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The Addition Of A Concurrent Bimanual Task Influences Postural Sway And Walking Speed Performance And Prioritization Across All Ages

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THE ADDITION OF A CONCURRENT BIMANUAL TASK INFLUENCES POSTURAL SWAY AND WALKING SPEED PERFORMANCE AND PRIORITIZATION ACROSS ALL AGES

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DEDICATION

This dissertation is dedicated to my grandparents: James and Ruby Skinner and Dorothy Liuzzo. They influenced my curiosity at a young age and encouraged me to always explore and question everything. They taught me the ideals of hard work and determination to follow through with everything I did, with a smile, until it was perfect. Without them, all of this would not have been possible. They were my first teachers, and their lessons will always be with me.

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ABSTRACT

As individuals age, there is an increase in attentional demands, a heavier reliance on vision, reduction in efficiency of both tasks, and longer processing intervals causing greater dual task interference on postural sway and walking speed. While cognitive-motor interference has been investigated, the impact of adding a functional, manual task while balancing or during gait is poorly understood across all ages. The overall purpose was to examine the relationship between age and task automaticity in dual-task conditions with a functional bimanual task, and describe how age influences attentional prioritization strategies. Older adults demonstrated differences in single and dual task performance for measurements of postural sway (center of pressure path length and 95% ellipse area) and walking speed (self-selected and fast paced walking) from adults younger than 60 years old. The dual task cost for one measurement of postural sway, the 95% ellipse area, was predicted by age, cognition, experiences with dual tasks, and the dual task cost of the bimanual task. Both self-selected and fast paced walking speeds dual task costs were predicted by functional reach and the perceived difficulty of dual tasks. Furthermore, mutual interference was experienced for all individuals during the postural sway task and fast paced walking task. Younger individuals chose to focus their attention on the self-selected walking speed while older adults experienced mutual interference more often. Therefore, single and dual task performance is related to age, however, other factors including cognition, mobility, and perceived abilities are better indicators of the dual task cost experienced by individuals during balance and walking dual tasks.

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CHAPTER 1

INTRODUCTION

One in three elderly adults, aged 65 or older, will experience a fall with some resulting in hazardous consequences including fractures, traumatic brain injuries, and severe injuries that could be debilitating or fatal.[1-3] Multiple systems (vestibular, visual, somatosensory, and proprioception) [4] contribute to balance and gait; however, these systems undergo a decline in function as aging occurs. In addition to the dampening of multiple systems contributing to postural control, the division of attention through multiple, concurrent tasks could severely decrease the stability of older adults in both postural sway and gait.[5-8] As individuals age, there is an increase in attentional demands during dual tasking,[7,9] a heavier reliance on vision,[8] reduction in efficiency of both tasks,[10] and longer processing intervals[11-13] causing greater dual task interference on postural sway and walking speed. This combination of events often increases an older adult's risk of a fall.[13,14] Simultaneous, cognitive tasks are the most commonly studied concurrent (dual) task as individuals perform talking, counting backwards, and mental math while attempting static balance and gait activities.[11,15-20] While age related cognitive-motor interference has been investigated extensively, the impact of adding a manual task while balancing or during gait is poorly understood in an older population.[21-31] Furthermore, many of the secondary tasks have limited functional application in real life setting. The full scope for this study was to: 1.) address the systems and theories behind the decline in aging and why division of attention is an important factor;

2.) examine current literature investigating how implementing cognitive and manual tasks impact postural sway and gait for older adults; and 3.) provide a sound, theoretical foundation for two studies examining the cost of adding a functional, simultaneous manual task to postural sway (Aim 1) and gait (Aim 2) across all ages.

The overall purpose of this study was to examine the relationship between age and task automaticity in dual-task conditions, and describe how age influences attentional prioritization strategies during dual-task performance.

The first aim was to examine if the following influenced dual-task interference, on measures of postural sway and preferred and fast walking speed: age, relative change on bi-manual task performance, perceived confidence, mobility, and balance. If automaticity of posture and walking speed deteriorated with age, then as age increased, there would be an exponential increase in dual task interference on postural sway performance and walking speed. Furthermore, decreased confidence, mobility, balance performance, and the increase in dual task interference of the bi-manual task will contribute to the increase in the dual task interference for postural sway performance and walking speed.

The second aim was to identify the default prioritization strategy in each dual-task combination (standing and walking with a bi-manual task) and determine if these strategies are influenced with age. If automaticity is affected similarly for the bi-manual task than as people age, there will be a greater magnitude of mutual interference on both tasks.

CHAPTER 2

REVIEW OF LITERATURE

2.1 Aging-Related Deficits and Dual Task Theories

Balance, both static and dynamic, requires a finely coordinated interplay between dynamic systems. The brain continually receives and interprets feedback from the vestibular, visual, and somatosensory systems in order to anticipate and adapt to sudden changes in the environment.[4,5] Young individuals usually have an excellent ability to use these systems without having to devote attention to any particular system to complete a simple postural or gait task.[4,5,30,31] Task automaticity is used to define this safe, fluid movement throughout a changing environment by using minimal attentional resources.[32,33] However, adding a secondary task can cause interference in completing the primary task, especially if the attentional demands outweigh the total capacity to perform each task.[14,31-33] The cost associated with the addition of the new task is called dual task interference.[30-33] Usually younger individuals display a greater task automaticity thereby complete dual tasks with minimal interference;[30,32,34] however, as people age, automaticity decreases forcing individuals to employ a variety of compensatory mechanisms including decreasing competing attentional demands,[34] adapatation,[4] habituation,[4] and substitution.[4]

Automaticity for safe static and dynamic balance begins to degrade as frontal cortical atrophy and white matter disruptions, a usual part of the aging process, lead to impairments with initiation and processing for posture and gait.[4-8,10,34] From this dampening of contact between systems, individuals must shift their attention to how they are performing a previously automatic task in order to complete it safely and accurately.[7] In addition, many older adults, whose somatosensory or vestibular system has degraded, increasingly rely on an often impaired visual system to help guide them through their environment.[8] Older individuals, in turn, require a trade-off to occur in order to maintain balance during static and dynamic activities.[10] For simple static balance activities, elderly individuals have increased sway in anterior and posterior directions as well as longer path length of their centers of pressure (COP) when compared to younger individuals.[10] However, when their base of support (BOS) is narrowed, older individuals decrease their degrees of freedom and decrease their sway in order to maintain their balance.[10] This reduction in degrees of freedom could also jeopardize safety by dampening the individual's ability to respond to various perturbations.[10] For instance, if a person locks their lower extremity joints to achieve stability, they are actually increasing their risk for falls as they will not be able to unlock and move their joints effectively to adapt and maintain balance. During gait, older adults opt for slower speeds, decreased stride lengths, and decreased efficiency often times in order to decrease their perceived risk for falls.[10] A conscious effort must be executed in order to continue these compensations while concurrently performing activities of daily living.[7] People require an ability to shift their attention to adequately and safely deal with competing attention demands during dual tasking. The more novel or more complex an activity may require a larger attentional demand. This conscious effort may require a person to prioritize one task over another thus degrading the older adult's ability to maintain safety and independence especially when taking into account the person's confidence, fear, and perceived abilities.[7,11,12] Prioritization refers to the individuals preference of a task over the other. The self-efficacy and fear of the individual coupled with novelty of task may influence what a person chooses to focus their attention on and this may influence how safely they complete the primary task. This prioritization strategy is examined by several theories.[11,12,13]

The shared capacity theory explains that individuals have a finite amount of resources, and when task demands exceed the availability of resources, we must determine which task is the most important to prioritize. An older adult may choose a reduction in their speed and not participate in conversation or in carrying objects in order to complete their ambulation safely.[11,12,13] In this example, the older adult would be choosing to prioritize their attention on walking, the primary task, instead of conversing, the secondary task. The person may continue to slow down their ambulation as they are thinking of the secondary activity. This continues to use resources thus increasing competing attentional demands and putting a strain on the finite resources. Another theory is the bottleneck theory. This theory notes that in neural processing a "bottleneck" of outgoing information is occurring leaving one or both tasks to deteriorate until the information can catch up.[12,13] This theory explains that information is not being analyzed at the same time (parallel), but one at a time (serial), creating a bottleneck of information processing and relay. Through this "bottleneck", a person may only complete one task efficiently at a time.[12,13] The bottleneck theory was the original theory describing how individuals perform multiple tasks; however, this theory only was true for simple novel tasks. When tasks are learned or involve different resources, then the bottleneck theory cannot explain performance because performance may not deteriorate as expected on the primary task. For instance, when someone is having a conversation while walking, there is not an overall deterioration in either the conversation or walking in healthy individuals. To improve this theory, the multiple resource model was developed to explain how some tasks may be performed simultaneously.[13] It states the brain is capable of performing multiple tasks at one time, without deterioration, only if both tasks do not share any of the same resources.[11,12,13] If both tasks, share visual or sensory resources and require similar processing channels, one or both performances may become impaired.[12,13] For example, having to process multiple visual or auditory stimuli at once can severely impair the individual's understanding or performance. There are four main keys to this theory: 1.) processing stages, 2.) visual channels, 3.) coding strategies, and 4.) perceptual modalities.[13] In part, the performance is based on a multitude of afferent input and efferent responses that must occur based on previous experiences.[13] However, Yogev-Seligmann et al. noted that no evidence overwhelming supports one model over the other, yet these models, either singularly or in combination, can explain why division of attention can impact static balance and gait.[11] While these theories explain why interference occurs, other factors must be taken into consideration to determine why people prioritize tasks in a certain way.

Yogev-Seligmann et al. noted that postural reserve, expertise, hazard estimation, affect, and nature of the secondary task are necessary components for people to prioritize and adapt to dual task situations effectively.[14] Postural reserve and hazard estimation reflect the two main concepts with the strongest influence over dual task interference.[14] Postural reserve is noted as the individual's capacity to oppose a postural threat efficiently and effectively.[14] The authors reported that as people age, deterioration in higher cortical centers severely decreases their postural reserve. Hazard estimation involves the person’s ability to assess a potentially hazardous environment and appraise, appropriately, their self-limitations.[14] Minor contributions to interference are anxiety, task automaticity, and complexity of the secondary task. Anxiety and fear have been shown to increase dual task interference along with a more complex task.[14]

To develop these concepts, researchers employed cognitive secondary tasks to determine if division of attention can further degrade a person’s ability to maintain postural stability and steady gait. To examine this degradation, clinicians and researchers have utilized postural sway and gait kinematics to analyze the cost associated with dual task conditions.

2.2 Cognitive Tasks and the Interaction with Postural Control and Gait

The addition of a secondary cognitive task may have a profound impact on postural control and gait in elderly populations. Multiple studies have employed three different dual tasks in order to investigate the influence of concurrent cognitive tasks on postural control.[10,16-20] One of the most commonly used dual tasks is serial subtraction, either mentally or out-loud usually by subtracting by 2’s, 3’s, 5’s, or 7’s.[15,17,19,20] Participants are often given a randomly selected number and told to subtract, repeatedly, by one of the above numeral sets while standing on a platform or movable platform.[15,17,19,20] In on study, the authors evaluated two different groups: one group mean age of 57 while the other with a mean age of 77.[15] The addition of a cognitive secondary task lead to longer sway path lengths between age groups ($p < .002$).[15] In addition, investigators noted that elderly individuals were slower to respond to physical perturbations during dual task conditions compared to younger individuals. Monitored through electromyography of the tibialis anterior and gastrocnemius muscles, older adults demonstrated longer activation times than younger individuals while standing on a movable force platform.[17] Authors also reported a greater increase in sway in the anterior and posterior direction during dual task condition relative to single task condition in older adults while the lateral direction demonstrated little to no change for older adults.[17]

Spatial and non-spatial memory tasks have also been investigated with older adults to determine the cost on postural performance.[18] During these experiments, participants demonstrated degradation in their performances for both recall tasks and balance activities.[18] Lastly, a modified Stroop test has also been employed to evaluate cognitive stress on postural control.[10] The original Stroop Test is a battery of three different conditions: saying the names of colors written in black ink, reading the color the words are written in, and reading the name of the color regardless of the ink they are written in.[10] The modified Stroop test list the names of colors in a color other than was named (for example, "blue" written in green ink).[10] Under a normal BOS, postural sway increased in the anterior and posterior direction for elderly individuals from single task 1.69(.11) cm to dual task 1.87(.16) cm (an 11% increase, $p < 0.05$).[10] COP path length for the participants with normal BOS for single task was 23.4(2.49) cm and dual task was 33.7(4.03) cm (a 44% increase, $p < 0.05$).[10] However, there was no significant difference for COP path length between single and dual task groups.[10] Narrowing the base of support did not cause changes in the COP path length, anterioposterior sway, or mean velocity, but a significance decreases ($p < 0.05$) were noted for elliptical area (a 23% decrease) and mediolateral sway (14% decrease).[10] This may be caused by the decreasing of the degrees of freedom to increase stability.

Secondary cognitive tasks and their influence on elderly individuals' gait have also been studied using primarily two different cognitive tasks. The secondary task is similar to the secondary task used with postural stability. Participants are asked to perform serial subtraction simultaneously with either a gait or mobility task.[21-24] One of the most common mobility tasks used was the Timed Up and Go.[21,23] During this task, the participant starts seated in a chair with their back against the back rest. Once the participants back leaves the back rest; a timer is started. The participant ambulates 3 meters, turns, and walks back to the chair and sits back down. They perform this mobility task with and without subtracting from a given number by a factor repeatedly.[21,23] Most of the studies demonstrated an increase in time for completion of the TUG when the cognitive task was added. "Non-fallers" demonstrated 8.4s on the TUG and 9.7s on the TUG Cognitive (a 15% increase in time, p <0.001) while "Fallers" demonstrated 22.2s on the TUG and 27.7s on the TUG Cognitive (a 24% increase in time, p <0.001).[21]

The second commonly used cognitive task is 'walking while talking'. The participants are asked to recite the alphabet or every other letter of the alphabet while walking. During these tasks, authors noted a decrease in gait speed for elderly individuals especially when the complexity of the task increased.[25-27] For example during the Walking While Talking Test, "Fallers" went from 17.5s to complete the 40 foot path to 28.9s with the addition of the complex task (a 65% increase in time).[25] "Non-fallers" in the same study ranged from 14.1s to 20.1s for the more complex task (a 43% increase in time).[25]

While cognitive tasks have been shown to be disruptive to motor performance for older adults, there are still limitations to the research. The previous studies only used selected groups of individuals (younger than 30, older than 60) and did not report varying activity levels or levels of confidence. While these individuals may be cognitively intact, there may be an age at which performance begins to degrade and may slowly or rapidly degrade afterwards. Placing all subjects in a group above a certain age may not be reflecting an accurate picture of how older adults approach and perform cognitive dual tasks. Furthermore, many of these studies divided groups by fallers and non-fallers based on history. One study included an outcome measure on the individuals' perception of their balance or fear of falling[21] which can greatly influence postural stability and gait.[7] Lastly, only one study stratified participants by ten-year age groups.[15] Though a relatively small sample size per group was apparent, the investigators demonstrated the degradation of postural control for each age group for quiet stance, spatial memory task, and non-spatial memory task; however, a larger sample may increase the power and confirm the results.[15]

2.3 Manual Tasks and the Influence on Postural Control and Gait

While cognitive tasks' effects on the elderly's postural stability and gait are a primary focus of the existing literature, division of attention through concurrent manual tasks may also have an impact. However, the effects of manual tasks on posture and gait are understudied. Moreover, many of the current studies utilize a simple manual task to evaluate its influence on postural stability and gait: either carrying a cup of water or a tray.[20,21,27-29] These tasks, however, are not discrete, measurable, manipulative tasks.

To examine postural stability, Anand et al. had participants stand on a force platform while holding a tray with empty cups on it.[20] The authors found that holding the tray increased sway for the elderly individuals and increased reliance on visual input.[20] Most of the literature on secondary manual tasks is explored in gait.

The most common test for manual tasks and gait is the Timed Up and Go – Manual (TUG Manual).[21,27] The test is conducted in a similar manner as the TUG and TUG Cognitive test except as the individual performs the test, they carry a full cup of water.[21,27] Both Lundin-Olsson et al. and Shumway-Cook et al. reported slower speeds for the TUG Manual when compared to the TUG .[21,27] "Non-fallers" demonstrated 8.4s on the TUG and 9.7s (a 16% increase in time) on the TUG Manual while "Fallers" demonstrated 22.2s on the TUG and 27.2s on the TUG Manual (a 23% increase in time).[21] Also, a difference of ≥4.5 seconds on the TUG Manual, in comparison to the TUG, indicates the individual has a harder time with the competing attentional demands when the manual task is added.[27]

An outcome measure that evaluated multiple aspects of mobility for elderly adults was developed known as the Multiple Task Test (MTT).[28] The test contained a variety of activities that could be performed from ascending or descending complexity. The manual, dual task, portion of the test required subjects to ambulate while holding either a loaded or unloaded tray.[28] The authors found slower speeds for elderly individuals and fewer hesitations were made compared to their younger counterparts. [28] Recently, Asai et al. developed a different way to assess a manual task's influence on gait.[29] Participants held a tray with a ball on it in their dominant hand while completing the 10 meter walk test.[29] Elderly adults demonstrated a mean gait speed of 1.40±.19 m/s without a concurrent task and 1.28(0.24) m/s with the manual task (an 11% decrease in speed, $p < 0.001$).[29]

However, the manual tasks in these studies may not be reflective of everyday tasks for older adults. Most of the tests are based off of isometric, balancing tasks. While individuals hold trays and cups, people are very likely to manipulate objects between hands or use both hands to complete an activity of daily living. For instance, someone may stand to fold laundry or reach into a bag to find an object while walking. For this proposal, we are interested in making the nature and complexity of these tasks more closely resemble an everyday task. Furthermore, an attempt was made by Asai et al. to establish fear of falling by asking individuals if they were, in fact, "fearful of falling".[29] The authors, however, only studied the trunk movement of individuals. They noted that there were differences in the mediolateral trunks movements but not in the performance of the dual task.[29] The performance may not have been different, however, because individuals may not have been accurately relaying if they are fearful of falling, fearful during both conditions, or avoid various activities. Stronger correlations may be gained using an assessment such as the Activities-Specific Balance Confidence Scale. Stratification of individual age groups may give a better representation of abilities and degradation of those abilities across all ages of adulthood.

The main focus through these studies has been on the degradation of the primary tasks. Many of the tasks used are not discrete tasks and can only be measured if water was spilled or a ball falls off a tray. Having a discrete secondary task allows the researchers to assess which task the participant is focusing their attention because the performance on both tasks can be quantified and compared. For instance, if the individual's performance on the secondary task does not change but performance on the primary (walking) task declines, then the investigators can infer the participant focused more attention on the successful completion of the secondary task. This can be analyzed with correlation, regressions, and analysis of the dual task effect between the costs in performance of both tasks to determine if one task is being emphasized more than the other.

2.4 Instructional Set Related to Dual Task

Instructions for research studies are specific and intended to guide the participant to demonstrate a certain ability or task. However, this specificity is problematic in studies involving dual task situations.[30] While instructions need to be specific for the individual tasks to be completed, too much emphasis on one task can lead to a forced prioritization of one task over the other. An example of these types of instructions is: "Take as many balls out of the bag, one at a time, as quickly as you can while you walk to the other cone". This may emphasize that the manual task is the most important task leading to an incorrect assumption about manual tasks while walking.

