as having difficulty producing the names of individuals and objects (Criterion A2a). Individuals with dementia may exhibit apraxia (i.e., impaired ability to execute motor activities despite intact motor abilities, sensory function, and comprehension of the required task (Criterion A2b). Failure to recognize or identify objects despite intact sensory function (agnosia) (Criterion A2c). Disturbances in executive functioning (Criterion A2d) which involves the ability to think abstractly and to plan, initiate, sequence, monitor, and stop complex behavior. These disturbances must represent a decline from a previous level of functioning (Criterion B).

Stages of Alzheimer's disease. Individuals with AD do not progress at the same rate, but researchers have identified stages of AD using common patterns of symptoms.

Staging provides a good frame of reference and aids in planning for the future.

The stages of AD according to Reisberg & Ferris (1985) are:

Stage 1: No impairment (*normal function*) – Unimpaired individuals experience no memory problems and symptoms are not evident to a health care professional during medical interview.

Stage 2: Very mild cognitive decline (*may be normal age-related changes or earliest signs of AD*) – Individuals may feel as if they have memory lapses, especially in forgetting familiar words or names or the location of keys, eyeglasses or other everyday objects. But these problems are not evident during medical examination or apparent to friends, family or co-workers.

Stage 3: Mild cognitive decline (*Early-stage Alzheimer's can be diagnosed in some, but not all, individuals with these symptoms*) – Friends, family or co-workers begin to notice deficiencies. Problems with memory or concentration may be measurable in clinical testing or discernible during a detailed medical interview. Common difficulties include: Word- or name finding problems; decreased ability to remember names when introduced to new people; performance issues in social or work settings; reading a passage and retaining little material; losing or misplacing a valuable object; and decline in ability to plan or organize.

Stage 4: Moderate cognitive decline (*Mild or early-stage AD*) - At this stage, a careful medical interview detects clear-cut deficiencies in the following areas: decreased knowledge of recent occasions or current events; impaired ability to perform challenging mental arithmetic; decreased capacity to perform complex tasks; reduced memory of personal history; and the affected individual may seem subdued and withdrawn, especially in socially or mentally challenging situations.

Stage 5: Moderately severe cognitive decline (*Moderate or mid-stage AD*) – Major gaps in memory and deficits in cognitive function emerge. Some assistance with day-to-day activities becomes essential. At this stage individuals may: be unable to during medical interview to recall such important details as their current address, telephone number, etc.; become confused about where they are or about the date, day of the week or season; have trouble with less challenging mental arithmetic; need help choosing proper clothing for the season or occasion; usually retain substantial knowledge about themselves and know their own name and the names of their spouse or children; and usually require no assistance with eating or using the toilet.

Stage 6: Severe cognitive decline (*Moderately severe or mid-stage AD*) – Memory difficulties continue to worsen, significant personality changes may emerge and affected individuals need extensive help with customary daily activities. At this stage, individuals may: lose most awareness of recent experiences and events as well as of their surroundings; recollect their personal history imperfectly, occasionally forget the name of their spouse; experience disruption of their normal sleep/waking cycle; have increasing episodes of urinary or fecal incontinence; experience significant personality changes and behavioral symptoms (e.g. suspiciousness, hallucinations, etc); and tend to wander and become lost.

Stage 7: Very severe cognitive decline (*Severe or late-stage AD*) – This is the final stage of the disease when individuals lose the ability to respond to their environment, the ability to speak and ultimately, the ability to control movement. Frequently individuals lose their capacity for recognizable speech, need help with eating and toileting, lose the ability to walk without assistance, then the ability to sit without support, the ability to smile, and the ability to hold their head up. Reflexes become abnormal and muscles grow rigid. Swallowing is impaired.

Stages 1 through 4 (with emphasis on early-stage AD) were the stages of interest for our investigation on whether individuals with impaired cognitive functioning are able to stabilize their postural motion to facilitate visual performance.

Mild Cognitive Impairment - Cognitive Pathology

MCI is a transition stage between the cognitive decline of normal aging and the more advanced symptoms caused by AD (Mayo Clinic, 2010). In the general population, the prevalence of MCI is estimated to be 3-4% in the eighth decade (Ganguli et al., 2004). According to the American College of Physicians, MCI affects about 20% of the population over the age of 70 (Mayo Clinic, 2010).

MCI can affect many areas of cognition and action – such as language, attention, reasoning, judgment, reading, and writing; but the most common complaint are memory problems (Mayo Clinic, 2010). The American Academy of Neurology (AAN) workgroup of specialists identified the following criteria for an MCI diagnosis:

1. an individual's report of his or her own memory problems, preferably confirmed by another person
2. measureable, greater-than-normal memory impairment detected with standard memory assessment tests
3. normal general thinking and reasoning skills
4. ability to perform normal daily activities (Alzheimer's Association, 2012)

Similar to Alzheimer's, there is no specific test to confirm a diagnosis of MCI. Instead a series of test (e.g. neurological, mental status, blood, MRI or CT) are performed to rule out other diagnosis that may have been responsible for the symptoms.

ATYPICAL COGNITIVE DEFICITS AND MOTOR BEHAVIOR

As previously discussed, as we age there is a qualitatively normal decline and slowing of cognition and motor function. Research has shown that the effect of aging are more pronounced when the task increases in complexity; thus showing that perception, cognition and motor function are connected ('embodied cognition'). This warranted further research into the pathological effects of cognition on motor behavior.

Cognitive Deficits and Fine Motor Skills

Several recent investigations have confirmed that the presence of cognitive deficits, such as those with MCI and AD, has a considerable impact on fine motor control. Aggarwal, Wilson, Beck, Bienias, and Bennet (2006) investigated the relation of impaired motor function in MCI to subsequent risk of AD. The longitudinal cohort study examined the relation of MCI to baseline motor function and the relation of baseline motor function in MCI to risk of incident AD. A group of 816 individuals, 558 had no cognitive impairment, 198 met the criteria for MCI, and 60 for Alzheimer's. At baseline, each participant underwent a uniform clinical evaluation, cognitive function assessment, and motor function assessment. Motor function was assessed using performance-based

measures of upper (Purdue Pegboard Test) and lower extremity function (modified version of the motor section of the Unified Parkinson's Disease Rating Scale). Clinical evaluations for dementia and AD were repeated annually for up to 10 years.

Results showed that upper and lower limb motor functions in participants with MCI were intermediate in relation to those of participants without cognitive impairment and those with AD at baseline. During a 6 year observation period, among those with MCI, the level of gait dysfunction and motor slowing predicted risk of AD. The researchers concluded that MCI is characterized by motor dysfunction and cognitive impairment and that the degree of motor impairment, especially gait dysfunction, may help identify those at risk for AD. Therefore, a person with impaired lower limb performance (10th percentile) was 2 to 3 times more likely to develop AD than a person with fine lower limb function (90th percentile). The main limitation of this study was the selections of participants based on a specific population group of Catholic clergy members. Further studies should include study participants that are representative of the general population.

Camarda et al. (2007) investigated the question of whether there was a match between the neuropsychological deficits of participants affected by amnesic MCI (aMCI) and early AD with their motor deficits. A group of 33 individuals participated (healthy=11; aMCI=11; and mild-moderate AD=11) in a battery of neuropsychological evaluations. At least a day later, participants completed a visuomotor task. From a seated position, participants were instructed to point and touch with their right index finger the light-emitting diode that illuminated with their maximal velocity and accuracy.

Results showed that individuals with mild-to-moderate AD, but not aMCI, are significantly associated with motor function deficits, which is consistent with previous research. The neuropsychological evaluation analysis showed that AD and MCI performed similar on the test exploring short and long term verbal memory. For the remaining tests, AD subjects performed significantly worse than aMCI group. In the kinematic evaluation, AD were significantly slower for movement time, reaction time, peak of acceleration, peak of velocity, and peak of deceleration. Results showed no difference in the kinematic evaluation between aMCI and controls. In addition, there was no relationship between the neuropsychological scores and kinematic performance in both aMCI and AD. The findings of this study are consistent with Aggarwal et al. (2006), showing that the AD group performed worse than the MCI and normal aging group. It was interesting to see no difference between the aMCI group and normals. This could be due to task complexity. These findings are limited in a sense as there was a lack of statistical power due to the small groups of subjects (i.e. eleven subjects in each group).

One cross-sectional exploratory study by Yan, Rountree, Massman, Doody, and Li (2008) sought to investigate whether the declines in fine motor control and coordination characterizes sensory-motor deficiencies of cognitively impaired populations like MCI and AD. Researchers evaluated the sensory-motor function using four handwriting type movements between MCI (n=9), AD (n=9) and normal aging control group (n=10). Participants sat in a chair and performed handwriting on the surface of a digitizer. Four patterns were used: up-down vertical movement, left-right

horizontal movement, forward-slanted, and backward slanted movements. Movement time and jerk were recorded used a MovAlyzer program (NeuroScript, Tempe, AZ).

Results showed that participants with a cognitive deficit moved slower and less smoothly than normal aging adults. In the analysis involving the MCI group, results showed a significant difference in movement time and jerk compared to the normal controls. The MCI group moved slower, less smoothly and less consistently than the normal controls. In the AD group, results showed an increase in movement time and jerk in a great scale than the MCI and normal control group especially on tasks that required coordination of the fingers and wrist (forward-slanted & backward slanted handwriting movements). Researchers concluded that difficulties in fine motor control and coordination is due to the impact of reduced sensory-motor function and adds to the current need to understand the full range of impairment of MCI and AD individuals. These findings are limited, however, due to the limited sample size.

Hall and Harvey (2008) sought to examine the factor structure of the Behavioral Dyscontrol Scale (BDS), a seven item motor control assessment tool, with a sample of elderly individuals. Further, Hall and Harvey wished to extend the work of Belanger et al. (2005) by including individuals with vascular dementia (VaD), AD, MCI and healthy control. Lastly, the researchers wanted to provide a more practical way to analyze data from the BDS for individual patients. Participants consisted of 74 individuals with VaD, 129 with AD, 24 with amnesic MCI, 22 with non-amnesic, and 11 normal controls. The assessment consisted of: two alternate hand-tapping items (tap twice with the right hand, once with the left and vice versa); two go no-go items (responsive tapping in which the examinee taps twice if the examiner taps once and vice versa); Luria's fist-edge-palm

task; the piano test (alternate touching of the thumb and fingers); the Head's non-mirroring task.

Results showed that the AD and VaD differed from the controls and the MCI group, but not from each other on the Motor Problem Solving factor (fist-edge-palm, head's test, go no-go, responsive tapping, and piano exercise). The controls and the MCI group did not differ from each other, suggesting that the factor contains more complex tasks that require a higher level of functioning. For the two alternating hand-tapping task (simple motor repetitive task), there was no difference between groups, suggesting this executive ability is still functioning for all groups until participants reach "moderately severe cognitive decline on the Global Dementia Scale." The authors concluded that behaviors that require problem-solving may help to discriminate between normal aging from MCI and dementia. These findings are consistent with those of Camarda et al. (2007) showed no difference between the MCI group and normal aging group. The research adds to previous findings of the motor deficits in various fine motor skills found in those with AD. Again, limitation in sample size continues to be an item of concern, as the normal control group consisted of 11, which was approximately half the number of subjects in the other groups.

Frittelli et al. (2009) sought to assess the effects of mild AD on driving performance on a simulator; to compare participants with mild AD with those with MCI and control participants; and to determine the relationship between subjects' performance on the simulator and mental status. Fifty-nine subjects were included in the study (AD=20; MCI=20; control=19). Each participant was administered the MMSE and underwent a standardized simulated road driving session (STISIM Driving Simulator).

Participants were instructed to drive exactly as they would in real conditions. The participants then took a simple visual reaction time (S-VRT) test where the participant had to press a button when a red light appeared on a monitor. Reaction performance was calculated as mean reaction time latency and SD (msec). Outcome variables at the simulated driving were: length of run (time spent in completion); number of infractions (speed limits violations, omission of stop at pedestrian crossings); number of stops at traffic lights; mean time to collision (time to contact the preceding vehicle if the test car kept moving under constant velocity); and number of off-road events (occurring when the center of the car's hood crossed the lateral border of the road).

Results showed that the AD participants had an impaired driving performance, overall, compared to the MCI group and healthy controls. AD participants performed significantly worse on driving behaviors, length of run, mean time to collision and the number of off-road events. For the MCI group, there was only limited impairment of driving capabilities compared to healthy controls, detecting only a significant difference on the mean time to collision factor. The AD group showed a significantly longer mean latencies in the simple visual reaction time compared to MCI and healthy controls, supporting the evidence of accidents due to disordered attention and psychomotor reaction. In addition, the AD showed a greater number of errors (higher number of omitted and wrong answers) compared to the other groups. There was no difference in reaction time between the MCI group and the normal controls. Driving performance and MMSE scores were not significant in regards to correlation. The authors concluded that the driving impairment in AD is related to changes in cortical function varying with

cognitive severity, reduced procession of visual motion cues, disordered attention, and visuospatial impairment.

Further research in the area of cognitive deficits, particularly AD and MCI, and fine motor skill is warranted. Particular attention of research should be between the stages of MCI and early-stage AD. Previous research provided sound evidence of fine motor impairment in individuals with even the mildest of Alzheimer's. Varying results of the fine motor impairment in MCI need to be further investigated. Differences may be due to the task complexity, individual characteristics of the population (unrepresentative), and small sample size.

Cognitive Deficits and Gross Motor Skills

Several studies have confirmed a decrease in lower-extremity function throughout the spectrum of AD. Pettersson, Olsson, and Wahlund (2005) aimed to describe motor function characteristics of those with MCI and compare them without cognitive impairment (NCI), AD and other dementias (OD). In addition, the study investigated the possible relationships between motor function and age, cognitive level, level of activity, medication and degree of white matter changes (WMC) as measured with brain imaging technique. A total of 140 participants took part in the study (NCI=33; MCI=59; AD=22; and OD=26). Participants completed an activity level assessment and a series of motor function assessments (i.e. Bergs Balance Scale, Fall Efficacy Scale (FES), Timed Up & Go (TUG), TUG manual (diffTUG), Tinetti gait, and Talking while walking).

Results showed that the participants with AD were slower on the basic mobility test and performed worse on the dual-task compared to the NCI and MCI group. The OD group was more impaired than the AD group, having increasingly impaired gait and

balance. The MCI group did not show a decline in motor function. All BBS, FES, and Tinetti gait scores reached ceiling effects, or close to, in all diagnostic groups indicating that these tests may not cover the whole spectrum of functioning. Interestingly enough, the AD subjects did not have difficulty completing the dual-task when the secondary task was manual (i.e. TUG manual-carrying a glass of water), but showed difficulty when concurrently completing a cognitive task. White matter changes were present and showed a link between age, motor function deficit and cognitive decline. The authors concluded that motor function is affected in very mild AD but not in MCI subjects as assessed with performance-based tests.

Persad, Jones, Ashton-Miller, Alexander, and Giordani (2008) sought to examine the performance accuracy of stepping with increased cognitive demands in groups with different cognitive impairments (i.e. MCI, AD). Participants include 12 healthy older adults, 24 MCI patients and 12 with AD. The MCI group was further broken down into the MCI+EF (n=10) group, those with memory and executive function deficits; and MCI-EF (n=14), those with only memory deficits. Participants were timed during a stepping accuracy test with increasing cognitive demand (Walking Trail-making test; W-TMT), which required stepping on instrumented targets with either increasing sequential numbers (W-TMT A) or with alternating sequential numbers and letters (W-TMT B).

Results showed that the MCI-EF did not differ in performance on any of the walkways from the healthy individuals. In contrast, the MCI+EF group performed similarly to the AD group. The difference in completion time for the W-TMT B between the MCI+EF did not differ significantly, but the AD group overall took longer. The AD group was found to differ significantly from the others only on a basic performance

measure of visual spatial ability. The authors proposes that the lack of difference between the MCI-EF and the healthy individuals on the walkways suggests that memory function do not play a major role in gait performance in older adults in certain tasks. The difference in performance of the two MCI groups, which the executive impairment differed, suggested that the increased risk of fall may be due to an executive dysfunction than memory early in the disease process. Persad et al. (2008) concluded that the executive function plays an important role for stepping performance, especially under more complex environmental conditions. This finding is consistent with Pettersson et al. (2005) showing the deteriorating motor function in early AD.

