CONCURRENT VALIDITY OF THE USE OF THE DARTFISH APPLICATION TO ASSESS MOTOR STRATEGY USE IN ADULTS

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DEDICATION

To my family and friends, I would not be here without your continued support and constant encouragement throughout this journey. Thank you for your never-ending reassurance and unwavering prayers.

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ABSTRACT

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Background: Motor strategy use changes with age, resulting in decreased balance and therefore an increased risk for falls. The importance of motor strategy activation in fall prevention is highlighted in current literature; however, physical therapists do not routinely examine motor strategy activation in clinical practice. There is limited available literature on how to objectively measure motor strategy use within a clinical setting given time and financial resource constraints. However, the use of the smart devices such as an iPad in clinical practice may provide a way to address this problem, and thus two studies were carried out. The purpose of the first study was to investigate the concurrent validity of the Dartfish ProSuite 7.0 software, which has been shown to be comparable to three-dimensional systems, and the Dartfish Express application (app) on an iPad 2 as a tool to measure start and stop ankle position during forward and backward ankle strategy activation. This affordable app has the potential to be used by clinicians in the clinic to objectively assess motor strategy use. The purpose of the second study was to investigate motor strategy use during an anticipatory stepping correction in an older adult sample compared with a younger adult sample using an iPad 2 and the Dartfish Express app. Comparisons of start and stop ankle position following forward and backward motor

strategy activation and the time from initiation to completion of a stepping strategy were examined.

Participants: 30 young adults (M= 26.5 ± 4.5 years) and 30 older adults (M= 72.6 ± 4.0 years).

Methods: A two-camera set up was used for study one: an iPad 2 and Sony camera lens at equal heights. A one-camera setup with an iPad 2 was used for study two. In both studies, markers were placed on bony prominences on participants' left side. Participants were read modified Mini-BESTest instructions for forward and backward compensatory stepping corrections. The Dartfish app and ProSuite software was used to measure the ankle start position (degrees) prior to initiation of an ankle strategy, stop position (degrees) immediately following the completion of ankle strategy use, and the time (seconds) it took to initiate and complete a compensatory step.

Results and discussion: In study one, Pearson's product moment correlation coefficient statistic showed an excellent relationship ($r > 0.75$) between the Dartfish ProSuite 7.0 software and the Dartfish Express app on an iPad 2 for all four positions. Thus, the app's use is appropriate to assess anticipatory motor strategies. Dependent t-test was used to compare means between the two devices. No significant differences were found between forward stop/start and backwards start/stop positions between devices. Therefore, only the iPad 2 and the Dartfish Express app were used in study two. For the second study, independent t-tests were used to compare the difference in ankle start and stop positions between the older and younger adults. A statistically significant difference

was found in the forward ankle stop position (p= 0.01) that could be indicative of a more reserved anticipatory postural response from older adults. The reserved anticipatory postural response could be a result of increased fear of falling, decreased confidence in the participant's ability to regain his or her balance beyond that point, or bias from previous experiences in loss of balance episodes. No other significant differences were found. Independent t-tests were also used to compare differences between forward and backward mean-time from initiation to completion of a stepping reaction; no significant differences were noted between older and younger adults.

Conclusions: Overall, findings of these studies support the use of the Dartfish Express app as a tool to measure motor strategies and reinforce the importance of clinically assessing motor strategies. Further investigations should evaluate the reliability of the Dartfish Express app, as one considers the use of the app as a primary outcome tool for an intervention targeting motor strategy training.

TABLE OF CONTENTS

APPENDICES

LIST OF TABLES

LIST OF FIGURES

Figure | Page

CHAPTER I

INTRODUCTION

Background

In 2014, a total of 27,044 unintentional falls resulting in death were reported for adults aged 65 years and older (Center for Disease Control and Prevention [CDCa], 2016). A 71.1% increase in the number of deaths from falls in this population was reported compared to 2005 with a yearly average increase of 6.2% (CDCb). The average increase in nonfatal falls treated in emergency departments is slightly less at 4.5% per year. Nevertheless, these nonfatal falls have grave consequences. In 2012, emergency departments in the United States documented 2.4 million nonfatal falls in older adults, leading to a direct medical cost of approximately $30 billion (Burns et al., 2016). Falls can result in multiple injuries including fractures. It is projected that by 2030, the total number of hip fractures will increase by 12% (Farahmand et al., 2005). Collectively, these national data illustrate the need for more effective strategies to prevent and recover from falls within the older adult population.