This improper prioritization has been tested before in dual task situations involving cognitive tasks. Investigators established that instructions greatly influence how the participant approaches the task.[30,31] The instructions read in two different ways giving emphasis to the cognitive task or the walking task while both tasks were performed simultaneously.[31] The investigators noted that performance in the task that wasn't emphasized degraded in both situations.[31]

Due to this effect of this prioritization, many studies involving dual tasks have begun to use non-specific instructions to attempt to investigate how a person approaches a task.[31,34] For these studies, instructions consist of language that attempt to have the person prioritize which task they feel they need to focus on to complete both tasks safely allowing a more accurate view of how individuals operate.[31,34] This is an important consideration in the proposed study to create instructions that do not emphasize prioritization of either task. The overall aim is to investigate how people, over a lifespan, adjust to the implementation of a manual task while walking. For this reason, the participant will be able to practice the manual task in sitting first. The person will be prompted to do their best on the bimanual task and subsequently the best they can performing the dual task. Then the person will perform the postural sway and walking tasks with the instructions "Please stand quietly (or walk on this pathway) while you perform the bimanual task as you have practiced it."

This gives little emphasis to either task and is specific enough for the individuals to complete both tasks safely. From this, we will be able to investigate which task people choose, if there is a difference across ages, and if either task degrades.

2.5 Measuring Postural Sway and Gait in Older Adults

2.5.1 Postural Sway Basics and Measurements

Postural sway is a key component of balance. Balance requires multiple systems collaborating and a continually interplay to keep individual upright. Postural sway is a person's continual attempt to keep their center of pressure (COP) within their base of support (BOS).[9,10] The COP is the ground reaction force from the person attempting to stand still. The BOS typically is the area under and between the person's feet, but it could also include the area under an assistive devices. There is a typical zone within the BOS where balance is optimum. If the BOS is too small or too wide, then the person becomes unstable more easily and is more likely to fall.[9,10] The COP must remain inside of the BOS for a person to keep their balance.[9,10] It is possible for the COP to briefly move outside of the BOS without the loss of balance; however, maintaining that position very long without having to use reactive strategies is unlikely. Therefore, the innate postural goal is to secure the COP constantly within the BOS. To ensure this goal is achieved, a person sways slightly to keep their COP in the optimum zone of their BOS.[9,10] This is performed mainly through ankle strategies and hip strategies with the former being the most common when standing on a firm surface within a comfortable BOS. Ankle strategies utilize the triceps surae and tibialis anterior of both legs to constantly pull the person posteriorly or anteriorly, respectively. For example, if a person sways too far anteriorly, the gastrocnemius and soleus concentrically contract on the fixed calcaneus to nudge the individual posteriorly. The tibialis anterior works in the same manner to pull the person anteriorly by pulling on a fixed navicular. Hip strategies are used for lateral movements and utilize the gluteus medius muscles. As people get older, these strategies begin to degrade through a decrease in strength and muscle reaction time therefore maintaining the COP within the BOS becomes increasingly harder.[9,10] Measuring the amount of sway is essential in recognizing a person's stability.

2.5.2 Measuring Postural Sway

There are multiple ways to capture and analyze postural sway. For many years clinicians and researchers have utilized a variety of techniques including balance performance monitors with visual and auditory feedback,[35,36] and posturography with force platforms.[37] Through various studies,[35-38] the method using the force platform is considered to be the gold standard for measuring COP and ground reaction forces. Force platforms can be used singularly or with multiple platforms depending on the task needing to be analyzed.[39-41] The AMTI force platform works by four separate strain gauges working in unison to give a 3D representation of the information. Information about the position of the COP is gathered on the x, y, and z axes.[42] The x axis measures the anterior/posterior (forward/backward) displacement of the COP. [42] The y axis refers to the lateral (side to side) displacement of the COP, and the z axis depicts the vertical displacement. [42]

One of the most common variables obtained is the COP path length. The path length refers to the total length the COP travels within the base of support during a designated time period.[43] The COP path length is usually measured in centimeters and is the pictured in Figure 2.1. [43]

Another useful analysis is the 95% Ellipse Area (EA). The EA is the area that 95% of all the values fall within on both the x and y axes.[43] This measurement gives a better representation of the true nature of postural sway without aberrant motions. The 95% EA gives the area that 95% of the points should lie within. This is a more accurate measurement than total circular area because total area may be stretched by outliers or aberrant motions. An angle can also be established to show the direction of sway that the person favors the most.[43] Ninety-five percent EA is usually defined by centimeters squared (cm^2). An example of the 95% EA is also pictured in Figure 2.1.

2.5.3 Measurement of Spatiotemporal Gait Parameters

Gait is a highly complex task that requires the coordination of multiple components in order to provide efficient locomotion. There is a fine interplay between several regions of the brain and spinal cord to produce this fluid movement, including:

the prefrontal cortex, frontal cortex, basal ganglia, cerebellum, reticulospinal tract, vestibulospinal tract, corticospinal, and rubrospinal tracts.[34] The cortico-basal ganglia circuit (including the prefrontal cortex, frontal cortex, basal ganglia, and thalamus) acts to initiate movement, rhythmically continue movement, and prepare for anticipatory situations.[34] The cortico-basal ganglia circuit is especially important for speed and stride length during gait as well.[34] The brainstem and spinal cord tracts act as feedback mechanisms for both static and dynamic posture.[34] Cadence during gait is also controlled primarily by these tracts.[34] The coordination of these systems decreases in the elderly because of atrophy in the cortex of the frontal region and diffuse white matter disruptions.[34] Due to the atrophy, regions in the frontal cortex controlling motor movement and planning may decrease in responsiveness or initiation causing the individual to poorly respond to more challenging environments. Because of these changes, multiple gait variables can be influenced by the addition of a dual task with stride length and gait speed being more sensitive measures.[30,34]

Gait speed has been referred to as the 6th vital sign;[44,45] it may help predict those who are more likely to fall, reduction in community mobility, or even future health status.[44,45] Gait speed of 1.0 m/s has been established as the cut off for separating older adults who are community ambulators from those who are at risk for disability.[46] Performing a simultaneous secondary task could ultimately reduce the speed that individuals walk by shifting the person's attention thus leading to decreased safety and falls. In addition to gait speed, stride length is also a variable that is susceptible to dual-task interference. Stride length is the distance measured from the heel strike of one foot until the heel strike occurs again on the same foot.[47] With the addition of a cognitive dual task, and in the author’s pilot study during self-selected a fast paced walking speeds, stride lengths have decreased. [30,34]

Cadence has also been reported in the literature to express how people change their stepping patterns but is less responsive to dual task interference because it involves regions in the spinal cord that are less likely influenced by corticofrontal atrophy.[34,47] Cadence is the general rhythm of the gait cycle and is usually defined by the amount of steps taken for a certain distance or time (typically, steps per minute).[47] Cadence maybe influenced by the height of the person, tightness of various muscles, and balance.[47] For instance, a taller individual may need to take fewer steps for a given distance versus a shorter person, or if a person feels more unstable they may take shorter steps thus increasing their cadence to maintain their same gait speed.

Due to the importance of gait speed, stride length, and cadence for understanding locomotor performance, all three variables were analyzed during the proposed study, however, stride length and gait speed will be the primary dependent variables. Cadence was collected in an attempt to support the model of corticofrontal atrophy having a smaller effect on spinal cord mediated functions; however, it may be possible that cadence was influenced from a shift in attention.[34]

2.5.4 Measuring Gait Parameters

There are numerous ways to assess gait, however, many of these measures focus solely on speed. For instance, the TUG and 10MWT all rely on gait speed as their only variable. Menant et al. published that gait speed alone may not be sensitive enough for discriminating fallers from non-fallers in elderly populations.[48] Therefore, more variables may need to be considered to fully and accurately distinguish the gait characteristics of fallers and non-fallers. An efficient way to measure all of the gait parameters is to use a device called the GaitRITE. GaitRITE is a walkway system used to measure various temporal and spatial of the gait cycle. The mat is approximately 6 meters long and can sample from a rate of 60-240 Hz.[49] The walkway needs at least four footfalls in order to make accurate measurements.[49] Webster et al. demonstrated the GaitRITE had excellent reliability for walking speed, cadence, step length, and step time with Intraclass Correlation Coefficients (ICCs) of .92-.99 for an elderly population.[49] This makes the GaitRITE an excellent tool to use with the elderly population for assessing spatial and temporal parameters of gait.

2.5.5 Dual Task Effect

A relatively new means of assessing interference, dual task effect is a way to assess change between single task performance and the performance with an added dual task. Dual Task Effect (DTE) is calculated using the following equation:[30,32,33]

(Dual Task Score – Single Task Score)/Single Task Score * 100%

The resulting calculated number is the percentage of change that occurs from the addition of the secondary task. These numbers could be positive or negative depending on whether the dual task score was greater or lesser than the single task score.[30,32,33] The DTE will be used in the data analysis explained in the Methods section. There are a few ways to present the DTE to determine if there was interference on both tasks. One such way is with a Cartesian coordinate system that uses the DTE of the primary and secondary tasks to see if one task was preferred over the other. This also is further explained in the Methods section.[33]

2.6 Summary and Dissertation Direction

Research investigating cognitive-motor dual task cost on postural sway and walking dominates the research in older adults. Through the use of counting backwards, talking while walking, and other cognitive tasks, investigators have determined that adding a cognitive task to postural sway or walking activities causes degradation in their motor performance. However, the addition of manual tasks as a secondary task has been understudied in the older adult population. Most of the task used involve holding a cup of water, a tray (unweighted or weighted), or balancing a ball on a tray while performing postural sway or walking tasks. While these tasks require the hands to be used, they do not reflect functional, real life tasks older adults must perform. For this reason, this study aimed to address the critical limitations of the other studies by implementing a more representative, bimanual functional task. Using the guidance of studies involving individuals with stroke and individuals with Parkinson's disease, a task was devised using a small bolt fitted with a movable nut that the participant turns against a spring. The participants needed to use both hands: one to hold the bolt and one to turn the nut against the spring. This task was more functional in that it required both hands to work in conjunction with each other and mimics the fine motor tasks of turning keys on a key ring or manipulating a bottle top which many individuals perform daily, often while walking.

In addition, the previous studies only provide a contrast between what the authors consider to be young vs older adults. While this demonstrates a difference in ages, this scenario does not provide a full representation of abilities across adults of differing ages. This gap needs to be filled to understand if and when there is a decline in abilities. This information could lead to earlier awareness and interventions that could help maintain those abilities over a lifetime. This study aimed to investigate if there was a difference in dual task abilities and prioritization by involving participants from age 20 up through age 90+. With careful selection, each age group was represented and a full picture was provided.

This study was designed to provide a foundation for future research involving concurrent manual tasks for a variety of ages and disease processes/disorders. Further inquiries could entail the use of: 1.) psychological measures (e.g. Activities Balance Confidence Scale) that could relay how the person feels about a situation (in this case: fear of falling); 2.) a hierarchal view to investigate if cognitive-motor dual tasks influence performance greater than or less than concurrent manual tasks in postural sway and walking; 3.) relating functional ability to dual tasks to develop a more sensitive and specific outcome measure to quantify disability and risk for injury. Therefore, the overall purpose of this study is to examine the relationship between age and task automaticity in dual-task conditions, and describe how age influences attentional prioritization strategies during dual-task performance.

2.6.1 *Specific Aim 1: Dual Task Cost on Postural Sway and Walking Speed*

The first aim of this study was to examine if dual-task interference, on measures of postural sway and preferred and fast walking speed, were affected by the following: age, relative change on bi-manual task performance, perceived confidence, mobility, and balance.

If automaticity of posture and walking speed deteriorates with age, then as age increases, there would have been an exponential increase in dual task interference on postural sway performance and walking speed. Furthermore, decreased confidence, mobility, balance performance, and the increase in dual task interference of the bi-manual task would contribute to the increase in the dual task interference for postural sway performance and walking speed.

2.6.2 *Specific Aim 2: Prioritization of Tasks*

The second aim of this study was to identify the default prioritization strategy in each dual-task combination (standing and walking with a bi-manual task) and if these strategies were influenced with age.

Task automaticity for postural sway performance and walking speed may have been greater for younger adults and degrades with age. If automaticity is affected similarly for the bi-manual task than as people age, there will be a greater magnitude of mutual interference on both tasks.

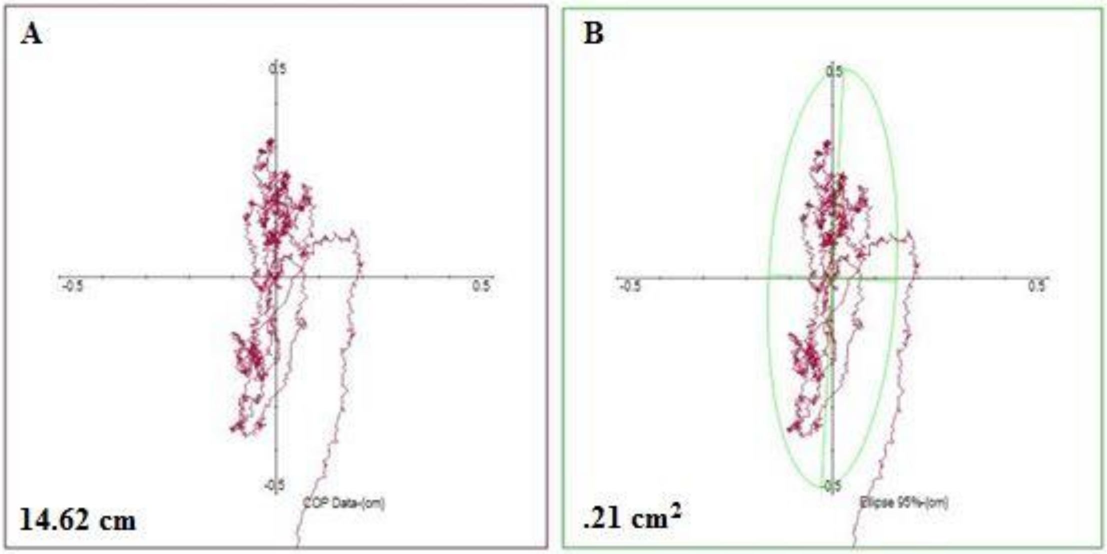


Figure 2.1: AMTI Balance Clinic software demonstrating a print out of the two variables required for this study: A.) Center of Pressure path length graph, and B.) The 95% Ellipse Area graph.

CHAPTER 3

METHODS

Design:

Cohort, Cross-Sectional

Approach:

Participants were recruited via word of mouth from Columbia, SC and surrounding communities. Inclusionary criteria consisted of individuals ≥ 18 years old. Participants were excluded from the study for: concurrent neurological disorders; reports of vestibular disorders or dizziness within the past month; loss of protective sensation to the hands or feet (5.07 [10g] by Semmes-Weinstein Filament Testing)[50]; the use of an assistive device that impeded the use of both hands; musculoskeletal injuries or surgeries within the past 6 months that impede ambulation or fine motor skills; scoring <23/30 points on the Montreal Cognitive Assessment indicating decreased cognitive ability.[51,67]

Procedural intervention: Prior to testing, the participant had the opportunity to have the study fully described to them and answered any questions they may have. On the day of testing, the participant signed the informed consent and began with the testing in the following order: 1.) Semmes-Weinstein Filament Sensation Testing, 2.) Montreal Cognitive Assessment, 3.) fall history self-report, 4.)activity self-report, 5.) Activities-specific Balance Confidence scale, 6.) Dual Task Activity Questionnaire, 7.)Handiness Questionnaire, 8.)the Functional Reach Test, 9.) the Four Square Step Test, and 10.) four total repetitions (two repetitions for the right hand and two repetitions for the left hand) for the Purdue Peg Board Test. This was performed in the above sequence because an individual could have been excluded from the study through their performance on the first two tests. Once the person passed the first two screens, then the remaining five evaluations concluded the testing. This section took approximately 25 minutes. Figure 3.1 briefly summarizes the progression of the entire project.

Description of Tests:

Participants underwent two preliminary, screening tests:

- Sensation Testing: Using Semmes-Weinstein filament at 5.07 (10 g), the participants hands and feet were tested for dampening of sensation. The participants were asked "can you feel the filament?". The filament was pressed "until it bows".[50] Being able to feel the filament on the hands and feet is indicative of intact protective sensation.[50] Protective sensation relates to the participants ability to feel deep pressure.[50] This sensation is important in proprioception and safely exploring environments. If the filament was not felt, the participant was excluded from the study. The participant was asked to close their eyes and keep their eyes closed while the filament was touched to their palms on the thenar eminence and the heads of the 3rd and 5th metacarpal.[50] These areas correlate to median and ulnar nerve function. The participant was also asked to announce the presence of the filament on the heads of the 1st and 5th metatarsal of both feet.[50] These areas correlate to medial and lateral plantar nerve function. The inability to feel the filament in 1 of 2 locations on an extremity excluded the participant from the study.[50]

- Cognitive Testing: The Montreal Cognitive Assessment was employed to assess cognitive function. The test assessed various aspects of older adults' cognitive function including temporal and spatial orientation, repetition, attention, language, and abstract thinking.[51,67] Higher scores on the exam (≥23/30) indicated high levels of cognitive ability. The single cut-off for decreased cognitive skill is <23/30.[51,67] This cut-off means that individuals were less likely to understand instructions, remember task specifics, or safely perform tests. Scoring ≥23 on the test means the individual had the cognitive ability to follow commands and participate safely.[51,67] Therefore, scoring a 23/30 or below on the test excluded the participant from the study.[51,67] The full test can be viewed in Appendix A.

After successful completion of the prior screens, the participants continued with the following sequence:

- Falls history self-report: Participants were asked about falls happening in the past year. In addition to if and how many times they have fallen, the participants were asked if they have had any falls, what were they doing before the fall, what they thought caused the fall, environmental factors leading to their falls (wet floor, external forces, etc.), and if injuries occurred.[52]
- Activity self-report: This questionnaire was the 7 Day Physical Activity Recall questionnaire. This investigator asked the respondent how many minutes they spend in the various levels of activities and during which part of the day. This questionnaire is further viewed in Appendix A.[63]
- Dual Task Activities Questionnaire: A new test to quantify how often individuals perform dual task activities (DTQ-F) and how difficulty these activities are

(DTQ-D). This questionnaire was developed by Plummer et al. and adapted from Tun et al.[64,65] See Appendix A for attached questionnaire.

- Handedness Questionnaire: With the manual task requiring the use of both hands, the handedness questionnaire aided in quantifying the handedness of each individuals. Many people use either hand for a variety of activities and this questionnaire allowed the investigators to further quantify and describe the population in addition to using a more appropriate hand for the working nut. The questionnaire was 12 questions and asked the individual their preference of hand to complete these activities (right, left, either).[66] The test was scored from 12-36.[66] The lower the score, the stronger preference for left handedness while the higher the score indicates right handed preference. Ambidextrous was denoted at 24.[66] This questionnaire can be viewed in Appendix A.
- Activities-specific Balance Confidence Scale: This 16 question form provided examples of multiple situations a person must safely navigate or balance in to perform independent activities of daily living and community ambulation.[53] The statements ranged from activities of household ambulation, community ambulation, reaching for objects at various heights, and balancing in different environments.[53] Participants scored each statement with how confident they were from 0%-100%. This test helped differentiate fallers from non-fallers as well as those who have limited mobility from those who are unrestricted (Cronbach's alpha = 0.96, test-retest reliability = 0.92, validity = 0.84 compared to the Fall Efficacy Scale).[53] This questionnaire can be viewed in Appendix A.

- Four Square Step Test: This test assessed a person's functional ability by assessing how fast the individual completed the test.[54] Using canes or PVC pipes perpendicularly placed to make four squares, the person was asked to step clockwise and counterclockwise through the squares.[55] The participant stood in square 1 moving to square 2, 3, and 4. The person then reversed order moving from 4 to 3, 2, and ending in 1 again.[55] The timer started when the lead foot contacted the 2nd square and the timer was stopped when the trailing foot contacted the 1st square on the return sequence.[54] This test previously demonstrated excellent test-retest reliability (ICC=0.98), sensitivity (85%), specificity (85% to 100%), and positive predictive value (86%).[54,55]
- Functional Reach Test: The participant stood next to a wall and held his or her hands up in shoulder flexion at a 90 degree angle. A meter stick was held up to the participant's third ray. The participant was instructed to reach forward by bending at the waist and keeping their hands in line with the meter stick. This was performed three times and the last two attempts are averaged. The participant used both arms to keep the participant from turning at the pelvis to gain more distance.[56] For community dwelling older adults, the test had a test-retest reliability of 0.89, an excellent correlation with walking speed at 0.71, and a person achieving <7 inches on the test was more likely to be home bound with decreased independence.[56]
- Purdue Peg Board Test: A test of manual dexterity and fine motor skills; the participants were instructed to place pegs of two and half cm length x two mm width from two concaved areas (pits) on their dominant side. The pits have a

diameter of 5 cm and depth of 1 cm at its lowest point. The participants had 30 seconds to fill as many of the 25 vertically oriented holes they could using only their dominant hand. Each hole was 1.27 cm apart. The person would only pick up one peg at a time and could not retrieve a dropped peg.[57] This procedure was performed 3 times. The test-retest reliability has been set at ICC = 0.81-0.89 while testing only one reduced the test-retest reliability to ICC = 0.37-0.61.[57]

- Practice Secondary Motor Task: Each of the participants was first asked to sit and perform a bimanual motor task called a spring bolt which is pictured in Figure 3.2. The spring bolt was a 20 cm long bolt with a 1.9 cm diameter. The bolt was fitted with two nuts 6.5 cm from the head of the bolt spot welded into place. These nuts were 1 cm hexagonal nuts with 1.9 cm bore. A washer was fitted after with a 1.9 cm bore. The spring was a basic tension spring with a length of 9.5 cm. Another washer and nut were affixed on top. This nut was mobile and was turned by the participant's dominant hand while the non-dominant hand held the bolt steady. Lastly, a 1 cm nylon stop nut was placed on top to insure the nut wasn't screwed off the bolt. The spring compressed at a constant and kept the participant from spinning the nut down the bolt. After completing the initial evaluation, the participant performed five practice trials of the manual task for 10 seconds each while seated. The time frame of 10 seconds was chosen since the longest time span the individual performed the task was 10 seconds during the balance and walking tasks. The participants were asked to practice the task to become comfortable with the task and to negate a learning effect for this study as well as establish a baseline for performance for the study without the person performing the postural sway or gait task. The displacement of the nut was measured in millimeters from the base of the spot nut to the top of the mobile nut. Following the practice trials, the participant performed two more seated trials that were used in data collection and to determine the dual task effect. The average of these two trials were considered using the manual task as a single task.

The following groups of tasks (force platform and gait analysis) were randomized among the participants as to which group they began with first. Each group of tasks were fully completed by each candidate:

- Force Platform Tasks: Participants were asked to step onto the force platform and asked to "stand comfortably" with their feet shoulder width apart. The participant first stood quietly for 10 seconds without the manual task: this task was performed twice. Then the participant stood on the platform for 10 seconds while performing the manual task: this also was performed twice. The average COP length and the 95% ellipse area were collected for each repetition:
    - Quiet Stance: The participant was asked to "Stand comfortably on the platform. Remaining as steady as possibly look at the red dot placed on the wall". The participant stood on the force platform for 10 seconds. This was performed a total of two times.
    - Addition of Manual Task: The participant was asked to "Stand comfortably on the platform. Without moving your feet, please perform the manual task as you have practiced." This test was performed for 10 seconds. This was performed a total of two times.

- Dependent Variables: Center of Pressure (COP) path length and 95% Ellipse Area (EA) were chosen because they were closely linked to describing sway and unsteadiness in individuals. COP path length is the distance the COP moves during the balance task.[43] Greater distance relates to great sway. However, the participant may be restricting or liberating their degrees of freedom. To understand which the participant was choosing, the EA was also employed and is the area the COP sways during the balance task. EA encompasses 95% of the points collected helping to exclude large motions that may artificially inflate the overall area.[43] A smaller area (relative to the quiet stance position) meant the participant had locked down their degrees of freedom and a larger area meant that the participant was sacrificing their degrees of freedom in order to complete the task.

- Gait Analysis: Participants walked several times for 10 second durations. The participant was encouraged to walk as far as they could within a 10 second time period which was performed with a countdown timer. The 10 second duration was chosen to standardize time across all tasks. In addition, >10 seconds caused aberrations and adaptations of the manual task for all participants. Speed was calculated by dividing the distance in meters, to the hundredths decimal place, by 10 seconds. The GaitRITE system (length 4.42 meters, 66 cm wide, sampling rate of 80 Hz) was situated 3 meters from the starting position and captured stride length, step length, base of support distance, and cadence for the beginning portion of the walk.[58] :

- Self-Selected Gait (no task): The participant was told “Walk at your usual speed”. This task was performed twice.
- Self-Selected Gait (concurrent bimanual task): The participant was told to “Walk at your usual speed, and perform the bimanual task as you’ve practiced when you beginning walking.” This task was performed twice.
- Fast-Paced Gait (no task): The participant was told “Walk at a safe, but swift, pace as if you were crossing a street as the light was changing”. This task was performed twice.
- Fast-Paced Gait (concurrent bimanual task): The participant was told to “Walk at a safe, but swift, pace as if you were crossing a street as the light was changing, perform the bimanual task as you’ve practiced when you begin walking.” This task was performed twice.
- Dependent Variables: The primary dependent variables for this aim were self-selected walking speed and fast-paced walking speed. These two variables were chosen because they reflect a person’s independence and mobility. If the participant reduces to under 1 m/s or if significantly slowed down during the dual task situation, the participant may become unbalanced and unsafe.[46] This study used two different tests that have not been compared yet for concurrent validity. However, gait speed was reliably measured using the 10 meter walk test for both self-selected (ICC = 0.93) and fast paced (ICC = 0.91) speeds with an SEM of 0.06 m/.s.[59,60] The ten meter walk test was the closest outcome measure to the one previously proposed. Gait speed has also reliably been collected by the

GaitRite device for healthy adults for self-selected (repeated measures ICC = 0.93) and fast paced (repeated measures ICC = 0.94) speeds.[61]

Proposed Data Analysis

Descriptive statistics were generated for each aim to provide background information on the study participants. Pearson correlation coefficients were generated to assess relationships between the dependent variables and the independent variables. Correlation coefficients were be generated to assess the relationships between the independent variables of each model to assess multicollinearity.

To assess if there were differences by ten-year age groups for single and dual task performance separately, multiple one-way Analysis of Variance (ANOVA) with Tukey post hoc analysis were performed the DTC for COP path length, 95% EA, self-selected walking speed, fast paced walking speed, and the performance of the bimanual task for each scenario. Repeated measure ANOVAs were utilized to assess if any interactions are seen between single and dual task performance by ten-year age group. When no interactions were noted, main effects were analyzed to determine if differences were apparent between groups or between conditions. Outliers were excluded from the analysis if their performance exceeded two standard deviations from the mean.

Regression analysis modeled the DTCs for COP path length, 95% EA, self-selected walking speed, and fast paced walking speed by the nine different independent variables. The independent variables included age, activity recall, MoCA, ABCS, FR, FSST, DTQ-D, and DTQ-F. An interaction variable was included in the regression models, however, no interaction was seen in the pilot study (n=10) between age and dual task cost ([{Dual Task Score – Single Task Score}/Single Task Score] *100%)[31-33] for the spring bolt in any category. No interaction was found, so no interaction variable was included in the model. Linear relationships were assessed first. Variables were removed stepwise to determine if they were not significant to the model. A prediction equation was produced for all significant models. Residuals plots were produced for each significant model.

Mulitcollinearity and outliers were potential problems for the regression analysis. Multicollinearity is when the independent variables are highly correlated: usually higher than 0.70.[62] Tolerance and Variance Inflation Factor (VIF) aided in determining if multicollinearity existed in the model.[62] Multicollinearity was indicated if tolerance fell below .10 and/or VIF was above 10.[62] The reason these values were selected was because the standard error in the model was increased by a factor of ten past these points.[62]

The second problem came from outliers. Outliers can skew the model by pulling the line towards them. This is known as leverage.[62] The further the outlier exists from the regression line and the further it lies towards the ends of the plot, the more leverage is exerted on the regression line. To detect outliers, the Mahalanobis distance and Cook's Distance were used. The Mahalanobis distance detected how far the data points in the model are from the mean regression line. When these numbers were generated, they were compared to a chi-square distribution with equation 1-Chi-Square$_{(\text{Mahalanobis Distance, 2})}$. If the value fell below 0.001, the participant was excluded from the model for being an outlier. The Cook's distance represented how much influence a data point had on shifting a line towards it. If Cook's distance was close to 1 and the corresponding Mahalanobis distance denoted the point as an outlier, then the point was removed from the model.

In addition to the regression analyses, an inference chart was used to assess if the primary task (the dependent variables), the added dual task, or both tasks' performance degraded. This analysis was a better representation of how people of varying ages approach a dual task situation. Plummer et al. had utilized this technique to analyze how a cognitive dual task interfered with walking.[33] In Figure 3.3, a Cartesian plane was constructed. The plane shows cognitive dual task effect on the x axis and gait on the y axis. When the dual tasks effects were calculated, they were plotted in the appropriate place.

In Figure 3.3, if the primary task was prioritized than the values fell in the upper left quadrant. Conversely, if the secondary task was prioritized than the values will fell in the lower left quadrant. There was a possibility that both tasks' performance will increase (mutual facilitation) or decrease (mutual interference).[33]

Sample Size Determination and Recruitment

Four separate, *a priori* power analyses were performed to estimate sample size. The power analyses were performed using G*Power 3.1.9.2. In the F test category, linear multiple regression fixed model with R^2 deviation from zero was selected with alpha level set at 0.05, expected power at 0.80, and effect size (Cohen f^2) estimated from the pilot data for each regression analysis. Cohen f^2 is calculate by $R^2/(1- R^2)$. Table 3.1 displays the estimated sample sizes.

In order to achieve power for the entire study, the projected sample size must be higher than 57 participants. To guard against outliers, the investigator recruited 81 participants. There were seven age groups: 18-29, 30-39, 40-49, 50-59, 60-69, 70-79, 80+. Each group had approximately 10 participants in each group. This allowed enough people to be recruited and equally distributed across ages.

Table 3.1: Estimated Sample Sizes for All Models for Pilot Study

	COP Path Length	*95% EA*	*Self-Selected WS*	*Fast-Paced WS*
R^2	0.25	0.52	0.16	0.15
Cohen f^2	0.33	1.07	0.19	0.18
Sample Size	42	13	54	57

R^2 is the measurement of variability explained by the model
Cohen f^2 represents the estimated effect size
Abbreviations: COP – Center of Pressure, EA – Ellipse Area, WS – Walking Speed

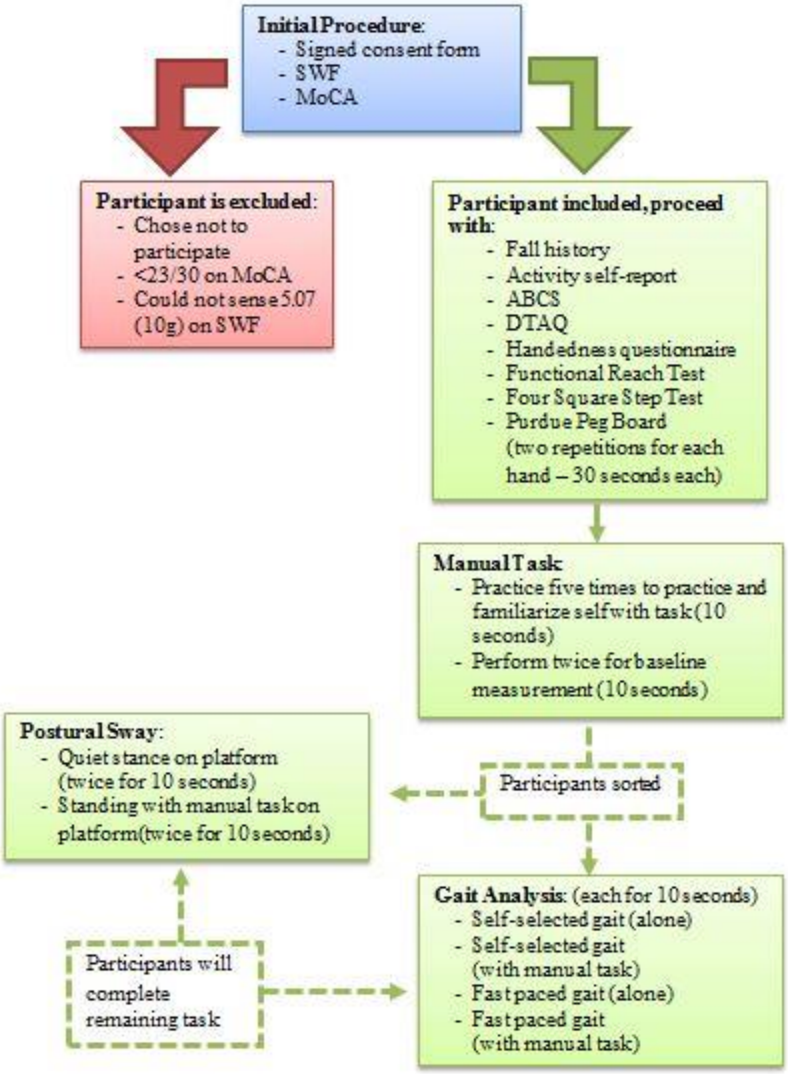


Figure 3.1: A flowchart depicting the progression of the overall study. Abbreviations: MoCA, Montreal Cognitive Assessment; SWF, Semmes Weinstein Filament; ABCS, Activities Balance Confidence Scale; DTAQ, Dual Task Activities Questionnaire

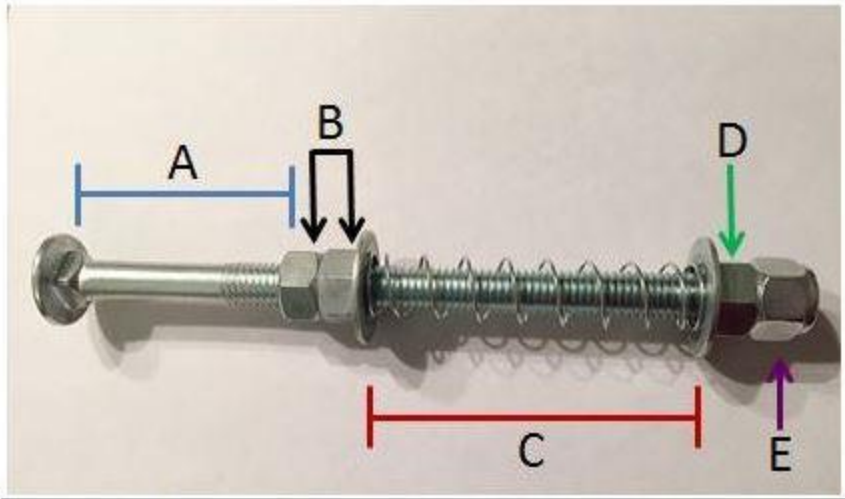


Figure 3.2: The spring bolt is the bimanual component to the dual task conditions. The components are: A.) stabilization area; B.) two spot welded stop nuts; C.) spring resistance; D.) working nut; E.) nylon stop nut

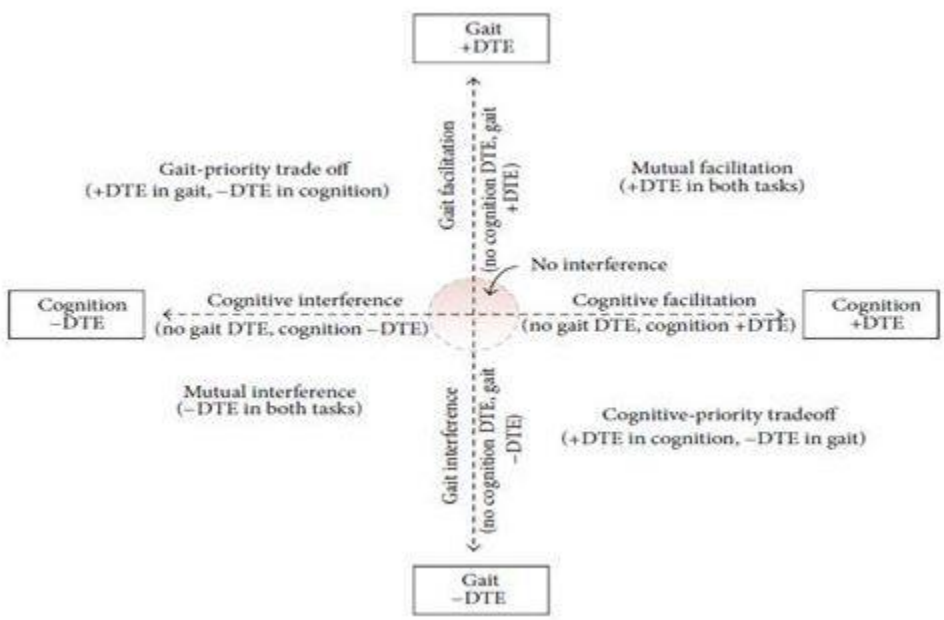


Figure 3.3: An example of the prioritization plot (Cartesian coordinate plane) used to plot the dual task cost associated with the primary and secondary task from Plummer et al. 2014. In this example, a cognitive task was used to influence gait.[33]
Abbreviations: DTE, dual task effect

CHAPTER 4

AGE INFLUENCES SINGLE AND DUAL TASK PERFORMANCE BUT ONLY PREDICTS THE DUAL TASK COST FOR THE 95% ELLIPSE AREA ACROSS ALL AGES[1]

[1] Liuzzo D.M., Plummer P., Stewart J.C., Beattie P., and Fritz S.L. To be submitted to *Physical Therapy Journal*.

ABSTRACT

Background: Cognitive-motor dual tasking is commonly studied for balancing activities. However, the effects of adding a bimanual task during balancing are poorly understood across all ages. Furthermore, how people prioritize during dual task conditions has not been investigated with healthy adults of all ages.

Objective: Determine if age is a primary predictor of the dual task cost (DTC) for center of pressure path length (COP) and 95% ellipse area (EA) during standing and to determine if adults of differing ages prioritize dual task situations differently.

Design: Cohort, Cross-sectional

Methods: After practicing the bimanual task five times, participants completed two trials. Then the participants stood quietly on a force platform: two trials were performed. Two more trials were performed as participants stood on the force platform performing the bimanual task. All trials were ten seconds each. Repeated measure analyses of variance and regression analyses were used to determine differences between age groups and conditions. Prioritization plots were also generated.

Results: Eighty-one participants (52 women, 29 men) were included. No interactions were found between age group x condition for neither the COP path length nor the 95% EA. Differences were found independently for age groups ($p<0.0001$ for COP and 95% EA) and by condition ($p<0.001$ for COP and 95% EA). No differences were found between age groups for the DTC of either variable. Regression analysis was significant for 95% EA (Adjusted $R^2= 0.33$, $p<0.001$) with age, cognition, frequency of dual task experiences, and the DTC of the bimanual task being predictors. Prioritization plots

emphasize that age may play a role in direction of attention as older adults are more likely to experience mutual interference.

Limitations: All adults were healthy and active which could have led to a general homogeneity for other independent variables possibly leading to no other predictors being found.

Conclusion: Older adults demonstrate larger measurements of sway and may not have the postural reserve to adapt to a change in sway compared to younger cohorts. The DTC for the 95% EA was predicted more than age indicating a need to include measurements of functional age as well. Older adults may prioritize tasks differently based on the perceived consequences while younger adults may be able to more accurately switch focus between tasks.

INTRODUCTION

Loss of task automaticity, the ability to perform a task with minimal attentional deficits or demands, may be a primary factor leading to falls with a greater incidence of injury.[1] One third of older adults will experience a fall with many having serious injuries that could lead to a further decline in health, serious injury, or death.[1-4] A division of attention, especially during cognitive or manual dual task activities, may hamper an individual's ability to smoothly and accurately perform the two tasks. Furthermore, task automaticity may be influenced by multiple factors other than age including cognition, postural reserve, hazard estimation, anxiety and complexity of the task.[1,5-7]

Previous research investigating dual task cost, the relative change in performance between single and dual task conditions, in older adults is dominated by study of adding a cognitive secondary task during a static balance activity. Serial subtraction tasks, spatial and non-spatial memory tasks, and the Stroop test have been employed to determine if postural sway is influenced by the addition of a cognitive task for older adults.[8-13] Investigators have determined that older adults will increase their center of pressure (COP) path lengths when their attention is divided. For example, when attention is divided by the Stroop Test, older adults experience a 44% increase in overall total COP path lengths.[8] Moreover, COP path length was greater for older adults when compared to a younger cohort during cognitive dual tasking.[9] The same decrease in performance has been demonstrated with the performance of a manual task in standing. Usually these studies employ carrying a cup of water by hand or on a tray during an evaluation of postural stability.[13-17] These studies demonstrated a larger increase in sway and reliance on visual input while holding a tray with empty cups on it.[13]

While the current evidence explains how older adults' postural sway responds to a secondary task, further inquiry is necessary to determine if older adults are truly responding in a different way than their younger counterparts. Many of these studies did not, or were unable to, record performance on the secondary task because the task was static or not continuous in nature. This information is necessary to understand which tasks individual chose to prioritize or if performance on both tasks is being affected. Furthermore, the evidence demonstrates a difference in abilities from younger to older individuals; however, this scenario does not provide a full representation of ages. Only one study attempted to determine the differences in postural sway performance across all age groups.[8] This gap needs to be filled to understand if and when there is a decline in abilities. If performance sharply declines at one age versus another, screening initiatives could be used to target individuals who may be at the highest fall risk. Moreover, the COP path length was the most commonly reported measurement of postural sway, but this only presents a portion of postural sway. The 95% ellipse area (EA), statistically 95% of all the COP points collected, should also be reported to help analyze if a person is swaying more within their base of support (BOS) **(**larger EA**)** or locking down their degrees of freedom **(**smaller EA**)**.[8]

Therefore, the overall purpose of this study was to examine the relationship between age and task automaticity for a bimanual dual-task condition, and describe how age influences attentional prioritization strategies during a manual dual-task situation for healthy adults. This study had two major aims. The first aim of this study was to examine the effect of a bimanual motor task on postural sway and to determine if performance was influenced by age, bimanual task performance, perceived confidence, mobility, and postural control. If automaticity of postural sway deteriorates with age, then as age increases, there will be an exponential increase in dual task interference on postural sway performance. Furthermore, decreased confidence, mobility, balance performance, and the increase in dual task interference of the bimanual task will contribute to the increase in the dual task interference for postural sway performance.

The second aim strove to identify the default prioritization strategy during the dual task condition and if these strategies were influenced by age. According to previous literature, task automaticity for postural sway performance should be greater for younger adults and degrade with age.[18-20] If automaticity was affected similarly for the bimanual, manipulation task than as people age, there will be a greater magnitude of mutual interference on both tasks.

METHODS

Participants

Eighty-one participants were recruited via word of mouth from Columbia, SC and surrounding communities. Inclusionary criteria consisted of individuals ≥ 18 years old. Participants were excluded from the study for: concurrent neurological disorders; reports of vestibular disorders or dizziness within the past month; loss of protective sensation to the hands or feet (5.07 [10g] by Semmes-Weinstein Filament Testing)[21]; the use of an assistive device that impedes the use of either hand; musculoskeletal injuries or surgeries within the past 6 months that impede ambulation or fine motor skills; or scoring <23/30 points on the Montreal Cognitive Assessment **(**MoCA**)** indicating mild cognitive impairment.[22]

Procedures

Participants were initially screened with Semmes-Weinstein Filament Sensation Testing, and the MoCA. After passing the screen, participants completed the following: 1.) fall history self-report, 2.) activity self-report, 3.) Activities-specific Balance Confidence scale, 4.) Dual Task Activity Questionnaire, 5.) Handedness Questionnaire, 6.) the Functional Reach Test, 7.) the Four Square Step Test, and 8.) four total repetitions (two repetitions for the right hand and two repetitions for the left hand) for the Purdue Peg Board Test. Activity level was assessed using the activity self-report. Scores were calculated on a six point scale with the ACSM recommendations. Six is the highest number with three indicating the person met the ACSM recommendation.[23] The Dual Task Activity Questionnaire is split into two components: frequency of experiencing dual task situations and perceived difficulty with dual task activities. Higher scores on the difficulty section indicate higher perceived difficulty with tasks while higher scores on the frequency component indicated more experience with dual task situations. The full procedure of the study is presented in Figure 4.1.

Following the initial testing, individuals were introduced to the bimanual task and given time to practice. This is pictured in Figure 4.2.

The bimanual task, known as a spring bolt, involved turning a nut on a bolt to mimic functional activities of finding a key on a key ring or removing a bottle cap. The spring bolt was a 20 cm long bolt with a 1.9 cm diameter. The bolt was fitted with two nuts 6.5 cm from the head of the bolt. These nuts were 1 cm hexagonal nuts with 1.9 cm bore. A washer was fitted after with a 1.9 cm bore. The spring was a basic tension spring with a length of 9.5 cm. Another washer and nut were affixed on top. This nut was mobile and was turned by the participant’s dominant hand while the non-dominant hand held the bolt steady. Lastly, a 1 cm nylon stop nut was used to insure the nut was not screwed off the bolt. The spring compressed at a constant and kept the participant from spinning the nut down the bolt. Each participant performed five practice trials of the bimanual task followed by two test trials that were used in analyses as the single task reference. All single task trials were performed in sitting and lasted 10 seconds each. Task performance was quantified as displacement of the nut in millimeters from the base of the stop nut to the top of the mobile nut.

Following the practice trials, participants stepped onto the force platform and were asked to “stand comfortably” with their feet shoulder width apart. The participants first stood quietly for 10 seconds without performing the manual task. The participants were instructed to “Stand comfortably on the platform. Remain as steady as possible while looking straight ahead of you". Two single task standing trials were completed. Then the participants stood on the platform for 10 seconds while performing the bimanual task. The participants were instructed to "Stand comfortably on the platform. Without moving your feet, please perform the manual task as you have practiced." This condition was also performed twice. The COP length, the 95% EA, and bimanual task performance were collected during single and dual task conditions.

Statistical Analysis

The dual task costs for the COP path length, 95% EA, and the bimanual task were calculated using the formula:[20,24,25]

$$\pm \left(\frac{\text{(Dual Task Performance} - \text{Single Task Performance)}}{\text{Single Task Performance}} \right) * 100\%$$

Descriptive statistics were generated for all groups and variables. Normality was assessed with the Shapiro-Wilk Test ($P<0.05$) for all variables. Pearson and Spearman correlations, for the 95% EA which was not normally distributed, were generated to assess relationships between the dependent variable and each independent variable: MoCA, activity self report, ABCS, FR, FSST, DTQ-D, DTQ-F, and the DTC bimanual task. Correlations were also used to examine the relationship between independent variables to help determine the presence of multicollinearity for regression analysis.

For the first aim of the study, individuals were grouped into ten-year age groups (e.g. 20-29, 30-39, etc). Outliers were excluded from the study if their performance two standard deviations from the mean. Repeated measure ANOVAs were utilized to assess if any interaction was seen between conditions (single task, dual task) x age (ten-year age group). If no interactions were detected, main effects were further analyzed to assess trends in the data using a Bonferroni analysis. Effect sizes (η^2) were also generated for each analysis. Effect sizes were small if <0.01, medium at 0.06 , and large if greater than 0.14.[26] One way ANOVA was used to determine if the DTC for COP path length and bolt performance differed by age group. A Kruskal-Wallis Test was utilized to determine if the DTC for the 95% EA differed by age group as the data was no normally distributed for statistical testing.

Multiple linear regressions were utilized to determine the predictors of DTC for COP path length or 95% EA. No interaction variables were noted throughout the analysis. Variables were removed stepwise from the model if the model itself did not meet significance ($p<0.05$) and the variables were not a significant part of the model ($p>0.20$). Variance Inflation Factor and Tolerance factors were incorporated to further assess collinearity. The Mahalanobis (chi-square ≥0.0001) and Cook's Distances (scores ≤1) were used to identify outliers in the model.

For the second aim of this study, a prioritization chart (a Cartesian coordinate plane) was used to help determine if participants chose to focus on the primary task or secondary task, or if the performance on both tasks suffered. Percentages of participants in each quadrant were calculated by: n participants in quadrant/total participants. If a participant appeared to be on a dividing line, the examiners used the calculated DTCs to place them in a quadrant.

RESULTS

Out of 81 initial subjects, 52 were women and 29 were men; 72 reported being right hand dominant. Table 4.1 presents means for all independent variables collected along with correlations between the dual task cost for each analysis and the nine independent variables: MoCA, activity self report, ABCS, FR, FSST, DTQ-D, DTQ-F, and the DTC bimanual task.

Center of Pressure Path Length Performance by Condition and Dual Task Cost

One subject was removed as an outlier for statistical testing for COP path length for both single and dual task analyses. A repeated measure ANOVA did not significantly demonstrate a condition (single vs. dual task) x age group interaction for COP path length ($n=80$, $p=0.889$, $\beta=0.15$, $\eta^2=0.08$). However, there were main effects between the different conditions ($n=80$, $p<.0001$, $\beta=1.0$, $\eta^2=.60$) and between the age groups ($n=80$, $p<.0001$, $\beta=1.0$, $\eta^2=.42$). There are differences noted between the two conditions and between the age groups, however, these differences are independent of each other. The age group differences are highlighted in Figure 4.3.A. Furthermore, no significant differences were observed between age groups for the DTC of the COP path length ($n=80$, $p=.413$, $\beta=0.07$, $\eta^2=0.08$) (Figure 4.3.D).

95% Ellipse Area by Condition and Dual Task Cost

No interaction was demonstrated for condition x age group for 95% EA ($n=81$, $p=0.168$, $\beta=0.57$, $\eta^2=0.11$), however, single and dual task performance was significantly different ($n=81$, $p<.0001$, $\beta=.99$, $\eta^2=.21$). Age groups were also significantly different ($n=81$, $p<.0001$, $\beta=.99$, $\eta^2=.37$). These results emphasize that there were differences detected between conditions and the age groups, but the results for the different conditions were not influenced by age group. This is further highlighted in Figure 4.3.B. No significant differences were noted using Kruskal-Wallis testing for DTC for 95% EA ($n = 74$, $p = .051$). DTC for the 95% EA by age group is further displayed in Figure 4.3.D.

Bimanual Task Performance by Condition and Dual Task Cost

No interaction was demonstrated for condition x age group for the bimanual task performance ($n=81$, $p=0.147$, $\beta=0.59$, $\eta^2=0.12$), however, single and dual task performance was significantly different ($n=81$, $p<.0001$, $\beta=1.0$, $\eta^2=0.28$). Bolt performance also was significantly different between age groups ($n=81$, $p<.0001$, $\beta=.97$, $\eta^2=0.25$). No significant differences were observed following a one-way ANOVA analysis of the DTC by age groups ($n=80$, $p=.333$, $\beta=0.07$, $\eta^2=0.09$). DTC for the bimanual task by age group is further displayed in Figure 4.3.D.

Predictors of Dual Task Cost for Center of Pressure Path Length and 95% Ellipse Area

Regression analysis was performed to determine if any of the independent variables were predictors of the DTC for COP path length and the 95% EA when the bimanual task was implemented. Two subjects for the DTC COP analysis were excluded as outliers during the regression analysis. No interaction was found between any of the independent variables, and all other variables were excluded from the model stepwise. Furthermore, no curvilinear relationship was discovered. Regression analysis for the DTC of COP path length found no predictors. Seven participants were excluded as outliers before the analysis since they were two standard deviations from the mean. Three more participants were excluded during the analysis because they exhibited large Mahalanobis and Cook’s distances. Seventy-two participants remained in the final model analysis. Participants’ age, MoCA score, answers on the DTQ-F, and the DTC of the bimanual performance comprise the final prediction model. The model explained 33% of the variance in performance (Adjusted R^2= 0.33, p<0.001). Age was the strongest predictor (p=<0.001, partial correlation= -0.43) with performance on the bimanual task (p=0.001, partial correlation= 0.347) along with DTQ-F (p=0.163, partial correlation=-0.14) and MoCA (p= 0.130, partial correlation=0.13) being weaker predictors. The regression equation was as follows:

DTC 95% EA = 52.41 - 1.83(Age) + 4.68(MoCA) - 1.06(DTQ-F) + 1.82(DTC bimanual)

Figure 4.4 reports the observed means with the model predicted values. Mean values for each age group were used to create the predicted model line. Figure 4.4 also presents the residual plots for the regression analysis. Residual plots should ideally have the mean residual land at zero with most residuals following between two standard deviations from the mean. This indicates that the differences between the observed values and the predicted values are minimal.

Prioritization of Tasks

Prioritization plots were produced in two distinct ways: DTC individually (Figure 4.5.A&B) and by mean DTC for each ten year age group (Figure 4.5.C&D). Seventy-two percent of all subjects demonstrated mutual interference for the DTC of the COP path length and bimanual task. The plot for the DTC of the 95% EA and bimanual task demonstrated 27% with preference for postural sway, 16% preference for manual task and 51%with mutual interference for both tasks. Six percent demonstrated mutual facilitation. Older adults were closer to the quadrant lines. The closer to the quadrant lines, the more likely a person is choosing to focus more closely on one task. For the DTC 95% EA comparison, older adults demonstrated a preference for the 95% EA not the bimanual task (figure 4.5.D, upper left quadrant).

Discussion

Healthy, active older adults (>60 years old) experience longer COP path length and greater 95% EA during single and dual task conditions than younger cohorts (<60 years old). Furthermore, the DTC seen between the two conditions was predicted by age, cognition, frequency of dual task experience, and the DTC experienced on the bimanual task. Also, individuals prioritize tasks differently by age possibly due to attentional resources available to the individual and the potential consequence involved by not prioritizing balance.

Older Adults Exhibit Decreased Postural Reserve Compared to Younger Cohorts

In previous research, the COP path length was used to infer older adults (>60 years old) sway more than younger cohorts during single and dual task conditions.[8-13] However, grouping older adults may have proven misleading since there may have been inherent differences between people who are in the 7th decade versus those in their 9th decade. This study is unique in providing all age groups to assess if those differences existed. However, there were no statistically significant differences between groups older than 60 for both conditions nor were there any differences for those under the age of 60. Therefore, those under the age of 60 demonstrate smaller measurements of COP path length than their older counterparts. This result is only the first piece of information to a much larger analysis.

To further explain how individuals sway during different conditions, the 95% EA was also taken into consideration. The participants over the age of 60 exhibits larger 95% EA during single task compared to those under the age of 60. However, during the dual task condition, there was not an increase in the 95% EA for older adults. In adults under the age of 60, there was an increase in 95% EA in the dual task condition (Figure 4.3.B). The older cohorts may not have the capacity to increase or adapt their sway more than younger adults who have a larger amount of change between conditions.[8] It should be noted that the 20-29 cohort demonstrated fairly large amount of sway for both conditions and was highly variable in their performance. This may be because this cohort is fairly confident in their abilities and may see no consequence if they fall as opposed to older groups that may be shift attentional focus in order not to fall.[27]

Age, Cognition, Experience, and Bimanual Performance Predict Dual Task Cost

Regression analysis did not yield age or any of the seven independent variables as predictors of DTC for COP. For this study, while participants demonstrated larger amounts of sway for single and dual task conditions, the DTCs were relatively similar across all age groups. While this appears to show that people experience change when adding in a secondary task about the same at all age groups, the 95% EA must be taken into consideration. The regression for the DTC of the 95% EA provided age, MoCA, frequency of dual task activities, and DTC for bimanual task performance as predictors of which age and performance on the bimanual task were the strongest predictors. Age showed a moderate, negative correlation to the DTC for 95% EA, this means that as age increased the amount of DTC decreased because older adults may not have the postural reserve to adapt their balance due to having a larger sway initially. The DTC of the bimanual task showed a small, positive correlation meaning that as the DTC of the bimanual task increases so will the DTC of the 95% EA. However, this cannot be inferred as prioritization, only that those who experience larger DTC for one are more likely to experience it for the other. The MoCA and DTQ-F should be considered, however, as they may have been included due to the generous set p-value of 0.2 for inclusion in the model. These two measurements may indicate varying degrees of functional age: explaining why people of the same age may present very differently.[28,29] Further investigation is necessary to determine if these two variables are contributing factors especially in populations with more variability in cognition and frailty.[28,29]

Task Prioritization

The majority of participants demonstrated mutual interference for both comparisons of the DTC of COP path length and 95% EA to the DTC of the bimanual task. This may initial indicate that adding a secondary task automatically causes the majority of individuals to have performance degradation on both tasks. However, more information about how people prioritize is gained from how individuals perform on average by age group. For the DTC COP path length comparison, all age groups experienced mutual interference (Figure 4.5.C). Taking both of the graphs into consideration, it is more likely the older adults did not have the capacity to attend to both tasks at once. This may also be influenced by fear of falling or the thought of a greater consequence if they were to lose their balance. All other age groups demonstrated mutual interference; however, this is more likely due to capacity. These individuals have the capacity to switch between tasks, or do not have to concern themselves with the consequences of losing their balance. From switching between tasks, the performance naturally degrades for both. Therefore, as individuals get older, they may be more likely to concentrate on their balance than a secondary task unless otherwise instructed.

This study was unique in several aspects. This study introduced a continuous, manipulative bimanual task instead of a discrete or static manual task. Furthermore, the study population was fairly homogenous across all age groups. Ultimately, this study emphasizes the need to further examine functional age (i.e. cognition and frailty) in comparison to biological age as this may lead to a wide variation in abilities for people of the same age.[28,29] Individuals in this study reported high levels of activity, displayed intact cognition, and were not defined as frail from initial screening.[28-30] This group is different than the majority of the clinical population and may present differently due to their current functional age.

This study does have some limitations. First, the homogeneity across age groups may lead to decreased external validity. However, this study provides a benchmark for healthy adult response to a bimanual dual task and allows other populations to be investigated and compared against them. Secondly, participants were not asked how difficult they perceived the bimanual task and completing that task while standing. The task may not have required a large attentional demand, and therefore did not cause younger individuals to consider the task as much as older adults. However, a further step would be to include various manual tasks that require differing attentional demands.

Future directions should include individuals of differing cognition and activity levels. These studies should also address how manual task of varying attentional demands affect prioritization and postural sway for a variety of ages and populations.

CONCLUSION

In conclusion, age influenced overall task performance. Postural sway was greater for older adults during both conditions; however, healthy, older adults may have less postural reserve, the ability to increase sway, than younger adults. Four factors were predictive of increased postural sway: age, cognition, frequency of dual task experience, and the change in bimanual task performance. While age and the change in bimanual task performance were the strongest factors, further investigation is necessary to determine if cognition and dual task experience are truly strong predictors. Lastly, older adults may not have the same attentional capacity to attend to postural sway and a bimanual task at the same time compared to younger adults. Furthermore, younger adults may not be as concerned of the consequences of a fall versus older adults. More investigations are necessary to determine if varying cognition, frailty, and fear are factors for dual task cost with aging.

Table 4.1: Descriptive Statistics for All Independent Variables, Pearson Correlations, and Spearmen Correlations

Mean and Standard Deviations for all Independent Variables

		Ten-year Age Groups						
	Overall	20-29	30-39	40-49	50-59	60-69	70-79	80+
N	81	10	10	10	12	16	13	10
Activity	4.1 (1.5)	5.4 (0.5)	4.1 (1.5)	**3.1 (2.1)**	4.0 (1.3)	4.5 (1.2)	3.9 (1.1)	3.7 (1.5)
MoCA	27.9 (1.9)	29.2 (1.2)	29.0 (1.5)	27.6 (2.3)	28.8 (1.7)	27.2 (1.9)	27.2 (1.4)	**26.7 (1.4)**
ABCS (%)	92.4 (8.6)	94.9 (6.9)	91.8 (13.3)	95.5 (3.8)	93.3 (7.1)	92.3 (8.1)	92.1 (7.4)	86.4 (11.1)
FR (inches)	12.3 (2.4)	14.3 (1.8)	13.8 (1.0)	12.2 (2.5)	12.5 (1.8)	12.5 (1.8)	**11.3 (2.4)**	**9.2 (1.5)**
FSST (sec.)	6.8 (2.0)	4.8 (1.3)	5.9 (1.9)	6.8 (2.2)	6.7 (1.1)	**7.1 (1.8)**	**7.3 (1.3)**	**9.1 (2.3)**
DTQ-D	58.7 (17.8)	56.8 (14.4)	50.9 (15.3)	47.8 (15.5)	54.5 (11.7)	54.9 (13.8)	**69.1 (22.4)**	**73.0 (19.6)**
DTQ-F	36.9 (10.2)	42.6 (4.4)	44.7 (6.4)	38.8 (6.1)	39.5 (8.2)	37.8 (9.3)	**28.5 (5.3)**	**23.8 (8.0)**

Pearson and Spearmen Correlations

	Age	Act.	MoCA	ABCS	FR	FSST	DTQ-D	DTQ-F	DTC-T
DTC-COP *p-value*	-.19 (.09)	-.03 (.79)	.19 (.09)	.04 (.72)	.13 (.23)	-.18 (.11)	-.004 (.97)	.01 (.91)	-.04 (.74)
DTC-EA*	**.28 (.01)**	-.03 (.82)	.17 (.12)	**.23 (.04)**	**.27 (.01)**	-.08 (.47)	-.20 (.07)	.16 (.15)	.12 (.27)

Activity is based on ACSM recommendations: numbers over three met recommendations with six being the highest amount.
DTQ-D: Higher values indicates higher difficulty with dual task activities
DTQ-F: Lower values indicates less frequency and experience with dual task activities
*Spearmen correlations used for non-parametric correlations.
Abbreviations: MoCa, Montreal Cognitive Exam; ABCS, Activities Balance Confidence Scale; FR, Functional Reach; FSST, four square step test, sec., seconds; DTQ-D, dual task activity questionnaire – difficulty portion; DTQ-F dual task activity questionnaire – frequency portion; Act., activity self-report; DTC, dual task cost; COP, Center of Pressure path length; EA, 95% Ellipse Area; DTC-T, dual task cost of bimanual task
Bold values for mean designates significant differences ($p<0.05$) from other age groups while **bold** values for correlations indicates significant correlations.

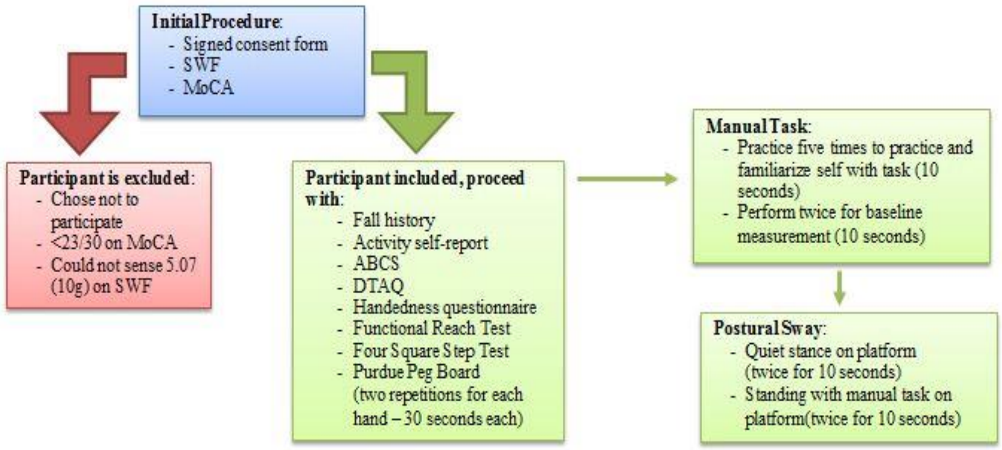


Figure 4.1: A flowchart depicting the progression of the study.
Abbreviations: MoCA – Montreal Cognitive Assessment, SWF – Semmes Weinstein Filament, ABCS – Activities Balance Confidence Scale, DTAQ – Dual Task Activities Questionnaire

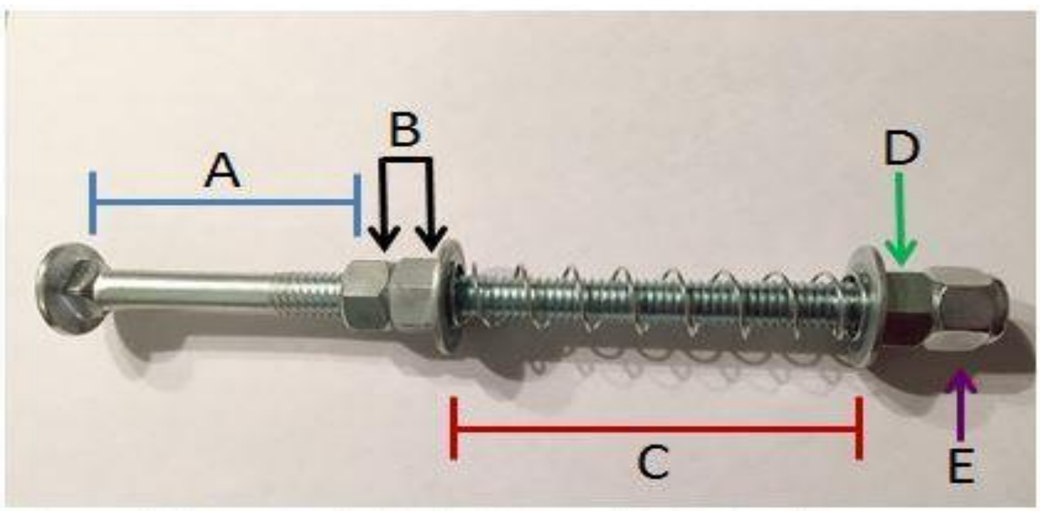


Figure 4.2: The spring bolt is the bimanual dual task. The components are: A.) stabilization area; B.) 2 spot welded nuts; C.) spring resistance; D.) working nut; E.) nylon stop nut.

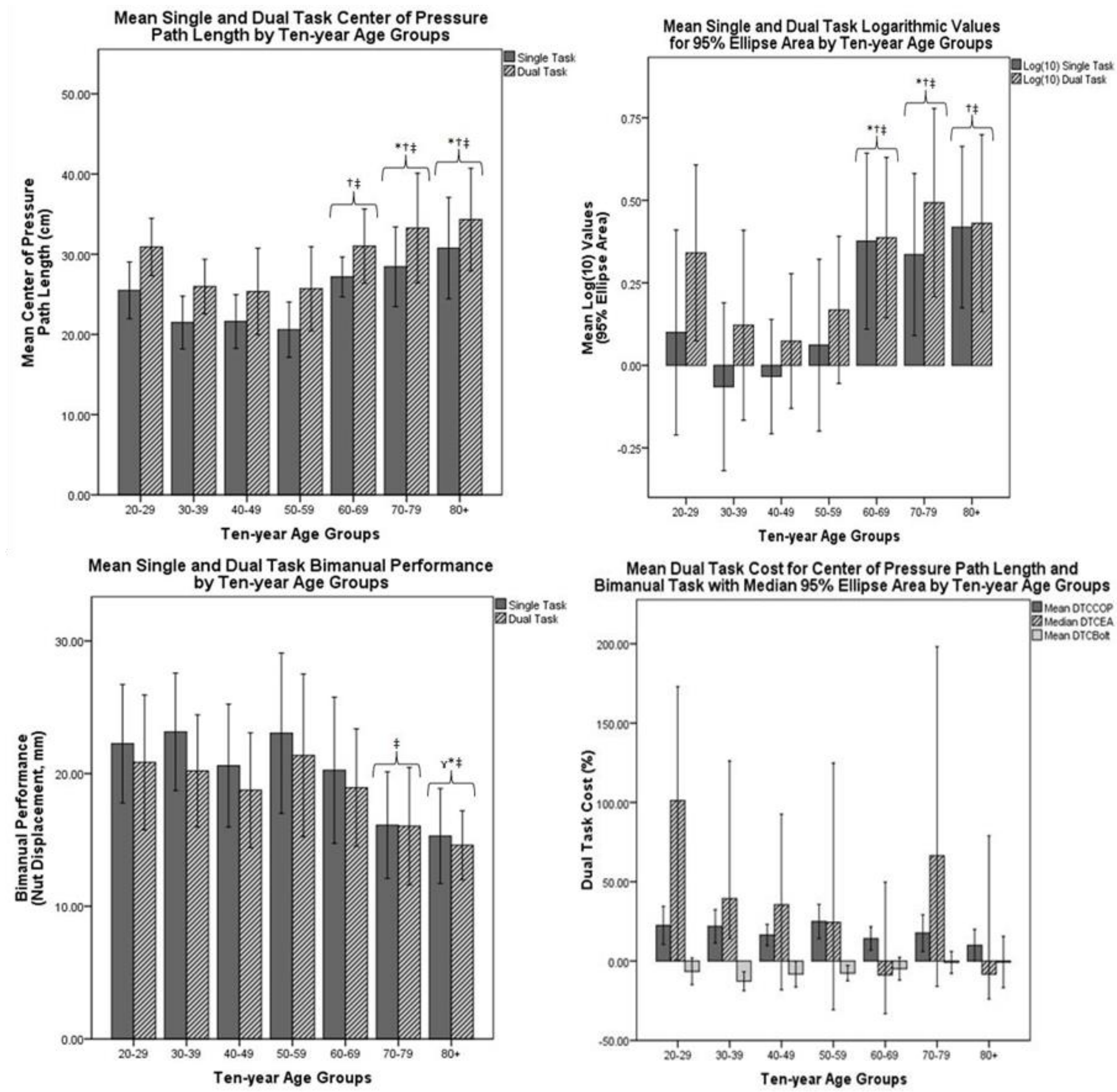
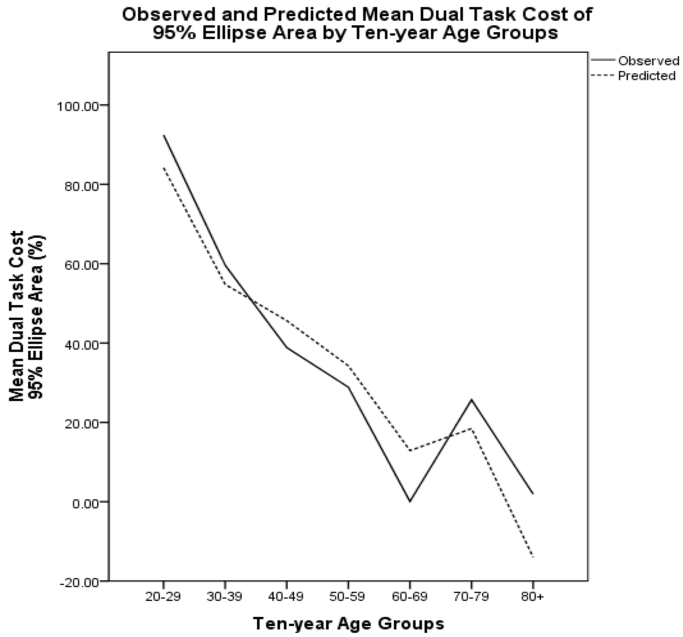


Figure 4.3: The means of the single and dual task performance for Center of Pressure (COP) path length, 95% Ellipse Area (EA), and means of the bimanual task by ten-year age groups are presented in charts A, B, and C. Chart D is the mean dual task cost for COP path length and bimanual task along with the median DTC for 95% EA by ten-year age groups.

Statistically significant differences (p <.05) are denoted by black symbols for differences between age groups: ɤ, 20-29; *, 30-39; †, 40-49; ‡, 50-59.



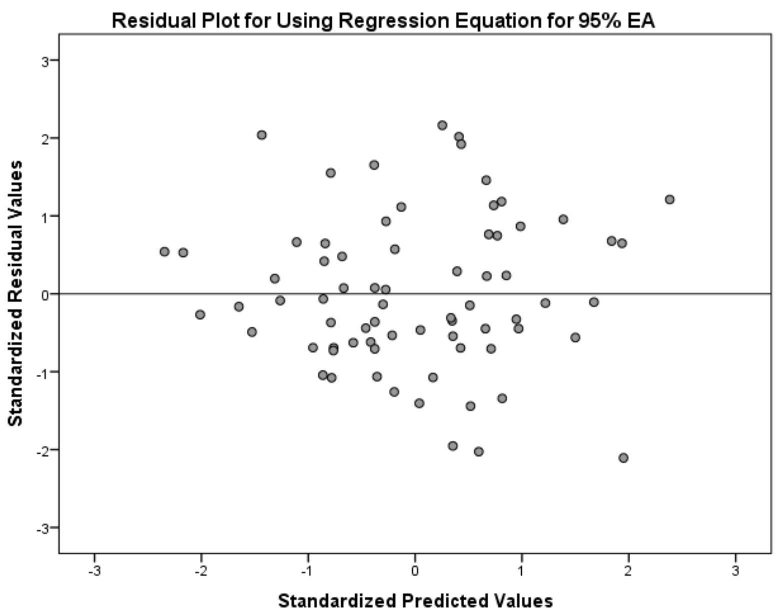


Figure 4.4: Chart A presents the observed 95% Ellipse Area mean dual task cost by ten-year age group and the predicted means using the regression equation and the mean age, Montreal cognitive exam score, Dual Task Activity Questionnaire – Frequency, and dual task cost for the bimanual task performance for each ten-year age group. Chart B provides the residual plot for the regression analysis performed for the 95% Ellipse Area dual task cost.

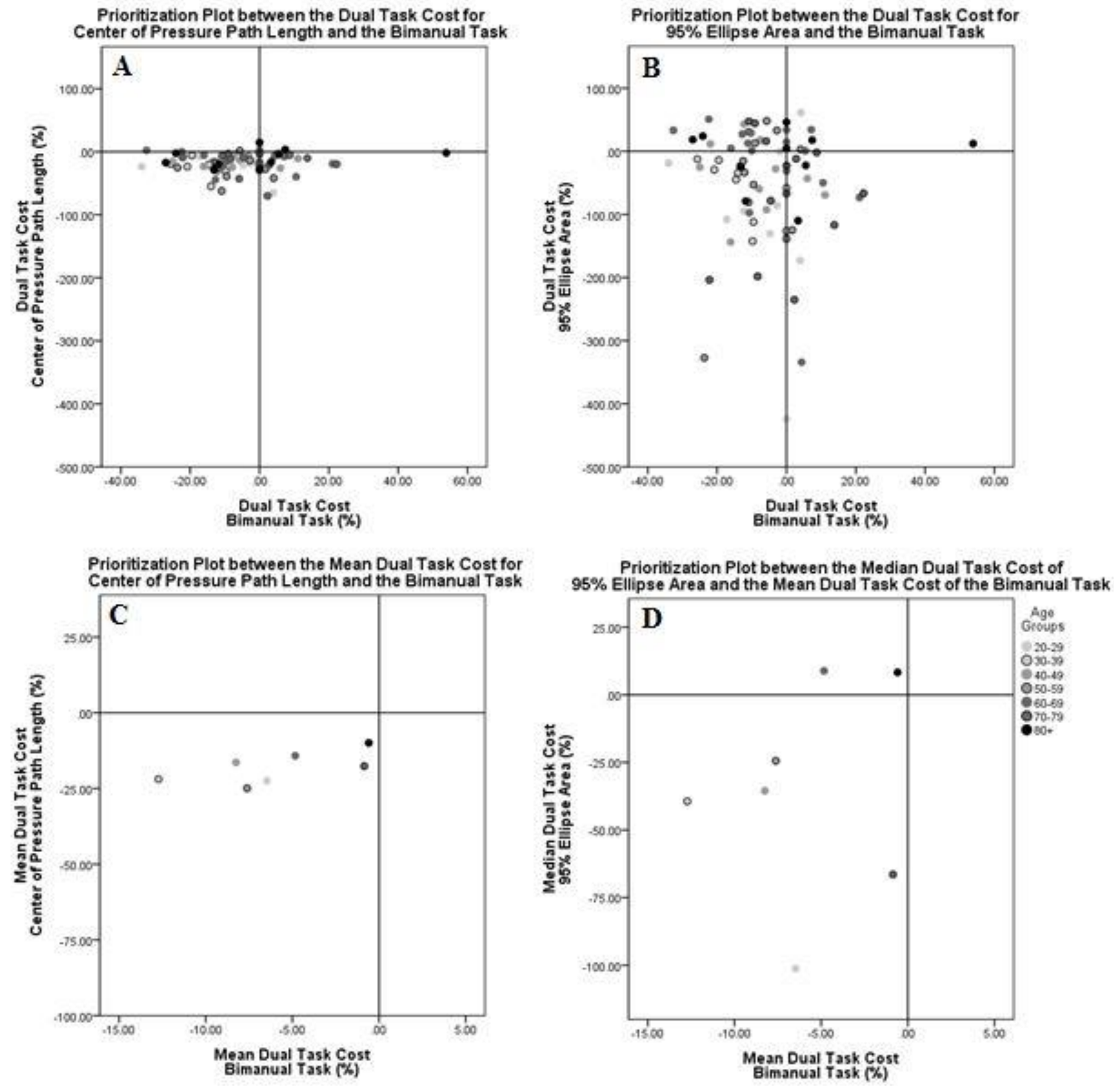


Figure 4.5: Prioritization plots for each analysis. Plot A and B compares the dual task cost (DTC) of the Center of Pressure (COP) Path Length (A) and the DTC of the 95% Ellipse Area (EA) (B) with the DTC of the bimanual task performance. Plots C and D depict the mean DTC of the COP path length (C) and the median DTC for 95% EA (D) by the mean DTC for the performance on the bimanual task by ten-year age groups. Points that fall in the upper, right quadrant demonstrate mutual facilitation where both performances demonstrated improvement. Points that lie in the upper, left or lower, right quadrant signify that individuals chose to focus on one task over the other. Points remaining in the lower, left quadrant demonstrate mutual interference where performances on both tasks degrade.

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CHAPTER 5

Functional Reach and Perceived Difficulty of Dual Tasks are Better Predictors than Age for the Dual Task Cost of Self-selected and Fast Paced Walking Speed[2]

[2] Liuzzo D.M., Plummer P., Stewart J.C., Beattie P., and Fritz S.L. To be submitted to *Physical Therapy Journal*.

ABSTRACT

Background: The effects of adding a bimanual task during walking are poorly understood across all ages, as many studies utilized unilateral or non-functional continuous tasks as the secondary motor task. Furthermore, how people prioritize which task to focus on during either self-selected or fast walking has not been investigated in healthy adults.

Objective: Determine if age is a primary predictor of the dual task cost (DTC) on self-selected and fast paced walking speed and to determine if adults of differing ages utilize different attentional prioritization strategies during dual task walking.

Design: Cohort, Cross-sectional

Methods: After practicing a bimanual motor task five times while seated, participants completed two, seated trials for ten seconds as a single-task measurement. The participants then performed the following, two trials each for 10 seconds: self-selected walking, self-selected walking with the bimanual task, fast-paced walking, and fast-paced walking with the bimanual task. Repeated measures Age x Condition analyses of variance were used to explore interactions and differences between ten-year age groups (range 20 to 86 years old) and the two different conditions during self-selected and fast paced walking. Regression analyses were performed to determine predictors of DTC on gait speed for separately for self-selected and fast walking. Prioritization plots were also generated to examine if individuals of differing ages focused on one task over the other.

Results: Eighty-one participants (52 women, 29 men) were included. No interactions were noted during analysis. The main effects of condition ($p<0.0001$) and age group ($p=0.024$) were significant for fast paced walking. Functional reach and perceived dual task difficulty were significant predictors of DTC on self-selected gait speed (R^2=0.07, p=0.02) and fast-paced walking speed (R^2= 0.08, p=0.02). Prioritization plots demonstrated mutual interference with increased age for self-selected walking speed while all age groups experienced mutual interference for fast walking speed.

Limitations: Fixed task order may have contributed to a learning effect for the progression of the study. All adults were healthy and active which could account for the lack of significant predictors of DTC in populations with differing functional age.

Conclusion: Age was not an overall predictor of DTC on gait speed for either slow or fast paced walking speeds. Measurements of functional age, functional reach and perceived difficulty of dual tasks were weak predictors of DTC on self-selected and fast paced walking speed in this population. Healthy active adults appear to prioritize their walking speed over a concurrent bimanual task; however, older adults may be more likely to experience mutual interference.

INTRODUCTION

Older adults' ability to perform additional tasks while walking is critical to continual involvement with daily activities of living and community participation.[1,2] The dampening of multiple systems with age (vestibular, somatosensory, proprioception, and visual[3]) begins to affect neural connectivity, decreasing neuromuscular coordination and motor reaction time during walking tasks.[2,4-6] Many older adults may experience a fall while performing a secondary task due to a age-related decreases in task automaticity for dual tasks.[2,7] Task automaticity refers to a person's ability to perform a task with minimal attentional demand.[7] Executing another cognitive or manual task while walking could decrease task automaticity through increased attentional demand,[1,8] increase reliance on vision,[6] lead to a reduction in efficiency of both tasks,[9] and longer intervals for cognitive processing.[10-12]

Performance of cognitive or manual tasks during walking has been shown to influence older adults' walking speed. During walking tasks, such as the 'walking while talking' test, older adults experienced a 43% increase, on average, in time to walk a 40 meter path.[13] Walking speed was also shown to decrease, on average, by 24% for older adults (1.21 m/s for single task, .97 m/s for dual task) while spelling a five letter word backwards compared to younger adults who decreased by 7% (1.46 m/s for single task, 1.35 m/s for dual task).[13] The effects of manual dual tasking on gait speed has been investigated by asking participants to walk while holding a cup of water or carrying a tray with articles on it. Older adults demonstrated an 11% decrease, on average, in speed (1.40 m/s for single task, 1.28 m/s for dual task) when required to balance a ball supported by a tray.[14] The percentage of change represent the dual task cost (DTC) associated with the addition of the secondary task. The DTC provides a window into how task automaticity is influenced by the secondary task. It has been hypothesized that as attentional demand increases so does the magnitude of DTC which represents a decrease in task automaticity.[7]

Current evidence is insufficient to determine if age is a predictor of the DTC associated with adding a second, simultaneous task during walking. Previous literature evaluated the difference in dual task walking between older (>60 years old) and younger adults (<30 years old), but there has been no analysis that has examined how people across all ages respond to a dual task condition while walking.[14-17] Moreover, the populations seen in the existing literature are heterogeneous with varying cognitive levels, fall risk, and activity levels. Healthy individuals across all ages must be assessed to provide an understanding of how people allocate their attentional resources during dual task conditions, and to estimate the magnitude of the DTC that is typical in different dual task combinations. Furthermore, the performance on the secondary tasks in previous literature was not always collected due to the nature of the task (i.e. holding a cup of water). Measuring the secondary task performance contributes to a better understanding of attentional prioritization and if novelty or complexity increases the DTC and affects task automaticity.[7]

Therefore, the overall purpose of this study was to examine the relationship between age and DTC in dual-task walking conditions, and describe how age influenced attentional prioritization strategies during dual-task walking. There were two distinct aims of this study. The first aim was to examine if the DTC during preferred and fast walking speed was affected by the following: age, the DTC of bimanual task performance, perceived balance confidence, mobility, and balance. We hypothesized that if automaticity of walking deteriorates with age, then as age increases, there would be an exponential increase in the DTC of walking speed. Furthermore, we expected that decreased confidence in dynamic balance, mobility, and the increase in DTC of the bimanual task was expected to contribute to the increase in the DTC on walking speed. The second aim was to identify the default prioritization strategy while walking with a bimanual task, and to evaluate if these strategies were influenced by age. It is possible that as people age, task automaticity decreases for walking when a secondary task is introduced. If automaticity is affected similarly for the bimanual task then as people age, there will be a greater magnitude of mutual interference on both tasks.

METHODS

Participants

Participants were involved in a larger study of DTC during balance and gait with analyses pertaining to balance variables reported separately. Eighty-one participants ≥ 18 years of age were recruited via word of mouth from Columbia, SC and surrounding communities. Participants were excluded from the study for: concurrent neurological disorders; reports of vestibular disorders or dizziness within the past month; loss of protective sensation to the hands or feet (5.07 [10g] by Semmes-Weinstein Filament Testing)[18]; the use of an assistive device that impeded the use of either hand; musculoskeletal injuries or surgeries within the past 6 months that impede ambulation or fine motor skills; or scoring <23/30 points on the Montreal Cognitive Assessment indicating mild cognitive impairment.[19.20] Participants were grouped by ten-year age groups accordingly: 20-29, 30-39, 40-49, 50-59, 60-69, 70-79, and 80+ years old.

Procedures

Following screening, participants completed the following: 1.) fall history self-report,[21] 2.) activity self-report,[22] 3.) Activities-specific Balance Confidence scale (ABCS),[23] 4.) Dual Task Activity Questionnaire including the perceived difficulty (DTQ-D) and experience frequency sections (DTQ-F),[24,25] 5.) Handedness Questionnaire,[26] 6.) the Functional Reach Test (FR),[27] 7.) the Four Square Step Test (FSST),[28,29] and 8.) four total repetitions (two repetitions for the right hand and two repetitions for the left hand) for the Purdue Peg Board Test.[30] The Dual Task Activity Questionnaire is a new, two-section questionnaire where individuals rate how difficult they perceived a particular everyday dual-task to be and how frequently they perform that activity (times per month).[24,25]

Following the initial testing, individuals were introduced to the bimanual task and given time to practice. This bimanual task involved turning a nut against a spring on a 20 cm long bolt with the participant's dominant hand. The bimanual task was designed to mimic a functional task such as turning a bottle cap. The participant performed five practice trials of the bimanual task while seated for 10 seconds each repetition. Following the practice trials, the participant performed two more seated trials: the measurements were used as the single task reference. The displacement of the nut on the bolt was measured in millimeters. For the full study protocol, participants were randomized to either a postural sway task or the walking speed task; however, conditions for walking speed were kept in a fixed order as to not influence the individuals walking speed. It was determined during pilot testing that the participants continued to walk at a face paced instead of at a self-selected pace if the fast paced trials were conducted first.

Following the bimanual task practice, participants were asked to complete several walking trials that lasted 10 seconds each. Walking speed (m/s) was calculated by dividing the distance (meters) by 10 seconds. Participants were first instructed to walk straight ahead down a 41m hall way at their "comfortable" walking speed for a period of 10 seconds. When the timer sounded, the participants were directed to stop in place and the distance was measured with a tape measure from their starting position to the calcaneus of their trailing leg. Participants were given up to 30 seconds of rest between walk trials. The participants walked at their self-selected pace for two repetitions. Afterwards, the participants performed two more repetitions at their self-selected pace while performing the bimanual task that they had previously practiced. Participants were given the same set of instructions but emphasized they walked at a fast pace as if they were "crossing the street with a changing light" both with and without the bimanual task. Figure 5.1 briefly summarizes the flow of activities specific to this study.

Statistical Analysis

The dual task cost (DTC) for self-selected walking speed, fast paced walking speed, and the performance on the bimanual task was calculated by using the formula:[27,32,33]

$$\pm \left(\frac{\text{(Dual Task Performance} - \text{Single Task Performance)}}{\text{Single Task Performance}} \right) * 100\%$$

Descriptive statistics were generated for all ten-year age groups and independent variables: activity score, MoCA, ABCS, FR, FSST, DTQ-D, DTQ-F. Normality was assessed with the Shapiro-Wilk Test ($P<0.05$) for all variables. Pearson correlations were employed to determine collinearity for regression analysis. The average descriptive statistics and Pearson correlations are displayed in Table 5.1.

Repeated measure analyses of variance (ANOVAs) were utilized to assess if any interactions were seen for condition x age group comparison. The absolute walking speeds and ten-year age groups were used for both self-selected and fast paced walking speed comparisons. If no interaction was noted, significant main effects were analyzed with Bonferroni pairwise analysis to determine which groups were statistically different.

Main effect means and mean differences were presented with the standard errors (SE). One-way ANOVAs with Tukey post hoc analysis were performed to assess differences in DTC across age groups for self-selected walking speed, fast paced walking speed, and the performance of the bimanual task. Outliers, defined as >2 standard deviations (SD) from the mean, were excluded from analysis. Effect sizes (η^2) were generated by the ANOVAs and were interpreted as follows: small if <0.01, medium at 0.06, and large if > 0.14.[34]

For the first aim of this study, multiple linear regressions were used to assess if any of the independent variables were predictors of DTC on either self-selected or fast paced walking speed. No interaction variables were noted throughout the analysis. Variables were removed stepwise from the model if the model itself did not meet significance ($p<0.05$) and the variables were not a significant part of the model ($p>0.20$). Variance Inflation Factor and Tolerance factors were incorporated to further assess collinearity. The Mahalanobis (chi-square ≤0.001) and Cook's Distances (scores ≥1) were used to determine if outliers were apparent in the model.

For the second aim of this study, a prioritization chart (a Cartesian coordinate plane) was used to help determine if participants focused more on performing the primary task or secondary task, or if the performance on both or neither tasks suffered. Individuals were counted in the quadrant in which their scores were displayed (Figure 5.3). If a person appeared to be on the boundary line, the investigator used the calculated totals to see which quadrant the person should be placed.

RESULTS

Eighty-one subjects participated in the study, 52 women and 29 men; 72 reported being right-hand dominant. Three individuals reported at least one fall within the past year: two in the 50-59 cohort and one in the 80+ age group. Means for all independent variables and walking speed for self-selected and fast paced trials by condition are presented in Table 5.1. Pearson correlations (Table 5.1) between the DTC for self-selected and fast paced walking speed and the nine independent variables: age, activity self report, MoCA, ABCS, FR, FSST, DTQ-D, DTQ-F, and the DTC of the bimanual task.

Age and Dual-Task Effects on Self-Selected Walking Speed

The means for single and dual task performance for self-selected walking speed are pictured in Figure 5.2.A. Two participants were removed as outliers as they both walked 2 SD faster than the mean. There was no condition x age group interaction effect on self-selected walking speed ($n=79$, $p=0.16$, $\beta=0.58$, $\eta^2=0.12$), nor were there significant main effects for condition ($n=79$, $p=0.18$, $\beta=0.27$, $\eta^2=0.03$) or age group ($n=79$, $p=0.31$, $\beta=0.45$, $\eta^2=0.09$). Therefore, self-selected walking speed for healthy adults was not influenced by condition (single vs dual task) or by age group. There was also no main effect of age group on DTC of self-selected walking speed ($n=79$, $p=0.141$, $\beta=0.11$, $\eta^2=0.14$).

Age and Dual-Task Effects on Fast Paced Walking Speed

Mean fast walking speeds for each age group are presented in Figure 5.2.B. There was no condition x age group interaction on fast walking speed ($n=81$, $p=0.88$, $\beta=0.16$, $\eta^2=0.03$). There were significant main effects of condition ($n=81$, $p<0.0001$, $\beta=1.0$,

η^2=0.39). The mean single task walking speed was 1.98(0.03) m/s and 1.89(0.03) m/s for the dual task condition. There was a mean difference of -0.09(0.01) m/s as the dual task condition was significantly slower than the single task condition. Main effects were also noted between age group (n=81, p=.024, β=.82, η^2=0.18). The 80+ year old group walked at an average 1.67(0.09) m/s which was significantly slower than the 60-69 year old group (2.03[0.72] m/s). The mean difference between these two groups was -0.36(0.11) m/s as this further illustrates the 80+ age group walked slower on average than the 60-69 age group. The ten-year age groups were not significantly different for DTC on fast paced walking (n=78, p=0.963, β=0.05, η^2=0.02).

Age and Dual-Task Effects on Bimanual Task Performance

Two outliers were removed for self-selected walking speed analysis. No condition x age group interaction was present for performance while walking at self-selected speed (n=79, p=0.27, β=0.48, η^2=0.10). There was a statistically significant main effect of condition (n=79, p<.0001, β=1.0, η^2=0.46). There was a mean difference of -2.81(0.29) mm as individuals turned the nut on average significantly less during dual task (17.74[0.47] mm) than during single task (20.02[0.54] mm). Furthermore, there were statistically significant differences between age groups (n=79, p<.0001, β=0.99, η^2=0.31). Significant differences were found between the 70-79 age group (15.71[1.18] mm) and the 30-39 (21.80[1.35] mm, p=0.02) and the 50-59 (21.44[1.23] mm, p=0.03) age groups. Furthermore, the 80+ age group (14.00[1.35] mm) demonstrated statistically significant differences from the 20-29 (21.05[1.35] mm, p=0.01), 30-39 (21.80[1.35] mm, p=0.002) and the 50-59 (21.44[1.23] mm, p=0.002) age groups. This indicates that the dual task effect on the bimanual task is not influenced by age, but that overall performance on the task deteriorates with increased age.

Similarly, no condition x age group interaction was detected for bimanual task performance during fast paced walking (n=81, p=0.809, β=0.18, η^2=0.04). There was a significant main effect of age group (n=81, p<.0001, β=0.99, η^2=0.36), but no main effect of condition (n=81, p=0.09, β=0.39, η^2=0.04). The 70-79 age group (15.94[1.08] mm) demonstrated significantly less nut displacement than the 20-29 (22.05[1.23] mm, p=.01), 30-39 (21.80[1.23] mm, p=0.01), and 50-59 (22.27[1.13] mm, p=0.003) age groups. Furthermore, the 80+ age group (14.80[1.23] mm) also demonstrated significantly less nut displacement from the 20-29 (22.05[1.23] mm, p=0.002), 30-39 (21.80[1.23] mm, p=0.003), 40-49 (20.68[1.23] mm, p=.03), and 50-59 (21.80[1.23] mm, p=0.001) age groups. These results indicate that increased age is a factor in overall bimanual task performance, but no overall interaction or change in the performance between single and dual task performance during fast paced walking.

The analysis for the DTC on the bimanual task yielded statistically significant main effect of age group (n=80, p=.01, β=0.31, η^2=0.25) for self-selected walking but not for fast paced walking (n=80, p=.058, β=0.13, η^2=0.15; Figure 5.2.C).

Predictors of DTC for Self-selected and Fast Paced Walking Speed

Regression analysis was performed to determine if any of the independent variables were predictors of the DTC for self-selected walking speed and fast paced walking speed when the bimanual task was implemented. No curvilinear relationship was discovered. Regression analysis found FR and DTQ-D were significant predictors for DTC of self-selected and fast paced walking speed. For DTC on self-selected walking speed, FR and DTQ-D explained 7.2% of the variance (R^2=0.07, p=0.02). These same variables explained 7.7 % of the variance (R^2= 0.08, p=0.02) for the DTC on fast paced walking speed. Partial correlations for FR were 0.25 for DTC on self-selected walking speed analysis and 0.31 for the DTC on fast paced walking speed analysis. The partial correlations for the DTQ-D were -.16 and -.17 respectively. The regression equations are listed as follows:

DTC Self-Selected Walking Speed = -4.32 +.68 (FR) -.06 (DTQ-D)

DTC Fast Paced Walking Speed = -15.8 +.67 (FR) -.05 (DTQ-D)

Task Prioritization during Dual-task Self-selected and Fast Walking

Figure 5.3.A&B provides the prioritization plots with the subjects being grouped by age. The mean DTC for the self-selected and fast paced walking speed compared to the mean bimanual performance during that condition are provided in Figure 5.3.C&D. At the self-selected walking speed, 49.4% of participants prioritized their self-selected walking speed over the bimanual task; 37% experienced mutual interference; 11.1% demonstrated mutual facilitation; 2.5% prioritized the bimanual task over their walking. The pattern of prioritization was slightly different for the fast paced walking speed condition, with more participants experiencing mutual interference (50.6%); 28.4% prioritized to the bimanual task over walking; 14.8% chose to focus their attention on walking over the bimanual task; 6.2% experienced mutual facilitation.

The self-selected walking speed plot illustrates that only two of the age groups (50-59 and 80+ age groups) demonstrated mutual interference while the remaining age groups preferred to focus on their walking speed. On average, all groups experienced mutual interference during fast paced walking (Figure 5.3.C&D).

DISCUSSION

In general, self-selected walking speed was not affected by condition or age. Fast paced walking speed, however, was influenced by both condition and age, but there was no interaction between the two. Individuals over 80 demonstrated slower walking speeds than 60 year olds. Also, participants collectively walked slower during the dual task condition than during the single task condition for fast paced walking. Dual task cost for both self-selected or fast paced walking speed was better predicted by functional reach and perceived difficulty of dual task rather than age as these factors both relate to self-efficacy and mobility.[27,35,36] This findings may allude to age not being a definitive factor in assessing how someone's DTC will be impacted. Other measurements of function may need to be further assessed to truly understand how healthy adults respond to dual task situations. Furthermore, individuals prioritized the tasks differently based on walking speed and age which may be explained by a decrease in attentional resources and the overall complexity of the tasks.

Self-Selected and Fast Paced Walking Speed by Age

The findings from this study suggest that chronological age was not a strong or significant indicator of the DTC for walking speed, at least for healthy, active adults. Previous studies indicated a difference between younger and older cohorts for dual task walking speed performance [13-17]; however, the results indicated the dual-task effect on walking speed was not influenced by age. This was demonstrated by the absence of any interaction effects on walking speed and the absence of significant age main effects on DTC on walking speed. There was, however, a significant effect of age on fast paced walking speed with those in the 80+ cohort walking slower than the 60-69 cohort. This finding may have been coincidental as there were larger variabilities in the covariance of the cohorts.

Dual task cost and differences in absolute walking speed between conditions may be better understood and predicted using measurements of functional age.[35-38] Age and walking speed is strongly related to declines in a variety of abilities: hand grip strength, cognition, mood, vision, and the presence of comorbid conditions.[35-38] This multifactorial theory possibly explains why the participants did not differ in regards to their single and dual task walking speed. All of the participants in this study were cognitively intact, and free of comorbid conditions or disease processes that would hamper their everyday lives. Without the concurrent disabilities and impediments, the participants were more likely to have higher confidence levels, mobility, and awareness to attend to their walking similarly in both conditions.

Predicting of Dual Task Cost for Self-Selected and Fast Paced Walking Speed

Functional reach and perceived difficulty of dual task situations predicted DTC of both self-selected and fast paced walking speed while age and the other independent variables did not. These two variables are closely related to functional mobility and frailty. Functional reach has previously been identified as an indicator of frailty with people reaching less than 6 inches qualifying as more frail.[27] In this study, both regressions found a positive relationship between the DTC on gait speed and FR. This means that as FR increased, gait speed during the dual task condition also increased.

Though the strength of this relationship is relatively weak, this result provides some evidence that individuals who are less frail are able walk more quickly while performing a bimanual task.

The DTQ-D addressed a psychosocial aspect of the individuals. It measured the participants' perceived difficulty with dual task conditions. The results demonstrated that as perceived difficulty increases, individuals walk slower during the dual task condition. This results is important, as decreased self-efficacy and mood have been shown to be further indicators of frailty, fall risk, and general health.[35,36] Both of these results depict a reality that using chronological age is not a strong tool to predict how someone will perform with dual task conditions. Instead, factors that address frailty and self-efficacy may be better tools to help clinicians appropriately dichotomize their patients and approaches.

Task Prioritization

The prioritization strategy differed between the two gait speed conditions, which imply differences in the attentional demands between self-selected walking and fast-paced walking. Indeed, there was a main effect of condition (single, dual) at fast walking speed but not a self-selected walking speed. This may indicate that fast walking speed may be a more complex task than self-selected walking speed. Furthermore, while age was not a main effect for the DTC of self-selected or fast paced walking speed, there was an influence of age on the DTC of the bimanual task for self-selected walking speed. The performance of the secondary task is influenced by age and may lead to differing attentional prioritization strategies.

At self-selected walking speed, older adults tended to demonstrate more mutual interference while younger individuals chose to focus more on their walking than the bimanual task. There may be a few reasons why these approaches differed. Older adults may perceive more difficulty with dual task conditions than younger adults. This belief may cause older adults to perceive more consequences for mistakes during dual task performance (i.e. falls with an injury). Moreover, the task may not have been challenging enough to cause younger adults to actually attend to the manual task, but the main effect of the DTC on the bimanual task for age indicates that older adults do not perform as well as younger which also may change attentional prioritization strategies. This manual task lacks a cognitive component and may provide different results than a manual task that requires more attentional demand such as texting. Therefore, younger adults chose to focus on walking over the manual task because they had the attentional capacity to shift their attention between walking and the manual task.

For fast paced walking, all age groups experienced mutual interference. This is possibly because fast paced walking is inherently a more complex task than self-selected walking speed.[7] Individuals use their self-selected walking speed for usual activities. This means that fast paced walking is practiced less and with possibly even less practice during dual task conditions (e.g. texting and cross a street quickly). The increased complexity of the walking may have led to a different approach to prioritization and a decreased ability to focus on one task or switch between tasks.

There were some limitations to this study. All adults in this study were active, healthy adults with no cognitive deficits and were not considered to be frail according to testing. While this may have led to homogeneity between age groups, the results emphasize the necessity to focus on measurements of functional age and self-efficacy as a means to predict performance. Secondly, the interaction analysis during the repeated measure ANOVA's may be underpowered. However, it should be noted that the effect sizes for these comparisons were small indicating a decreased likelihood an error occurred. Furthermore, the main effects reported excellent power and large effect sizes. The results from the regression analysis indicate weak partial correlations; however, the results were significant for this study and help to emphasize the need to address functional age and self-efficacy. Also, there may have been a fixed order effect; however, this protocol was maintained as self-selected walking speed may have been inflated when it followed the fast paced walking speed during pilot studies.

CONCLUSION

In conclusion, chronological age was not an indicator or predictor of performance or DTC. Measurements of functional age and self-efficacy may be more important to predict a patient's performance at dual task conditions. Clinicians may need to focus on measurements of functional age and self-efficacy, as these may provide a better representation of the person's abilities during everyday situations.

Older adults experienced more mutual interference than younger adults during self-selected walking speed. Moreover, individuals prioritized differently for each condition suggesting that fast paced walking speed may be more demanding in regards to attention. This illustrates the necessity to examine different levels of complexity for both tasks in clinical populations as different levels of complexity influence prioritization.

Further research is necessary to investigate how varying degrees of functional age influence DTC and prioritization. This is necessary for clinicians to appropriate categorize their patients and chose appropriate treatments.

Table 5.1: Average Descriptive Statistics for All Independent Variables, Average Walking Speed for Self-selected and Fast Paced Walking by Condition, and Pearson Correlations between the Dual Task Cost for each Walking Speed Task and the Independent Variables

Mean and Standard Deviation for all Independent Variables							
	Activity	MoCA	ABCS (%)	FR (in)	FSST (s)	DTQ-D	DTQ-F
Mean (SD)	4.1 (1.5)	27.9 (1.9)	92.4 (8.6)	12.3 (2.4)	6.8 (2.0)	58.6 (17.8)	36.9 (10.2)

Mean and Standard Deviation for Walking Speed by Age Group and Condition							
Age Groups (years)	20-29	30-39	40-49	50-59	60-69	70-79	80+
N	10	10	10	12	16	13	10
SS (m/s)	1.39 (0.15)	1.38 (0.26)	1.48 (0.17)	1.35 (0.22)	1.43 (0.30)	1.48 (0.20)	1.32 (0.18)
SS-B (m/s)	1.41 (0.13)	1.41 (0.27)	1.54 (0.17)	1.34 (0.27)	1.49 (0.31)	1.49 (0.20)	1.28 (0.19)
FP (m/s)	2.08 (0.19)	2.08 (0.31)	2.05 (0.24)	1.89 (0.36)	2.05 (0.26)	1.96 (0.31)	1.68 (0.24)
FP-B (m/s)	2.01 (0.20)	1.97 (0.31)	1.96 (0.29)	1.84 (0.27)	1.95 (0.29)	1.86 (0.29)	1.59 (0.26)

Pearson Correlations									
	Age	Act.	MoCA	ABCS	FR	FSST	DTQ-D	DTQ-F	DTC-T
DTC-SS *p-value*	**-.25 (.03)**	.06 (.61)	.07 (.57)	.12 (.30)	**.27 (.02)**	-.16 (.16)	-.19 (.09)	.22 (.05)	.02 (.92)
DTC-FP *p-value*	-.10 (.38)	.17 (.13)	-.05 (.65)	.15 (.20)	.16 (.16)	-.14 (.20)	.01 (.95)	.11 (.34)	-.10 (.38)

Activity is based on ACSM recommendations: numbers over three met recommendations with six being the highest amount.
DTQ-D: Higher values indicates higher difficulty with dual task activities
DTQ-F: Lower values indicates less frequency and experience with dual task activities
Abbreviations: MoCa, Montreal Cognitive Exam; ABCS, Activities Balance Confidence Scale; FR, Functional Reach; in, inch; FSST, four square step test; s., seconds; SS, self-selected walking speed; SS-B, self-selected walking speed during dual task; FP, fast paced walking speed; FP-B, fast paced walking speed during dual task; m/s, meters per second; DTQ-D, dual task activity questionnaire – difficulty portion; DTQ-F dual task activity questionnaire – frequency portion; Act., activity self-report; DTC, dual task cost; COP, Center of Pressure path length; EA, 95% Ellipse Area; DTC-T, dual task cost of bimanual task
Bold for correlations indicates significant correlations.

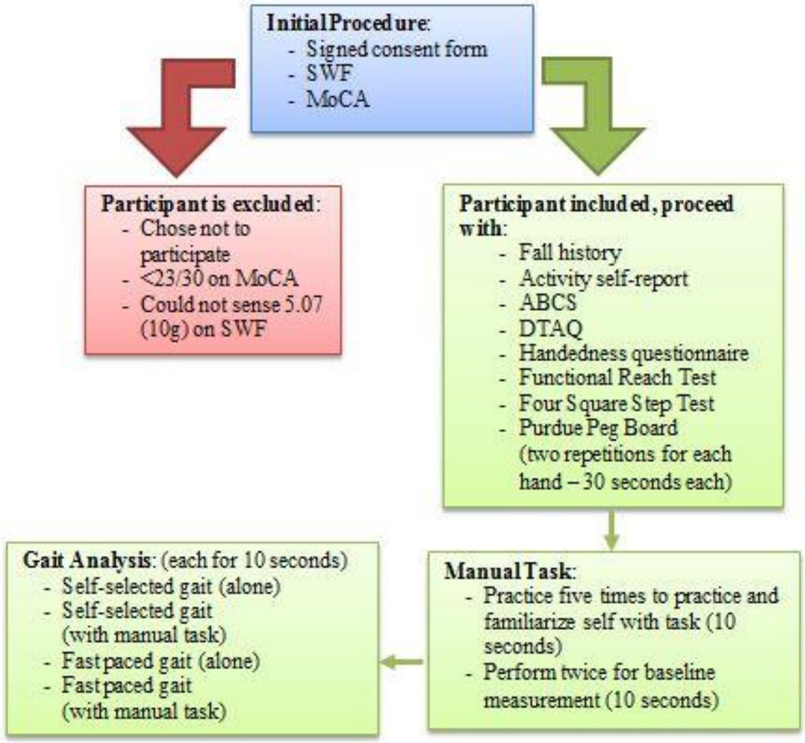

Figure 5.1: A flowchart depicting the progression of the study.
Abbreviations: MoCA – Montreal Cognitive Assessment, SWF – Semmes Weinstein Filament, ABCS – Activities Balance Confidence Scale, DTAQ – Dual Task Activities Questionnaire

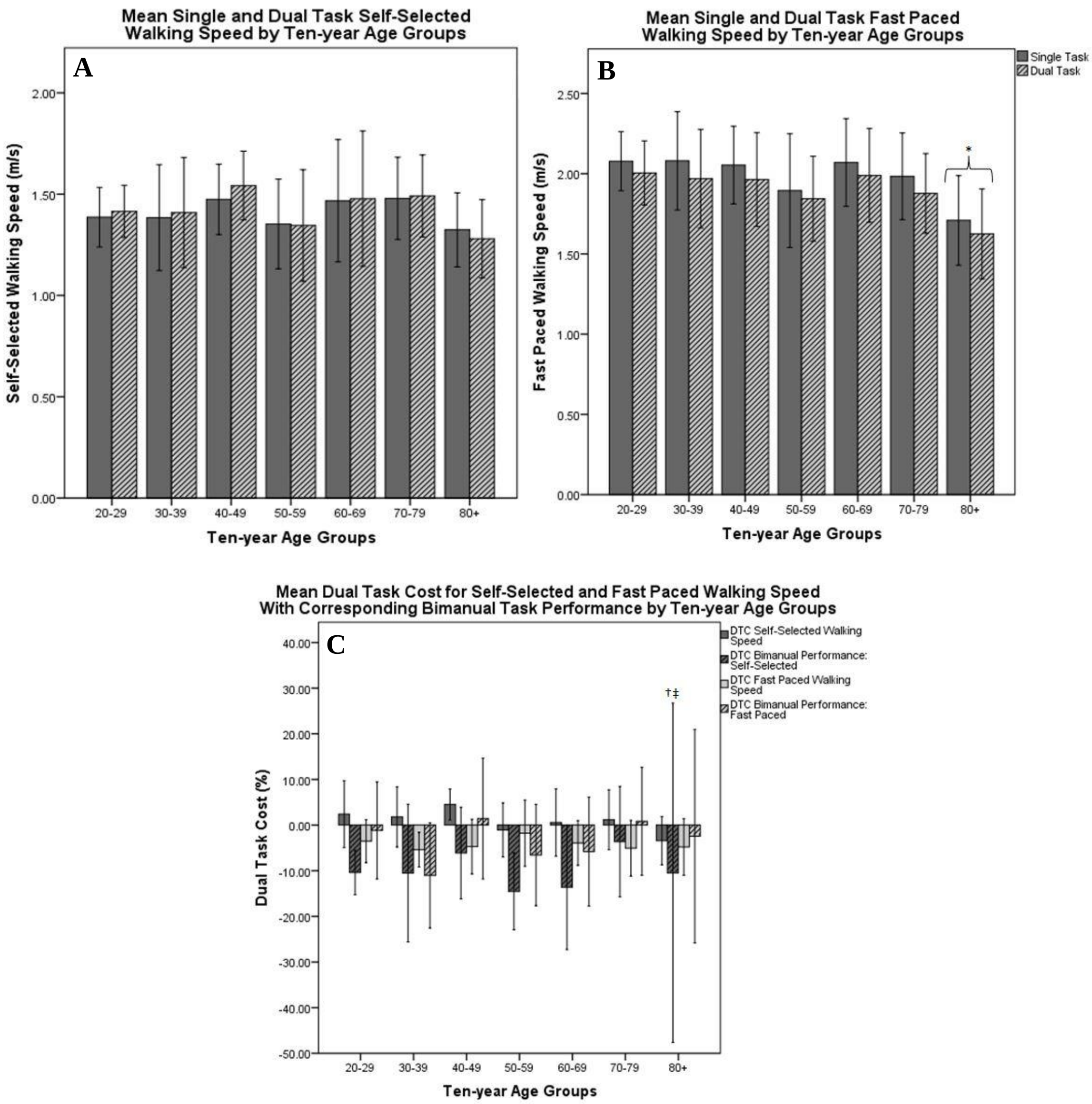

Figure 5.2: Mean single and dual task self-selected and fast paced walking speed (Chart A) and the bimanual task performance (Chart B) are presented by ten-year age groups. Chart C depicts the dual task cost (DTC) by ten-year age groups for the self-selected walking speed, fast paced walking speed, and bimanual task during both activities. Statistically significant differences ($p < .05$) are denoted by black symbols for differences between single task conditions (and DTC) and grey symbols for differences between dual task conditions. Age groups are denoted by: †, 40-49; *, 60-69; ‡, 70-79.

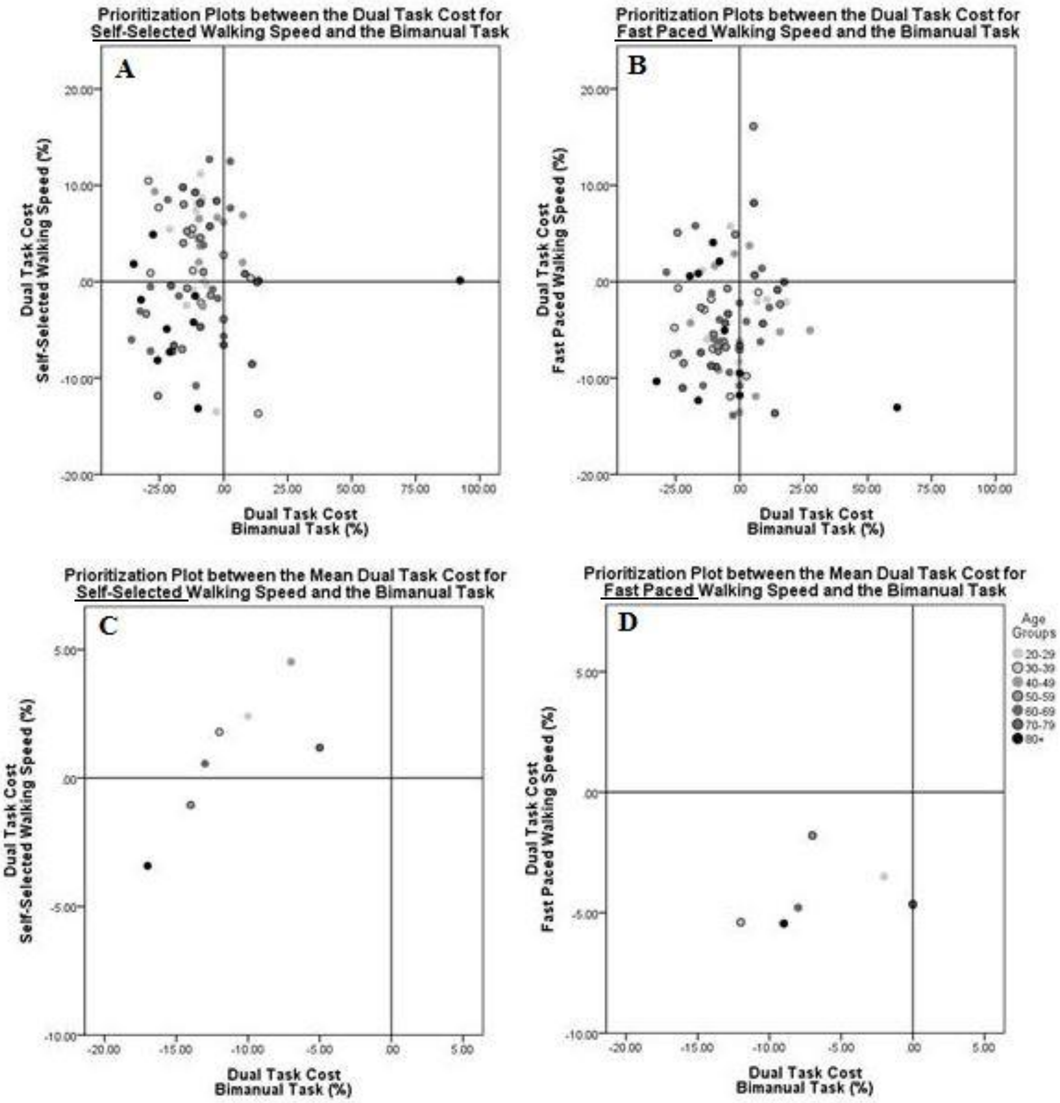

Figure 5.3: Prioritization plots for the dual task costs (DTC) of the self-selected and fast paced walking speed versus the DTC of the bimanual task (A and B). Prioritization plots for the mean DTC of self-selected and fast paced walking speed by the mean DTC of the bimanual task for the ten-year age groups. The points in the upper, right quadrant demonstrate mutual facilitation. The points in the upper, left and lower, right quadrants depict more attention given to either the walking task or bimanual task, respectively. The points in the lower, left quadrant show the participants experience mutual interference.

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CHAPTER 6

SUMMARY OF FINDINGS

6.1 Center of Pressure and 95% Ellipse Area are affected by Age and Measurements of Function

Chronological age appeared to be factor in postural sway and postural sway reserve. Older adults exhibited greater postural sway than their younger counterparts (<60 years old) during both conditions. This may indicate that older adults have less postural reserve which would influence their ability to correct their balance if a perturbation were to happen.[10] Measurements of cognition, frequency of experiencing everyday dual task situations, and the dual task cost of the manual task also were predictors of the dual task cost for the 95% ellipse area. This indicates that measurements of function (variations of functional age) must be taken into consideration in addition to chronological age when determining how much dual task cost for the 95% ellipse area is associated with the addition of a bimanual task. For prioritizing tasks, older adults may not have the capacity to attend to both tasks equally as well as may perceive more consequences (i.e. falls, injuries) than their younger counterparts.

6.2 Functional Measurements hold a Bigger Influence on Walking Speed than Chronological Age

Chronological age was not associated with varying walking speeds for both self-selected and fast paced walking for either condition. Functional measurements, functional reach and perceived difficulty with everyday dual task situations, were weak predictors of the dual task cost associated with both self-selected and fast paced walking speed. These measurements are indicators of frailty as well as self-efficacy which are important in maintaining healthy walking techniques.[56,68,69] This emphasizes a need in the clinical setting to focus on measurements of functional age as they may lead to a better understanding of the patient's quality of life and ability to improve. For prioritization, younger adults (<60 years old) chose to prioritize the walking task over the bimanual task while older adults experienced mutual interference of both tasks. This may be from a variety of reasons: the bimanual task was not complex;[70] the younger adults perceived few consequences (i.e. falls, injuries) from dual tasking; or the older adults may not have had the capacity to switch between tasks adequately. For fast paced walking, all groups experienced mutual interference as increasing the speed increased the complexity of the task. Fast paced walking is not usually performed continuously and, very rarely, performed with another task simultaneously.[70] In conclusion, the complexity of the tasks and individual's functional age should be taken into consideration when determining the dual task cost on walking speed when implementing a bimanual task.[68-70]

6.3 Limitations for the Overall Study

The overall study did have a few limitations. First, all subjects were considered healthy and active individuals. This may have caused some independent variables that would be predictors for varying health statuses to be excluded from the model. However, measurements of functional age (e.g. Montreal cognitive exam, functional reach) were predictors of dual task cost and further lead investigators to explore these and other measurements of functional age with varying populations. Secondly, despite the randomization of the balance and walking tasks, the sub-tasks were not randomized and may lead to a fix order effect. However, for the walking speed tasks, performing fast paced walking speed before self-selected walking speed may artificially increase their self-selected walking speed. Lastly, the individuals were not asked about the complexity of the tasks, therefor it is not possible to determine if the dual task cost was based upon the subjective complexity of the tasks. Future studies should utilize varying degrees of health and activity, subjective questions about perceived complexity of the tasks, and questions of fear and avoidance of dual tasks.

6.4 Clinical Implications

Clinicians would benefit from this information as this study reports that measurements of functional age need to be measured to fully understand the abilities of the patient. Measuring functional age gives a better representation of frailty, cognition, and perceived difficulty with dual tasking. Older adults, much like any patient, are very complex and vary depending on health status and activity level. While more research is needed to determine how people of varying abilities and activity levels differ, understanding how individuals perform dual tasks could lead to better screening, evaluation, and treatment of older adults and increase their overall quality of life.

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APPENDIX A

PRELIMINARY OUTCOME MEASURES

A.1 Fall History Questionnaire[52]

1.) In the past year, how many times have you fallen?

2.) What were you doing at the time of your fall?

3.) What do you think contributed to you fall? (ex: slick surface, catching toe)

4.) Did any of these falls result in an injury?

  a. If yes, what was the injury?

  b. Did you seek medical treatment?

A.2 Activity Self-Report[63]

7-Day Physical Activity Recall

PAR#: 1 2 3 4 5 6 7 Participant______________________________

Interviewer______________ Today is________ Today's Date_ ______

1. Were you employed in the last seven days? 0. **No** (Skip to **Q#4**) 1. **Yes**
2. How many days of the last seven did you work? ____ days
3. How many total hours did you work in the last seven days? ____ hours last week
4. What two days do you consider your weekend days? ____________ ____________ (mark days below with a squiggle)

WORKSHEET **DAYS**

	SLEEP	1 __	2 __	3 __	4 __	5 __	6 __	7 __
MORNING	Moderate							
	Hard							
	Very Hard							
AFTERNOON	Moderate							
	Hard							
	Very Hard							
EVENING	Moderate							
	Hard							
	Very Hard							
Total Min Per Day	Strength: ______ Flexibility:	______	______	______	______	______	______	______

4a. Compared to your physical activity over the past 3 months, was last week's physical activity more, less, or about the same?

1. More 2. Less 3. About the same

A.3 Dual-Task Activities Questionnaire[64,65]

Patient name: ________________________________ Date: ______________

Dual-Task Activity Questionnaire

This questionnaire asks about how difficult it is for you to combine two activities at once (e.g., to carry on a conversation while driving in a car) and how frequently you perform these types of multi-tasking activities. For each item below, please consider the activity combination and decide **how difficult** the activity is to perform, from "very easy" to "very difficult" and indicate **how frequently you encounter that situation** in a typical month (none, a few times, or often). Please provide one answer for difficulty and frequency for each item.

	How difficult is this?					*Times per month*		
	Very easy	Easy	Moderate	Hard	Very hard	None	Few (1-6)	Often (>6)
1. Driving while talking with someone else who is in the car with you								
2. Driving while talking on the phone to someone								
3. Driving while reading road signs (e.g., to exit from a highway or find a particular street name)								
4. Driving while listening to music								
5. Driving while planning a schedule or a shopping list								
6. Watching TV while reading a book or magazine								
7. Talking with someone while a television show is on in the room								
8. Talking while playing cards or a board game								
9. Talking to someone while searching for something on a computer or cellular phone								
10. Talking to someone in the midst of a crowd of people talking loudly nearby								
11. Talking to someone while preparing a meal								
12. Listening to a group conversation while reading/typing on your cellular phone								
13. Talking on the phone while checking a calendar or appointment book								
14. Talking on the phone while someone in the room is talking to you								

Patient name: ______________________ Date: ______________

	How difficult is this?					*Times per month*		
	Very easy	Easy	Moderate	Hard	Very hard	None	Few (1-6)	Often (>6)
15. Listening to music while reading								
16. Listening to music while doing paperwork								
17. Listening to someone talk while planning your reply								
18. Remembering a person's name while you are being introduced								
19. Doing household chores while thinking about other things								
20. Walking while having a conversation with someone who is walking with you								
21. Walking while having a conversation with someone on the phone								
22. Walking while typing a text message or email								
23. Walking while reading a text message or email								
24. Walking while carrying a drink or cup that is full								
25. Walking while searching for something in your pocket or bag								
26. Walking while putting on or buttoning a jacket								
27. Talking while exercising (running, biking, elliptical, etc.)								
28. Reading while exercising on a machine								

Difficulty score: ______ **Frequency score:** ______

Scoring:

Difficulty score: sum of all items, with very easy = 1, easy = 2, moderate = 3, hard = 4, very hard = 5.

Frequency score: sum of all items, with none = 0, few = 1, often = 2.

P Plummer, CA Giuliani, JA Feld, LA Zukowski. University of North Carolina at Chapel Hill, Chapel Hill, NC

Questionnaire adapted from Tun PA, Wingfield A. Does dividing attention become harder with age? Findings from the Divided Attention Questionnaire. Aging and Cognition 1995;2(1):39-66.

A.4 Handedness Questionnaire[66]

Which hand to you use to….	Left Hand	Right Hand	Either
Write			
Draw			
Throw a ball			
Hold a racket			
Hold a toothbrush			
Hold a knife to cut			
Hold a hammer			
Hold a match to light			
Hold an eraser			
Remove a card from a deck			
Hold thread to thread a needle			
Hold a fly swatter			
Total Responses			
Adjusted			
Score and Handedness			

Determining Score:

1.) Count number of Left, Right and Either responses
2.) Multiply the number of Right responses by 3.
3.) Multiple the number of Either responses by 2.
4.) Add R + E + (number of Left responses). Sum is the Handedness Score.

Interpretation	
Score	Handedness
33 - 36	Strongly Right Handed
29 - 32	Moderately Right Handed
25 - 28	Weakly Right Handed
24	Ambidextrous
20 - 23	Weakly Left Handed
16 - 19	Moderately Left Handed
12 - 15	Strongly Left Handed

A.5 Activities-specific Balance Confidene Scale[53]

The Activities-specific Balance Confidence (ABC) Scale*

For each of the following activities, please indicate your level of self-confidence by choosing a corresponding number from the following rating scale:

0% 10 20 30 40 50 60 70 80 90 100%
no confidence completely confident

"How confident are you that you will not lose your balance or become unsteady when you…

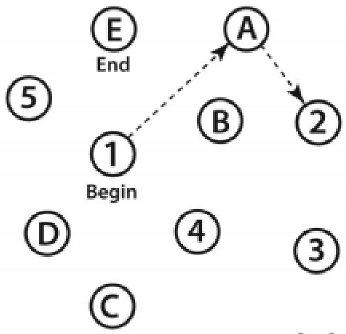
____% walk around the house?
____% walk up or down stairs?
____% bend over and pick up a slipper
____% reach for a small can at eye level?
____% stand on your tiptoes and reach for something?
____% stand on a chair and reach for something?
____% sweep the floor?
____% walk outside to a car?
____% get into or out of a car?
____% walk across a parking lot?
____% walk up or down a ramp?
____% walk in a crowded mall?
____% are bumped into by people?
____% step onto or off an escalator while you are holding onto a railing?
____% step onto or off an escalator while not holding the railing?
____% walk outside on icy sidewalks?

A.6 Montreal Cognitive Assessment[51,67]

MONTREAL COGNITIVE ASSESSMENT (MOCA)
Version 7.1 Original Version

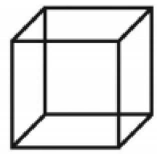
Education :
Sex :
Date of birth :
DATE :

VISUOSPATIAL / EXECUTIVE | POINTS



[ ]

Copy cube



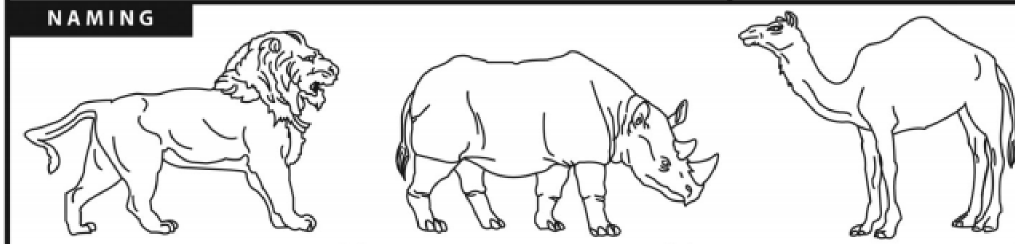
[ ]

Draw CLOCK (Ten past eleven)
(3 points)

[ ] Contour [ ] Numbers [ ] Hands

__/5

NAMING



[ ] [ ] [ ]

__/3

MEMORY Read list of words, subject must repeat them. Do 2 trials, even if 1st trial is successful. Do a recall after 5 minutes.

	FACE	VELVET	CHURCH	DAISY	RED
1st trial					
2nd trial					

No points

ATTENTION Read list of digits (1 digit/ sec.).
Subject has to repeat them in the forward order [ ] 2 1 8 5 4
Subject has to repeat them in the backward order [ ] 7 4 2
__/2

Read list of letters. The subject must tap with his hand at each letter A. No points if ≥ 2 errors
[ ] F B A C M N A A J K L B A F A K D E A A A J A M O F A A B
__/1

Serial 7 subtraction starting at 100 [ ] 93 [ ] 86 [ ] 79 [ ] 72 [ ] 65
4 or 5 correct subtractions: **3 pts**, 2 or 3 correct: **2 pts**, 1 correct: **1 pt**, 0 correct: **0 pt**
__/3

LANGUAGE Repeat : I only know that John is the one to help today. [ ]
The cat always hid under the couch when dogs were in the room. [ ]
__/2

Fluency / Name maximum number of words in one minute that begin with the letter F [ ] ____ (N ≥ 11 words)
__/1

ABSTRACTION Similarity between e.g. banana - orange = fruit [ ] train – bicycle [ ] watch - ruler
__/2

DELAYED RECALL	Has to recall words **WITH NO CUE**	FACE [ ]	VELVET [ ]	CHURCH [ ]	DAISY [ ]	RED [ ]	Points for UNCUED recall only	__/5
Optional	Category cue							
	Multiple choice cue							

ORIENTATION [ ] Date [ ] Month [ ] Year [ ] Day [ ] Place [ ] City
__/6

 www.mocatest.org Normal ≥ 26 / 30 TOTAL __/30

APPENDIX B

INFORMED CONSENT

UNIVERSITY OF SOUTH CAROLINA

THE NORMAN J. ARNOLD SCHOOL OF PUBLIC HEALTH

Study to Assess the Task Automaticity and Prioritization of Postural Sway and Walking Speed when Performing a Bi-manual Task

Primary Investigators: Derek Liuzzo, DPT and Stacy Fritz, PT, PhD

Introduction
You are being asked to take part in a research study offered by the Department of Exercise Science at the University of South Carolina. This form provides you with information about the study. The Principal Investigators (the people in charge of this research) or a member of the research staff will also describe this study to you and answer all of your questions. Before you decide whether or not to take part, read the information below carefully and ask questions about anything you do not understand. You will be given a copy of this form to keep for your records.

Purpose of Study
Performing two tasks at once is an essential part of life. People need to be able to interact with things around them while standing and walking to allow us to complete everyday activities. Simple tasks such as turning keys on a key ring, folding laundry, and searching through a bag require a level of attention and skill. Usually individuals are able to complete these tasks easily without affecting their balance and walking. However, as people age, this ability is likely to decrease causing an increased risk for falls. It is unknown how much of a decrease occurs over time, at what age this decrease becomes a concern, and if people chose which task to complete differently as they age. Therefore, **the purpose of this study is to determine if walking speed and balance decreases with age when a task that uses two hands is performed and if people of different ages accomplish these tasks differently.**

Description of Study Procedures

OVERVIEW

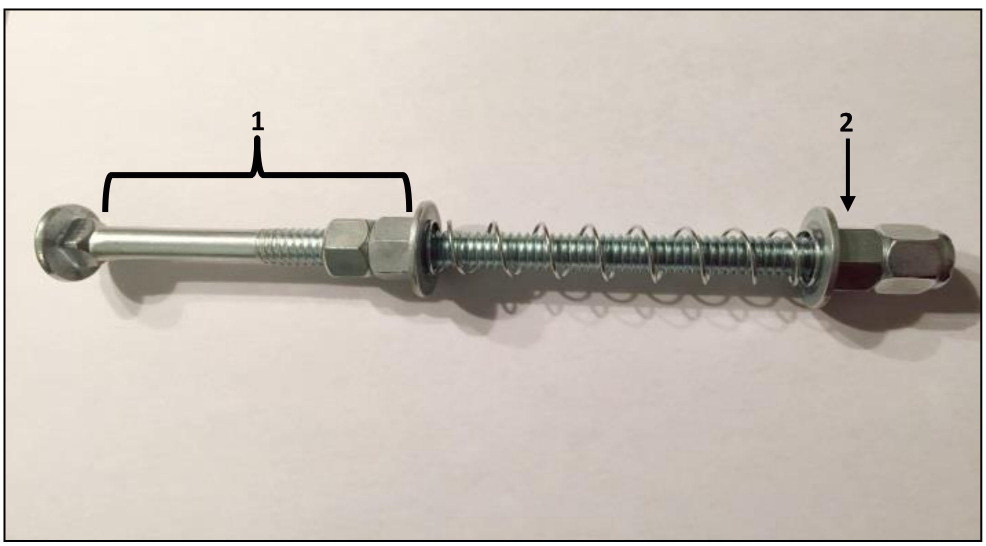
You are one of 70 subjects being asked to participate in a study that is investigating how your performance for balancing and walking is affected while you use your hands to complete a task. You are being asked to participate in this research because you are a healthy individual older than age 18. Additionally, you do not have 1.) neurological disorders (ex. Stroke, Traumatic Brain Injury), 2.) dizziness or lightheadedness within the past month, 3.) musculoskeletal problems that would affect your hand use, balance, or walking, 4.) loss of sensation in your hands or feet, and 5.) cognitive disorders (ex. Dementia, Alzheimer's Disease). All of these conditions could affect your balance and walking.

Duration of Involvement

For this study, you will be asked to participate in a 45 minute, one-time evaluation session.

EVALUATION SESSION

During the 45 minute evaluation session, you will be asked to complete questionnaires and perform tests that assess your memory, confidence with different activities, ability to move freely, the use of your hands, balance, and walking speed at your preferred pace and fast pace. For example, you may be asked to stand and lean as far as you can to test how well you can balance. Throughout the testing you will have someone with you at all times to ensure your safety. All that is requested is your best attempt.



Bi-manual Task: 1.)Held with the non-dominant hand & 2.) the nut turned with the dominant hand.

You will be given multiple chances to practice and familiarize yourself with the bi-manual task. The task is turning a nut on a bolt (pictured below). You will be asked to turn the nut at your preferred speed for 10 seconds for each attempt.
After you have practiced this task, you will be asked to either perform the balance or walking tasks first. The balance task consists of you standing on a small, flat force platform that measures how much you sway. You will be asked to stand comfortably on this platform for ten seconds for two attempts. You will then repeat while performing the bi-manual task.

The walking tasks will examine your preferred speed and your fast pace speed. Each set will have two attempts for 10 seconds. You will repeat these tasks again while performing the bi-manual task.

During the evaluation session, you may be recorded and/or photographed. **These videos and photographs will be shown for the purposes of research and education at the University of South Carolina; and for presentations at scientific meetings outside the University.** Your name and personal information will not be associated with your image in the photographs or videos; however, when the videotapes and photos are shown, others may recognize you. The Principal Investigators of this study, Derek Liuzzo and Dr. Stacy Fritz, or their successors, will keep the media files in a locked cabinet or on a secure server.

Risks of Participation

- Activities during the session may tire you. If so, you may take a rest break at any time.
- During the session, you may be at risk for a fall; however, precautions are being taken to keep you safe and decrease that risk. A spotter, trained to prevent falls, will accompany you at all times.

If you wish to discuss the information above or any discomforts you may experience, you may ask questions now or call the Principal Investigator.

Benefits of Participation

The benefits to you include improved knowledge about your abilities to perform two tasks at once and your fall risk. This information will allow you to determine if you need to modify your current activities or be more aware of performing two tasks at once as you age. Furthermore, you will be aiding in providing information that could improve screening and rehabilitation for those who may be at risk for falls.

Costs

There is no direct cost for participation in this research study. However, you may have costs for travel depending on how far you live from the evaluation sites.

Payments

You will not be reimbursed for participation in this study.

Compensation for Injury
In the unlikely event that you sustain an injury related to the research, the research staff will provide first aid and assist you in obtaining appropriate medical care; however, medical expenses will have to be paid by you or your insurance provider.

Confidentiality of Records
Authorized persons from the University of South Carolina and the Institutional Review Board have the legal right to review you research records and will protect the confidentiality of them to the extent permitted by law. No names will be used in reporting results in this study and in the process of data collection. All information used will be coded with an identification number given to the individual before any data is collected. This identification number will be used for all purposes of this research. Otherwise, your research records will not be released without your consent unless required by law or court order. The media files (video and images) will only be viewed by current and/or future research staff and may be used during presentations at scientific meetings outside the University or in educational presentations. In the case that your media files are not used for presentations, they will be destroyed. All research data, including media, will be kept in locked file cabinets in the offices of Derek Liuzzo, Dr. Stacy Fritz, or a secure server. If the results of this research are published or presented at scientific meetings, your identity will not be disclosed.

Contact Persons
- For more information concerning this research, you should contact Derek Liuzzo at (803) 968-2393.
- If you believe that you may have suffered a research related injury, contact Derek Liuzzo at (803) 968-2393 for further instructions.
- Questions about your rights as a research subject are to be directed to, Lisa Marie Johnson, IRB Manager, Office of Research Compliance, University of South Carolina, 1600 Hampton Street, Suite 414D, Columbia SC 29208, phone: (803) 777-7095 or email: LisaJ@mailbox.sc.edu. The Office of Research Compliance is an administrative office that supports the University of South Carolina Institutional Review Board (USC IRB). The Institutional Review Board consists of representatives from a variety of scientific disciplines, non-scientists, and community members for the primary purpose of protecting the rights and welfare of human subjects enrolled in research studies.

Voluntary Participation
Participation in this study is voluntary. You are free not to participate or to withdraw at any time, for whatever reason. In the event that you do withdraw from this study, the information you have already provided will be kept in a confidential manner.

Signatures/Dates
I have read (or have had read to me) the contents of this consent form and have been encouraged to ask questions. I have received answers to my questions. I give consent to participate in this study. I have received (or will receive) a copy of this form for my records and future reference.

____________________________________ ____________

Signature of Adult Consenting for Self **Date**

As a *representative of this study*, I have explained to the participant, the procedures, the possible benefits, and the risks of this research study; the alternatives to being in the study; and how privacy will be protected.

____________________________________ ____________

Signature of Person Obtaining Consent **Date**

For IRB Staff Use Only
University of South Carolina
IRB Number: Pro00053784
Date Approved 4/4/2016
Version Valid Until: 4/3/2017