Leandri et al. (2009) compared the balance characteristics of individuals with amnesic MCI (aMCI), mild-moderate AD, and normal controls using stabilometry. Stabilometry is used to detect subtle, pre-clinical alterations of posture. Each group (aMCI, AD, and normal) consisted of 15 participants. A static platform using ARGO software was used recording the following measurements: antero-posterior sway, latero-lateral sway, area of confidence ellipsis. The study consisted of two conditions: with eyes open and eyes closed, to assess the effect of visual control on the participants balance.

Results showed a steady increase in antero-posterior sway from the normal controls, to aMCI, to AD participants. Antero-posterior was the only parameter impaired in aMCI group, suggesting early changes in balance in this population. Thus the researchers infer that there is an error in the balance controlling mechanisms of the central nervous system that more readily affect the antero-posterior balance. Analysis showed that there is an increase in reliance on visual control between the normal group,

aMCI and AD participants (the difference between aMCI and AD participants just failed to reach statistical significance). In the AD group, there was a strong correlation between impairment in orientation and balance in the eyes closed condition, consistent with previous findings of impairment (Pettersson et al., 2005; Persad et al., 2008). In conclusion, the researchers suggest that different stabilometric parameters, especially antero-posterior sway, maybe an early sign of impairment of central control.

Eggermont and colleagues (2010) examined differences in lower extremity function in cognitively healthy, those with MCI, and those diagnosed with AD. Evidence has suggested that lower extremity disturbance present in milder stages of AD maybe related to level of cognitive impairment. This in turn may predict future cognitive decline and dementia. A group of 66 individuals (Normal=22; MCI=22; and AD=22) participated in the study. Covariates such as co-morbid condition, Parkinsonian sign, and depressive symptoms were taken into account. Participants completed a four-meter timed walk test (4MWT) for walking speed, the Timed Up & Go (TUG) to test for functional mobility, and the Sit-to-stand test (STS) to test lower body strength.

Results showed a difference between all three groups for walking speed (4MWT); difference between normal controls and AD for functional mobility (TUG); and there were no group differences for lower body strength (STS). The analysis of walking speed showed that participants with MCI and AD showed a slower walking speed than normal controls. For functional mobility the AD groups performed worse compared to both the MCI and normal control group. Not surprising, since individuals with AD are at an increased risk for falls. The lower body strength test showed a lack of group differences, possibly due to a high number of missing values. In conclusion, researchers suggest that

the walking speed test is an easy yet sensitive clinical measure to assess and detect cognitive impairment and lower extremity function impairments, which put individuals at risk for falls.

Maquet, Lekeu, and Warzee (2010) sought to assess gait characteristics during simple and dual-task in individuals with MCI, mild AD, and those of healthy aging. Fourteen participants with MCI, 6 individuals with mild AD and 14 healthy controls were included in the study. A gait analysis system was used to study and record a steady walking state of 20-48 sec. Comfortable walking speed, stride frequency, stride length, step symmetry, and the number of stops during walking in simple and dual-tasks were calculated. Two conditions were randomized: simple task of walking and a dual-task of walking while concurrently counting backwards.

Results showed that changes of walking speed and stride frequency (dual versus simple task) were significant in the healthy elderly subjects, suggesting that the dual-task interfered with gait parameters. In the same group, there was an improvement of step symmetry in dual-task walking. The AD group had a shorter stride length, reduced walking speed and lower regularity specifically during dual-task conditions. In addition, the AD group resulted in an increase in errors during the backward counting. The MCI group showed a walking speed different from normal group and the AD group. Also, the stepping frequency during the simple and dual-task was lower in the MCI than the normal aging group. The authors conclude that the protocol provides a specific gait pattern for each cognitive deficiency profile.

In conclusion, gross motor skill and cognitive deficits appear to be well correlated, as found in the research findings involving individuals with AD. Further

research in the area would be beneficial. Research involving fine motor skills in this clinical population should pay particular attention to the various stages of MCI and early-stage AD. Previous research, as reviewed above, provided sound evidence of group difference in a variety of gross motor skills. Again, differences among the research findings could be attributed to the makeup of the study participants, the protocol for categorizing individuals in the MCI group versus the AD, type and demand of the test implemented and small sample size.

THE CONTROL OF STANDING POSTURE

The Traditional View

The traditional view as it relates to postural control stems from the philosophy of Rene Descartes. Descartes (1644) and other dualists (John Locke), believed that the human body is composed of two substances – mind and body (Hoffman, 2009). The various branches of cognitive science have viewed the mind as an abstract information processor, whose connection to the outside world was of little *theoretical* importance. Therefore, perception and the control of standing posture are traditionally assumed to be largely self-regulating of other behavior in which people are simultaneously engaged (Prado et al., 2007; Stoffregen et al., 2000) and that suprapostural goals have no instructive or predictive role in the organization of postural control (Stoffregen et al. 2000). Thus, traditional researchers conclude that postural control is autonomous and reflexive.

Central processing resources follow the traditional perspective of the control of posture. Central refers to the brain being the central location of where the executive

“decision maker” functions. Within the cortex location is a limited capacity of resources, or a limited capacity of the amount and nature the executive system can process (“work load”). For example, a study conducted by Teasdale, Bard, LaRue, and Fleury (1993) examined the effect of cognitive processing on adjustments needed for maintain upright stance and whether the attentional demands for balance increased with age. Nine elderly and 8 young adults participated in an auditory stimuli task (reaction time) while conditions of vision and surface were manipulated. The results showed that in the elderly group, as sensory information decreased (no vision, altered surface), reaction time suffered because the attention resources were allocated more towards postural control task. The researchers concluded that central processes are important in postural control. In addition, that the aging process reduces the central processing ability to allocate the resources appropriately between concurrent tasks.

Other researchers have also explained the results in this manner as well, where postural and suprapostural activity are considered two separate tasks, with each drawing on a central pool of cognitive processing resources (e.g., Lajoie, Teasdale, Bard & Fleury, 1993; Marsh & Geel, 2000; Teasdale & Simoneau, 2001). With this view of “competition” among a limited pool of central processing resources, researchers generally hypothesize that combining the suprapostural task and postural control will lead to a decline in performance of postural control (e.g. increase in displacement of the center of pressure or increase in sway variability), of the suprapostural task (e.g. increase in reaction time), or both.

Dual-Task Paradigm. The dual-task paradigm has been the traditional approach to investigating the role of cognitive demands/attention in postural control. This

paradigm is a framework in which postural control, (considered to be the primary task) and a secondary task are performed simultaneously (Woollacott & Shumway, 2002). For example, study procedures with balance and dual-task include the experimenter instructing the participant to stand on a force platform, stand as still as possible and concurrently engage in a secondary cognitive task, such as mental arithmetic, spatial memory, etc. (e.g. Maylor, Allison, & Wing, 2001; Swan, Otani, Loubert, Sheffert, & Dunbar, 2004). This methodology is typically connected to the information processing view so as to conclude the control of posture must “compete” with other activities for a limited pool of central processing resources (Prado et al., 2007).

Hauer et al. (2003) studied the effects of cognitive impairment on postural control. The researchers investigated the influence of dual-tasks, cognitive strategies, and fear of falling on postural control with participants with or without cognitive impairment and with a history of falls. Twenty healthy young adults (mean age 25.4 years), 20 participants with a history of falls without cognitive impairment (mean age 82.6 years; MMSE 27.8) and 20 participants with a history of falls with cognitive impairment (mean age 83.2 years; MMSE 19.2). COP of standing upright static position with eyes open was recorded as the single task. Then the participants performed two dual-tasks of repeatedly adding 2 to or subtract 7 from the previous number as fast as possible. Participants were instructed to perform the cognitive tasks in a balanced position simultaneously as best they could. Two trials for each condition were conducted, each lasting 30 seconds. Postural COP data was recorded using the Balance Performance Monitor (Sandland Manufacturing Services, UK), a balance measuring unit.

The results showed a significant age difference in which the older adults had a higher variability on single and dual-tasks than the younger participants. For the young group, there were no differences in postural control between the single and dual-tasks. Participants with a history of falls without cognitive impairment recorded higher postural variability but no difference between tasks. For the participants with a history of fall with cognitive impairment, postural control decreased significantly during both dual-tasks. This group recorded higher postural control variability in the more demanding dual- task of subtracting by 7, indicating a profound influence of dual-task on postural control in individuals with cognitive impairment. The researchers concluded that even simple tasks, such as addition, decreases postural stability due to attention-related cognitive deficits in cognitively impaired individuals. This could explain the increased incidence of falls in this population.

Research by Manckoundia, Pfitsenmeyer, d'Athis, Dubost, and Mourey (2006) investigated the effects of cognitive task on static posture in AD and in healthy elderly adults. Thirteen elderly adults (mean age 79.7 years; MMSE range 18-23) with mild AD and 17 healthy elderly participants (mean age 78.5 years; MMSE range 28-30) participated in the study. The participants watched a short video on a TV screen while in a seated position. The single task participants were instructed to step onto a force platform, used to analyze postural sway, maintain their position without moving any part of the body and look straight ahead at a circle for 13 seconds. The dual-task consisted of the participants maintaining their same position while answering 3 questions about the video. There were 5 trials for each phase. The results showed no difference in postural control between the single and dual-task in the healthy elderly subjects. In contrast, the

AD group recorded a significantly higher postural variability compared to the healthy elderly subjects; and higher postural variability in the dual-task compared to the single task. The researchers concluded that static balance was impaired by the cognitive task in AD group. This finding is consistent with Hauer et al. (2003) study of postural instability in individuals with cognitive deficits when engaged in dual-tasks, thus contributing to the previous research knowledge of increased risk of falls in AD individuals and postural response to task demand.

Ecological View

This alternative view of the control of standing posture is based upon the ecological psychology of James Gibson. Gibson's (1986) ecological psychology views perception as direct, and focuses on the individual/organism, its environment, and how this interaction creates both constraints, and offers opportunities for perception and action; we act to perceive, we perceive to act. Thus, perception and action are linked to so that movement enhances perception, perception enhances movement. The relationship is dynamic. This contrasts with the traditional view, which believes that the mind depends on symbolic representation and that perception is indirect.

Also, the ecological view disagrees with the idea of a higher center that issues commands (internal models) and regulates *all* action. If the executive function makes every mental calculation, it would likely be overwhelmed; an alternative view regards perception as direct, thus "relieving" some of the duties of the executive system (Haywood & Getchell, 2007). In relation to standing posture, direct perception comes with the movement of the body, head, etc. (Gibson, 1986). For example, Riccio & Stoffregen (1988) incorporates the individual, environment and task interaction with the

control of posture by arguing that the “patterns of intermodal stimulation” picks up information about properties of the environment which ultimately manipulates the control of behavior. Furthermore, the behavior is influenced by the task goals of the individual.

Suprapostural Task Paradigm and Typical Populations. The suprapostural task paradigm is a relatively new ecological approach to perception-action as it relates to the control of standing posture. Stoffregen et al. (2000) tested the proposition that body sway may be modulated in response to the need for stabilization of the visual system relative to visual targets. Targets were placed at two different distances (0.5 m and 3.0 m). This manipulation was crossed with variation in the nature of the visual task: on some trials, the visual target was a blank sheet of paper, and participants were asked only to keep their gaze on the paper (Inspection task). On other trials the target was a block of text, and participants were asked to count the number of instances of designated target letters (Search task). Results indicated that the magnitude of sway was reduced during viewing of nearby targets (relative to sway when viewing more distant targets). The magnitude of sway was also influenced by the nature of the visual task: sway was reduced during performance of the Search task, relative to sway during performance of the Inspection task. Each of these results is consistent with the hypothesis that postural sway was modulated in response to the need for stabilization of the visual system in support of suprapostural tasks. In the Search task, for example, a sequence of rapid fixations and eye movements was needed to scan the text for target letters. By contrast, in the Inspection task maintaining gaze within the boundaries of the blank sheet of paper imposed relatively little demand on either fixation or eye movements. In conclusion, there was a functional integration between postural control and the suprapostural task

acting to constrain the control of posture. This work supports the findings of Stoffregen, Smart, Bardy, and Pagulayan (1999), who reported that the organization of postural sway is sensitive and is influenced by variations in a suprapostural task. This idea contrasts with the traditional view which suggest that posture is independent of the environment and the task has no predictive role in posture.

Consequently, there is growing body of additional evidence that is consistent with the idea that posture is not an autonomous system but is linked functionally to cognitive and perceptual activities. For example, Prado et al. (2007) studied the postural sway of healthy young and elderly adults while engaged in dual-tasks. Twelve active elderly adults (ages 65-75 years) and 12 young adults (ages 22-39 years) participated in the study and had no history of diseases. The participants performed suprapostural tasks and control tasks while standing. The suprapostural tasks consisted of four conditions (inspection versus search and visual target near versus far) similar to the methodology in Stoffregen et al. (2000). The control tasks were used to evaluate the effect of vision. These tasks consisted of the participant standing with the eyes open and other with the eyes closed. The suprapostural task consisted of three trials and the control task consisted of one, each lasting 70 seconds. Postural COP data was recorded.

The results showed a significant difference between age and vision on postural sway speed in the anterior-posterior direction and of vision on postural sway speed in the medial-lateral direction. For the suprapostural tasks, the young adults exhibited the same effects as the subjects in Stoffregen et al. (2000) paper, by reducing their sway when engaged in more demanding visual tasks. This effect was also seen in the elderly group, where the amplitude of sway was reduced when engaged in the search task versus the

blank task and when looking at a near target versus far. For the control tasks, when the eyes were closed, the elderly subjects exhibited greater overall sway than the younger counterparts, but exhibited the same pattern of sway over the conditions as the younger adults. The researchers concluded that, irrespective of an increase in sway due to aging, elderly adults modulate postural control to facilitate visual performance, thus integrating and not leading to a decline in neither posture or task performance. This is said to raise questions regarding the widely held traditional view that age-related changes in postural sway are related to competition between other activities for central processing resources and postural control.

In conclusion, theory provides a strong base in which results of experiments are interpreted in the research findings. The control of standing posture and suprapostural task is a research topic of great interest with different views to explain the notion of human movement. As described above, this is surely a newer topic that needs further investigation across the lifespan and as well with clinical groups, paying close attention to the variation of suprapostural tasks.

Suprapostural Task Paradigm and Atypical Populations. The influences of suprapostural visual tasks on postural control of children with and without autism spectrum disorder (ASD) were tested by Chang, Wade, Stoffregen, Hsu, and Pan (2010). Sixteen (mean age = 8.75 years) male ASD participated in the study. The group diagnoses consisted of mild autistic disorder (n=8) and Asperger's syndrome (n=8). The typically developing group consisted of 22 age and sex matched children (mean age = 8.93 years). Consistent with Stoffregen et al. (2000), two suprapostural tasks were used; an Inspection task (IT) and a Search task (ST). The IT consisted of a white paper target

in which participant were required to stand, without moving their feet and hands, and “stare intently” at the target for 70s. The ST consisted of white paper with printed lines of Arabic numerals were the children were instructed to count the number of instances a designated numeral occurred. Postural activity of the head and torso in both the anterior-posterior and medial-lateral axes was recorded using a magnetic tracking system (Flock of Birds).

Results showed an overall higher postural motion among the ASD group compared to typically developing children, consistent with previous studies. Both groups showed reduced sway variability in the AP direction during the ST, relative to sway during the IT. These findings is consistent with Stoffregen et al. (2000) and Prado et al. (2007) results on young and older adults. This research extends the modulation effect to children as young as 8 years old. These findings add to previous research that there is a functional integration of postural activity with the demands of suprapostural tasks.

Chen et al. (2011) study investigated the effects of varying the perceptual demands of a suprapostural task on the standing postural activity of children with and without developmental coordination disorder (DCD). Thirty-two children (mean age = 9.40 years) with DCD participated in the study, with a matched typically developing group (TDC) (mean age = 9.21 years). Postural motion of the head and torso was recorded using Flock of Birds, a magnetic tracking system. The suprapostural task was a signal detection task, which was a visual stimuli comprised of a pair of vertical lines presented on a computer screen. Each task had two levels of difficulty; low (LD) and high (HD) difficulty. Each participant performed 6 trials, lasting 120 second per trial.

Overall, postural activity was greater for the DCD group compared to that of the TDC group. Task difficulty had an effect on group in which the TDC group reduced postural motion in the HD task relative to the LD task. The DCD did not modulate their postural motion, but in fact increased; thus the researchers concluded that DCD may reduce the strength of functional integration of postural activity with suprapostural task demands.

A follow-up study to Chen et al. (2011), investigated varying the cognitive/memory demands, rather than perceptual demand, of a suprapostural task on the standing posture of children with and without DCD (Chen, Tsai, Stoffregen, Chang, & Wade, 2012). Seventy-six children participated in this study (DCD – n = 38, mean age = 9.37 years; Control – n = 38, mean age = 9.21 years). Participants completed the Digit Memory Test to determine the maximum digit span each participant can retain for 10 seconds. The suprapostural cognitive task consisted of a high-difficulty (HD - maximum number of recall digits); and a low difficulty (LD - 50% of the high difficulty number). Postural motion of the head and torso was recorded in the anterior-posterior and medial-lateral direction using Flock of Birds, while participants rehearsed the digit span for 120 seconds.

Results showed an influence of task difficulty in which the typically developing group modulated their postural motion when engaged in the HD task. This result is consistent with previous research on suprapostural task performance. On the other hand, the DCD group failed to show functional integration of postural activity with suprapostural task demands. This research confirms Stoffregen et al. (2000) argument

that posture is not autonomous but a part of the perception-action link; and that posture is modulated to facilitate visual performance.

Summary

Current research has shown that not only AD, but also MCI can impact both fine and gross motor skills. The research studies reviewed above all seem to base their discussion and concluding remarks on the same theoretical standpoint – the traditional perspective. The traditional perspective is based on the information processing theory. This theory believes within the brain there is an executive functioning system or “central processor” that computes information received from different parts to the body to produce all movements. For example, Leandri et al. (2009) described the detrimental effect on gross motor skill in the study as a result of an “error” in the balancing control mechanism within the central nervous system. Maquet et al. (2010) describes the competition of attentional resources with the “central processor” as the theoretical framework encompassing the results.

As reviewed above, the results across the studies seemed to vary in relation to the MCI groups, which could have possibly been a result of the complexity and type of task that was incorporated in the study. More studies are needed based on the ecological approach/perspective, using the suprapostural task paradigm, to the investigation of clinical groups as did Chang et al. (2010) and Chen et al. (2011 & 2012), to understand how the diagnosis of the individual impact the perception-action system as it relates to different tasks requiring varying levels of cognitive demand.

This doctoral dissertation adds to the research need of clinical populations based on the embodied cognition approach using the suprapostural task paradigm. Individuals

with early-stage AD, MCI, and a group of Normal controls were included in the study in order to investigate how cognitive deficits might impact the postural control system (i.e. reduce postural sway to facilitate visual performance) when engaged in suprapostural tasks requiring cognitive effort, from an ecological perspective and embodied cognition standpoint.

CHAPTER III

METHODS

Confirmation of AD is made via post-mortem using its signature markers of plaques and tangles in the cortex of the brain. Antemortem, a team of doctors make a “judgment” to determine if AD is the cause of the patient’s symptoms by using reports from the patient and family, various assessment tools (e.g. neuropsychological exams) brain imaging, etc. This “judgment” is called a *consensus diagnosis* and its accuracy has varied across research. Most research has noted an approximate 90% accuracy, with one study reporting 97% sensitivity and 100% specificity (Knopman et al., 2001; Snowden et al., 2011). On the other hand, one preliminary study reported a 50% misdiagnosis of AD (Hendrick, 2011).

Embedded within the consensus diagnosis is the MMSE, one of several cognitive screening tools. As the most commonly used test for dementia, the MMSE is viewed as a relatively valid and reliable method of screening for AD. One study reports that a higher MMSE cut off score of 27 is needed to maximize diagnostic accuracy, especially in individuals with college degrees. A MMSE score of 27 out of 30 yielded 79% sensitivity and 90% specificity (Spering et al., 2012). Analysis comparing results between the consensus diagnosis and the MMSE score are explored below.

Consensus Diagnosis for Participants

Consensus diagnosis for participants was provided by the Minneapolis Veterans Affairs Medical Center (VAMC) Geriatric Research, Education and Clinical Center’s (GRECC) Memory Loss Clinic which specializes in the interdisciplinary evaluation of cognitive disorders and diseases in older adults. After review of the published diagnostic

criteria for MCI, specific etiologies of dementia, and other causes of cognitive impairment, an interdisciplinary work group identified the key criteria to be used in diagnosis. The key criterion elements of history, examination, mental status, and ancillary tests necessary to meet any of the identified diagnostic criteria were identified, operationally defined, and assessed in each patient.

The Minneapolis VA GRECC department consensus diagnosis procedures were as follows:

Patients were assigned a consensus diagnosis following formal presentation and discussion with voting members of the clinical team (neurologist, geropsychiatrist, internist, and neuropsychologist). Diagnosis was in two stages: (1) Dementia vs. cognitive impairment (CI)/not demented vs. no CI; (2) Primary and secondary etiologies of CI. Data collection for the history and examination were based on the National Alzheimer's Coordinating Center (NACC) Universal Data Set (UDS). The specific procedures for conducting the neurological examination were operationalized. Subjects with MMSE \geq 18 were given the same customized neuropsychological battery [tests referenced in Table 1. (See Appendix)] All patients were administered a performance-based functional assessment, the Cognitive Performance Test (CPT). Neuroimaging with brain MRI included all parameters from the AD Neuroimaging Initiative (ADNI). All patients had recommended blood tests. Ancillary tests and interventions, such as sleep studies and medication adjustments, were done at the discretion of the primary physician. Definitions for MCI, dementia, and AD were operationalized [Table 1 (See Appendix)]. Criteria for other specific etiologies of CI were taken from the literature. The formal procedure incorporating these elements into the consensus process was initiated in May, 2006 (American Psychiatric Association, 2000; McKhann et al., 1984; Peterson, 2004)

I. Participants

After assessment and consensus diagnosis by the VA GRECC, volunteers were recruited to participate in the study, subject to written informed consent. Protocols were approved by the Veteran Affairs Medical Center and the University of Minnesota Institutional Review Board.

A total of 65 males volunteered for this study. The participant population consisted of three groups: (1) Alzheimer's disease group (AD, $n = 31$), (2) mild cognitive impairment group (MCI; $n = 19$), and (3) a typically aging group (Normals; $n = 15$).

The 31 AD participants were diagnosed in accordance with criteria used by the VA GRECC clinicians (consensus diagnosis). The AD participants MMSE scores ranged from 12 – 30 (mean = 20.8, SD = 4.7). The AD participants ranged in age from 60 – 90 years (mean = 77.5, SD = 8.4) and in formal education from 8 – 16 years (mean = 13.1, SD = 2.2)

The 19 consensus diagnosed MCI participants had MMSE scores ranging from 23 – 30 (mean = 27, SD = 2.2). The MCI participants ranged in age from 63 – 89 years (mean = 75.8, SD = 7.3) and in formal education from 9 – 21 years (mean = 14.1, SD = 3.2).

The 15 typically aging adults were matched closely as possible to the AD and MCI groups for age and education. MMSE scores ranged from 27 – 30 (mean = 28.7, SD = 0.7). The Normal participants ranged in age from 72 - 85 years (mean = 78.2, SD = 3.9) and in formal education from 12 - 16 years (mean = 13.3, SD = 1.5)

To be included in the study, participants had to range in age from 60 to 90 years and not have a pre-existing gait disturbance, postural instability, significant peripheral neuropathy, or visual impairment.

Participant demographics are presented in Table 2.

Characteristic	AD (n=25/31)	MCI (n=19)	Normal (n=15)
MMSE	20.8 (4.7)	27.0 (2.2)	28.7 (0.7)
Range	12-30	23-30	27-30
Age	77.5 (8.4)	75.8 (7.3)	78.2 (3.9)
Range	60-90	63-89	72-85
Education	13.1 (2.2)	14.1 (3.2)	13.3 (1.5)
Range	8-16	9-21	12-16

Table 2: Summary of older adults assigned by clinical diagnosis – Alzheimer’s disease (AD); Mild Cognitive Impairment (MCI); Normal Aging (Normal). Mean values with standard deviation in parentheses. MMSE (Mini-Mental State Exam; Age & Education reported in years)

II. Apparatus

The study was conducted in a conference room (dimensions 7.6 m x 6.1 m) located at the Minneapolis VA Medical Center. The protocol described by Stoffregen et al. (2000) was followed. The visual task comprised of two conditions; one blank task (Inspection) and the other a counting task (Search). The Inspection target was a plain white poster board, 33.75 cm x 42.5 cm; the Search target was the same size poster board as the Inspection task, but displayed, in random order, 156 printed letters of the English alphabet. The height of the poster board was adjusted to the eye level of each participant (See Figure 2a & 2b).

Postural motion was recorded using the Wii Balance Board System which functioned as a stabilograph (See Figure 2a & 2c). The Wii Balance Board measured ground reaction forces from changes in foot pressure of standing posture. COP data was computed from changes in the medial-lateral (ML) (X) and anterior-posterior (AP) (Y)

planes of motion. Data was recorded in centimeters at 32 Hz. Data was stored for later analysis.

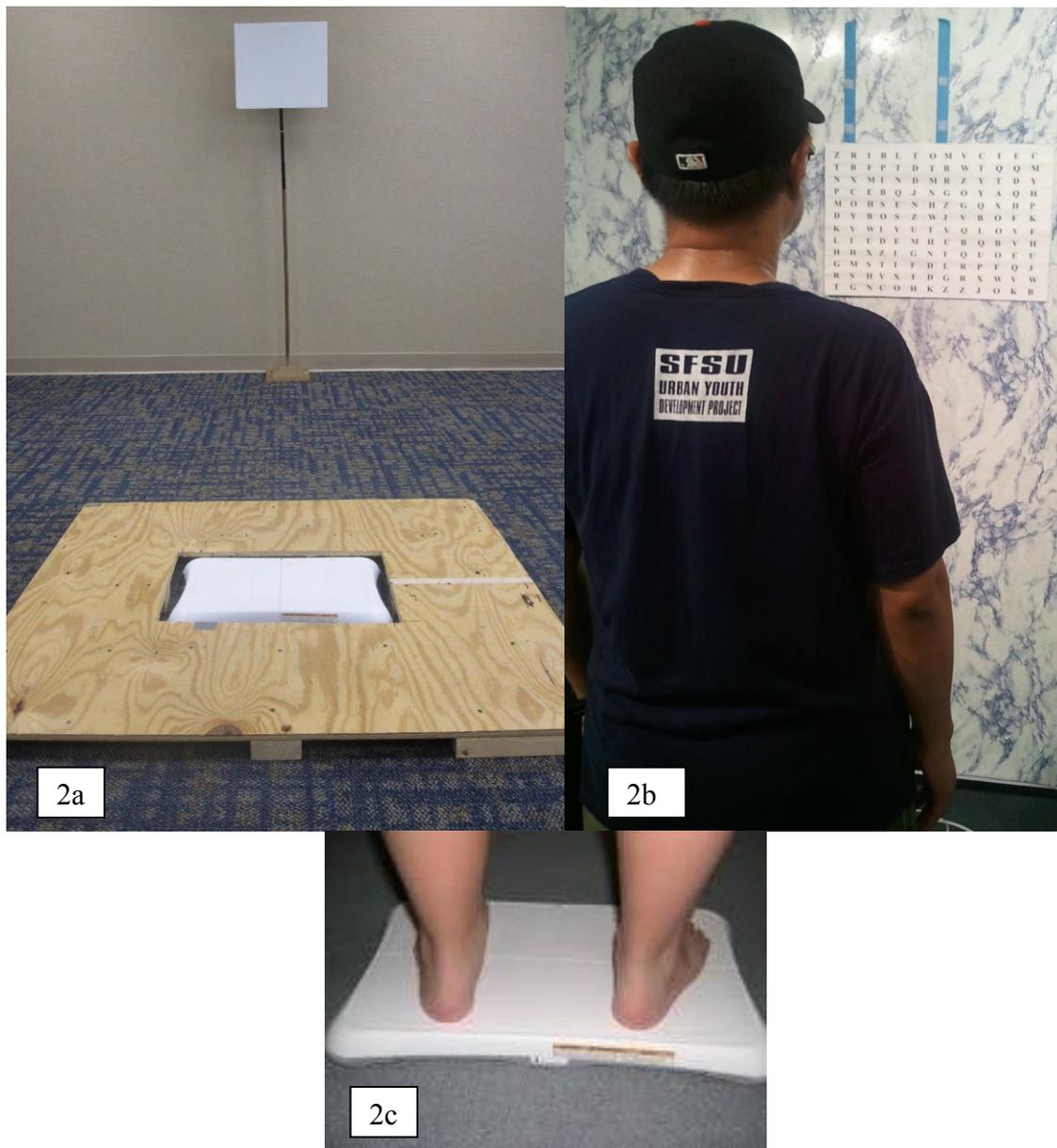


Figure 2: Experimental Set-up. Wii Balance Board placed inside a stable platform with Inspection task in the distance (2a); a subject engaged in the Search task (2b); a subject standing on the Wii Balance Board (2c).

III. Procedure

After the procedure was explained by the experimenter, each participant signed an informed consent form agreeing to participate. If the participant was unable to give informed consent, the procedure was explained to a guardian, and the guardian provided consent. Participants stood on the Wii Balance Board placed 2.5 meters from the target. Surrounding the Wii Balance Board was a wooden platform to provide support if needed, and minimize tripping (See Figure 2a). In all conditions, the participants were asked to stand comfortably with hands at their sides; participants removed their shoes, so that shoe type was not a factor in the study.

Each participant completed two 60 second trials for each of the two conditions. For the Inspection condition, participants were instructed to look only within the perimeter of the blank target board. For the Search task, participants were instructed to count the frequency of a designated letter during each trial. Two different target letters were used; M and T, one for each trial. There were 7 M's and 11 T's randomized within the 156 printed letters on the board. Participants were instructed that if they completed the text block before the end of the trial, they should start back at the top of the text, and "check their count". At the end of each trial, participants reported the total number of target letters counted.

The presentation of the task conditions (Inspection and Search) were presented in random order for each participant. In addition, observational data, such as excessive body movements and repositioning of arms, on each participant was recorded. For the data analysis, all participants completed a minimum of one trial per condition, only the first completed trial was analyzed. If a participant failed to complete at least one trial for

each condition e.g. moving their hands from their sides, talking during data collection, unable to comfortably stand unassisted, not engaged in the condition for the 60 sec, data for that participant was eliminated from the analysis. Because of this five AD subjects were excluded from the analysis.

IV. Design and Analysis

Postural Motion. We evaluated the COP data of each participant for both the medial-lateral (ML) and anterior-posterior (AP) planes of motion. A Group x Task (3 x 2) Analysis of Variance (ANOVA) was conducted on the COP data for each plane of motion. In the case of a significant finding (Alpha level was set at .05), a Bonferroni (Bonferroni, 1935) Post hoc analysis was utilized. Statistical analyses were conducted using the IBM Statistical Package for the Social Science (SPSS) Version 19. A priori power calculation using Prado et al., 2007 results were used to determine the sample size required to achieve an adequate large effect size ($d=.80$) and statistical power (.95); each group (AD, MCI, and Normal) assumed 20 participants for a total of 80 subjects. At the end of the experiment the actual number of participants for each group was as follows: 25 AD, 19 MCI, and 15 Normal.

Visual Performance. For the Inspection task, visual performance was not recorded; following Stoffregen et al. (2000) it was assumed that participants maintained their gaze at the featureless target. In addition, the experimenter recorded observational data and made note if the subject's gaze deviated from the Inspection target. For the Search condition, visual performance was assessed as percent accuracy (ratio of the number of letters reported to the total number present in the display). A pairwise

comparison was performed to compare the differences between the three groups. In addition, a Spearman rank order correlation was computed to determine the relationship between MMSE score, % accuracy and COP motion in both the ML and AP planes.

CHAPTER IV

CONSENSUS DIAGNOSIS - RESULTS AND DISCUSSION

The results are reported in the order of the listed hypotheses.

- H₁ Individuals with cognitive deficits will exhibit higher overall postural motion, than typically aging individuals, irrespective of task load.
- H₂ Individuals diagnosed as AD or MCI will exhibit a weaker perception-action link when engaged in a demanding suprapostural task.
- H₃ Performance scores (% correct) on the designated task will show superior performance by the typically aging group compared to those diagnosed with cognitive deficits.
- H₄ Overall correlations measuring postural motion and level of task difficulty will be negative, supporting an ‘embodied’ relationship between posture and task engagement.

Participants were assigned to three groups using two separate classification procedures. For the first analysis, participants were grouped according to their consensus diagnosis of AD, MCI or Normal aging. These diagnoses are defined by a clinical team using several metrics that included a battery of neuropsychological exams, performance-based functional assessments, neuroimaging, etc. For the second analysis, participants were grouped according to their most recent score on the MMSE, widely regarded as a relatively quick screening device for dementia. It is widely used in early clinical assessment of patients, but does not provide a complete clinical work up for diagnosis.

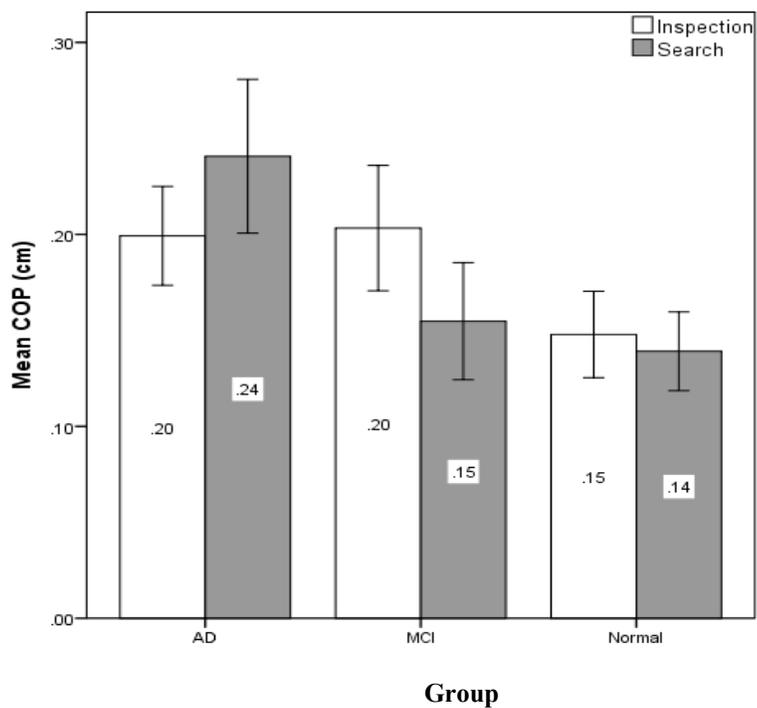
RESULTS FOR CONSENSUS DIAGNOSIS CLASSIFICATION

Postural Motion Scores (COP)

Group Effect. *Medial-Lateral Plane (ML).* Figure 3 presents the mean postural change scores for the ML plane of motion. Figure 3A shows the mean and standard error (SE) scores (cm) for the Inspection and Search task. For the Inspection task the AD and MCI groups recorded the same scores (a mean of .20 cm, SE \pm .02 cm and a mean of .20 cm, SE \pm .03 cm, respectively). The Normal group recorded a mean of .15 cm and a SE of \pm .03 cm for the Inspection task. In the more demanding Search task, the AD group recorded a score of .24 and a SE of \pm .03 cm; the MCI group recorded a score of .15 cm and a SE of \pm .04 cm; the Normal group recorded a score of .14 cm and a SE of \pm .04 cm.

Figure 3B is a graphic representation of the data illustrated in Figure 3A. A Group x Task (3 x 2) ANOVA for the ML data was not significant; although it can clearly be observed in Figure 3B, that the AD group increased their postural motion switching from the Inspection task to the Search task. The MCI and Normal groups reduced their postural motion when switching tasks. Thus, the AD group showed movement in the hypothesized direction, but this effect was not significant.

A.



B.

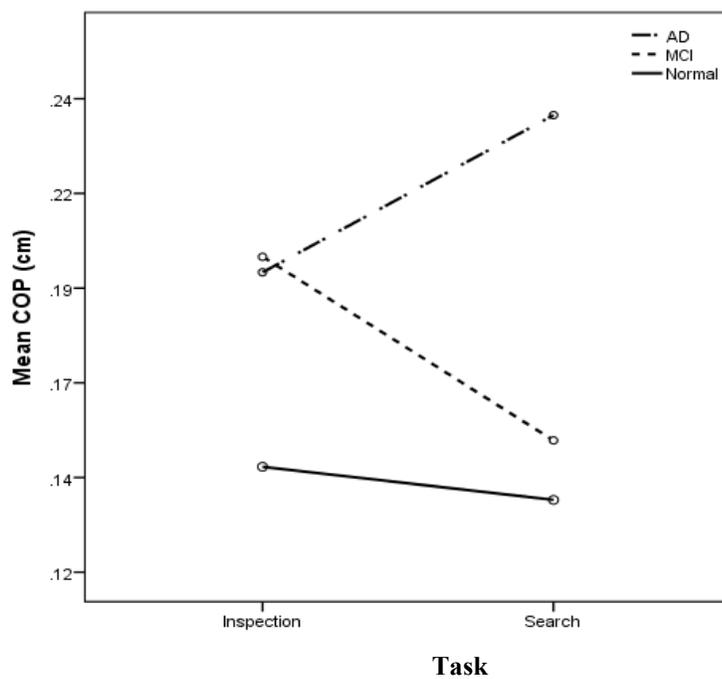


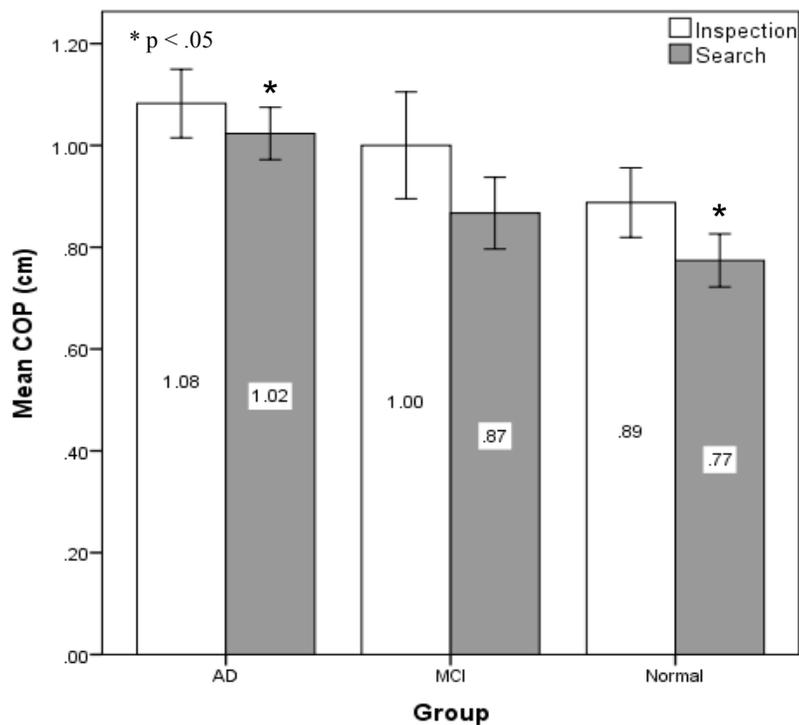
Figure 3. CONSENSUS DIAGNOSIS: Postural motion (cm) recorded as center of pressure (COP) for the medial-lateral (ML) plane: (A) Bar graph; bars indicate standard error scores (B) Line graph.

Anterior-Posterior Plane (AP). Figure 4 presents the mean postural scores for the AP plane of motion. Figure 4A shows the mean and SE scores for the Inspection and Search task. For the Inspection task the AD group scored 1.08 and a SE of $\pm .07$ cm; the MCI scored 1.00 cm and a SE of $\pm .08$ cm; and the Normal group scored 0.89 cm and a SE of $\pm .09$ cm. For the Search task: AD scored 1.02 cm and a SE of $\pm .05$ cm; 0.87 cm and a SE of $\pm .06$ cm for the MCI group; and .77 cm and a SE of $\pm .07$ cm for the Normal group.

Figure 4B shows a graphic representation of the data illustrated in Figure 4A. A Group x Task (3 x 2) ANOVA for the AP plane detected a main effect of group ($F(2, 56) = 3.36, p = .04$). Bonferroni post hoc analysis indicated the AD group had significantly higher postural motion in the Search condition than the Normal group ($p = .01$), but no differences between the Normal and MCI group; or between the AD and MCI group.

All groups in the AP direction reduced their postural motion switching from the Inspection to the Search task. Overall postural motion was highest for the AD; next highest was the MCI group; and the lowest motion scored were recorded by the Normal group.

A.



B.

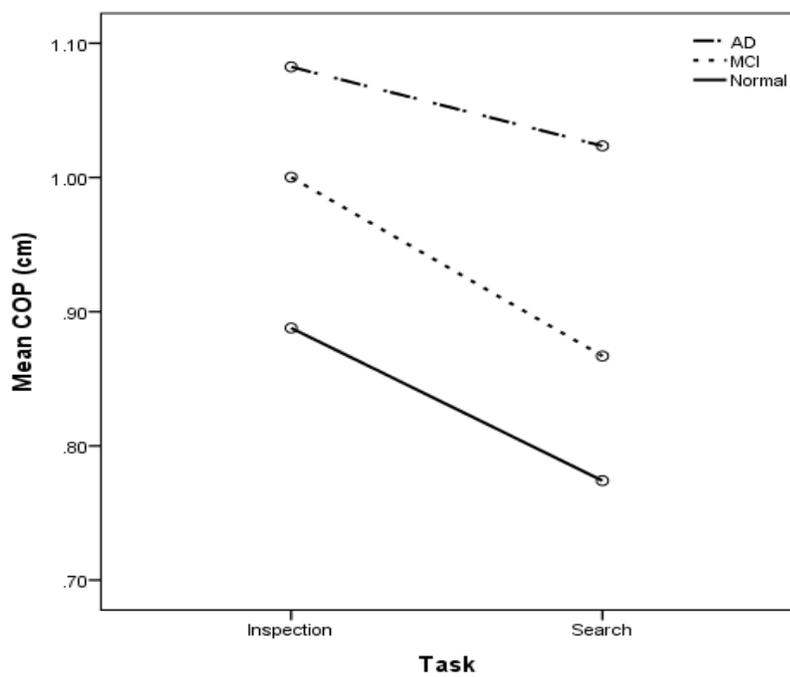


Figure 4. CONSENSUS DIAGNOSIS: Postural motion (cm) recorded as center of pressure (COP) for the anterior-posterior (AP) plane: (A) Bar graph; bars indicate standard error scores (B) Line graph.

Task Effect. *ML Plane.* Figure 5A illustrates the mean postural motion scores for the task effect summed across groups. The same score of .18 and a SE of $\pm .02$ cm were recorded for both task conditions. The same score for both task conditions are more than likely due to the AD group's increase in postural motion switching from the Inspection to the Search task added to the effect of the decreases recorded by both the MCI and Normal groups.

AP Plane. Figure 5B, shows the changes in the AP plane. The mean for the Inspection task condition was .99 cm and a SE of $\pm .05$ and for the Search task the mean was .89 and a SE of $\pm .04$ cm. Variance analysis showed this difference to be significant ($F(1, 56) = 4.92, p = .03$), showing that overall the Inspection task recorded higher postural motion than the Search task.

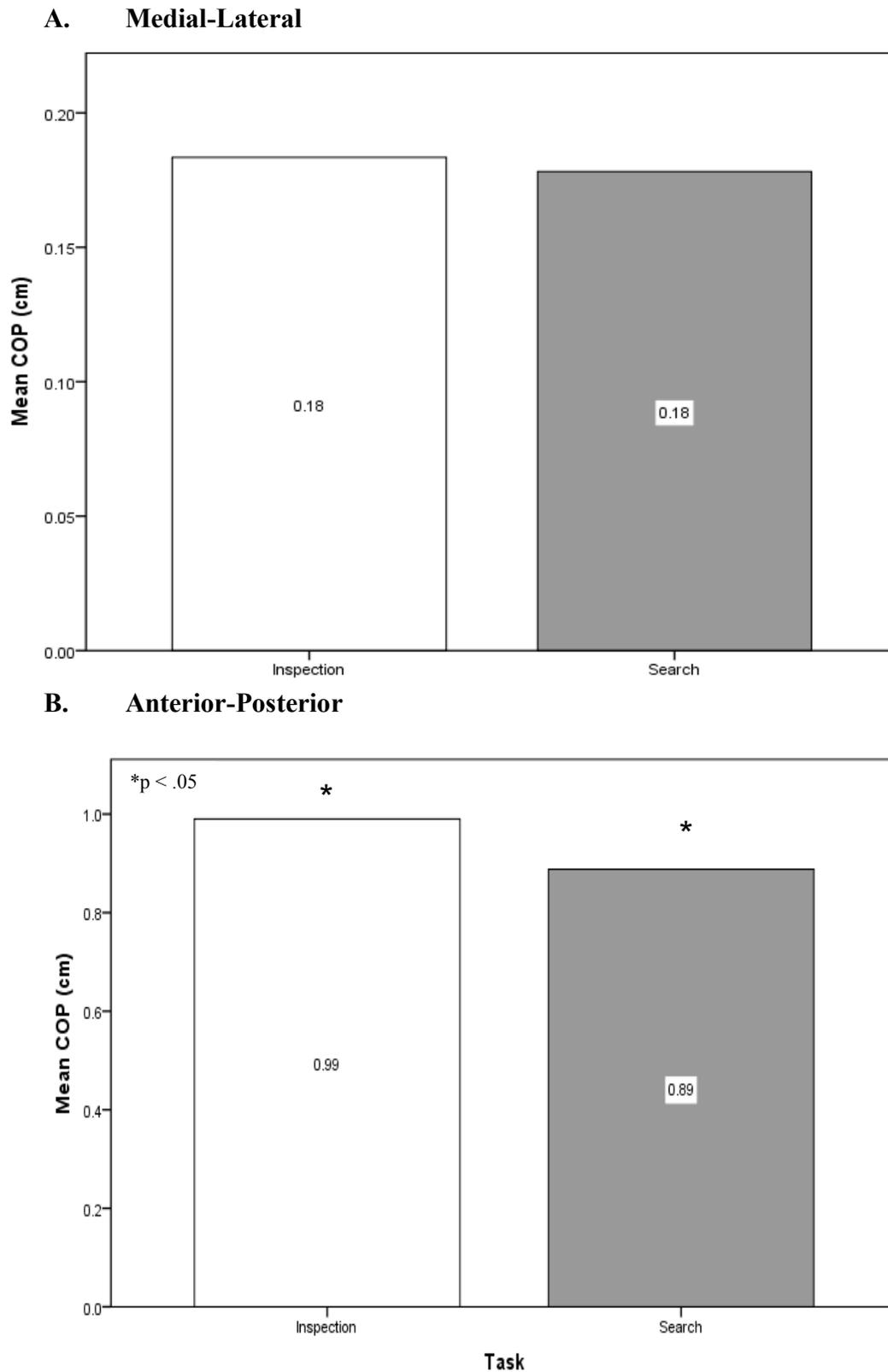


Figure 5. CONSENSUS DIAGNOSIS: Mean COP (cm) for main effect of task for the medial-lateral plane (A) and the anterior-posterior plane (B), summed over groups, for the Inspection and Search Condition.

Visual Task Performance

Figure 6 summarizes the data (mean and SE) for task performance. Accuracy scores for the AD group was 82.7% (mean errors was 1.8); MCI was 89.6% (errors = 1.6); and Normal was 92.2% (errors = 1.1). The AD group recorded the lowest score on the Search task, followed by the MCI, and the Normal scoring highest. This supports our hypothesis that accuracy scores favor the Normal group over the AD group. A Pairwise comparison of the accuracy scores between the AD and Normal group was significant ($p = .05$).

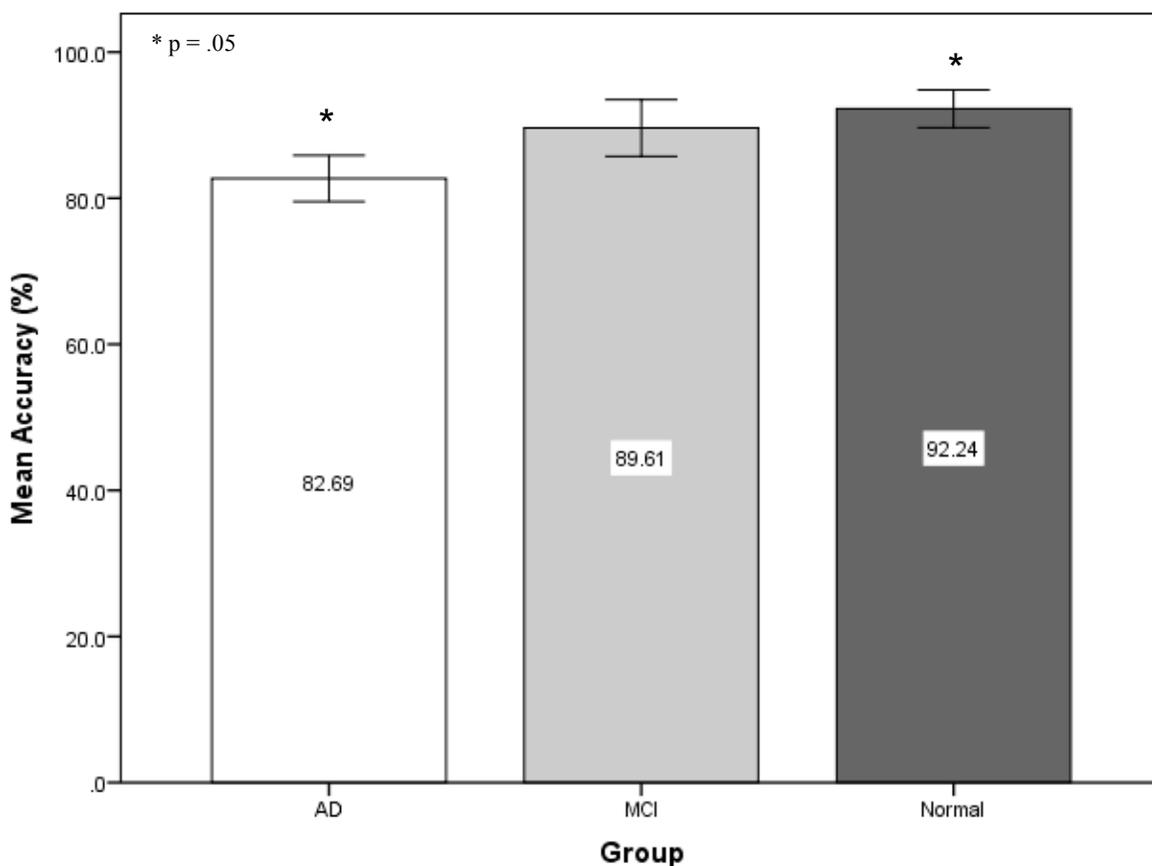


Figure 6. CONSENSUS DIAGNOSIS: Mean and standard error percentage accuracy scores for groups AD, MCI and Normal.

Correlations: Accuracy and Postural Motion. A Spearman's rank order correlation was computed to test the hypothesized negative correlation between % correct and postural motion reflecting a reduction in postural motion as performance increases. Figure 7 (See Appendix B) illustrates the correlation scores for task performance (percentage accuracy) on the Search task for both the ML and AP planes of motion. The correlation in the ML plane was $r = -.26$, statistically significant ($p = .05$). Increased performance on the Search task produced reduced postural motion in the ML plane. For the AP plane, the correlation was $r = -.24$ but was not significant.

DISCUSSION FOR CONSENSUS DIAGNOSIS CLASSIFICATION

Postural Motion. With respect to postural support for task performance, the hypothesis was that individuals with cognitive deficits would be less able to reduce postural motion when engaged in the Search task. Data from the present study provides support for earlier data from our laboratory (Chen et al., 2011). The underlying mechanisms in AD may include a perceptual-motor control deficit reflected in a diminished perception/action coupling when a motor response (posture) is linked to increased task engagement.

The AD group recorded higher overall postural motion, in both the ML and the AP plane of motion, compared to the MCI and Normal group. This supports our first hypothesis and was consistent with previous research findings that reported individuals with AD have higher postural sway, which might put them at increased risk for falls, than individuals without cognitive deficits (Horikawa et al., 2005).

There was no Group x Task interactions for either plane of motion. The ML plane did show a trend that the level of task difficulty and the underlying mechanisms of Alzheimer's disease may interact in their effect on postural motion. The non-significant interaction in the AP plan showed no such trend, suggesting that the effect of task difficulty on postural motion in this plane of motion was not present.

A significant Group x Task interaction was not detected in the ML, but there was a clear trend supporting hypothesis #2. Figure 3 shows the AD group increasing postural motion when switching to the more demanding Search task from the Inspection task; the MCI and Normal group both decreased their postural motion switching to the Search task. Thus, it appears that the ML plane of motion is sensitive to the perceptual-motor

deficits in individuals with AD. In the AP plane of motion there were significant differences in level of motion between the AD and Normal groups in the more demanding Search task. The AD group recorded the highest postural motion, followed by the MCI group, and then the Normal group; but all three groups reduced their postural motion in the AP plane switching from the Inspection to the Search task.

The overall differences in postural responses between the ML and AP direction maybe due to the AP plane providing greater postural stability than the ML plane. It is suggested that the ML plane of motion is more susceptible to postural instability. Postural response in both the ML and the AP plane support our hypothesis that the cognitive deficits in AD individuals do not permit a comparable reduction in postural motion for suprapostural task activity as the Normal group.

There were no significant differences in postural responses for the main effect of task in the ML. This was possibly due to the AD group's increase in postural motion in the ML plane. There was a significant task effect present in the AP direction, consistent with earlier findings (Stoffregen et al. 1999 & 2000) in adults and Prado et al. (2007) in healthy elderly, which demonstrated that healthy young and elderly adults modulate postural motion to facilitate visual task performance.

Accuracy of Visual Task Performance. The motivation for this section was to test the hypothesis that postural motion is reduced in order to facilitate visual performance. The hypothesized outcome predicted a negative correlation between performance (percentage accuracy) and postural motion in the Search task. The results of the study confirmed this hypothesis (ML: $r = -.26$, $p < .05$; AP: $r = -.24$, AP).

Visual performance was determined based on the ratio of the total number of reported target letters and actual number of target letters per trial. The AD group was less accurate compared to the MCI and Normal group. For the Search task, the AD group recorded higher postural motion, and was less accurate than the Normal group who recorded lower postural motion and higher performance scores. This was supported by the negative correlation findings between accuracy and postural motion. Overall, postural motion decreased as accuracy increased on the counting letters task (i.e. Search). This confirmed our research hypothesis and adds to previous research that posture not autonomous but acts to support visual task performance (Stoffregen et al, 2000; Prado et al., 2007).

CHAPTER V

MINI-MENTAL STATE EXAM - RESULTS AND DISCUSSION

The initial group assignment was based on a consensus diagnosis that included both standard tests (e.g. Stroop Interference, Boston Naming Test) and a clinical neurological evaluation. This produced what is termed ‘consensus diagnosis’ and represents standard evaluations for patients showing dementia. The results in this section represent group assignment based on each participant’s most recent score on the Mini-Mental State Examination (MMSE), widely regarded as a relatively quick screening device for dementia. The reassignment to groups based on MMSE is presented in Table 3.

Out of a 30 possible points on the MMSE, individuals scoring 11-20 were considered having a “Low” MMSE score (highly cognitively impaired); a score of 21 – 26 were considered having a “Middle” MMSE score; and ≥ 27 “High”. The same exclusion criterion as the consensus analysis was used. In addition, participants that had an MMSE score older than 4 months prior to testing were eliminated from the analysis (4 from the AD group and 6 from the MCI group). Table 3 shows a summary of the participant characteristics based on MMSE classification. It should be noted that from the consensus group assignment, 11 individuals scored below a MMSE of 20.

Characteristic	Low (n=11)	Middle (n= 11)	High (n=27)
Original Clinical Diagnosis			
AD	11	7	3
MCI	0	4	9
Normal	0	0	15
<hr/>			
MMSE	17.4 (2.5)	23.2 (2.1)	28.6 (0.8)
Range	12-20	21-26	27-30
<hr/>			
Age	77.7 (9.3)	79.2 (6.9)	75.9 (6.1)
Range	60-90	64-88	61-85
<hr/>			
Education	12.6 (1.6)	13.5 (3.3)	14.1 (2.3)
Range	10-16	8-18	10-21

Table 3: Summary of older adults assigned by Mini-mental State Exam score. Mean values with standard deviation in parentheses. AD (Alzheimer’s disease); MCI (Mild Cognitive Impairment); MMSE (Mini-Mental State Exam); Age and Education reported

RESULTS FOR MINI-MENTAL STATE EXAM CLASSIFICATION

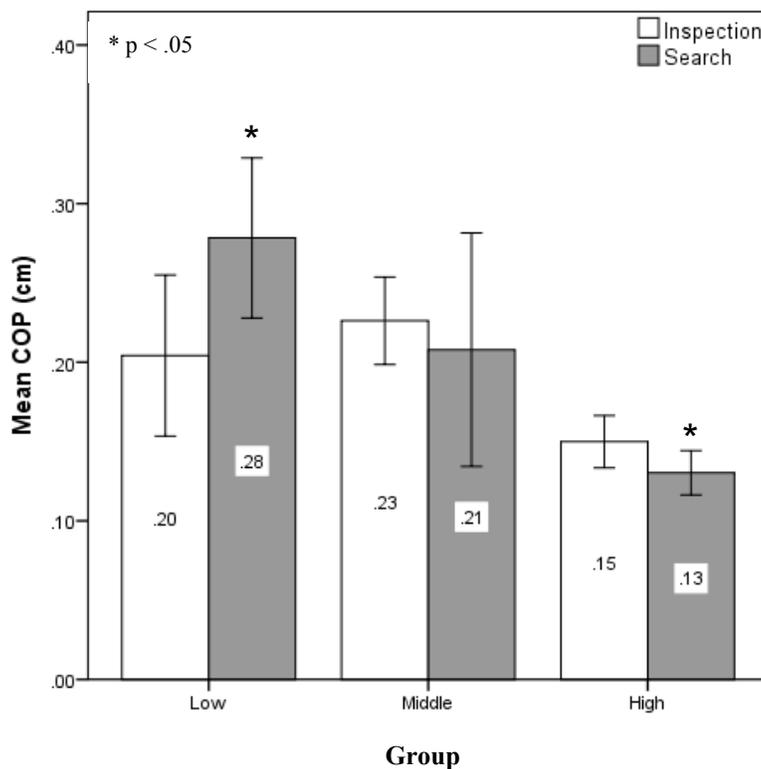
Postural Motion Scores (COP)

Group Effect. *ML Plane.* Figure 8 presents the mean postural changes for the ML plane of motion. Figure 8A shows the mean and SE scores (cm) for the Inspection and Search task. For the Inspection task the Low group recorded a mean score of .20 cm and a SE of $\pm .03$ cm; the Middle group a mean score of .23 cm and a SE of $\pm .03$; and the High group a score of .15 cm and a SE of $\pm .02$ cm. In the more demanding Search task, the Low group scored .28 cm and a SE of $\pm .03$ cm; the Middle group a score of .21 and a SE of $\pm .04$ cm; and the High group, a score of .13 and a SE of $\pm .03$ cm.

Figure 8B illustrates a more graphic representation of the data shown in Figure 8A. A Group x Task (3 x 2) ANOVA for the ML plane revealed a significant main effect of group ($F(2, 46) = 4.60, p = .01$). Bonferroni post hoc analysis indicated that the Low group recorded significantly higher postural motion in the Search task than the High group ($p = .02$), but no significant difference between the High and Middle group; or the Low and Middle group. As shown in Figure 8B, the Low group increased their postural motion switching from the Inspection condition to the more demanding Search condition, while the Middle and the High group both decreased their postural motion when switching task conditions.

There was no significant Group x Task interaction, although the direction supported the hypothesis that the changes in postural motion would differ between the Low group and the High group. The level of task difficulty and the level of cognitive deficits show signs of an interaction effect on postural motion in the ML, but this trend was not statistically reliable.

A.



B.

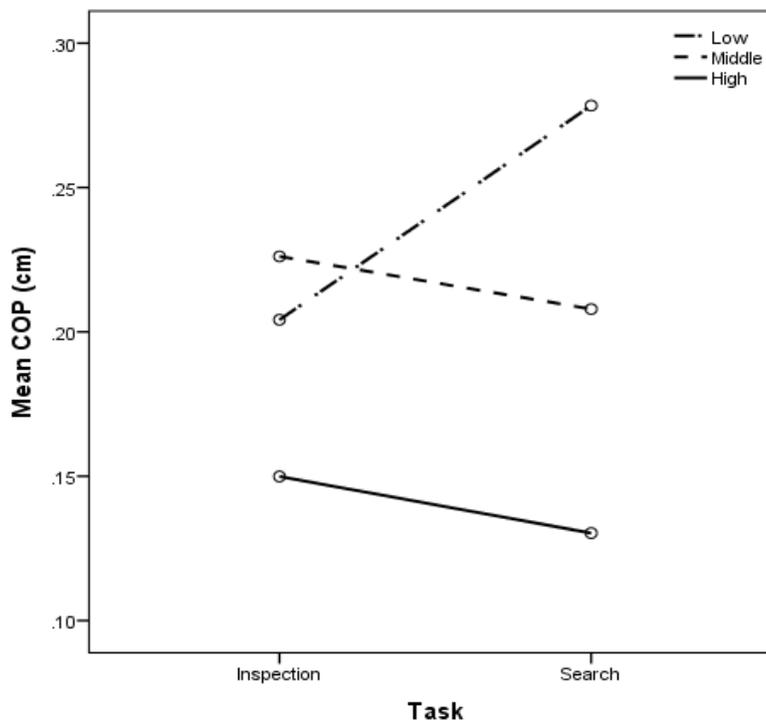
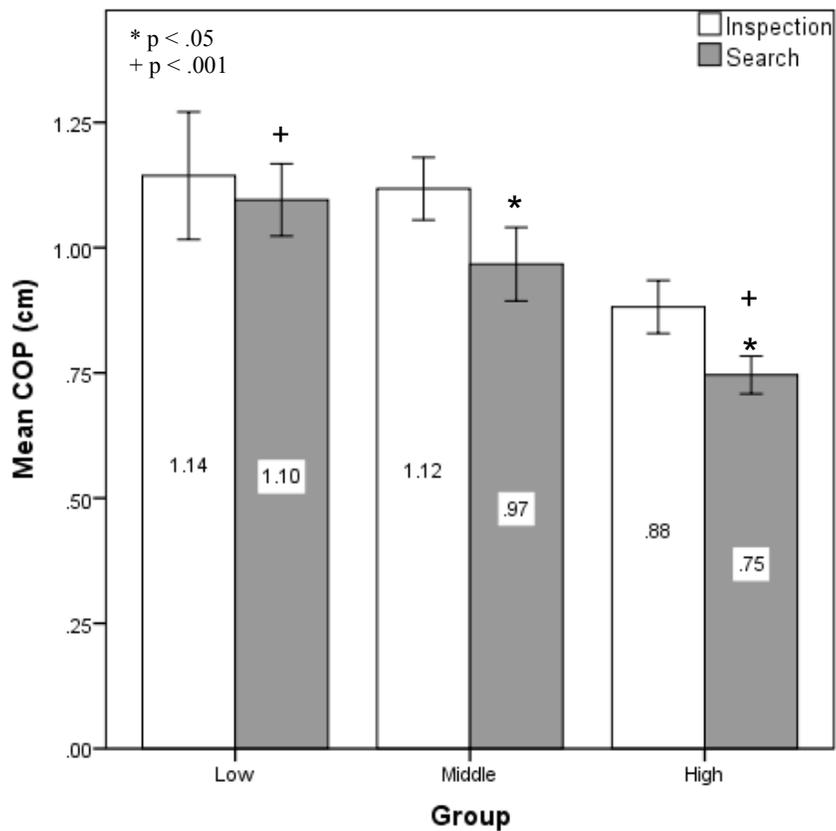


Figure 8. MINI-MENTAL STATE EXAM: Postural motion (cm) recorded as center of pressure (COP) for the medial-lateral (ML) plane: (A) Bar graph; bars indicate standard error scores (B) Line graph.

AP Plane. Figure 9 presents the postural changes for the AP plane of motion. Figure 9A shows the mean and SE scores for the Inspection and Search task. For the Inspection task the Low group recorded a mean score of 1.14 and a SE of $\pm .09$ cm; the Middle group recorded a mean score of 1.12 cm and a SE of $\pm .09$ cm; and the High group recorded a mean score of .88 cm and a SE of $\pm .06$ cm. A similar linear decline was present for the Search task: a mean of 1.10 cm and a SE of $\pm .06$ cm for the Low group; a mean of .97 cm and a SE of $\pm .06$ cm for the Middle group; and a mean score of 0.75 cm and a SE of $\pm .04$ cm for the High group.

Figure 9B shows the graphic representation of the data illustrated in Figure 9A. A Group x Task (3 x 2) ANOVA for the AP plane detected a main effect of group ($F(2, 46) = 8.93, p = .00$). As illustrated in Figure 9B, the group effect represented a difference in magnitude of postural motion. Bonferroni post hoc analysis indicated the Low ($p = .00$) and the Middle ($p = .02$) group displayed significantly higher postural motion in the Search task compared to the High group, but no difference between the Low and Middle group. All groups in the AP direction reduced their postural motion switching from the Inspection to the Search task. There is no interaction which indicated that the effect of task difficulty on postural motion in the AP plane does not depend on the level of cognitive deficiency (Low, Middle, and High MMSE scores).

A.



B.

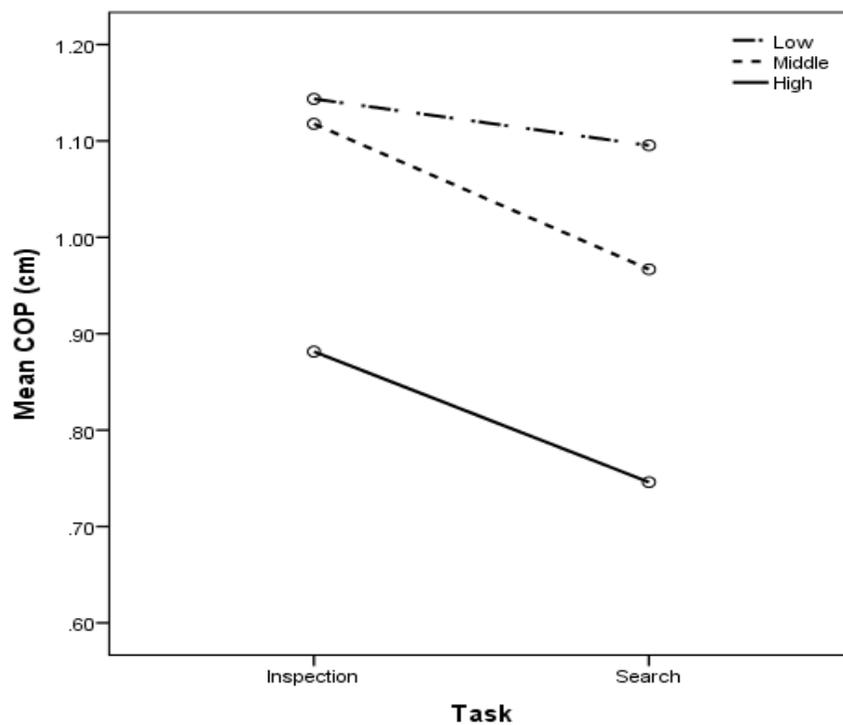


Figure 9. MINI-MENTAL STATE EXAM: Postural motion (cm) recorded as center of pressure (COP) for the anterior-posterior (AP) plane (A) Bar graph; bars indicate standard error scores (B) Line graph.

Task Effect. *ML Plane.* Figure 10A illustrates scores for the task effect in the ML plane of motion. The Inspection task mean score was .19 cm and a SE of $\pm .02$ cm. The Search task score was .21 cm and a SE of $\pm .02$ cm. There was a slight increase in postural motion when switching from the Inspection task to the Search task, likely due to the Low group's significant positive increase in postural motion in the ML plane when switching to the more demanding Search task, while the Middle and High group decreased. The main effect of task was not significant which indicated there was no difference in postural responses between the Inspection and the more demanding Search task.

AP Plane. The task effect for the AP plane of motion is illustrated in Figure 10B. The Inspection task mean score was 1.05 cm and a SE of $\pm .05$ cm; and the Search task score was .94 and a SE of $\pm .03$. Analysis of variance for the main effect of task revealed a significant difference ($F(1, 46) = 6.83, p = .01$), between the Inspection task and the Search task.

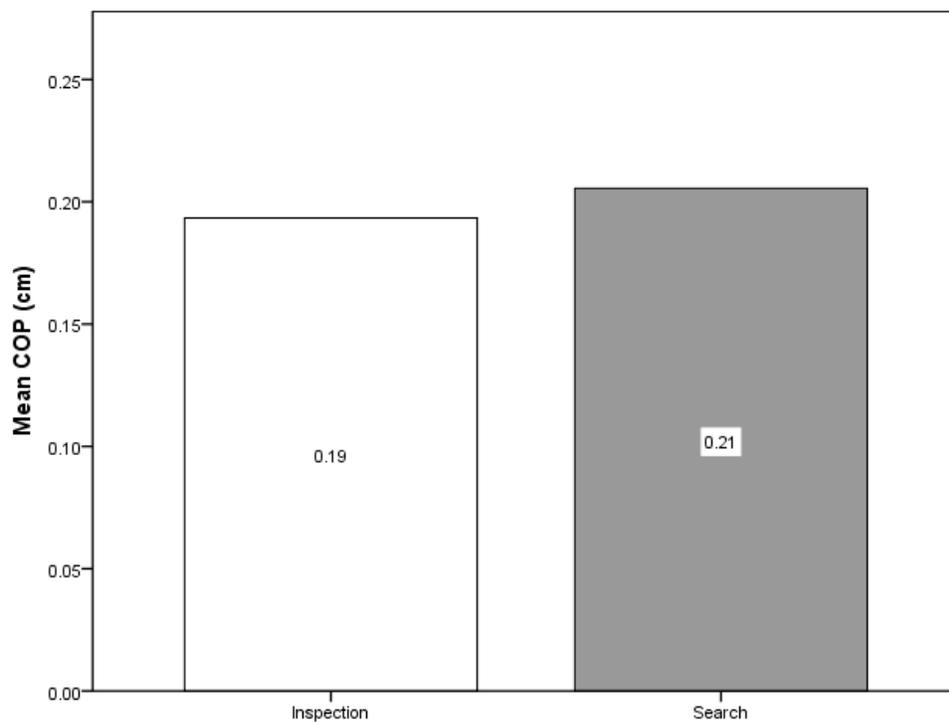
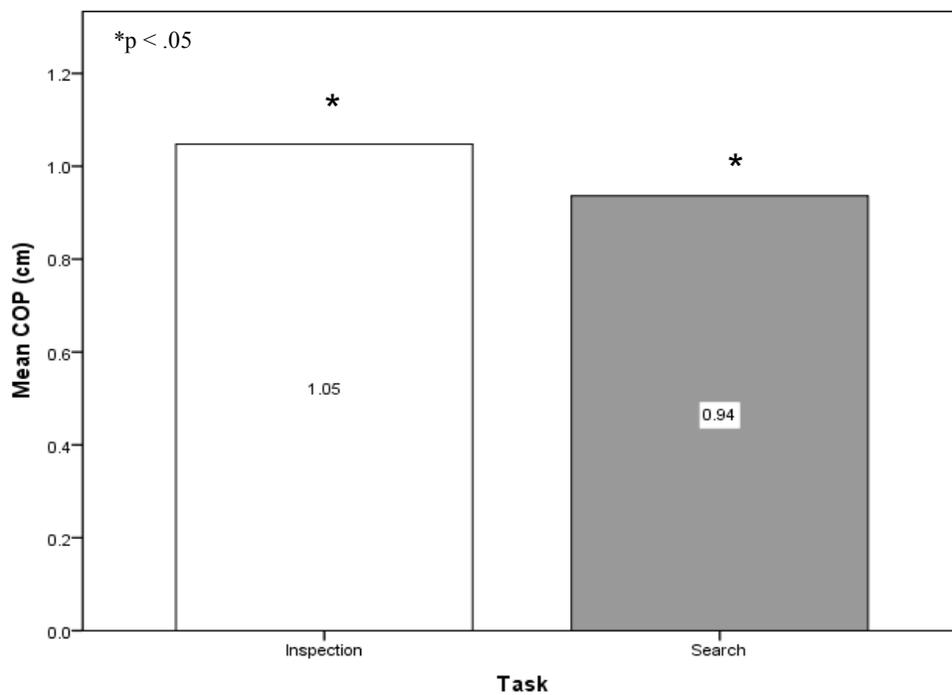
A. Medial-Lateral**B. Anterior-Posterior**

Figure 10. MINI-MENTAL STATE EXAM: Mean COP (cm) for Main Effect of Task for the medial-lateral (A) and anterior-posterior (B) plane of motion, summed over groups, for the Inspection and Search Condition.

Visual Task Performance. Figure 11 summarizes the data (mean and SE) for Search task performance for Analysis 2. Accuracy scores for the Low group was 77.2% (mean number of errors was 2.16); Middle was 85.9% (errors = 1.7); and High was 90.2% (errors = 1.48). The High group recorded the highest score, followed by the Middle, and then the Low group recording the lowest score. This supports our hypothesis that performance favors the High group over the Low group. A Pairwise comparison of accuracy scores revealed no significant differences between performance, but an otherwise close difference between the Low and High group ($p = .07$).

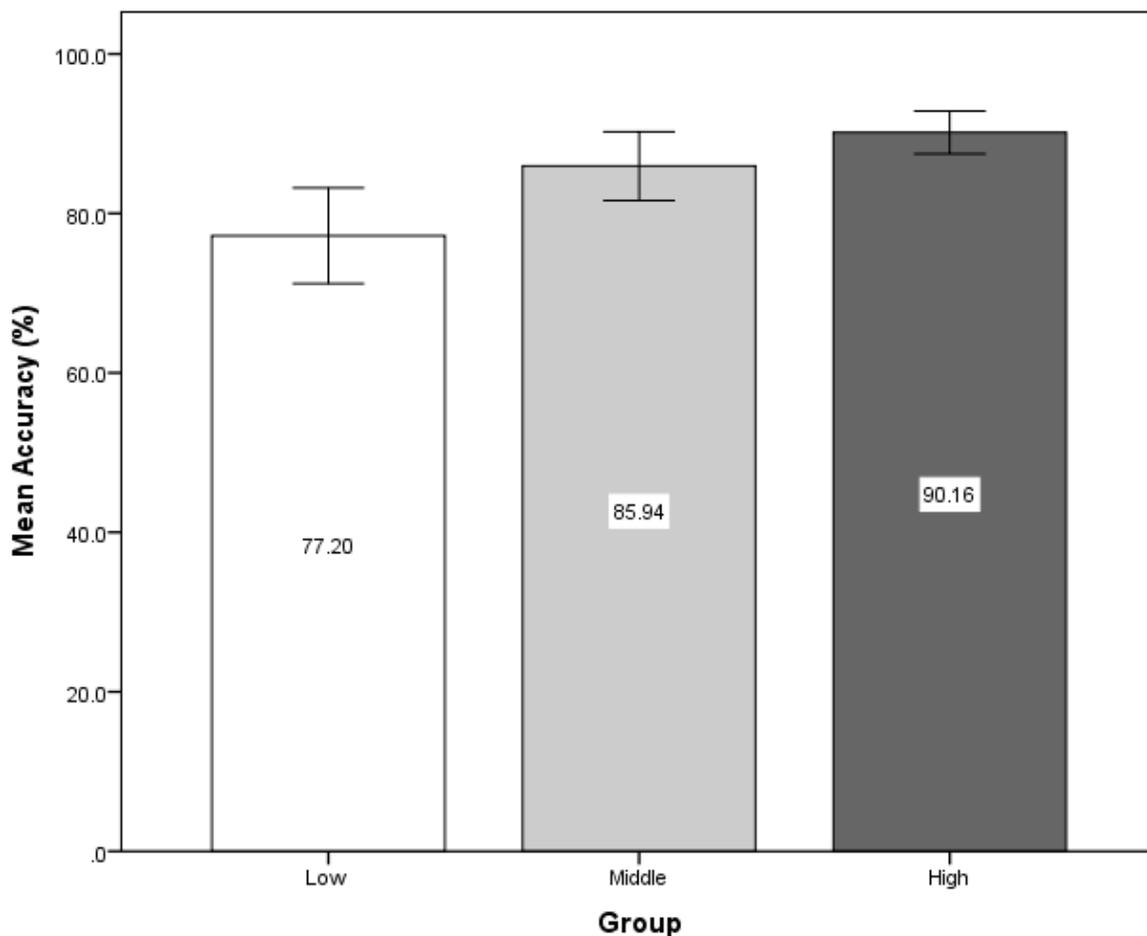


Figure 11. MINI-MENTAL STATE EXAM: Mean and standard error percentage accuracy scores for groups; Low, Middle, and High.

Correlation: Accuracy and Postural Motion. The results of a Spearman's rank order correlation can be viewed in Appendix B. The negative correlations between accuracy percentages and postural motion (COP) for both the ML and AP plane of motion were statistically significant (ML: $r = -.38$, $p = .01$; AP: $r = -.39$, $p = .01$). These correlations confirm our hypothesis that participants who performed more accurately on the more demanding Search task (i.e. counting letters), had lower postural motion in both the ML and AP plane.

Correlations: Visual Performance, MMSE Scores and Postural Motion. The second analysis was based on the level of cognitive deficit (MMSE scores). Additional correlations were conducted with these scores. Figures 13 and 14 (See Appendix B) illustrate the results of a Spearman's rank order correlation in the ML and AP planes of motion.

Figure 13 (See Appendix B) shows a positive correlation between performance and level of MMSE score, which was significant ($r = .38$, $p = .01$). This indicated that those with a high score on the MMSE were more accurate on the Search task condition. In Figure 14 (see Appendix B), there was a negative correlation between level of cognition (MMSE scores) and postural motion, which indicates that a low score on the MMSE predicts higher postural motion in both the ML ($r = -.45$, $p = .00$) and AP ($r = -.51$, $p = .00$) planes of motion when engaged in the more demanding Search task condition.

DISCUSSION FOR MINI-MENTAL STATE EXAM CLASSIFICATION

Postural Motion. Participants were grouped according to their recent MMSE scores in order to get a better indication of the complexity of diagnosis and the impact of the level of cognitive deficit may have on the perception-action link.

The Low group recorded higher overall postural motion, in both the ML and AP planes of motion, compared to the Middle and High group. These data are consistent with the earlier consensus diagnosis results that older adults with cognitive impairment record higher postural motion compared typically aging adults.

The level of cognitive deficit revealed that the effect on postural motion switching from an easy to a more demanding task was not present in all groups. In the ML plane, the Low group increased their postural motion significantly compared to the High group, which reduced their postural motion in the more demanding task. In the AP plane, there were significant differences in level of postural responses between the three groups. The Low group and the Middle group recorded higher overall postural motion and were less able to modulate their postural motion compared to the High group. It appears that grouping by MMSE scores alone provided a more sensitive measure of the impact of cognitive deficits on visual task performance and postural control.

In the ML plane the Low group increased postural motion when engaged in the Search task, while the Middle and High group decreased. It seems that the level of task difficulty and the level of cognitive decline interact so as to impact the strength of the perception-action coupling in the ML plane. This trend was not present in the AP plane; all participants decreased their postural motion suggesting that the task effect on postural motion in this plane of motion does not depend on the level of cognitive decline (defined

by Low, Middle, and High MMSE scores). This indicated that cognitive decline impacts the plane of postural motion in varying ways; and thus cognitive deficits have a greater impact in the ML plane of motion.

Summed over groups, postural motion increased slightly when switching from the Inspection condition to the Search condition in the ML direction. In the AP plane, all participants reduced their postural motion in the Search condition, which is consistent with the “Consensus Diagnosis” analysis, and earlier results reported by Stoffregen et al. (1999 & 2000) and Prado et al. (2007).

Visual Performance. Visual performance results were consistent with the Consensus Analysis. The Low (77.27%) group was less accurate compared to the Middle (85.9%) and High (90.2%) group. The Low group recorded higher postural motion and was less accurate on the Search task, while the High group recorded a lower postural motion and performed better on the Search task. This is supported by the correlation findings which showed that participants who were more accurate on the Search task moved less in both the ML and AP plane of motion. This confirms our hypothesis that postural motion is functionally modulated to facilitate visual performance. Higher MMSE scores produced more accurate scores on the Search task. Lastly, participants with higher MMSE scores moved less during the Search task. Again, this was consistent with previous research indicating higher postural motion in individuals with cognitive deficits.

CHAPTER VI

SUMMARY AND CONCLUSION

SUMMARY

Previous studies have shown that AD demonstrates dual-task impairment compared to healthy controls (Foley et al., 2007). The current research demonstrates a similar impairment in suprapostural task performance and the hypothesized perception-action link. A consensus diagnosed AD individual with a “High” score on the MMSE (scores of 27-30) and their *ability* to modulate their postural motion when engaged in a more demanding visual task, could mean they are in the “early” stages of the disease. A consensus diagnosed individual with “Low” cognitive scores on the MMSE (score of 11-20) and their *inability* to modulate their postural motion when switching to the Search task, may indicate they are at a later stage of the disease. From the results, it appears that the perception-action link is diminished in individuals diagnosed as AD via consensus diagnosis and those with MMSE score of ≤ 20 . Irrespective of a classifying cognitive deficit (AD), the results provide evidence a deficit in cognitive ability impacts the motor capabilities (postural motion) and task performance, as described in this protocol.

Clearly the changes in postural motion as a function of level of perceptual and/or cognitive effort differentiate populations of older adults who sit on the spectrum of cognitive disorder; from MCI to early and advanced AD. Compared to the consensus diagnosis analysis, the reclassification by recent MMSE scores resulted in additional significant results. This indicates that the more robust results based on level of cognitive decline, is a significant contributor to postural response differences in suprapostural task

performance; and that the “gold standard” MMSE is an excellent predictor of a possible decrement in the established perception-action link.

Irrespective of the level of perceptual or cognitive abilities, the relative strength of the ‘embodied’ relationship between functional motor ability and the support it provides to perform perceptual or cognitive tasks varies as a function of the cognitive status of the actor.

CONCLUSION

The central question of this study asked if changes in the perceptual and or cognitive status of older adults would disrupt an established, embodied relationship between a biomechanical system (posture) and a perceptual/cognitive task? The capacity to reduce postural motion when engaged in a task requiring cognitive or perceptual effort in typically developed individuals is well established in the current research literature (Stoffregen et al., 2000; Prado et al., 2007). Our previous research reports that this perception-action link is degraded in children at risk for developmental coordination disorder (DCD) (Chen et al., 2011; Chen et al., 2012). The present study addressed the same protocol with older adults with varying degrees of cognitive ability, those with AD, MCI and a control group of typically aging individuals. The following conclusions from the present study are:

1. The overall level of postural motion in the AP plane showed that the AD group recorded the highest level of motion; followed by the MCI group; and then the typically aging group the lowest. This denotes that cognitive status impacts overall postural motion irrespective of task effect.
2. Posture recorded in the ML plane of motion showed that the AD participants were unable to reduce postural motion when switching from the Inspection task to the Search task. This was a trend for the AD participants assigned according to a consensus diagnosis. This was a significant effect when participants were assigned based only on their current MMSE score.

3. All three groups of participants reduced their postural motion in the AP plane when switching from the easy task (Inspection) to the more demanding Search task.
4. The overall results demonstrate that the 'embodied' relationship between perception is a robust effect across the lifespan, irrespective of level of cognitive or perceptual ability.
5. Irrespective of diagnostic classification postural control recorded during a suprapostural task protocol may provide additional information with respect to variation in cognitive status.

FUTURE RESEARCH

Currently, an estimated 5.4 million American have AD. The Alzheimer's Association (2012) estimates a \$200 billion annual cost for caring for patients with AD and other dementias. Early diagnosis of AD is critical to generate successful, early therapeutic interventions that may reduce overall health care costs. The current study provides preliminary results of a potential movement assessment tool that detects a motor related correlate of onset of dementia. To confirm this hypothesis, a longitudinal study will be needed to determine if individuals, who are less able to modulate their postural motion when engaged in a demanding suprapostural task are more likely to progress first to an MCI diagnosis and then to a diagnosis of AD.

Increased postural sway has been correlated with an increased incidence of falls in the elderly (Overstall, Exton-Smith, Imms & Johnson, 1977; Shumway-Cook, Woollacott, Baldwin, & Kerns, 1997). The number of people aged 65 and over diagnosed with AD is projected to reach 7.7 million by 2030, with an annual cost of care of \$1.1 trillion by year 2050, 50% + increase from the current situation (Alzheimer's Association, 2012). Further research could provide insight into the movement behaviors specific to cognitive deficits. Further investigations in this area are warranted.

1. Future studies should consider task selection, as varying task may produce different postural responses.
2. Incorporation of a comparison between cognitive (e.g. math problems) and perceptual tasks (e.g. signal detection).
3. Increase in sample size, inclusion of women, and various ethnicities to have a representative population sample.

4. Investigation of the differences in consensus diagnosis by clinicians and standard cognitive deficits assessments warrants additional investigation.
5. Further examine whether impairment in the strength of the perception-action coupling could be used as an early detection of AD.
6. Further examine, longitudinally, the relationship between postural responses to a suprapostural visual task in MCI participants that progress into AD and those who remain MCI or show evidence of recovery.
7. Other types of dementias are present in older adults. Further investigation into any differences in dementia (i.e. AD, Frontal Temporal dementia, and Dementia of Lewy Bodies) would be a study of interest.

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APPENDIX A

OPERATIONALIZED CRITERIA FOR MCI AND AD

A.

Mild Cognitive Impairment

A. Cognitive complaint corroborated by an informant

1. Patient report of cognitive problems (exam or MFQ-10)
2. Family report of cognitive problems (exam)
3. Provider reports patient has cognitive problems

B. Single or multiple domain (maximum 2 domains) cognitive impairment consistent with MCI (1.5 SD below same age norms on neuropsychological testing; majority of tests in a category)

1. Memory: Logical Memory, RCFT recall, CVLT-II
2. Executive: Trail B, WCST, Stroop Interference, F-A-S
3. Language: Boston Naming Test, Animals, F-A-S
4. Visuospatial: RCFT copy, Block Design, MMSE figure copy
5. Attention: Digit Span, Digit Symbol, Trail A, Stroop C & W

C. Intact global cognitive functioning

1. other neuropsychological tests within range of estimated premorbid ability (individual outliers may be excluded)
2. MMSE \geq 24

D. Intact functional ability

1. Cognitive Performance Test between 5.2 and 6.0

E. Not demented

Probable MCI: A1; A2 or A3; impairment in majority of B1, B2, B3, B4, and/or B5 (maximum 2 domains); C1 or C2; D; E

Possible MCI: Any 1 of A1-A3 (does not require A1)

Reasons for considering a label of Possible MCI include:

- specific impairment in memory (B1) \rightarrow does *not* require a majority of tests, but *does represent a decline in function* (by hx or prior testing)
- evidence of significant *decline* relative to estimated premorbid cognitive function (as opposed to 1.5 SD from age-based norms)

* *NOTE: MCI patients must not have functional impairment. If a patient has a single domain of cognitive dysfunction severe enough to cause functional disability, an alternate diagnosis should be considered (e.g. possible AD - due to the atypical onset/progression).*

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B.

Alzheimer's Disease	
DSM-IV Dementia	
A. Memory impairment	
<ol style="list-style-type: none"> 1. Rey figure 3m recall 2. CVLT delayed free recall 3. Logical Memory II 4. < 3/3 on MMSE recall (for those w/ MMSE < 19) 	
Plus one the following deficits (B-E):	
B. Aphasia	
<ol style="list-style-type: none"> 1. Poor performance on Boston Naming, animals, F-A-S (NP) 2. < 8/8 on MMSE language items (for those w/ MMSE < 19) 3. History of expressive language problems (evident on exam) 4. History of receptive language problems (evident on exam) 	
C. Apraxia	
<ol style="list-style-type: none"> 1. Poor performance on Rey figure copy or Block Design (NP) 2. Error on MMSE pentagons (for those w/ MMSE < 19) 	
D. Agnosia	
<ol style="list-style-type: none"> 1. Boston Naming > 15 outside of category (NP) 2. Poor performance on Fuld (exam or NP) 3. Category error on MMSE naming (for those w/ MMSE < 19) 	
E. Executive dysfunction	
<ol style="list-style-type: none"> 1. Poor performance on WCST, Trail B, Stroop C/W (NP) 2. Inability to learn the Luria (exam; for those w/ MMSE < 19) 	
AND cognitive deficits:	
F. Cause impairment in social or occupational functioning	
<ol style="list-style-type: none"> 1. CPT score < 5.2 2. Report of Interpersonal disinhibition (exam, NPI) 	
G. Symptoms represent a decline	
H. Do not occur exclusively during delirium	
I. Are not due to other CNS or systemic disease or substance induced	
J. Are not better accounted for by another DSM-IV Axis I disorder	
<p><i>* NOTE: Dementia patients must have functional impairment (includes ADLs, IADLs, social, or occupational). If a patient has 2 or more domains of cognitive impairment, but no functional disability, an alternate diagnosis should be considered (e.g. cognitive impairment no dementia or cognitive impairment etiology unknown).</i></p>	
<p>American Psychiatric Association. (1994). <i>DSM-IV</i>. Washington, DC: Author.</p>	
NINCDS-ADRDA Alzheimer's Disease	
A. Course of gradual onset and continuing decline	
B. Deficits are not due to another CNS or systemic disease	
C. Deficits are not due to another Axis I disorder	
<p>Possible AD: A dementia syndrome with an <i>atypical onset, presentation or progression</i>, and without a known etiology; any <i>co-morbid diseases</i> capable of producing dementia are not believed to be the cause (B & C only); or <i>memory impairment only</i> with functional impairment and onset/course consistent with AD (<i>does not meet full criteria for DSM-IV dementia</i>)</p>	
<p>Probable AD: A, B & C</p>	
<p>American Psychiatric Association. (1994). <i>DSM-IV</i>. Washington, DC: Author. McKhann et al. (1984). NINCDS-ADRDA Work Group. <i>Neurology</i>, 34, 939-944.</p>	

Table 1: Operationalized Criteria for MCI (A) and AD (B). This criterion was used to diagnose older adults with MCI or AD. (MCI – Mild Cognitive Impairment; AD- Alzheimer's disease)

Operationalized Criteria for MCI and AD Definitions:

MFQ: Memory Functioning Questionnaire

RCFT: Rey Complex Figure Test

CVLT – II: California Verbal Learning Test

WCST: Wisconsin Card Sorting Test

F-A-S: Functional Assessment Staging

MMSE: Mini-Mental State Exam

Stroop C & W: Stroop Color and Word Test

CPT: Cognitive Performance Test

NPI: Neuropsychological Impairment

CNS: Central Nervous System

DSM-IV: Diagnostic and Statistical Manual

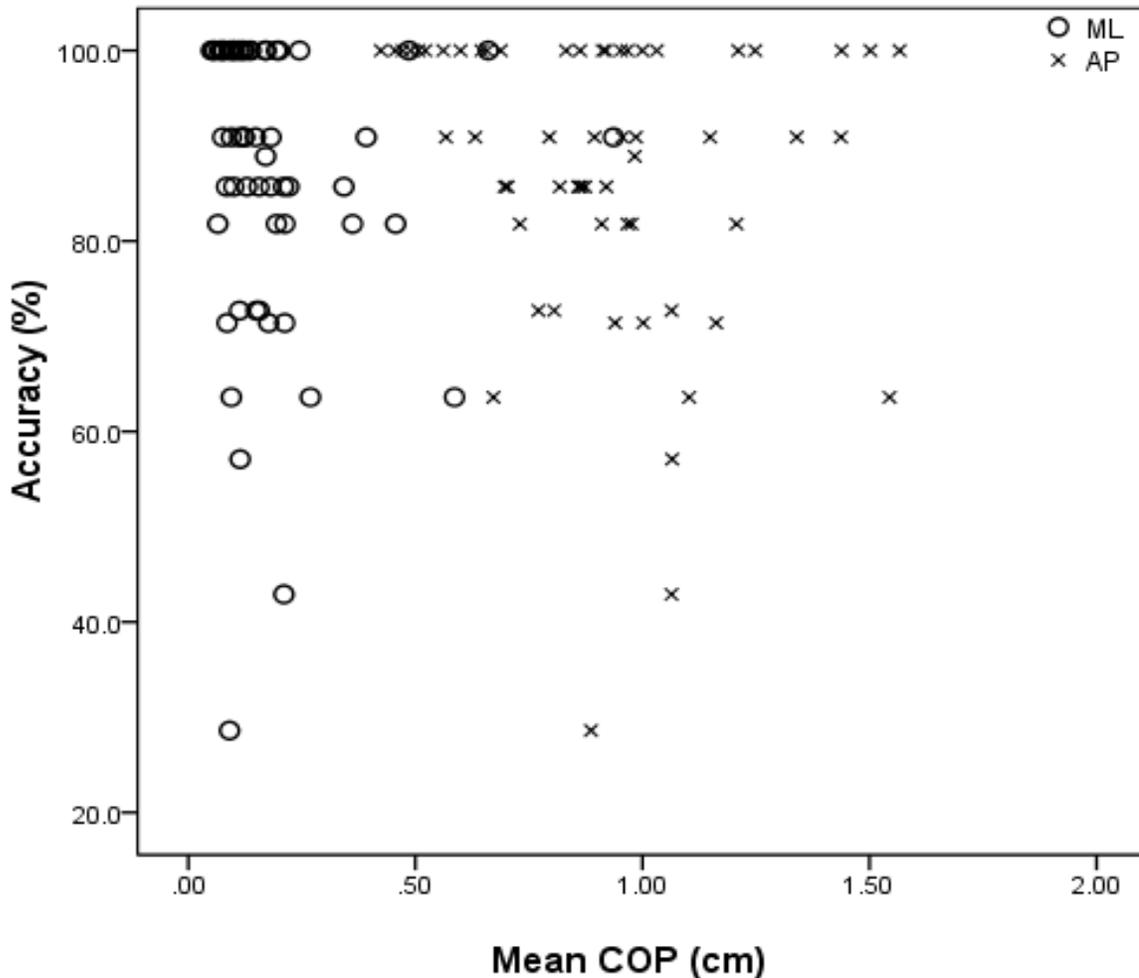
ADL: Activities of daily living

IADL: Instrumental activities of daily living

NINCDS-ADRDA: National Institute of Neurological and Communicative Disorders
and Stroke – Alzheimer’s Disease and Related Disorders Association

APPENDIX B

CORRELATIONAL DATA:



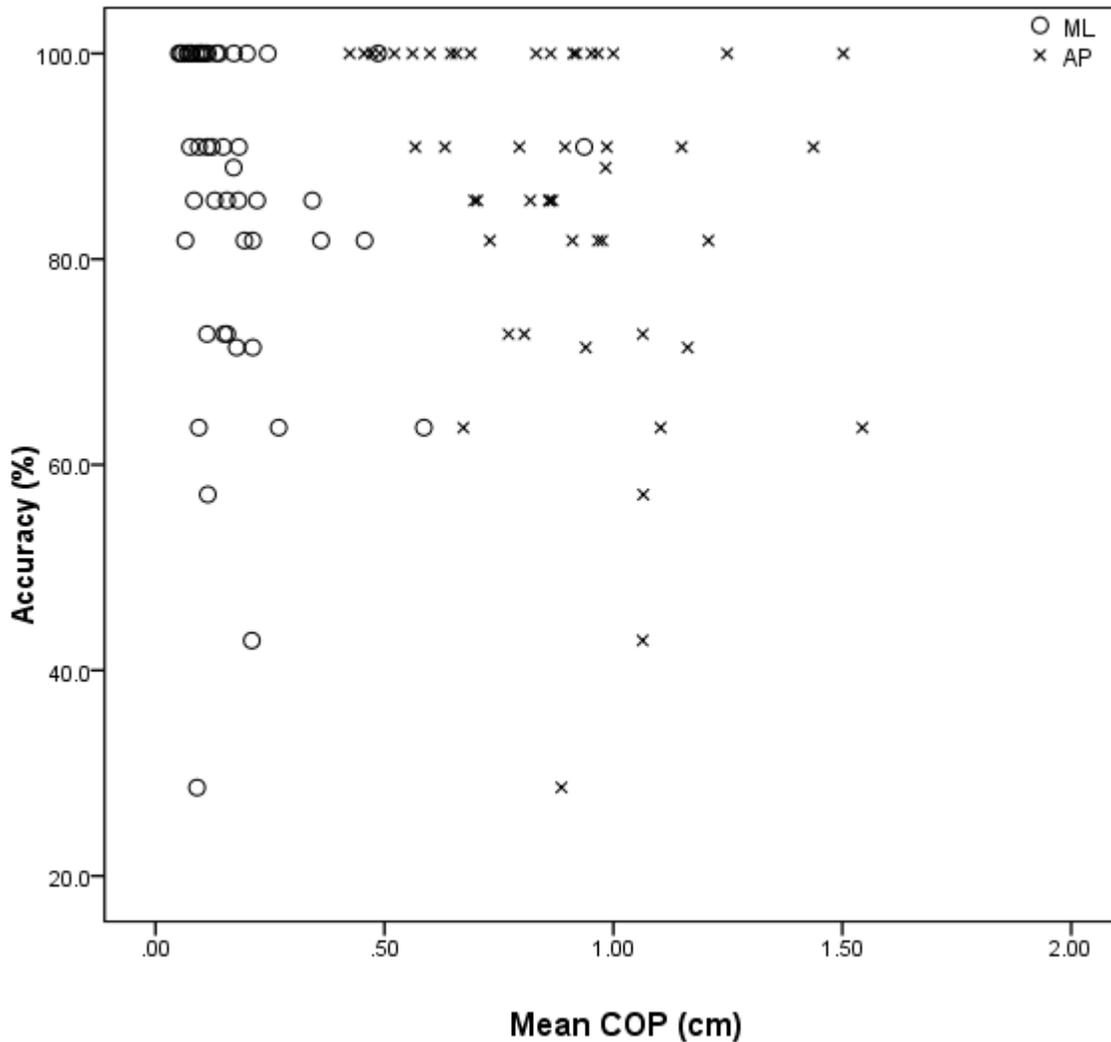


Figure 12. MINI-MENTAL STATE EXAM: Correlation: Accuracy and Postural Motion. Shows a negative correlation between performance (percent accuracy) and postural motion. Correlation .38 for ML (p < .05) and .39 in the AP plane (p < .05).

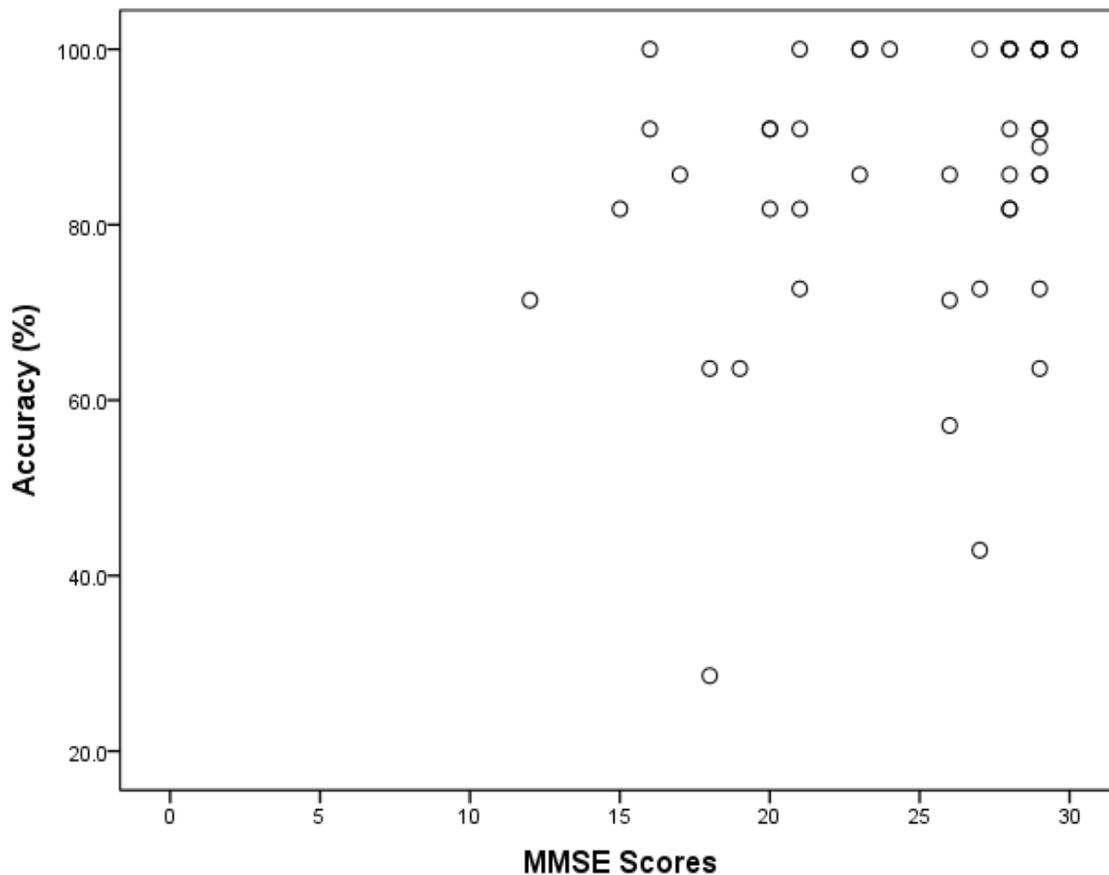


Figure 13. MINI-MENTAL STATE EXAM: Correlation: Accuracy and MMSE. Shows a positive correlation ($r = .38$, $p = < .05$) between performance (% accuracy) and level of cognitive deficit (MMSE).

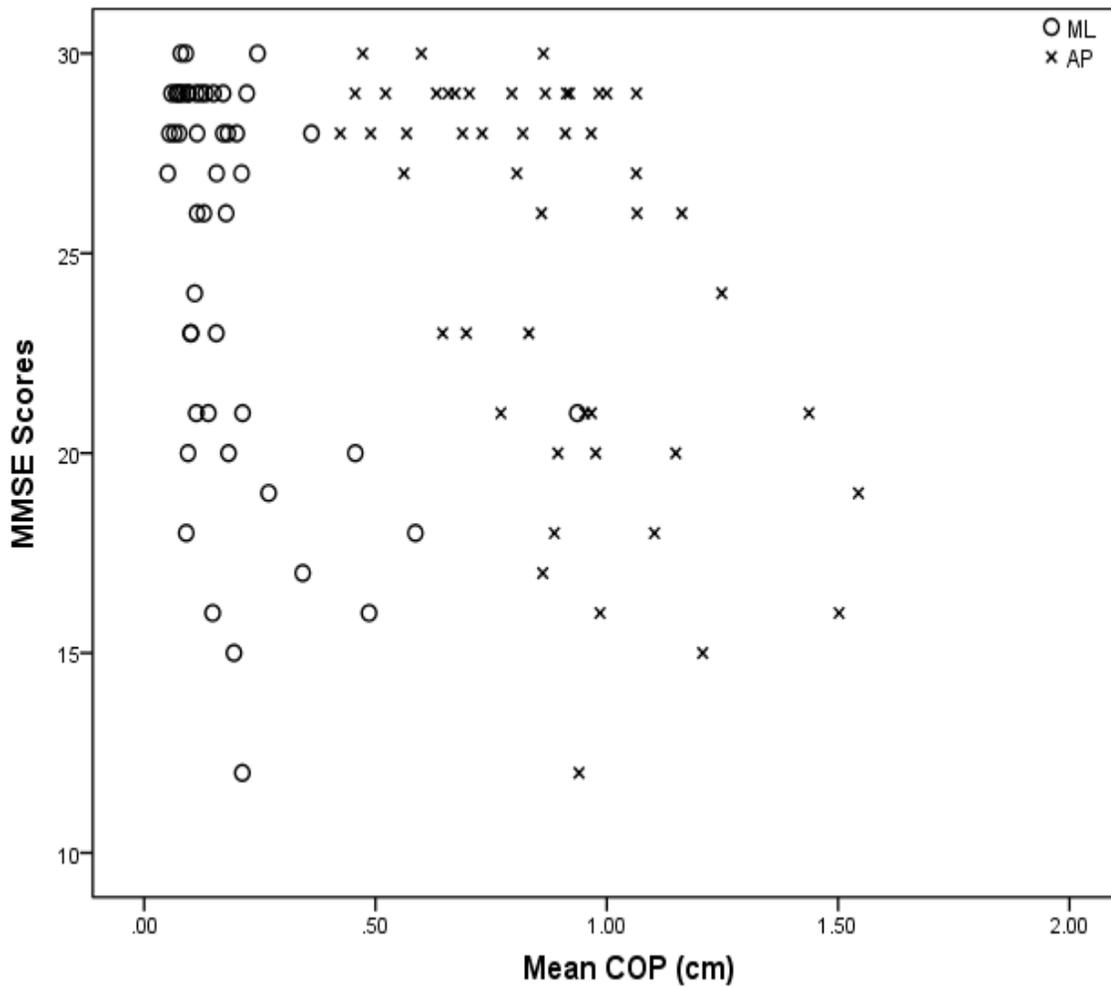


Figure 14. MINI-MENTAL STATE EXAM: Correlation: MMSE and Postural Motion. Shows a negative correlation between level of cognitive deficit and both the ML ($r = -.45, p < .05$) and AP ($r = -.51, p < .50$) planes.

APPENDIX C

GENERAL DATA:

Sub #	Diagnosis	Age	Educ	Group MMSE	MMSE	COP-ML-I	COP-ML-S	COP-AP-I	COP-AP-S	Errors
6	AD	79.53	16	MED	21	0.2472	0.9363	1.5254	1.4369	-1
7	AD	80.65	15	MED	26	0.1967	0.1770	1.2206	1.1622	-2
8	AD	80.84	16	MED	23	0.1413	0.3918	0.7900	1.3394	-1
11	AD	59.76	14	LOW	20	0.2162	0.1821	0.9169	0.8943	1
12	AD	85.64	12	LOW	16	0.6182	0.4859	2.0744	1.5021	0
13	AD	90.78	12	LOW	18	0.1423	0.0908	1.3637	0.8867	-5
14	AD	61.94	14	HIGH	30	0.0731	0.0898	0.5313	0.4722	0
17	AD	72.68	16	HIGH	24	0.1581	0.1094	1.0973	1.2485	0
18	AD	64.21	12	MED	23	0.1479	0.1558	0.9412	0.6964	-1
20	AD	77.12	14	HIGH	28	0.1381	0.0650	1.3810	0.7304	-2
21	AD	85.13	8	MED	21	0.3522	0.1385	1.0957	0.9525	0
25	AD	80.45	16	HIGH	28	0.3496	0.1709	0.9472	0.9663	0
26	AD	88.88	16	MED	21	0.1948	0.1126	1.2723	0.7710	3
27	AD	69.51	12	LOW	20	0.1412	0.0947	1.3973	1.1491	-1
30	AD	83.20	9	MED	21	0.1212	0.2127	0.8391	0.9667	-2
31	AD	81.30	12	LOW	17	0.0654	0.3427	0.7243	0.8615	-1
32	AD	74.77	13	LOW	14	0.0932	0.0853	1.0661	1.0017	-2
34	AD	75.21	12	LOW	20	0.1700	0.4564	0.5900	0.9759	2
36	AD	85.02	12	LOW	20	0.1763	0.2099	0.8446	0.8740	-1
46	AD	77.23	12	LOW	16	0.1978	0.1479	1.3992	0.9855	-1
49	AD	84.21	16	LOW	12	0.1416	0.2122	0.8414	0.9399	-2
50	AD	78.93	10	LOW	15	0.0787	0.1941	1.2737	1.2073	-2
53	AD	66.51	14	LOW	19	0.0612	0.2688	1.1719	1.5439	-4
55	AD	69.08	13	HIGH	28	0.3441	0.1002	0.9276	0.9203	-1
63	AD	85.25	12	LOW	18	0.4135	0.5862	0.8268	1.1030	-4
2	MCI	75.67	15	HIGH	27	0.2292	0.2105	0.9767	1.0638	4
4	MCI	74.18	10	MED	26	0.2934	0.1143	1.2567	1.0654	3
29	MCI	69.48	17	HIGH	27	0.2615	0.1225	2.4717	0.9556	-1
33	MCI	63.44	16	HIGH	29	0.1674	0.0689	0.8831	0.4559	0
35	MCI	84.91	16	HIGH	27	0.0678	0.0508	0.4952	0.5615	0
37	MCI	80.65	9	MED	25	0.2099	0.1203	0.8519	1.2109	0

38	MCI	65.17	10	HIGH	29	0.2030	0.0840	0.5668	0.7027	1
39	MCI	89.02	12	HIGH	27	0.2569	0.6605	1.1360	1.5662	0
40	MCI	73.65	16	HIGH	30	0.1357	0.2451	0.9513	0.8629	0
41	MCI	67.19	21	HIGH	29	0.1077	0.0954	1.3744	0.6574	0
44	MCI	84.05	18	MED	23	0.1101	0.1005	1.1524	0.8315	0
47	MCI	70.83	16	HIGH	29	0.0573	0.0946	0.5995	0.6720	-4
48	MCI	78.57	16	HIGH	28	0.0726	0.0756	0.7654	0.5674	-1
51	MCI	73.52	12	HIGH	28	0.0922	0.1694	0.6376	1.0314	0
52	MCI	85.04	10	MED	23	0.6470	0.1945	1.4720	1.4386	0
56	MCI	68.22	14	HIGH	29	0.0561	0.1230	0.5087	0.5069	0
60	MCI	82.53	14	MED	23	0.3750	0.1008	1.0910	0.6451	0
64	MCI	78.22	12	HIGH	28	0.2288	0.1810	1.0102	0.8184	-1
67	MCI	76.64	14	MED	26	0.2900	0.1290	0.8032	0.8588	-1
3	N	76.17	16	HIGH	28	0.1552	0.0547	0.8502	0.4893	0
5	N	72.85	13	HIGH	29	0.0800	0.0774	1.2069	0.9999	0
9	N	84.49	14	HIGH	27	0.0873	0.1565	0.6349	0.8055	-3
15	N	76.14	15	HIGH	28	0.1966	0.1143	0.7528	0.6881	0
28	N	75.01	12	HIGH	29	0.0872	0.0729	1.2785	0.9129	0
42	N	81.62	12	HIGH	29	0.3533	0.1132	1.0176	0.7948	-1
43	N	79.20	13	HIGH	29	0.1302	0.1232	0.8217	0.6321	-1
57	N	85.72	12	HIGH	28	0.1391	0.1999	0.8951	0.4240	0
58	N	77.28	12	HIGH	29	0.0740	0.0590	0.6484	0.5219	0
59	N	77.22	12	HIGH	29	0.2611	0.1327	1.3605	0.9191	0
61	N	80.89	12	HIGH	29	0.1439	0.1705	1.0987	0.9839	-1
62	N	75.40	12	HIGH	30	0.0672	0.0793	0.4508	0.5992	0
65	N	80.41	16	HIGH	29	0.2627	0.2217	0.9035	0.8670	-1
68	N	77.80	14	HIGH	29	0.1378	0.1499	0.8258	1.0641	-3
69	N	72.57	14	HIGH	28	0.0416	0.3615	0.5720	0.9104	-2

Table 4: GENERAL DATA: Sub # - Subject number assigned to participant; Diagnosis – Consensus Diagnosis of AD (Alzheimer’s disease), MCI (Mild cognitive impairment) or N (Normal); Age – listed in years; Educ – Education, listed in years; Group MMSE – Mini-mental state examination Classification of Low, Middle, and High scoring on the MMSE; MMSE – Mini-mental State Examination score; COP ML-I – Postural motion of the center of pressure (COP) for the Medial-Lateral (ML) plane in the Inspection task (I); COP ML-S – for the Search task (S); COP AP-I – for the Anterior-Posterior (AP) plane; COP AP-S; Errors – the number of errors made on the Search task (negative number is underestimation, positive number is overestimation).