The significant rise in the number of falls in the older adult population is related to health comorbidities and leads to considerable healthcare expenses (Shumway-Cook et al., 2009). Therefore, disciplines across the healthcare spectrum continue to investigate how to reduce the number and severity of falls occurring in the older adult population (Ambrose et al., 2013). Task forces have designed fall prevention guidelines for use in hospitals, long-term care facilities, and home care settings (Choi & Hector, 2012; Miake-

Lye et al., 2013). Up to a 12% reduction in falls was noted with the utilization of initial and follow-up design interventions (Choi & Hector). Thus, individualized patient interventions have the potential to reduce the healthcare burden through fall prevention strategies. Providing an appropriate intervention includes assessing the individual's risk factors, predisposing and psychological factors, fall history, and current disease process. Even with proper intervention strategies, not all falls can be prevented; however, a multifaceted intervention approach should be utilized to prevent falls (Choi & Hector).

Physical therapists, as movement specialists, play a vital role in multidisciplinary fall prevention including the assessment and training of motor strategies. Motor strategy use is necessary to maintain balance (Shumway-Cook & Woollacott, 2012). All individuals use motor strategies, but they are used differently across the lifespan (Shumway-Cook & Woollacott, 2012) resulting in decreased balance and an increased risk of falling in older adults (Lajoie & Gallagher, 2004; Melzer et al., 2004). Activating a motor strategy when a disturbance occurs assists an individual in maintaining postural control (Kuo & Zajac, 1993). Ideally, aging adults would activate the most appropriate motor strategy to prevent loss of balance.

Motor strategies have been categorized as ankle, hip, and stepping (Horak & Nashner, 1986; Shumway-Cook & Woollacott, 2012). An ankle strategy is described as a means to "recover from a small displacement at the hips" (Horak & Nashner; Shumway-Cook & Woollacott); hip strategy is a means to recover from "a larger displacement" (Horak & Nashner; Shumway-Cook & Woollacott); a stepping strategy is a response when in-place strategies no longer control the center of mass with respect to base of support (Horak & Nashner; Shumway-Cook & Woollacott). In all individuals regardless of age, motor strategies typically occur distal to proximal, including various muscle synergies appropriate for responding to a balance threat (Shumway-Cook & Woollacott, 1985).

In older adults, researchers have identified differences in motor strategy use between fallers and non-fallers (Chandler et al., 1990; Lajoie & Gallagher, 2004; Melzer et al., 2004). Reduced reaction times, inadequate somatosensory and motor responses to a perturbation have been cited as contributing to these differences (Horak et al., 1997; Lajoie & Gallagher). There is a potential to lose the ability to prevent or recover from a loss of balance if individuals fail to activate motor strategies when the center of mass (COM) is threatened outside the limits of stability (Maki & McIlroy, 1996; Sibley et al., 2011). While contemporary literature highlights the importance of motor strategy activation in fall prevention, physical therapists are not routinely assessing this aspect of balance in clinical practice (Sibley et al.). This gap in current literature and the relation to physical therapy practice may result in the neglect of assessing and training appropriate motor strategy activation in an older adult population.

Clinical Relevance

Due to the lack of readily-available, objective outcome measures, clinicians most commonly assess motor strategy use through visual examination. This may include the use of an outcome measure like the pull test, push and release test, or a subset of the BEST and Mini-BESTest (Sibley et al., 2011). These measures ask the clinician to classify motor strategies based on a provided list or scale. For example, descriptors may be classified as one of the following: “independently took a step,” “took more than one step,” “no step taken,” or “unable to recover” (Horak et al., 2009; Jacobs et al., 2006; King & Horak, 2013). These scales provide a general overview of the participant’s ability to respond to a threat to their balance by performing a motor strategy, but don’t provide specific information on which and how the strategy was used. Therefore, this raises the question of how to measure the activation of motor strategies and how to apply the information in a clinical setting.

Limitations to visual observation include threats to its validity and reliability. Due to the limitations of visual observation it is unknown if clinicians can visualize the activation of a motor strategy quickly enough to determine what strategy was used and in what progression strategies were activated. Several studies have been conducted in attempts to provide clinicians with a method and tool for assessing motor strategy use. Researchers have utilized cable-pull systems with a support harness to apply and measure the individual’s response to a standard perturbation (Lurie et al., 2013; Mansfield et al., 2011; Martinez et al., 2013); however, this is not feasible to perform outside of a research laboratory due to equipment needs. Researchers have also used electromyography (EMG) to evaluate muscle activation prior to, during, and following a reactive response (Gatev et al., 1999). However, measurement via EMG is expensive and requires special equipment, training, and time. As such, limitations of cable-pull systems and EMG forces clinicians to visually assess motor strategies; there exists a great need for novel, innovative methods for assessing motor strategies, especially in older adults.

Dartfish is a user-friendly simple portable two-dimensional (2D) motion analysis software program that can be downloaded on a laptop or conveniently downloaded as an application (app) on a smart phone or tablet. Dartfish is cost-effective, retailing for approximately $4.99 or a small monthly fee for the app download (Bergonzoli, 2016). The combination of the device's camera and the software efficiently picks up small, high-velocity movements that human eyes cannot detect (Bergonzoli, 2016). Clinicians can readily incorporate the Dartfish Express app in their examination and treatment without a financial burden or loss of valuable time. The app has the potential to provide clinicians a more specific tool that can provide objective measurements regarding patient responses to perturbations and motor strategy use. The convenience and accessibility of the app eliminates the need to travel to a motion analysis laboratory for a more in-depth assessment.

A recent study compared the Dartfish 2D software to the Vicon three-dimensional (3D) motion technology analysis system, the current gold standard for measuring biomechanical motion (Eltoukhy et al., 2012). Researchers noted a ±5 mm difference in values measured on lower extremities during a squatting activity between the two systems (Eltoukhy et al.). Despite this small variance, other reliability and validity questions remain regarding the use of 2D motion analysis. Assessing motion from a 2D standpoint condenses and limits the amount of information obtained, thus providing less room for calculation errors (Eltoukhy et al.). Further studies are needed to determine if 2D motion analysis provides valid and reliable information that can be applied within the scope of physical therapy practice. Evidence from this two- study dissertation have the potential to support the validity of the 2D Dartfish Express app in clinical use as a tool to measure a motor strategy reaction to a reactive postural disturbance. Furthermore, these studies will also provide greater insight on the similarities and differences between younger and older adult motor strategy activation and use.

Study One: Concurrent Validity of the Dartfish Application to Assess Motor Strategy Use in Younger Adults

Purpose and Hypothesis

The purpose of the first study was to establish the concurrent validity of the Dartfish Express app on an iPad 2 compared to the Dartfish ProSuite 7.0 software to measure the motor strategy use during a compensatory stepping correction in a young adult population. We hypothesized:

- There will be a strong relationship between the Dartfish software and the Dartfish Express app in mean angle (degrees) of the start position and stop position (initiation of a motor strategy) in young adults leaning forward.
- There will be a strong relationship between the Dartfish software and the Dartfish Express app in mean angle (degrees) of the start position and stop position (initiation of a motor strategy) in young adults leaning backward.
- There will be no significant difference between the Dartfish software and the Dartfish Express app in mean angle (degrees) of the start position and stop position (initiation of a motor strategy) in young adults leaning forward.

- There will be no significant difference between the Dartfish software and the Dartfish Express app in mean angle (degrees) of the start position and stop position (initiation of a motor strategy) in young adults leaning backward.

Study Two: Motor Strategy Use in Older Versus Younger Adults as Assessed by Dartfish Application

Purpose and Hypothesis

Once the validity of the Dartfish Express app on an iPad 2 was established, the purpose of the second study was to investigate whether motor strategy use measured with the Dartfish Express app in an older adult sample was comparable with a younger adult sample. Also, between the sample cohorts, we assessed stepping strategy reaction time in the forward and backward directions. We hypothesized:

- There will be a significant difference between older adults and younger adults leaning forward in the mean angle (degrees) of the start and stop position (initiation of a motor strategy).
- There will be a significant difference between older adults and younger adults leaning backward in the mean angle (degrees) of the start and stop position (initiation of a motor strategy).
- There will be a significant difference in the mean-time (seconds) from stop position to completion of a step in older adults compared to younger adults in a forward direction.

- There will be a significant difference in the mean-time (seconds) from stop position to completion of a step in older adults compared to younger adults in a backward direction.

Operational Definitions that Apply to Both Studies

The following list provides important terms that are operationally defined specifically for the context of the two studies. Defining these terms provides clarity regarding the background knowledge, methods, and clinical application.

- *Adaptive postural control*: the act of maintaining, achieving, or restoring a state of balance during an activity (Pollock et al., 2000); modifying sensory and motor response to change with environmental demands (Shumway-Cook & Woollacott, 2012).
- *Balance "postural stability"*: the ability to keep the body's center of mass within the limits of the base of support (Shumway-Cook & Woollacott, 2012).
- *Postural control system*: complex interaction between the musculoskeletal and neural systems to control body position in space (Shumway-Cook & Woollacott, 2012).
- *Fall*: "any event in which a person inadvertently or intentionally comes to rest on the ground or another low level such as a chair, toilet, or bed" (Tideiksaar, 2010, p.13).

- *Motor strategies*: three common movement approaches utilized to maintain postural control when a disturbance occurs including ankle, hip, and stepping (Horak & Nashner, 1986; Kuo & Zajac, 1993; Shumway-Cook & Horak, 1989)
- *Ankle strategy*: a means to recover from a small displacement at the hips through activation of muscles centered on the ankle joint, typically the first pattern for controlling upright sway (Horak & Nashner, 1986; Shumway-Cook & Horak, 1989).
- *Hip strategy*: a means to recover from a large fast displacement producing a rapid motion at the hip joint to restore the center of mass (Horak & Nashner, 1986; Shumway-Cook & Horak, 1989).
- *Stepping strategy*: the action of taking a step to ensure center of mass falls within a wide base of support and is used when in-place strategies no longer control the center of mass with respect to the base of support (Horak & Nashner, 1986; Shumway-Cook & Horak, 1989).
- *Postural perturbation*: a sudden change in conditions that displaces the body away from equilibrium (Horak et al., 1997).
- *Response time*: the mean-time (seconds) it takes for older and younger adults to initiate and complete a motor response to a perceived balance threat.

Assumptions that Apply to Both Studies

The following assumptions were made for this study:

- Participants were representative of apparently healthy younger and older adults.

- Validity and reliability of the Dartfish ProSuite software is assumed as described in the literature (Eltoukhy et al., 2012; Norris & Olson, 2011).
- Ankle strategy can be measured with the use of kinematic measurement tools (in degrees) given the execution of motor strategies is a combination of muscle synergies and kinematics including joint motion (Horak et al., 1987).

Limitations that Apply to Both Studies

The following limitations are recognized in this study:

- The participants were a sample of convenience, potentially limiting the generalizability of the results.
- An external perturbation was not applied to participants to evoke the postural reaction due to limited clinical techniques for measuring the force and standardization difficulty. Therefore, each participant responded to testing differently based on their comfort and participation level.
- Participants may have misunderstood the instructions read to them for the forward and backward protocol and thus resulting in an undesired movement pattern or the need for repeated instructions.
- Participants may have prior experiences that may evoke fear or anxiety affecting their response to testing, thus resulting in a guarded reaction, over reaction, or limited response.

Significance of the Studies

Physical therapy practice relies on specific outcome measures to guide the patient's care plan and measure improvements in clinical practice. Clinicians also rely on these outcome measures to demonstrate and justify the need for initiating, continuing or discontinuing therapy. The Dartfish Express app is a potential solution that may provide a tool to objectively measure motor strategy activation; Dartfish may provide a cost-effective and convenient tool for clinicians to objectively quantify small changes that cannot be detected or appreciated visually.

The first study provided knowledge on the concurrent validity of the Dartfish Express app compared to the Dartfish ProSuite software when used as a tool to measure motor strategy use in younger adults. Study one established the concurrent validity between the Dartfish software and app as a tool to assess motor strategy use in younger adults; the second study investigated older versus younger adult motor strategy use. The results and clinical application of these studies will begin to bridge the gap between research and clinical practice regarding the implications and importance of measuring motor strategies in all clinical settings. Furthermore, Dartfish could also potentially be used as a tool to objectively assess patient response to a given plan of care.

CHAPTER II

REVIEW OF THE LITERATURE

The overall goal of this dissertation was to explore the use of Dartfish two-dimensional (2D) motion software as a tool to capture motor strategies in response to an anticipatory postural reaction. Potentially, Dartfish could be a tool to objectively assess what and how postural reactions are being activated. This dissertation investigated the concurrent validity of the Dartfish ProSuite 3.0 software and Dartfish Express application (app) as tools to measure motor strategy use in younger and older adults. The differences between these two groups were also assessed. The answers to the questions investigated in this dissertation will assist in bridging the gap between lab experimentation and clinical application regarding the ability and importance of measuring motor strategies.

Two studies were designed to address the purposes of this dissertation. The purpose of the first study was to establish the concurrent validity of the Dartfish ProSuite 7.0 software compared to the Dartfish Express app on an iPad 2 to measure motor strategies use following an anticipatory postural reaction in young adults. We investigated the relationship between the Dartfish app and software for mean angle (degrees) of the start position and stop position (initiation of a motor strategy) in young adults. The purpose of the second study was to investigate the comparable ankle and stepping strategy use between older and younger adult populations when measured with the Dartfish Express app.

The following review of literature provides further understanding and explanation of the overarching goal of this dissertation. This review will explore current demographics of falls in the older adult population within the United States, components of balance including perturbations and postural control, current practice for examining and training reactive postural control, the Activities-Specific Balance Confidence scale, and the integration of Dartfish as a tool within the field of physical therapy.

Falls in the United States

For the purpose of this dissertation, a fall was defined as "any event in which a person inadvertently or intentionally comes to rest on the ground or another low level such as a chair, toilet, or bed" (Tideiksaar, 2010). Healthcare providers tend to define falls based on the consequences of the fall, while researchers tend to define falls based on the description of the events that occurred (Zecevic et al., 2006). In the clinic, healthcare providers seek to define falls on a more general functional level. Researchers seek to define falls on a more objective level within the context of an operational definition (Zecevic et al.). Defining falls in a clinical or research context can increase the possibility of early detection of those at risk for falling (Zecevic et al.).

Falls have a wide-scope of potential consequences, especially in the elderly. Falls frequently lead to a decline in general health and mobility, an increased financial burden, and increased mortality (Stoeckel & Porell, 2009). Falls are also predictive of a housing relocation within two years of the occurrence (Stoeckel & Porell). Patients recently discharged from the hospital face an increased risk of falling post-discharge. The rate of falling per 1000 adults age 65 and older post-hospital discharge is 53% and increased fall rates were also linked to increased mortality (Moudouni & Phillips, 2013). The mortality rate in this same population was found to be 33.2% with greater odds of death reported with additional comorbidities, dehydration, and intracranial fractures (Moudouni & Phillips). Significant mortality and injury rates in older adults secondary to falls includes a 71.1% increase in the number of deaths from falls with a yearly average increase of 6.2% in fall deaths since 2005 and a 4.5% per year average increase in nonfatal falls treated in emergency departments (Center of Disease Control and Prevention [CDCb], 2016).

Other consequences of falls in an older adult population include increased fear of falling, psychological and social anxiety, and decreased ability to perform activities of daily living (Denkinger et al., 2015; Scheffer et al., 2008). Psychological consequences reported after falling include increased levels of anxiety and depression, while social factors include activity avoidance and social withdrawal (Hughes et al., 2015). Older adults also reported decreased confidence in their balance and ability to safely perform activities of daily living following a fall event (Hughes et al.).

Falls are multifactorial in nature and are more common in the older adult population (Oliver et al., 2010). Literature has investigated the predictive criterion of the likelihood of a fall occurring (Tinetti et al., 1995). An example criterion includes a 2.2-time increased risk of falling in the presence of at least two chronic conditions: low body mass index and cognitive impairment (Tinetti et al.). Degenerative changes that take place throughout all major body systems with the aging process increase older adults risk for falling (Ambrose et al., 2013). Polypharmacy, drug side effects, dizziness, visual changes, strength and balance deficits, orthostatic hypotension, and patient co-morbidities also increase the risk of falling among older adults (Ambrose et al.). Fall prevention continues to be on the forefront of our healthcare systems initiatives due to the continued high volume and fatal outcomes resulting from falls in the older adult population (CDCa; Cigolle et al., 2015).

It is estimated that approximately 30% of community-dwelling adults over the age of 65 fall each year (CDCa, 2016). In a study focused on understanding and preventing falls among older adults, 471 fall incidents were screened for causality. Of these incidents, a total of 46% occurred with a simple change in position and 23% occurred during activity (Ramsey et al., 2015). These statistics demonstrate the need for re-examination of the medical professionals' approach to falls and to ensure falls are being addressed consistently across settings. While the study of fall prevention and the effective practice management of people who fall are important, the measurement and training of motor strategy responses as a means to address the problem of falls has largely been ignored. Therefore, this dissertation focuses on motor strategy response to a postural threat to prevent falls from occurring.

Perturbations

One way to assess fall risk and recovery is through response to a perturbation (Maki & McIlroy, 1996). A perturbation is defined as an external force or an internal interruption to the body (Maki & McIlroy). Examples of an external force include tripping over an object, moving objects such as a pet or small child, or a slipping on a slick surface (Maki & McIlroy). Internal interruptions may include orthostatic hypotension, disruption of sensorimotor systems, cardiac involvement, transient ischemic attack, or other interferences within the brain or brainstem processing (Maki & McIlroy). Both the presence of an external or internal perturbation and the failure of the person's postural control system to compensate appropriately to that perturbation are required in order for a fall to occur (Maki & McIlroy).

External perturbations can further be broken down and defined as a collision, trip, or slip (Maki & McIlroy, 1996). A collision displaces the center of mass (COM) outside of the base of support (BOS), while a trip or slip prevents the BOS from being properly aligned within the COM (Maki & McIlroy). The majority of falls among the elderly are thought to be a result of inadequate responses to perturbations (Horak et al., 1997). Perturbation-related falls from trips or slips are responsible for approximately 60% of outdoor falls in the older adult population (Luukinen et al., 2000). Maki and McIlroy (1996) found that out of 120 falls reported through interviews of individuals age 62 to 95, a total of 54% were classified as a slip trip fall where the BOS was perturbed and unable to realign under the COM, 32% were classified as push collision where the COM was displaced beyond the BOS, and 14% were classified as internal interruptions. Physical therapists have the training, understanding, and ability to address balance, reactive control, and environmental factors. Addressing these factors may have the potential to impact the 86% of these falls that are related to external interruptions (Maki & McIlroy).

Balance and Postural Control

Changing position, activity, and static postures are a part of everyday life. These activities are unavoidable and are considered the most basic activities of daily living. The implementation of balance assessments and interventions in a patient's care plan can make decrease fall risk (Mansfield et al., 2010; Van Iersel et al., 2008). Before clinicians can properly assess an individual's risk for falling with available tools, a working understanding of balance and postural control must be attained.

Contemporary understanding of postural control consists of a dynamic systems framework rather than a top-down hierarchical concept (Horak et al., 1997). A systems approach describes postural control as a goal-directed neural organization involving the interaction of multiple systems (Horak & Nashner, 1986; Horak et al.). The systems approach also describes postural control as a fundamental learned motor skill that can be influenced by motor learning principles such as practice, feedback, experience, and education (Horak et al.). As described above, the concept of postural control provides therapists with a framework to approach postural stability more holistically by accounting for motor learning principles and multiple system involvement (Horak et al.).

Postural control can be defined as the act of maintaining, achieving, or restoring a state of balance during an activity or any static posture (Pollock et al., 2000). Postural control may also be defined as a complex interaction between the musculoskeletal and neural systems to control the body's position in space (Shumway-Cook & Woollacott, 2012). Postural control strategies may be predictive or reactive and may involve a fixed or unpredictable environmental surface. A person's state of balance, or position within his or her BOS, is a reflection of postural control at that moment. Postural control requires a combination of maintenance of posture, voluntary movement, and reaction to a predicted or unpredicted movement (Pollock et al.).

Postural control can be classified as either reactive or predictive. Reactive postural control is the body's response to an unpredicted disturbance (Pollock et al., 2000). For example, consider an individual walking on a sidewalk. They suddenly trip over an uneven crack in the cement. An individual with an intact balance system will quickly react to this event, with the most appropriate response determined by the central nervous system (CNS), thus preventing a fall. The term reactive may be used interchangeably with compensatory (Pollock et al.).

Conversely, predictive or anticipatory postural control is the body's voluntary responses to an anticipated disturbance; the term predictive postural control is used interchangeably with anticipatory postural control (Pollock et al., 2000). An individual can control their response to a predictive postural reaction if the perturbation is known in advance (Maki & McIlroy, 1996). Predictive control occurs when clinicians assess balance by performing a pull test or announcing to their patient they will be applying a perturbation. By asking the patient to do whatever possible to avoid falling, the patient is prepared, in anticipation of a disturbance, to activate motor strategies and respond appropriately.

Balance can be described as the ability to keep the body's COM within the limits of the BOS (Shumway-Cook & Woollacott, 2012). A decrease in the BOS alters stability, leading to the displacement of the center of gravity, resulting in decreased balance (Pollock et al., 2000). Balance can also be defined as a combined effort of the musculoskeletal system, body mechanics, and the CNS (Maki & McIlroy, 1996).

The body utilizes three characteristic postural strategies to maintain postural control in the presence of a perturbation (Shumway-Cook & Woollacott, 1985). These include two in-place strategies (i.e., ankle and hip), and a stepping strategy (Shumway-Cook & Woollacott). An ankle strategy is defined as the method by which one recovers from a small displacement at the hips through activation of muscles centered on the ankle joint; it is typically the first motor pattern used for controlling upright sway (Horak & Nashner, 1986; Shumway-Cook & Horak, 1989). A hip strategy is defined as the means to recover from a larger, fast-displacement producing a rapid motion at the hip joint to restore center of mass within the base of support (Horak & Nashner; Shumway-Cook & Horak). A stepping strategy is defined by the result of in-place strategies no longer being able to control the center of mass with respect to base of support (Horak & Nashner; Shumway-Cook & Horak).

Early postural control literature provides insight into motor strategies and their movement categorization following a balance threat; there is a relationship between motor strategies, postural control, and range of motion (Nashner, 1977; Nashner et al., 1979). Execution of motor strategies is a combination of muscle synergies and kinematics including joint motion and torques (Horak et al., 1997) which can be measured through use of electromyography and moveable surfaces to confirm muscle activation occurs around the joint in response to a balance threat (Horak & Nasher, 1986). For example, ankle strategy occurs around the joint including the activation of the gastrocnemius followed by the hamstrings and paraspinal muscles (Shumway-Cook & Woollacott, 2012). Consequently, limited or excessive range of motion and decreased strength can result in compensatory motions affecting an individual's motor strategy response (Horak, 1987). As a result, by measuring range of motion and muscle strength, we are able to draw conclusions about motor strategies. Regardless of age, it is necessary for the body to effectively use motor strategies in order to maintain balance and prevent falls.

Postural control strategies being to develop in children as early as age 15 to 31 months, with children demonstrating a greater dependence on visual input compared to adults (Shumway-Cook & Woollacott, 1985). There is a slow shift towards "adult-like" motor strategies, described above, around four to six years old, and by seven to ten years old children have adult responses (Shumway-Cook & Woollacott). This adult form is marked by the CNS using sensory inputs to fine tune ankle-joint proprioception and postural synergies in preparation for a loss of balance (Shumway-Cook & Woollacott).

As adults age, individuals begin to use the adult form motor strategies less efficiently resulting in decreased balance and an increased risk of falls (Tang & Woollacott, 1998). When recovering from an unexpected displacement of the COM in a healthy adult, the CNS selects the most appropriate response. Recovery is a quick process where most often the strategies are used discreetly to provide the appropriate compensation. Muscle activity begins within 90 to 100 milliseconds following a perturbation (Nashner, 1977). These strategies occur more quickly and discreetly than the human eyes can capture (Shumway-Cook & Woollacott, 2012). