THE IMPACT OF AN INTENSIVE PHYSICAL EXERCISE PROGRAM (IPE) ON MENTAL PROCESSING SPEED AND POSTURAL CONTROL IN OLDER ADULTS

by

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ABSTRACT

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One in three Americans over the age of 65 fall each year. In 2000, this equated to an annual cost of $19 billion in healthcare costs and this cost is expected to rise to $54 billion by 2020. One factor related to the increased risk of falls is a slowing mental processing speed. Mental processing speed is the speed at which a person is able to successfully process and respond to stimuli. As people age, they are not able to process information as quickly as younger adults. A positive correlation between physical speed and mental processing speed has been found such that those who physically move more quickly also tend to process mental information more quickly and are less likely to fall. However, the cause/effect relationship is not well established. This relationship was investigated in the current experiment by comparing the change in processing speed with the change in postural control (as measured by computerized dynamic posturography) during an 11-week Intensive Physical Exercise Program (IPE).

Participants significantly increased their postural control across four time points (pretreatment, 4 weeks, 8 weeks, and 12 weeks) and processing speed also increased across the time points, as measured by a Letter Comparison (LC) task. However, the change in processing speed across the time points was not a significant predictor of the change in postural control.

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CHAPTER 1

INTRODUCTION

One in three older (over 65) adults falls each year (Hornbrook, Stevens, Wingfield, & Hollis, 1994; Hausdorff, Rios, & Edelber, 2001). These falls amounted to over 1.46 million emergency room visits by this group due to non-fatal falls in 2008 (Center for Disease Control and Prevention [CDC], 2010a). Results of falls include contusions, fractures, head trauma, and death (12,900 deaths in 2002; CDC, 2010b). Injuries from falls are the most common preventable cause of an emergency room visit in nursing home populations (CDC, 2010b). This is especially true of those aged 65 and older in nursing homes, where emergency room visits from slips and falls account for 36% of the visits. This is higher than heart conditions (19%) and Pneumonia (12%), combined (CDC, 2010b). Of the 1.69 million falls reported annually for persons age 65+, 57% were associated with “slipping, tripping, or stumbling.” The next closest cause was “loss of balance, dizziness, fainting, seizure” accounting for 26.7% of cases (CDC, 2010b). With the growing elderly population worldwide, it is necessary to understand the underlying causes of falls in an effort to reduce their occurrence.

1.1 Costs

1.1.1 Financial/Medical Costs

In 2000, the overall costs associated with falls among persons 65 years of age and older was $19 billion, in medical care, in the United States (CDC, 2010a). In community-dwelling older adults, falls are one of the twenty most expensive medical conditions (Carroll, Slattum, & Cox, 2005). In 2002, 22% of community-dwelling older adults reported falling within the past year, with an average cost per fall between $9,113 and $13,507 (Shumway-Cook et al., 2009). These costs increase with age. For example, the average cost per fall for people 72 years of age and older is $19,440.

The first baby boomer reached 65 this year. This is expected to change the demographics in the United States from 13% of the population being over 65 in 2010 to 20% of the population in 2050 (U.S. Census, 2010). As more and more "boomers" move into this age group the annual cost of injuries due to falls is estimated to reach $54.9 billion (not adjusted for inflation) by the end of this decade (2020).

This is not just an American trend. Countries around the world are either currently facing or will soon be faced with a disproportionate number of older adults and the needs that are associated with them (U.N., 2007). Japan has already begun to experience this as their aging population (over 60) in 2007 accounted for 27.9% of their population. In fact, in 2007 the United States only ranked 43rd worldwide in percentage of the country's population that is over the age of 60.

It is worth noting that the cost estimates above do not include long-term care costs associated with the falls. The American Association of Retired Persons (AARP, 2009) estimates that the average annual cost of a nursing home is $50,000 and growing. A more affordable option, assisted living, at half the price of a nursing home, is still a large financial burden for the patient, loved one who is financially supporting the patient, or the government, via Medicaid, when a patient's funds are depleted. This results in an increase in the annual cost to the (already overburdened) U.S. healthcare system.

1.1.2 Hip Fractures

Of the injuries sustained during a fall, hip fractures are the most common fall-related fracture among elderly adults with long-lasting effects. A short review by Craik (1994) found that 17% to 70% of patients never fully recover their prefracture ambulation at 1 year following a hip fracture and continue to live with pain and movement difficulties. The authors noted that the large variability is due to different methodologies, follow-up lengths, and definitions of recovery. The results of hip fractures may even necessitate long-term care, such as a nursing home or assisted living, for the patient, and the results of the hip fracture are related to an increased mortality rate in this group (Haentjens et al., 2010; Craik, 1994). A meta-analysis by Haentjens and colleagues found that adults over the age of 50 who suffer a hip fracture display a mortality rate 5 to 8 times greater than an age-matched control group during the first 3 months following the fracture. Although this difference decreases over time, the effect persists even after 10 years.

1.1.3 Emotional Costs

In addition to high physical and financial costs, the emotional impact of fall-related fractures is high as well. Following fall-related injuries, such as hip fractures, patients report increased rates of anxiety and depression (Holmes & House, 2000). This may be due to a fear of falling again and reduced self-efficacy with regard to falling (i.e., an external locus of control [LOC]) which is related to depressive symptoms (Chou, Yeung, & Wong, 2005; Stevens, Corso, Finkelstein, & Miller, 2006). An external LOC is associated with increased anxiety and fear. An older person who has experienced a fall-related injury and has an external LOC does not believe that he is in control of whether or not he falls.

Overmier and Seligman (1967) found that when animals are unable escape a noxious stimulus (e.g., an electric shock) over an extended period of time this results in decreased escape behavior. This learned helplessness is related to anxiety and depression, and is seen in older adults who believe that they are unable to prevent another fall. In addition researchers have found posttraumatic stress symptoms in older adults following their fall (Chung et al., 2009). The majority of these symptoms are acute and only last a short time; however, roughly one quarter of patients develop chronic posttraumatic stress symptoms following a fall.

With such a large economic, physical, and emotional impact it is important to better understand what causes falls to occur in the first place.

1.2 Underlying Causes of Falls

Not all slips result in falls. Most of them are corrected by making a postural adjustment such as shifting weight before the fall occurs. What causes falls to happen in some cases, but not others? A comprehensive explanation is needed to explain individual differences which lead to increased fall rates. Postural control provides a multicomponent, comprehensive account of how and why falls do or do not occur. Therefore, to understand the components that disrupt normal functioning and increase the risk of falls, particularly in older adults for this research, it is important to first understand the process of postural control. In general, postural control is comprised of three major components that detect imbalance, determine the most appropriate response to the imbalance, and then execute the response. Each is vital to maintaining balance and a disruption of any one of these components can undermine the system (Shupert & Horak, 1999). Sensorineural, neuromuscular, and skeletomuscular processes are recruited to facilitate postural control and adjustments which increase fall prevention. Each will briefly be summarized below.

1.2.1 Sensory Input

With age, loss of sensory input is more common, thus disrupting the sensorineural component of postural control. Of particular importance to decreased postural control is impaired vision (Ray & Wolf, 2008) and sensory loss due to diabetic neuropathy (Shupert & Horak, 1999), both of which become more likely with increasing age. If an older adult experiences reductions of sensory input from other areas (e.g., vestibular feedback), they may be more likely to rely on visual input when attempting to determine balance perturbations (Ray & Wolf, 2008). With only a portion of the sensory information to determine a perturbation and its cause, older individuals with vision impairment are at an increased risk of falling (Jeka, Allison, & Kiemel, 2010). This is because they are unable to detect subtle indications that a slip is occurring and have less information available, such as the direction of the change, with which to determine the best course of action (e.g., which direction to shift weight). In this case, those who over rely on an impaired sensory system (e.g. impaired vision) may have difficulty using sensory reweighting. Sensory reweighting is used to prioritize the use of sensory information between multiple, functional, systems and may be impaired, though it still exists, in fall-prone older adults (Jeka, Allison, & Kiemel, 2010).

If an individual has access to adequate sensory input during a perturbation such as a slip, he must next determine the appropriate response (e.g., which muscles to flex and which direction to move). Because of this need for decision-making, reduced attentional resources (Verghese et al., 2002), reduced working memory/mental processing speed (Holtzer et al., 2007), and generalized cognitive decline (Antsey, Wood, Kerr, Caldwell, & Lord, 2009) have all been linked to a decrease in postural control and an increase in the risk of falls. Unfortunately, all of these risk factors are associated with aging. Therefore, an older individual who is mentally slower or has reduced attentional resources, perhaps due to the slowed mental processing speed, will either not be able to process the sensory information (e.g., visual information that indicates a slip in a particular direction) quickly enough or only be able to process a portion of the information in order to prevent a fall. This can result either in slowed or inappropriate responding, both of which increase the likelihood of falling.

1.2.2 Skeletomuscular Predictors

Skeletomuscular predictors of reduced postural control include abnormal gait (Hausdorff, Rios, & Edelber, 2001; Tinetti, Doucette, Claus, & Marottoli, 1995), reduced physical fitness (Weerdesteyn et al., 2006; Voukelatos, Cumming, Lord, & Rissel, 2007), and reduced lower-limb power (Chu et al., 1999). Given these reductions in physical power and abnormalities of movement, when an individual has adequate sensory input and is able to determine the appropriate course of action in response to a slip or balance perturbation, their reduced strength and/or abnormalities may result in the physical response not being adequate to overcome the slip and results in a fall. Stated more simply, although the individual has the information and is able to make the appropriate decision, he does not have the strength to carry it out and prevent the fall.

To summarize, all three components of postural control (sensorineural, neuromuscular, and skeletomuscular) are necessary to maintain balance. This is like a three-legged stool. If just one of the legs is removed, the stool falls. The same is true in humans. If any one of the components of postural control is lacking and the person begins to slip, there is an increased likelihood that it will end with a fall. Research is being conducted on methods to increase available sensory feedback as well as lower-limb power. It is very important to understand how these interventions, especially those most common to the field, such as physical exercise, also contribute to increases in mental processing speed. Methods for measuring the components of postural control are listed below.

1.3 Measuring Postural Control

A variety of postural control measures exist. They consist primarily of balance (e.g. balancing on one leg) and gait measures. Each is explained in greater detail below.

1.3.1 Gait

Gait measures focus on abnormalities associated with bipedal movement. For example, individuals may be asked to walk across a mat of a certain length. During this walk, a researcher may measure the time that it takes the individual to travel the specified distance (Menz et al., 2004). Another measure used by researchers is double-stance time. This is a measure of the amount of time that an individual contacts the floor with both feet, at the same time, while walking. Younger individuals, without any difficulty, maintain their posture and spend very little time with both feet on the floor while they are walking. Instead, they quickly transfer weight between the feet in a smooth, gliding style. Thus, increased double-stance time may be an indicator of poorer postural control. Similarly, step length is an indicator of the state of an individual’s postural control. Shorter steps indicate less postural control. With newer measurement techniques, other more advanced measurements can be made, such as the specific base of support and the angle of the feet and toes may also be used as indicators of postural control. Gait measures are robust indicators of postural control and are easily explained to a participant (e.g. "walk from here to there"). However, one limitation is that the ability to modify the sensory input is not available with gait measures. Sensory modification is, however, available with computerized dynamic posturography (CDP).

1.3.2 Computerized Dynamic Posturography (CDP)

Computerized dynamic posturography (CDP) provides measures of dynamic postural control while participants' sensory systems (visual, vestibular, and proprioception) are disrupted (see Figure 1.1). These disruptions occur as part of the Sensory Organization Test (SOT) and provide outcome measures which are significant predictors of functional performance (Topp, Mikesky, & Thompson, 1998). The SOT is able to determine the individual's ability to ignore the disruptive information and appropriately use the non-disrupted information in order to maintain balance and prevent a fall from occurring. Though costly, CDP is an excellent method of measuring postural control.

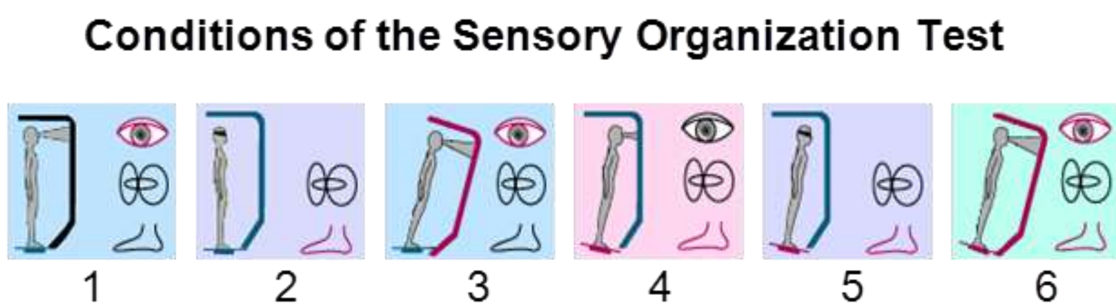

Figure 1.1. Six sensory conditions of Sensory Organization Test (SOT) protocol. Eye graphic denotes visual system, the circles graphic denotes vestibular system, and the foot graphic denotes somatosensory system.

1.4 Working Memory/Processing Speed

Processing speed is considered one of two components of *working memory*, the other being storage (Babcock & Salthouse, 1990). Working memory is used to process and manipulate items in short-term memory, such as the location of objects in a room. Working memory is the executive function that allows the mental juggling required to keep all needed items in conscious awareness. This is similar to the way that a juggler maintains active control over multiple items in the air. Just like the juggler, there is a limit to how many items can be kept in conscious awareness at a time and it is different for each person (Miller, 1956).

With aging, working memory capacity declines. This has been found to be linked both to changes in storage capacity, as well as processing speed (Babcock & Salthouse, 1990). In older adults, processing speed is a major associate of cognitive decline (Bashore, 1989). This is due to the need for storage and the increased time for decay of information with a slower processor. Items in working memory are only stored for approximately 15 to 30 seconds if they are not attended to. Therefore, as storage time is finite, the amount of time that is needed to attend to each item (i.e., processing speed) affects the total number of items that can be kept in awareness at a given time. For instance, with age and mental slowing, an individual who has just slipped will not be able to process as much important sensory information at once. Rather than being able to process the vestibular sense of falling, the visual change of the horizon, and the feeling of weight shifting from one foot to the other, the individual may only be able to process the first two. With reduced information, it becomes more difficult to determine what the appropriate response is which could have prevented a fall.

A person with a faster processing speed, however, will be able to quickly process each item and move on to the next, resulting in an increase in the total number of items that can be kept in awareness during a 15 to 30 second span and can be used to make decisions. Thus, the individual with the faster processor who has just slipped will be able to use all three pieces of sensory information to make a quick and appropriate decision about what postural adjustments will be best to prevent him from falling. It is worth noting that processing speed, though important, is irrelevant in the absence of adequate sensory input and neuromuscular strength. Therefore, attention should be paid to interventions that seek to increase neuromuscular strength and/or sensory input, as well as mental processing speed (e.g. physical exercise).

1.4.1 Knowledge

Paradoxically, although overall mental processing speed slows with aging, world knowledge (e.g., vocabulary) remains steady (if not slightly increases) into older adulthood (see Figure 1.2; Park et al., 2002; Salthouse, 2004; Salthouse, 2000; Park & Reuter-Lorenz, 2009). The result of these age-associated changes is that as individuals age they are still able to access previously-learned information, but it takes longer to retrieve it. Therefore, it may not be that older adults are unaware of how to make postural changes that will terminate a fall; instead, it may be that slips and falls happen in such a short amount of time that they are unable to process the information and then execute the appropriate response.

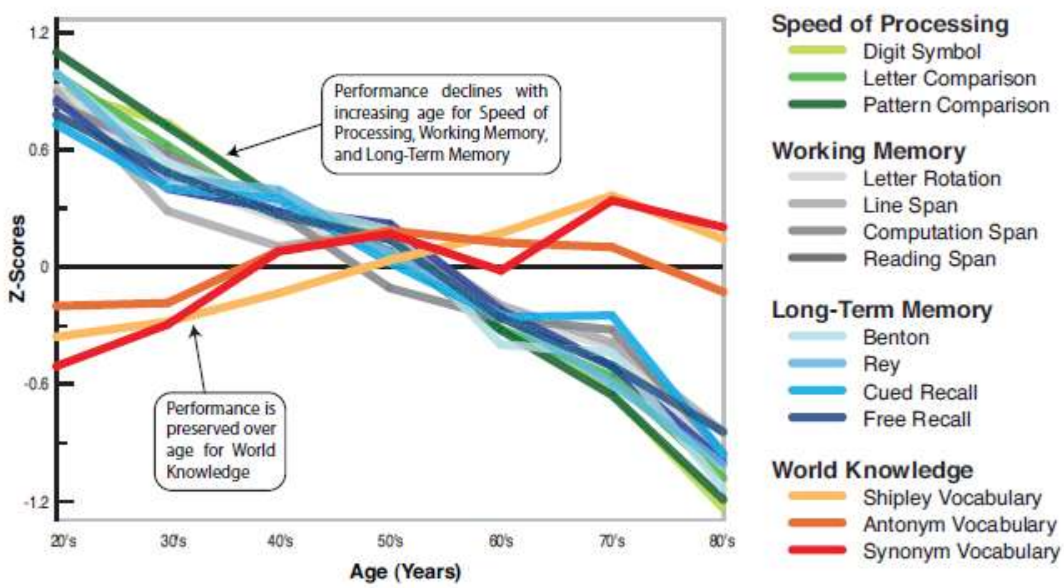

Figure 1.2. Cross-sectional measures of *speed of processing, working memory, long-term memory (LTM),* and *world knowledge* from Park & Reuter-Lorenz (2009). As noted, steady age-related declines are seen for *speed of processing, working memory,* and *LTM*, but not for *world knowledge*.

Returning to the example of the juggler, as the juggler ages he slows down and is unable to juggle as many items at one time. This is true of mental aging as well; as we age, our mind slows and we are no longer able to mentally "juggle" as many pieces of information at one time. This makes decision-making, such as how to adjust one's posture to prevent a fall, more difficult due to the reduction in usable information, much the way that impaired sensory input reduces postural control. It is important, then, to better understand the mechanisms of processing speed and how they may be increased to improve postural control and reduce falls. Processing speed can be measured in many ways (e.g., *decision speed, perceptual speed, psychomotor speed, reaction time, psychophysical speed,* and the *time course of internal response*; Salthouse, 2000). Each type is described in more detail below.

1.5 Measuring Processing Speed

1.5.1 Decision Speed

Decision speed tasks ask participants to make a decision about a relatively complex set of stimuli (e.g., matrices, analogies, vocabulary tasks; Danthiir, Wilhelm, & Schacht, 2005) and measure the amount of time that it takes for the participant to make the decision (i.e., reaction time). With age, the speed at which decisions are made slows as processing speed slows. Perhaps this is because individual differences unrelated to processing speed (e.g., personal cognitive ability) are involved in these tasks. This results in an increased reaction time (RT) in these types of tasks. Increases in RT when making a decision can be dangerous with regard to slips and falls. The longer that an individual takes to decide how to respond to indications of a potential fall (e.g., slipping or vestibular imbalance) the more likely he is to fall because by the time he reacts, he is already falling. However, these tasks are confounded by individual differences in prior experience and may result in increased variability unrelated to mental processing speed (Salthouse, 2000).

1.5.2 Perceptual Speed

In an effort to control for cognitive ability, perceptual speed tasks may be used. Rather than complex stimuli, perceptual speed tasks involve the comparison of relatively simple stimuli. For example, in a letter comparison task, participants are asked to compare two strings of letters (e.g., “arg” and “arb”) and answer if they are the *same* or *different* as quickly as they can (see Figure 1.3 for an example). This takes place during a given set of time. At the end of the allotted time, the measure of the total number of correct answers are calculated and used as a measure of processing speed (average RT may also be used). Other stimuli include numbers, pictures, and symbols.

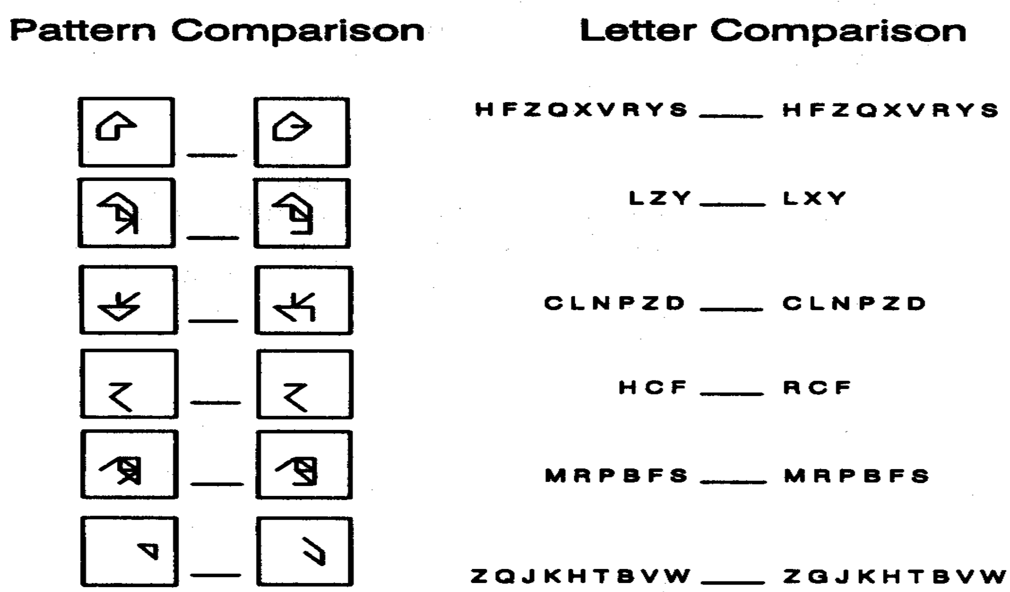

Figure 1.3. Examples of the pattern comparison and letter comparison task used by Salthouse (1991).

Substitution is another popular perceptual speed task. In a substitution task, a participant is provided with a string of, typically, symbols and a key that matches each symbol with a number. The task is to make as many correct substitutions as possible in a given amount of time. Again, the number of correct substitutions is used as a measure of processing speed. With aging, the total number of items that an individual is able to substitute during each trial is reduced (Park & Reuter-Lorenz, 2009). In the real world, as with the decision speed tasks, lower numbers of substitutions can indicate an increased risk of falling. When a person slips, he must make multiple postural adjustments (e.g., flexing the hips, rotating the ankles) to prevent a fall. If he is only able to make half as many adjustments in a given time, he is less likely to prevent the fall. These measures are ideal for many experimental situations as they are not confounded by differences in cognitive ability and they are simple to administer/respond to.

1.5.3 Psychomotor Speed

Psychomotor speed tasks, as the name suggests, involve physical movement (e.g., finger tapping and drawing lines) with simple stimuli. An example of this is the Trails A task. This is a standard task used in patient populations to assess current functioning (Reitan, 1955). Trails A is designed very much like "connect-the-dots" in that participants are asked to connect numbered circles as quickly as possible in the correct order (1, 2, 3…25). Other versions exist and follow a similar format (e.g., Salthouse, 2011). Older participants tend to take longer to complete this task than younger participants (Salthouse & Fristoe, 1995). In addition to slowed physical ability, this slowed performance suggests that older adults need more time than younger adults to process the information, decide which dot to draw the next line to, and draw the dot (i.e., their mental processing speed is slower than that of younger adults). This measures the same components necessary for postural control and has also been linked to an increased risk of falling (Holtzer et al., 2007). Given its simplicity, this type of measure also reduces the risk of confounds, but may be more difficult to respond to if a flat surface is not readily available to write on.

1.5.4 Reaction Time

Reaction time (RT) procedures are very popular and simply measure the amount of time that it takes a participant to react to a stimulus. These have been used for quite some time, but have become increasingly popular as technology has enabled increased specificity and accuracy in calculating RT. An example of this type of task may be flipping a particular switch when the center light, in a series of three lights, flashes (Spirduso & Clifford, 1978). The experimenter then uses the RT (usually calculated in milliseconds) as a measure of processing speed. Participants with slower processing speed are able to complete this task, but it takes them longer to respond to the items which results in an increase in RT. Again, this slowed response may result in a delayed response to a slip and, thus, a fall. This type of task has the same benefits as perceptual speed tasks and is free of confounds related to individual ability.

1.5.5 Psychophysical Speed

Measures of psychophysical speed focus on the accuracy of judgments following briefly presented auditory or visual information. The rationale behind these types of measure is that, given the short presentation time, the faster a participant is able to process each piece of information, the more likely he is to be accurate in his decisions. If a participant is too slow in processing the information, he will miss too much of the information to provide an accurate judgment. These are somewhat different from the previous measures in that the stimulus is only presented for a short time and the participant must process the information quickly in order to provide the correct answer. As processing speed slows, participants are unable to fully process the stimulus before it disappears. With less information with which to make a decision, slower participants are more likely to make errors. Similarly, if an older adult is unable to process information quickly enough, he may miss important information that was briefly present, but that would have allowed him to make an appropriate response in order to avoid a fall. These tasks reduce the variability attributable to differences in cognitive ability, but they fail to completely eliminate the confound.

1.5.6 Time Course of Internal Responses

More recently, with the advent of technology to support this line of research, psychophysiologists have relied on physiological measures which are thought to reflect the internal time course of responses. Event-related-potentials (ERPs) are measures of the change in electric charges in the brain. These can be measured internally in animals and in some human cases (e.g., during brain surgery) or externally using equipment such as electroencephalogram (EEG). The variation in time course is thought to reflect variations in speed of transmission between the neurons and give a more accurate correlate of processing speed. Thus, decreased processing speed is indicated by slowed electrical transmission.

Aging is associated with changes in the brain such as reduced cortical volume and demyelination of axons. The myelin sheaths that surround axons act as an insulator and increase the speed of transmission between neurons. The degradation of the myelin sheaths with aging results in slower transmission between neurons (Sullivan, Rohlfing, & Pfefferbaum, 2010). This is thought to be a partial cause of the reduced processing speed that is seen with aging. This reduction in the ability to transmit a signal from one neuron to another may affect both cognitive as well as musculoskeletal responses. These delayed cognitions may lead to slowed decision-making, while slowed musculoskeletal responses may compound the effect of slowed decision-making. For instance, a slightly slowed decision about how to respond to a slip also takes longer to reach the muscles that are needed to relax or contract to produce the desired movement. This slowing may result in a fall. Although this type of measure is physiological in nature and greatly reduces the confounds of cognitive ability, the equipment as well as setup (e.g. placing the electrodes and reducing interferences from sound and light sources) can be costly and time-consuming.

When determining which measures to use, a measure lacking in confounds and easily presented/responded to is ideal. Of the measures described above, the perceptual speed, RT, and psychophysical speed measures meet these criteria. However, psychophysical speed measures can be costly and difficult to setup. Because of that the three mental processing speed measures used in this experiment consisted of two perceptual speed measures (letter and pattern comparison) and RT.

1.6 Link to Movement/Postural Control

Mental processing speed in older adults has been found to be associated with walking speed in that increased processing speed was related to quicker walking speeds in older adults (Holtzer, Verghese, Xue, & Lipton, 2006). Processing speed has also been linked with the likelihood of preventing falls, in that faster processing speed in older adults is related to a reduced likelihood of falls (Holtzer et al., 2007). Additionally, increased demand for cognitive resources has been related to a reduction in postural control. For instance, a typical task for evaluating older adults' postural control and risk of falling is to have the individual walk while completing a cognitive task (e.g., reciting the letters of the alphabet; Verghese et al., 2002; Holtzer et al, 2006). While completing the walking while talking (WWT) task, older participants, particularly those with a higher risk of falling, tend to slow or even stop walking completely in order to complete the cognitive task and then resume walking. This result is due to limited working memory resources which are necessary for both tasks (walking and talking). For example, if an older person is only able to process 5 items at a given time, due to reduced mental processing speed, and walking requires the processing of 3 items and talking requires the processing of 4 items, there are not enough attentional resources available for both tasks to occur simultaneously. Thus the older adult may stop walking to allocate resources to the cognitive task and then start walking again when the cognitive task is complete. Although in this example physical movement is impeding cognitive ability by using needed resources, physical activity has been found to buffer the cognitive decline that is at the heart of this difficulty (Spirduso & Clifford, 1978; Kramer et al., 2003).

1.6.1 Physical Activity

Physical activity has also been found to enhance processing speed and slow the cognitive decline related to aging (Spirduso & Clifford, 1978; Kramer et al., 2003). Spirduso and Clifford (1978) found that reaction time (RT) in physically active older adults was faster than sedentary older adults. More striking was their finding that RT for physically active older adults was equivalent to sedentary younger adults who were approximately 40 years younger. More recently, physical interventions have been found to reduce the incidence of falls and increase postural control in older adults (Weerdesteyn et al., 2006; Voukelatos et al., 2007). Based on this and the link between physical activity and processing speed, it is likely that these reductions in fall incidence (as well as increased postural control) may be due, in part, to increases in processing speed as a result of the physical intervention. A more direct analysis of changes in mental processing speed during a physical intervention is necessary to better understand the cause and effect relationship between physical exercise and changes in mental processing speed.

1.6.2 Language

Given the relation between physical movement (e.g., walking speed; Holtzer et al., 2006) and mental processing speed, some research has also connected physical movement and language (Glenberg, Sato, & Cattaneo, 2008; Taylor & Zwaan, In Press). For example, Glenberg and colleagues had participants move beans from a cup full of beans to an empty cup which was either closer to the participant, thus the participant moved the beans toward himself, or farther from the participant, so the participant moved the beans away from himself. Once this was complete, the researchers asked participants to judge whether or not sentences were grammatically correct. They found that when the movement ("toward" or "away") described in a sentence was congruent with the direction of the response (moving an item toward or away), the response was faster than when it was incongruent (Glenberg, Sato, & Cattaneo, 2008). Similarly, when Taylor and Zwaan (in Press) asked participants to squeeze a rubber bulb to make sensibility judgments about sentences, they found that the amount of force described in a sentence (e.g., "He pushed the car" versus "He started the car") predicted the amount of force used by participants to respond to the sentence (i.e., participants squeezed the ball with greater force when the verb indicated greater force). These researchers have found that movement can affect sentence comprehension and that word choice can affect movement.

These findings suggest that there is a strong relationship between physical movement and the speed at which individuals are able to mentally process ideas.

From a language learning standpoint it is reasonable to infer that language would be associated with the physical movements to which it refers. When a child is learning language he or she will be taught by associating the word with the action, thus a direct link is formed. For example, when a person is having difficulty remembering a word, the use of physical movements (e.g., a kicking motion) can cue the person to the word that he was having difficulty remembering (e.g., “soccer”). Physical movements are not only used to cue a word that one is having difficulty remembering, but can be used as a part of an entire speech. Gesticulating while speaking can enhance the overall flow of a speech and provide the speaker with constant cues and, thus, easy access to his or her words. In this way, physical movement acts much like written cue cards. The only difference is that the sensory information on the cue card is written and the sensory information from the physical movement is kinesthetic, but both cue the person’s lexicon.

Therefore, given the association between physical movement and a person’s lexicon (e.g., the kicking motion mentioned above linking to the word “soccer”), it is possible that the cognitive decline experienced by many older adults may be partially related to their limitations in physical movement. In other words, as they physically slow down it takes them longer to provide the cues to aid their language; thus, they slow down cognitively as well. If this is considered based on the cue card example, the physical slowing down is similar to the slowing of how quickly a new cue card is presented. In that case, the individual does not receive their cues as quickly and is consequently slower at accessing the next word. Even more importantly, this delayed cuing can, in the case of an older adult trying to right himself as he is slipping, result in a delayed decision about the best method to use to right himself and end with a fall. This is congruent with the fact that those individuals who take part in regular exercise and/or have a faster walking speed have both increased mental processing speed and a reduction in the likelihood of falling.

Additionally, links to physical movements are not only related to language, but also to any other association such as thoughts, ideas, and feelings (e.g., smiling can make you *feel* happy; Strack, Martin & Stepper, 1988). Participants who are asked to hold a pen in their mouth with their teeth (causing them to form a smile) later rated a cartoon as funnier than either participants who held the pen with their lips (resulting in a frown) or those who held the pen in their non-dominant hand. This was evidence that facial feedback can influence emotions.

Some of the most interesting research in the area of facial feedback has involved the use of botulinum toxin-A (Havas, Glenberg, Gutowski, Lucarelli & Davidson, 2010). In this experiment, participants were patients receiving cosmetic subcutaneous injections of botulinum toxin-A which causes temporary paralysis of the facial muscles in order to treat lines (frown lines in this example) and wrinkles on the face. Participants were asked to read and answer YES/NO comprehension questions about emotional sentences before and after treatment with botulinum toxin-A. No difference in sentence comprehension was found before and after treatment. However, participants' RTs increased following the injection of the botulinum toxin-A. Thus, the facial paralysis caused by this treatment reduced participants' ability to provide feedback cues (e.g., frowning when reading a sad sentence). This resulted in participants taking longer to make a judgment and is directly in accord with the sensory feedback hypothesis presented here. Because movement can provide so many links, it stands to reason that the reduction in processing speed related to increased aging is, partially, moderated by physical movement. This may be a major link to why increased physical movement is related to increased mental processing speed.

As stated above, no single component of postural control will alleviate the increased risk of falling associated with aging. All three components of postural control must be targeted. Therefore, the most effective intervention method will be an intensive physical exercise (IPE) program. This will be performed with a group of community-dwelling older adults over the course of 11 weeks. Although physical exercise and mental processing speed are strongly correlated, to understand the cognitive component of postural control, it will be important to track changes in both postural control, as well as mental processing speed, while the IPE progresses. Thus, measures of mental processing speed and postural control were collected at 4-week intervals to provide adequate time between measures for change to occur.

Although the complete IPE will be conducted over 11 weeks, as noted by Zhou (2003), individuals new to a strength training program show large increases in strength during the first weeks of training. This increase seems to be related to neural adaptation as it occurs in the absence of muscular increases. Because of that, this project predicted that changes during the first 8 weeks of the IPE would show the greatest difference for measures of postural control and mental processing speed across the four time points (pre-program, 4 weeks, 8 weeks, and 12 weeks).

1.7 Hypotheses

1.7.1 Hypothesis 1

It was hypothesized that participation in a (IPE) program will lead to an increase in postural control over pre-program levels as measured by Sensory Organization Test (SOT) of the NeuroCom EquiTest, a CDP measurement device.

1.7.2 Hypothesis 2a

It was also hypothesized that participation in an IPE program would lead to an increase in mental processing speed over pre-program levels as measured by changes in letter comparison, RT, and pattern comparison scores.

1.7.3 Hypothesis 2b

It was believed that improvements in mental processing speed (letter comparison, RT, and pattern comparison) would be greater from baseline to 4 weeks after initiation of the IPE program relative to changes occurring from week 4 of the IPE to the end of the 11^{th} week.

1.7.4 Hypothesis 3

The third hypothesis was that increases in mental processing speed (letter comparison, RT, and pattern comparison) would be positively correlated with increases in postural control as measured using the Sensory Organization Test (SOT) of the NeuroCom® EquiTest, a computerized dynamic posturography (CDP) device. The SOT consists of six balance tasks which measure postural control during a variety of sensory disturbances, including visual, vestibular, and proprioception (see Figure 1.1).

CHAPTER 2

MATERIALS AND METHODS

2.1 Participants

Twenty-eight older adults (17 female) age 55 to 92 (*M*=75.54, *SD*=7.87) were recruited from a cohort of older individuals taking part in an 11-week exercise intervention through the Center for Healthy Living & Longevity (CHLL) at the university of Texas at Arlington (see Table 2.1 for participant characteristics).

Table 2.1. Participant demographic characteristics.
Note: Age is displayed as *M* (*SD*).

Characteristic	Wii (*n*=10)	Pilates (*n*=18)
Age	74.80 (7.07)	75.94 (8.45)
50s	0	1
60s	3	3
70s	4	10
80s	3	2
90s	0	2
Gender		
Female	6	12
Male	4	6
Ethnicity		
White	8	17
Black	1	0
Indian	1	1

Participants taking part in this intervention must provide physician's consent to participate. In addition, all participants must be able to safely ambulate for 6 minutes without assistance to confirm that they are able to safely participate in an exercise intervention. All participants provided informed consent per the Institutional Review Board (IRB) at the University of Texas at Arlington.

2.2 Procedure

2.2.1 Exercise Training

Participants took part in an 11-week Intensive Physical Exercise Program (IPE). The IPE consisted of three exercise sessions per week. Each exercise session was approximately 1 hour long. Participants were randomly assigned to one of two exercise conditions (balance training using the Nintendo® Wii Fit device or Pilates).

2.2.2 Postural Control

The NeuroCom® EquiTest is a CDP device that was used to measure each participant's sensory contributions during a six different balance scenarios. The Sensory Organization Test (SOT) consists of six conditions in which an individual's visual, vestibular, and/or proprioceptive senses are disrupted (e.g. participants are asked to close their eyes; Figure 1.1). These outcomes are significant predictors of functional performance (Topp, Mikesky, & Thompson, 1998). Therefore, in order to obtain information regarding the participant's balance abilities at each time point, this test was conducted on each participant at each time point (pretest, 4-weeks, 8-weeks, and 12-weeks).

In Figure 1.1, the "eye" denotes the visual system, the "circles" denote the vestibular system, and the "foot" denotes the somatosensory system. To ascertain the deficits in each participant's use of these systems, the SOT protocol was employed. For safety reasons, prior to the assessment, participants were given a safety harness to put on which was attached to the machine. Once successfully harnessed, the participants received inaccurate information through their eyes, feet, and joints. This was accomplished through "sway referencing" (adjusting the support surface on which the participant is standing, as well as the visual surround). Each condition was performed three times in serial order (1, 2, 3, 4, 5, 6). The SOT provides specific scores for each condition as well as a composite score.

Conditions 1, 3 and 6 were used for additional testing of mental processing speed due to the increased integration needed to combine vision, somatosensory and vestibular systems.

These measures were used because we believed that they would provide a good opportunity to study the effects of multitasking. Conditions 1, 3 and 6 were chosen because these conditions more closely resemble "real world" situations and all three are conducted with eyes open which allowed the participants to complete the visual processing speed tasks. The additional tests included the three mental processing speed measures described below (digit span, reaction time, and pattern comparison).

2.2.3 Processing Speed

Three measures of mental processing speed were employed to provide processing speed factor scores for the participants. In an effort to reduce the influence of previous experience, the measure used required only basic perception and discrimination. Additionally, participants were given practice trials of each measure to reduce practice effects. These measures included letter comparison, reaction time (RT), and a pattern comparison task. The order of these tasks was counterbalanced.

The first and third mental processing speed measures that were used were a letter and a pattern comparison task (see Figure 1.3). In these tasks, participants were presented with two letter combinations/patterns at a time, on a computer screen, and were asked to determine whether or not the two letter combinations/patterns are the "same" or "different." They were then to answer as quickly as they can by pressing either the "same" button or "different" button, respectively. A total of 15 letter and 15 pattern comparisons were given to the participants and the average number of letter combinations/patterns that participants were able to correctly judge as "same" or "different" was used to create the participant's letter/pattern comparison speed. This was repeated while the participant performed the SOT.

Reaction time (RT) was measured as the amount of time (in msec) that a participant took to respond to a change in the color of the screen (black to white) of an LCD monitor. Participants were instructed to press a button when the screen color changed from black to white. The average RT of 15 trials was used as the participant's RT. This was repeated while the participant performed the SOT.

CHAPTER 3

RESULTS

Four participants were unable to complete the final session. In addition, computer malfunctions led to eight missing data points (<1%). Linear mixed modeling is better able to handle missing data than more traditional methods of analysis (e.g. ANOVA). Therefore, it was used in all analyses. All analyses were performed using the SAS 9.2 software using compound symmetry for the covariance structure and residual maximum likelihood (REML) as the estimation type. An alpha level of .05 was used for all statistical tests.

3.1 Fatigue

During the first two time points, researchers became concerned that the testing scenario may be fatiguing to the participants, therefore potentially affecting outcome measures. This was particularly true for the testing that took place in the NeuroCom. Therefore, a 37-item version of the Profile of Mood States (POMS; Appendix I; Shacham, 1983) was given to participants during the third and fourth time points just prior to testing (Pre) in the NeuroCom and again just after exiting the NeuroCom (Post). The POMS consists of questions on which participants rate how well a word describes how they are feeling on a scale from 0 (Not at all) to 4 (Extremely). The average ratings for the items that assess fatigue (*worn-out, fatigued, exhausted, weary, bushed*) were analyzed to determine if the level of fatigue changed from before the testing in the NeuroCom to after the testing in the NeuroCom. Therefore, a two-way (Pre and Post) mixed effects model with repeated measures (Time: third and fourth sessions) was performed for the POMS fatigue measures. No increase in fatigue occurred between the pre (M = .63, SD = .78) and post (M = .90, SD = .99) measures, $t(27) = 2.02$, $p = .0539$. No significant main effect for time or the interaction of Pre/Post on time was detected, $F(1, 23)$ =

.65, p = .428 and $F(1, 23)$ = .12, p = .731. Therefore, fatigue was not included for any further analyses.

3.2 Balance Efficacy

To test whether self-efficacy for the domain of balance improved with fitness training, a two-way (Exercise group: Wii and Pilates) mixed effects model with repeated measures (Time: pre-program, 4, 8, and 12 weeks) was performed for the aggregate scores on the Balance Efficacy Scale (BES; O'Sullivan & Schmitz, 2007; Appendix II). The Balance Efficacy Scale is an 18-question scale that asks participants to rate their confidence, on a scale from 0 to 100%, in achieving a variety of balance related tasks (e.g. *How confident are you that you can get up out of a chair (using your hands) without losing your balance?*). No main effect for exercise group was present nor was the interaction of group with time statistically significant, $F(1, 26)$ = .12, p = .733 and $F(3, 78)$ = .21, p = .888. There was, however, a main effect for time, $F(3, 78)$ = 3.20, $p<.05$. Post-hoc analyses revealed that efficacy scores did not change between pre-training (M = 88.187%, SD = 27.827%) and week 4 (M = 90.623%, SD = 14.202%), $t(78)$ = 1.01, p > .10. However, balance self-efficacy did have a significant increase between week 4 and week 8 (M = 92.854%, SD = 11.490%), $t(78)$ = 2.59, p < .05. The change between 8 weeks and 12 weeks (M = 91.068%, SD = 18.160%) was not statistically significant $t(27)$ = -1.87, p = .065.

3.3 Accuracy

A two-way (Item type: Letter Comparison [LC] and Pattern Comparison [PC]) mixed effects model with repeated measures (Time: pre-program, 4 weeks, 8 weeks, and 12 weeks) was performed for the accuracy of those measures. The analysis revealed that participants were more accurate for the LC task (M = 96.405%, SD = 8.978%) than the PC task (M = 91.091%, SD = 12.033%), $t(27)$ = 4.63, p < .001 (see Figure 3.1). No significant main effect for time or interaction of time with item type was detected, $F(3, 77)$ = .51, p = .676 and $F(3, 77)$ = .71, p = .551.

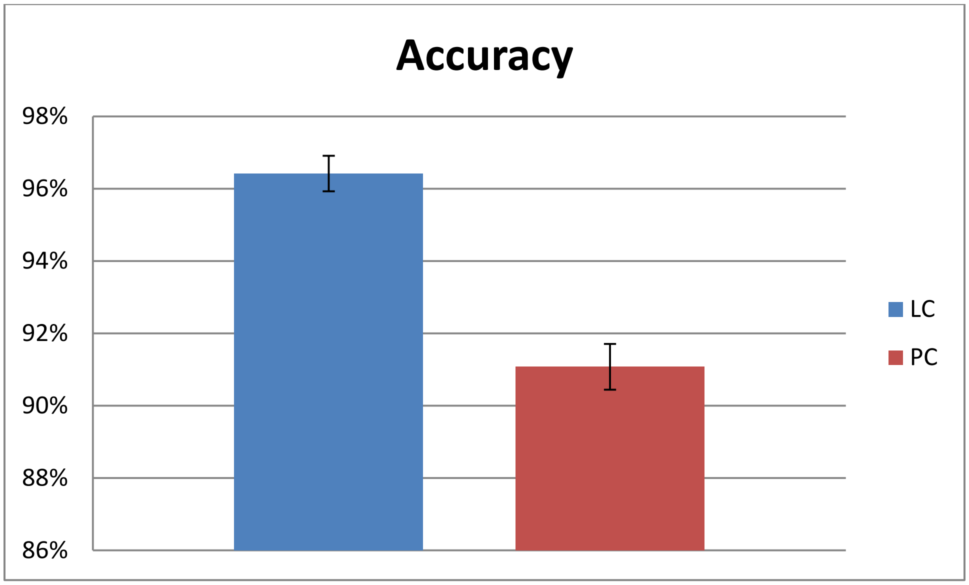

Figure 3.1. Participants were significantly more accurate for the Letter Comparison (LC) task (*M* = 96.405%, *SD* = 8.978%) than the Pattern Comparison (PC) task (*M* = 91.091%, *SD* = 12.033%), $t(27) = 4.63$, $p < .001$.

3.4 Changes in Postural Control

To test the hypothesis that participation in an IPE program will lead to an increase in postural control over pre-program levels, a two-way (Exercise group: Wii and Pilates) mixed effects model with repeated measures (Time: pre-program, 4, 8, and 12 weeks) was performed for the aggregate postural control score at all four time points. There was a significant main effect for time, $F(3, 78) = 7.824$, $p < .001$. However, no significant main effect for exercise group or interaction of time with exercise group was found, $F(1, 26) = .02$, $p = .899$ and $F(3, 78) = .05$, $p = .983$. Post-hoc analyses revealed that there was no increase in postural control between pre-program levels (*M* = 73.57, *SD* = 7.15) and 4 weeks (*M* = 73.25, *SD* = 8.93), $t(78) = -.31$, $p = .756$. Nevertheless, postural control scores did increase between 4 and 8 weeks (*M* = 75.93, *SD* = 8.41) as well as between 8 and 12 weeks (*M* = 77.68, *SD* = 7.75), $t(27) = 2.679$, $p < .01$ and $t(27) = 1.750$, $p < .05$, respectively (see Figure 3.2).

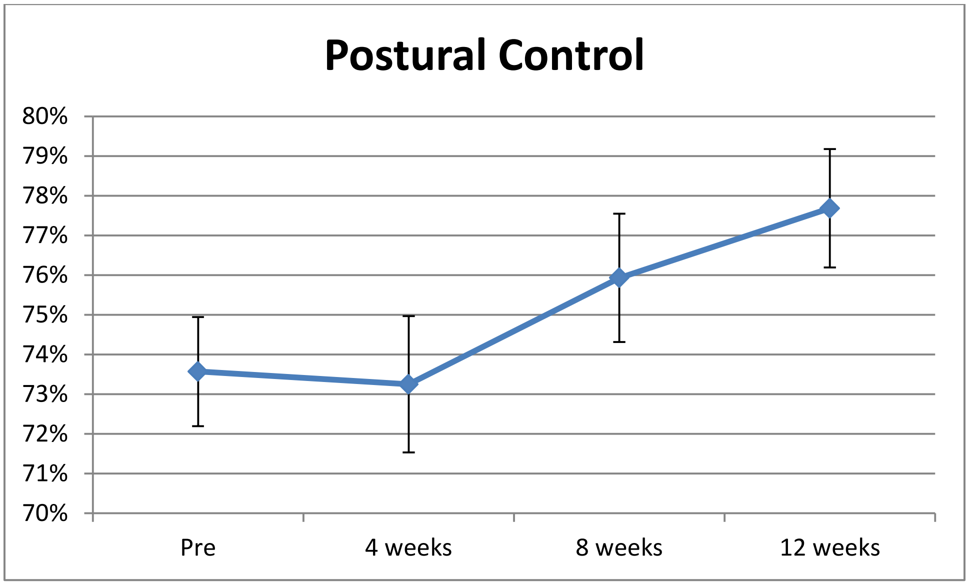

Figure 3.2. There was no significant increase in postural control between pre-program levels (*M* = 73.57, *SD* = 7.15) and 4 weeks (*M* = 73.25, *SD* = 8.93), *t*(78) = -.31, *p* = .756. Nevertheless, postural control scores did increase between 4 and 8 weeks (*M* = 75.93, *SD* = 8.41) as well as between 8 and 12 weeks (*M* = 77.68, *SD* = 7.75), *t*(27) = 2.679, *p* < .01 and *t*(27) = 1.750, *p* < .05, respectively.

3.5 Changes in Mental Processing Speed

To test the hypothesis that participation in an intensive physical exercise (IPE) program will lead to an increase in mental processing speed over pre-program levels, a two (Exercise group: Wii and Pilates) X four (Testing condition: Computer only, NeuroCom Condition 1, NeuroCom Condition 3, and NeuroCom Condition 6) mixed effects model with repeated measures (Time: pre-program, 4, 8, and 12 weeks) was performed for each of the three processing speed measures (Reaction Time, LC, and PC).

3.5.1 Reaction Time

No significant main effect of time was found for RT, *F*(3,74) = 1.59, *p* = .20. However, main effects for exercise group and testing condition were significant, *F*(1,26) = 5.91, *p* < .05 and *F*(3,78) = 15.27, *p* < .001, respectively. No significant group by condition interactions were found. Post-hoc analyses for the main effect of exercise group revealed that those in the Pilates group (*M* = 358.23 msec, *SD* = 48.98 msec) had slower RTs than those in the Wii group

(M = 322.31 msec, SD = 59.18 msec). Post-hoc analyses for the main effect of condition found that when participants were tested in the computer only condition (M = 304.04 msec, SD = 91.24 msec), their RT was faster than when they were in NeuroCom Condition 1 (M = 342.78 msec, SD = 79.97 msec), 3 (M = 341.13 msec, SD = 74.94 msec) or 6 (M = 373.13 msec, SD = 84.73 msec), $t(78) = 4.63$, $p < .001$, $t(78) = 3.66$, $p < .001$, and $t(78) = 5.91$, $p < .001$, respectively. When participants were in NeuroCom Condition 1, their RT was not different than when they were in Condition 3, $t(78) = .25$, $p = .801$, but it was significantly faster than when they were in condition 6, $t(78) = 3.01$, $p < .01$. Lastly, when participants were in NeuroCom Condition 3 their RT was faster than when they were in Condition 6, $t(78) = 3.97$, $p < .001$.

3.5.2 Letter Comparison

Main effects for time, $F(3, 74) = 6.32$, $p < .001$, and testing condition, $F(3, 78) = 13.05$, $p < .001$, were significant. The main effect for exercise group was not statistically significant, $F(1, 26) = .22$, $p = .0.642$. The main effect of time was qualified by a significant interaction of time with testing condition, but the group by time and group by condition interactions were not significant, $F(9, 214) = 2.99$, $p < .01$, $F(3, 74) = 1.36$, $p = .261$, and $F(3, 78) = .43$, $p = .731$, respectively . Additionally, the two-way interaction of time by testing condition was qualified by a three-way interaction (time by exercise group by testing condition), $F(9, 214) = 2.14$, $p < .05$ (see Figure 3.3). Post-hoc analyses for the three-way interaction showed that, when in the computer only condition, participants in the Pilates group became faster between the pretesting (M = 1895.71, SD = 1036.24) and week 4 (M = 1645.00, SD = 994.78) as well as between weeks 4 and 8 (M = 1443.98, SD = 868.90), $t(214) = 2.68$, $p < .05$ and $t(214) = 3.78$, $p < .05$, respectively. Post-hoc analyses also found that, when in the computer only condition, Participants in the Wii group, similarly, became faster between the pretesting (M = 1923.49, SD = 2061.92) and week 4 (M = 1683.16, SD = 1356.34) as well as between weeks 4 and 8, $t(214) = 1.95$, $p = .053$ and $t(214) = 3.36$, $p < .05$, respectively. Additional post-hocs for the three-way interaction found that when participants performed the LC task in the NeuroCom under

Condition 1, those participants in the Pilates group showed an increase in speed between 4 (*M* = 1594.01, *SD* = 1363.243) and 8 weeks (*M* = 1356.12, *SD* = 687.94), but not between pretesting (*M* = 1573.32, *SD* = 1085.16) and 4 weeks or 8 weeks and 12 weeks (*M* = 1438.40, *SD* = 788.68), $t(214) = 3.14$, $p < .05$. No significant change for this condition was measured for the Wii group. No other post-hoc comparisons were significant (see Table 3.1 for all comparisons).

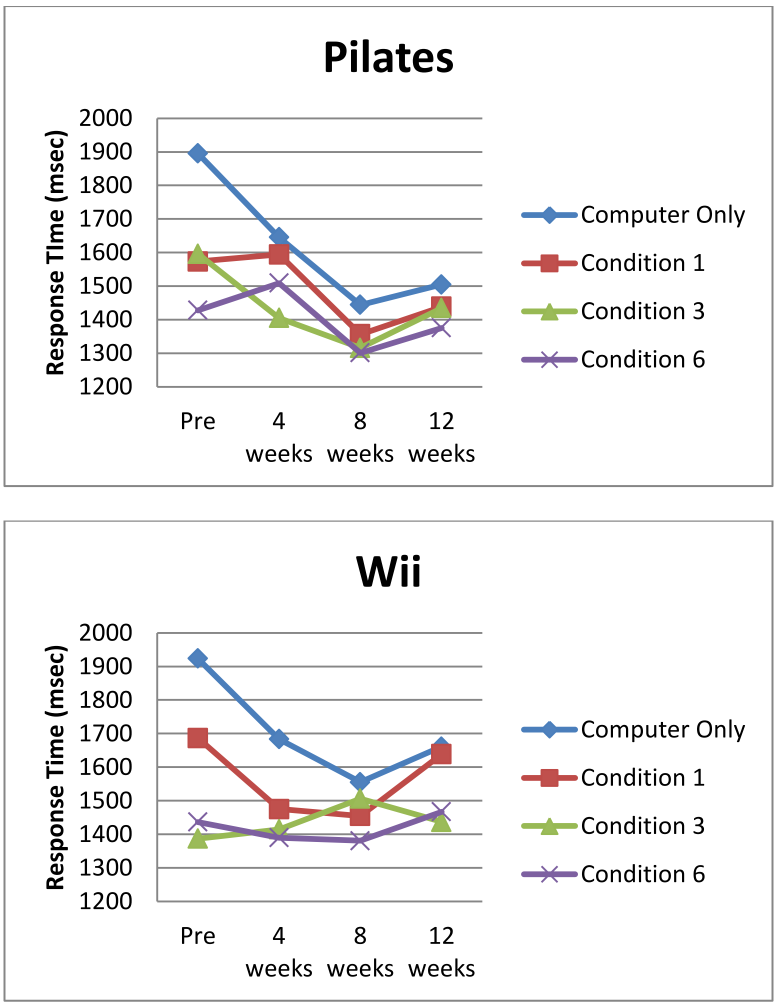

Figure 3.3. Three-way interaction of exercise group X time X condition for the Letter Comparison task, $F(9, 214) = 2.14$, $p < .05$ (see Table 3.1 for all comparisons).

Table 3.1. Complete pairwise comparisons for the Three-way for the Letter Comparison (LC) task interaction of exercise group X time X condition. Displayed are *t*-values for each comparison. Degrees of freedom (DF) for all comparisons are equal to 214. Note: "*" denotes $p < .05$.

Exercise Group	Testing Condition	Pre-4 weeks	4-8 weeks	8-12 weeks
Pilates	Computer Only	2.68*	3.78*	-0.80
	Condition 1	-0.25	3.14*	-1.35
	Condition 3	1.55	0.86	-1.38
	Condition 6	-0.74	1.94	-0.94
Wii	Computer Only	1.95	3.36*	-1.64
	Condition 1	1.37	0.17	-1.69
	Condition 3	-0.32	-1.04	0.83
	Condition 6	0.66	0.08	-1.00

3.5.3 Pattern Comparison

No main effect of time or exercise group was present, $F(3, 74) = .92$, $p = .438$ and $F(1, 26) = .00$, $p = .997$. A main effect for condition was also observed, $F(3, 78) = 5.02$, $p < .01$. A significant interaction of time by exercise group qualified the main effects, $F(3, 74) = 4.15$, $p < .01$, but was further qualified by a three-way interaction of time by exercise group by testing condition, $F(9, 213) = 2.11$, $p < .05$ (see Figure 3.4).

Post-hoc analyses found that processing speed, as measured by PC under NeuroCom Condition 6, increased from pretesting ($M = 1495.74$, $SD = 1349.35$) to 4 weeks ($M = 1296.86$, $SD = 1013.99$) for participants in the Pilates exercise group, but not for those participants who were in the Wii exercise group, $t(213) = 2.14$, $p < .05$ and $t(213) = -.64$, $p = .522$, respectively. Additionally, participants in the Wii group showed an increase in processing speed for NeuroCom Condition 1 between 8 ($M = 1585.84$, $SD = 2108.32$) and 12 ($M = 1356.84$, $SD = 2106.28$) weeks, $t(213) = 2.57$, $p < .05$. This change was not statistically significant for the Pilates group, $t(213) = -.27$ $p = .785$. No other comparisons were significant (see Table 3.2 for all comparisons).

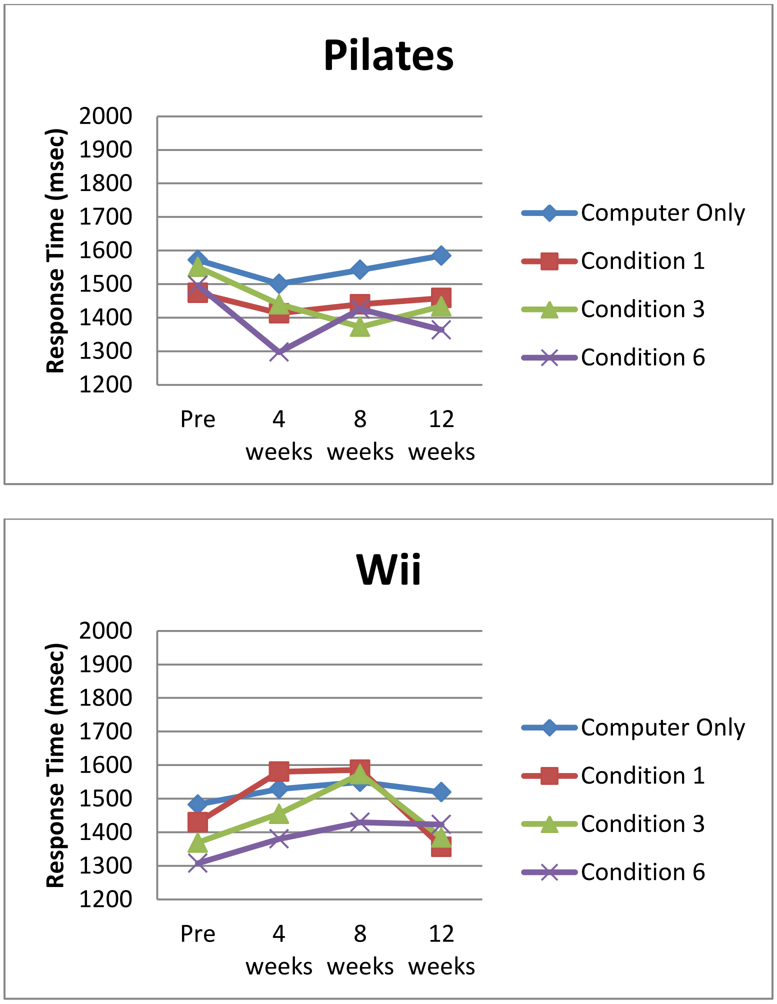

Figure 3.4. Three-way interaction of exercise group X time X condition for the Pattern Comparison task, $F(9, 213) = 2.11$, $p < .05$ (see Table 3.2 for all comparisons).

Table 3.2. Complete pairwise comparisons for the Three-way for the Pictue Comparison (PC) task interaction of exercise group X time X condition. Displayed are *t*-values for each comparison. Degrees of freedom (DF) for all comparisons are equal to 213. Note: "*" denotes $p < .05$.

Exercise Group	Testing Condition	Pre-4 weeks	4-8 weeks	8-12 weeks
Pilates	Computer Only	0.79	-0.57	-0.49
	Condition 1	0.72	-0.40	-0.27
	Condition 3	1.09	0.85	-0.86
	Condition 6	2.14*	-1.66	0.81
Wii	Computer Only	-0.65	-0.39	0.43
	Condition 1	-1.07	-0.05	2.57*
	Condition 3	-0.73	-0.77	1.58
	Condition 6	-0.64	-0.42	0.07

3.6 Relation of Mental Processing Speed Changes to Changes in Postural Control

Hypothesis 3 was concerned with whether or not the changes in processing speed during an IPE are related to changes in postural control. Therefore, RT and PC were removed from the following analysis as they did not change over time. In addition, the versions of the LC task conducted in the NeuroCom also did not change over time and were, therefore, removed from the analyses. Therefore, the computer only version of the LC task was the only measure of mental processing speed used in the following analyses. In addition, as the traditional, computer only, version of the LC task showed the most significant changes across multiple time-points and showed similar trends for both groups, compared to the other conditions, the computer only condition was the only measure of processing speed used in the predictive model. A predictive linear mixed effects model (with SOT as the outcome variable and LC [computer only] by Time [pre-program, 4, 8, and 12 weeks] as the predictor variables) was constructed to test the hypothesis that increases in mental processing speed was related to increases in postural control. This model found no significant main effects for the predictors of time and LC on postural control scores (SOT), $F(3, 73) = 1.33$, $p < .05$ and $F(1, 73) = .04$, $p = .838$. The interaction of the two variables was also not significant, $F(3, 73) = .62$ $p = .606$.

CHAPTER 4

DISCUSSION

The goal of this study was to gain a better understanding of some key factors associated with loss of balance in older adults that could lead to slips and falls. While improved physical fitness is key, quick decision-making when there was a threat to loss of balance was presumed to also be critical to regaining postural control. In the context of a fitness program for older adults, I examined the extent to which improved cognitive processing accounted for improvements in postural control. As expected, postural control improved over the 12 weeks that participants engaged in the fitness program which is consistent with previous intervention studies (e.g. Steadman, Donaldson & Lalit, 2003). As hypothesized, changes in processing speed (as measured by the traditional, computer only, version of the LC task) also occurred over the 12-week period which is also consistent with other exercise intervention studies which have found increases in cognitive processing speed in older adults following an exercise intervention (see Colcombe & Kramer, 2003 for meta-analysis). However, even though performance on the letter comparison task was significantly correlated with improved postural control scores across time, changes in processing speed did not predict the improvements in postural control. This finding is in contrast with the idea that physical movements, and in this case increased physical movements, provide cues which allow individuals to process information more quickly (Glenberg, Sato, & Cattaneo, 2008; Taylor & Zwaan, In Press; Strack et al., 1988; Havas et al., 2010). If physical movements provide cues allowing individuals to process information more quickly, we would have expected to find that changes in both measures were related.

It is possible that increases in mental processing speed found in this sample of older adults who were taking part in an intensive physical exercise program do not provide individuals with the additional abilities that are necessary to increase postural control. Perhaps changes in postural control resulted from another factor such as increased lower limb strength from engaging in physical activity. Another possibility is that the measure of balance used in this experiment (CDP) was not sensitive enough to provide sufficient variance in order to provide a predictive relationship between it and measures of mental processing speed. A potential reason for this is that postural control may have less of a linear relation to changes in the three components that make it up. Instead, the change may be more asymptotic in shape which would be indicative of a threshold. This is a logical possibility for a measurement such as the Sensory Organization Test which provides a variety of perturbations to test the participant's ability to maintain his balance. In this case it is likely that postural control needs a minimum amount of mental processing speed, but that these participants, being more active than the average older adult, may have had sufficient cognitive processing abilities to respond to the balance challenges they experienced in the SOT to keep them upright. Perhaps their increased processing speed, while likely important to other aspects of their functioning, might have been superfluous to improving postural control.

The Sensory Organization Test (SOT) may not have mimicked real world conditions. When participants are completing this test they are focused on maintaining their balance and are less likely to be distracted by thinking about something else (e.g. getting to a doctor's appointment on time or thinking about what to get at the grocery store). I mentioned earlier that mental processing speed is a component of working memory (Babcock & Salthouse, 1990). As we age processing speed decreases and, consequently, working memory decreases as well (Park & Reuter-Lorenz, 2009). Working memory holds information in consciousness so that it may be used or manipulated (Miller, 1956). This includes the ability to use sensory information that is necessary to maintain balance. In a real world setting with multiple cognitive distractors depleting working memory resources, an older individual with a slower mental processing speed and, therefore, fewer working memory resources will have fewer resources available to maintain his balance when he slips. That same individual who is completing the SOT in a quiet, non-distracting, environment has the same total resources, but because they are not being depleted by environmental distractors he may have adequate resources to maintain his balance. This may have been what happened in this experiment.

Finally, research that explores the connection between movement and cognition has focused on more active movement (e.g. walking; Verghese et al., 2002; Holtzer et al, 2006) than the task that was employed in this study. The SOT does not require much dynamic movement. The participant keeps his feet planted in the same location throughout the task. This is not as active as a measure such as gait. The theory behind this experiment was that movement was providing additional cognitive cues to the individual which allowed them to think more quickly (i.e. increased processing speed). It may be that because the SOT does not require as much active movement as other tasks the link between it and cognitive processing speed measures is not as strong as other measures.

4.1 Postural Control

A significant change in postural control with participation in the exercise program was expected and was found. However, this effect was not seen until week 8 of the study. Athletic trainers have known for some time that the first month of training is the most difficult (Rothman, n.d.). Individuals who are able to continue past the first month find that later sessions become easier, potentially resulting from improvements in strength, stamina, and mental processing speed. This finding provides scientific support to the intuition of athletic trainers.

4.2 Task Effects and Processing Speed

The processing speed measures employed in this experiment are reliable measures in their traditional paper and pencil forms (Salthouse, 2000). However, a computer administered version was used in this experiment. The use of the computer program may have impacted the PC measures. The computerized version had not been previously validated and it may have had an unforeseen flaw. Giving credence to this possibility is the fact that participants selfreported that the PC task was the most difficult of the two comparison tasks even though it had the fastest response time. This may have caused the low accuracy for the PC task by causing participants to guess more for this task than the simpler LC task.

In addition, the reaction time measure may have been too simple for the participants in this cohort. Szabo and colleagues (2008) studied fall risk in older women residing in Australia and used a simple reaction time measure like the one used in this study. Their control group was a group of healthy older community dwelling women in their mid-seventies which was similar to the cohort used in this study which consisted of mostly women with an average age in the mid-seventies. On 15 trials of a visual simple reaction time measure they averaged 299.1 msec (*SD*=48) which was significantly faster than the comparison group of older (*M*=81.3) adults who were suffering from age-related macular degeneration (*M*=343.4, *SD*=95.1). This suggests that the individuals in this experiment were similar in their mental processing speed to healthy community dwelling older adults.

An experiment was conducted in the Netherlands to study the effects of recruitment type (active vs passive recruitment) for an exercise intervention on physical and cognitive measures (van Heuvelen, Stevens, & Kempen, 2002). The researchers were attempting to compare a sample that suffered from self-selection bias (passive recruitment) with a more normal sample (active recruitment). The researchers found that women 75 years of age or greater who were actively recruited to a physical fitness program has a simple reaction time of 292 msec (*SD*=81.1) and those women who were passively recruited had a simple reaction time of 249 (*SD*=44). The performance of the actively recruited group is consistent with the average reaction time for the current cohort on the computer only version of the task of (*M* = 304.04 msec, *SD* = 91.24 msec) which was also actively recruited. Although the performance of the individuals in the passively recruited group was faster than the more normal, actively recruited, group as well as the group studied in this experiment, the researchers point out that an actively recruited sample such as the one they collected may still suffer from bias and may still perform at a higher level than the normal population. This is because the individuals are still volunteering to take part in an experiment and had to meet inclusion criteria (e.g. non-institutionalized).

The cohort used for this experiment was higher functioning than the average adult of their age. Because of this, participants may have been performing at their maximum speed for this task at the pretest. This is called a ceiling effect (Keppel & Wickens, 2004). A ceiling effect is the point at which an increase in one variable (e.g. mental processing speed) no longer results in an increase in another variable (e.g. postural control). This may be thought of as a point of diminishing returns.

In addition to measurement flaws and ceiling effects, practice effects must be considered in any longitudinal design. The participants performed the cognitive processing tasks multiple times (computer only, NeuroCom Condition 1, NeuroCom Condition 3, and NeuroCom Condition 6) on multiple occasions. In an attempt to reduce the effect of practice, participants were allowed to practice each task multiple times prior to performing the task for data collection purposes in order to induce practice effects at baseline. Doing so should have reduced practice effects during later testing sessions and any remaining practice effect should have been equally distributed across all time points. If practice effects were driving the results we would expect to see similar improvements for all of the measures across time. Because improvements were seen for some, but not all measures, it was not likely that practice effects had a major impact on the outcome.

The only task that showed a significant change across time was the computer version of the LC task. Participants were highly accurate (96% correct) for this task, which indicated that they were able to understand the task and perform it as intended. Because of this it was used to predict changes in SOT scores during the intervention.

4.3 Relation of Mental Processing Speed Changes to Changes in Postural Control

The purpose of this experiment was to determine if changes in mental processing speed predicted changes in postural control. Mental processing speed (computer only, LC) was significantly correlated with postural control (Sensory Organization Test), r=-.26, p<.05, which is consistent with findings by Holtzer and colleagues (2006) that mental processing speed was significantly related to measures of gait. However, the results did not bear out the relationship between the change in mental processing speed and the change in postural control which may have been because when using a “super normal” sample the individual RTs may have been at a floor level at the beginning of the IPE. This may have been due to the simple nature of the task and the very active sample that was taking part in this study.

4.4 “Super Normal” Sample

The types of measures used for this study generally show declines in performance across age groups in samples that are representative of the normal population (Park et al., 2002; Salthouse, 2004; Salthouse, 2000; Park & Reuter-Lorenz, 2009). In the present sample however, age was not related to the measures (see Figure 3.5).

The individuals in the present sample sought out a physical fitness program, were healthy enough to participate (as determined by their physician and their ability to ambulate without assistance for 6 minutes), and took part in moderate physical activity for approximately 3 hours/week. According to a study conducted by the Center for Disease Control (2012) from January to September 2011, only 41.2% of adults between the age of 65 and 74 (39% of the sample) and 27.7% of adults over the age of 75 (61% of the sample) engaged in regular physical activity (moderate or vigorous). The average age in this sample was approximately 75 years. Therefore, individuals in this sample are unique in the amount of exercise that they take part in on a regular basis. This increase in physical activity may have resulted in their above average performance on the postural control measure at baseline. Twenty-four (85.7%) of the participants' baseline scores on the postural control measure (SOT) were above age- and gender-matched norms.

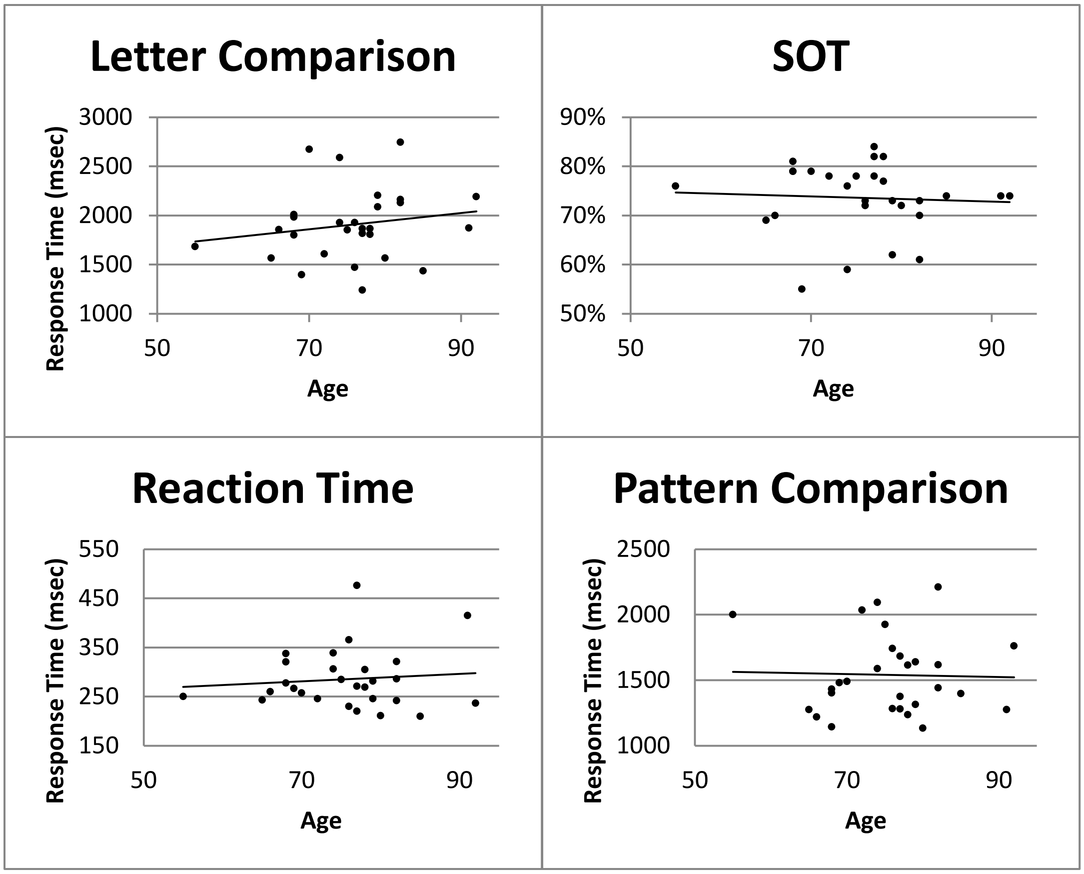

Figure 3.5. Scatterplots with trend lines comparing age with Letter Comparison (*r* = .178, *p* > .10), Sensory Organization Test (*r* = -.060, *p* > .10), Reaction Time (*r* = .097, *p* > .10), and Pattern Comparison (*r* = -.029, *p* > .10).

It is worth noting that these norms are only available up to the age of 79. Therefore, individuals age 80 and above (*n*=7) were compared to norms for 79 year-olds. In this sample, all individuals age 80 and above scored higher than the 79 year-old average. Perhaps the effects under study would be more robust in a sample more typical of the average American older adult.

4.5 Limitations

4.5.1 Sample Size

The sample used in this experiment was a subsample of an existing cohort taking part in any other research being conducted at the Center for Healthy Living & Longevity (CHLL). They included individuals who were willing to spend time testing in addition to the time that they were already spending exercising that was approximately 1 ½ hours/session every 4 weeks. This unfortunately resulted in a small sample size and a potential self-selection bias. Between-group comparisons (Pilates [*n*=18] vs Wii [*n*=10]) may have been affected by the small sample size, resulting in reduced power to adequately test the study hypotheses. Group differences in a small group can be driven by a very small number of participants, thus increasing the risk of type I and type II errors.

To reduce these risks linear mixed modeling was used to calculate fixed effects as well as random effects. In the analyses, the participant variable was treated as a random effect to better estimate the error variance specifically attributable to the fixed effects. With four time points this improved the ability to estimate the effect attributable to the random participant variable. This reduces the risk of a type I or type II error, but does not eliminate it. Perhaps future studies comparing a Wii group and a Pilates group with a larger sample may find group differences which were unable to be detected in this experiment.

4.6 Conclusion

The major conclusions of this experiment are as follows: a) postural control was significantly increased during an IPE, b) mental processing speed, as measured by the traditional Letter Comparison (LC) task, increased significantly during an IPE, but c) the change in mental processing speed was not related to the change in postural control. This lack of relation between the change in mental processing speed and the change in postural control may have been a result of the measures used. Future research into this should use measures of postural control which require more active movement (e.g. gait) than what was used in this experiment (i.e. SOT).

Taking part in an IPE has significant physical and mental benefits. Not only are these benefits available to individuals who are less active, but even a relatively active individual can realize improvements in both their postural control and mental processing speed. Also, based on the results of this study, individuals taking part in either a Pilates class or a program using the Nintendo® Wii Fit will both see improvements in both the domain of postural control and mental processing speed. This can be taken as a recommendation for older adults to increase physical activity to improve their physical well-being and mental health.

APPENDIX A

BALANCE EFFICACY SCALE (BES)

BALANCE SELF-EFFICACY SCALE (BES)

Listed below are a series of tasks that you may encounter in daily life. Please indicate how confident you are, today, that you can complete each of these tasks without losing your balance. Your answers are confidential. Please answer as you feel, not how you think you should feel.

(CIRCLE ONE NUMBER FROM 0 TO 100%)

1. How confident are you that you can get up out of a chair (using your hands) without losing your balance?

0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%
not at all confident — somewhat confident — absolutely confident

2. How confident are you that you can get up out of a chair (**not** using your hands) without losing your balance?

0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%
not at all confident — somewhat confident — absolutely confident

3. How confident are you that you can walk up a flight of ten stairs (using the handrail) without losing your balance?

0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%
not at all confident — somewhat confident — absolutely confident

4. How confident are you that you can walk up stairs (**not** using the handrail) without losing your balance?

0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%
not at all confident — somewhat confident — absolutely confident

CIRCLE ONE NUMBER FROM 0 TO 100%

5. How confident are you that you can get out of bed without losing your balance?

0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%
not at all confident — somewhat confident — absolutely confident

6. How confident are you that you can get into or out of a shower or bathtub (with the assistance of a handrail or support wall) without losing your balance?

0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%
not at all confident — somewhat confident — absolutely confident

7. How confident are you that you can get into or out of a shower or bathtub (with no assistance from a handrail or support wall) without losing your balance?

0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%
not at all confident — somewhat confident — absolutely confident

8. How confident are you that you can walk down a flight of ten stairs (using the handrail) without losing your balance?

0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%
not at all confident — somewhat confident — absolutely confident

9. How confident are you that you can walk down a flight of ten stairs (**not** using the handrail) without losing your balance?

0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%
not at all confident — somewhat confident — absolutely confident

CIRCLE ONE NUMBER FROM 0 TO 100%

10. How confident are you that you can remove an object from a cupboard located at a height that is level with your shoulder without losing your balance?

0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
not at all confident				somewhat confident						absolutely confident

11. How confident are you that you can remove an object from a cupboard located above your head without losing your balance?

0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
not at all confident				somewhat confident						absolutely confident

12. How confident are you that you can walk across uneven ground (with assistance) when there is good lighting available without losing your balance?

0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
not at all confident				somewhat confident						absolutely confident

13. How confident are you that you can walk across uneven ground (with **no** assistance) when there is good lighting available without losing your balance?

0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
not at all confident				somewhat confident						absolutely confident

14. How confident are you that you can walk across uneven ground (with assistance) at night without losing your balance?

0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
not at all confident				somewhat confident						absolutely confident

CIRCLE ONE NUMBER FROM 0 TO 100%

15. How confident are you that you can walk across uneven ground (with **no** assistance) at night without losing your balance?

0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%
not at all confident — somewhat confident — absolutely confident

16. How confident are you that you could stand on one leg (with support) while putting on a pair of trousers without losing your balance?

0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%
not at all confident — somewhat confident — absolutely confident

17. How confident are you that you could stand on one leg (with **no** support while putting on a pair of trousers without losing your balance?

0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%
not at all confident — somewhat confident — absolutely confident

18. How confident are you that you could complete a daily task quickly (e.g., answer a ringing phone, remove a pot of water that is boiling over on stove, etc.)without losing your balance?

0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%
not at all confident — somewhat confident — absolutely confident

Lastly, we are interested in understanding what factors affect your confidence levels. Please provide reasons for **why** you answered the way you did for questions 1 through 18 on the lines below. For example, if you answered that you were not very confident, **why** do you feel that way? If you were not very confident about an activity because you no longer do it very often e.g., climb stairs, walk on uneven ground, etc. we would like to know that also.

____
____
____
____

APPENDIX B

PROFILE OF MOOD STATES (POMS)

Below is a list of words that describe feelings people have. Please read each one carefully. Then circle the number to the right of the word that best describes **HOW YOU FEEL <u>RIGHT NOW</u>**. The numbers refer to the following phrases:

0 = Not at all
1 = A little
2 = Moderately
3 = Quite a bit
4 = Extremely

		Not at all	A little	Moderately	Quite a bit	Extremely			Not at all	A little	Moderately	Quite a bit	Extremely
1.	Tense	0	1	2	3	4	20.	Discouraged	0	1	2	3	4
2.	Angry	0	1	2	3	4	21.	Resentful	0	1	2	3	4
3.	Worn Out	0	1	2	3	4	22.	Nervous	0	1	2	3	4
4.	Unhappy	0	1	2	3	4	23.	Miserable	0	1	2	3	4
5.	Lively	0	1	2	3	4	24.	Cheerful	0	1	2	3	4
6.	Confused	0	1	2	3	4	25.	Bitter	0	1	2	3	4
7.	Peeved	0	1	2	3	4	26.	Exhausted	0	1	2	3	4
8.	Sad	0	1	2	3	4	27.	Anxious	0	1	2	3	4
9.	Active	0	1	2	3	4	28.	Helpless	0	1	2	3	4
10.	On edge	0	1	2	3	4	29.	Weary	0	1	2	3	4
11.	Grouchy	0	1	2	3	4	30.	Bewildered	0	1	2	3	4
12.	Blue	0	1	2	3	4	31.	Furious	0	1	2	3	4
13.	Energetic	0	1	2	3	4	32.	Full of pep	0	1	2	3	4
14.	Hopeless	0	1	2	3	4	33.	Worthless	0	1	2	3	4
15.	Uneasy	0	1	2	3	4	34.	Forgetful	0	1	2	3	4
16.	Restless	0	1	2	3	4	35.	Vigorous	0	1	2	3	4
17.	Unable to concentrate	0	1	2	3	4	36.	Uncertain about things	0	1	2	3	4
18.	Fatigued	0	1	2	3	4	37.	Bushed	0	1	2	3	4
19.	Annoyed	0	1	2	3	4							

Below is a list of words that describe feelings people have. Please read each one carefully. Then circle the number to the right of the word that best describes **HOW YOU FELT <u>DURING THE TASK</u>**. The numbers refer to the following phrases:

0 = Not at all
1 = A little
2 = Moderately
3 = Quite a bit
4 = Extremely

		Not at all	A little	Moderately	Quite a bit	Extremely			Not at all	A little	Moderately	Quite a bit	Extremely
1.	Tense	0	1	2	3	4	20.	Discouraged	0	1	2	3	4
2.	Angry	0	1	2	3	4	21.	Resentful	0	1	2	3	4
3.	Worn Out	0	1	2	3	4	22.	Nervous	0	1	2	3	4
4.	Unhappy	0	1	2	3	4	23.	Miserable	0	1	2	3	4
5.	Lively	0	1	2	3	4	24.	Cheerful	0	1	2	3	4
6.	Confused	0	1	2	3	4	25.	Bitter	0	1	2	3	4
7.	Peeved	0	1	2	3	4	26.	Exhausted	0	1	2	3	4
8.	Sad	0	1	2	3	4	27.	Anxious	0	1	2	3	4
9.	Active	0	1	2	3	4	28.	Helpless	0	1	2	3	4
10.	On edge	0	1	2	3	4	29.	Weary	0	1	2	3	4
11.	Grouchy	0	1	2	3	4	30.	Bewildered	0	1	2	3	4
12.	Blue	0	1	2	3	4	31.	Furious	0	1	2	3	4
13.	Energetic	0	1	2	3	4	32.	Full of pep	0	1	2	3	4
14.	Hopeless	0	1	2	3	4	33.	Worthless	0	1	2	3	4
15.	Uneasy	0	1	2	3	4	34.	Forgetful	0	1	2	3	4
16.	Restless	0	1	2	3	4	35.	Vigorous	0	1	2	3	4
17.	Unable to concentrate	0	1	2	3	4	36.	Uncertain about things	0	1	2	3	4
18.	Fatigued	0	1	2	3	4	37.	Bushed	0	1	2	3	4
19.	Annoyed	0	1	2	3	4							

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BIOGRAPHICAL INFORMATION

As an undergraduate John worked under Drs. Valerie F. Reyna and Charles Brainerd. In addition to memory research, this research also focused on human decision making, particularly the reduction of risky decision making in adolescents. John Biggan completed his Bachelor's degree in August of 2005, studying Psychology and Theatre. He then began his graduate work which focused on Human Learning & Memory as well as Cognitive Neuroscience. He completed his Master's degree in December of 2010 studying the effects of stereotype threat on memory. Now that he has completed his graduate training, he intends to pursue a postdoctoral fellowship researching aging and cognition.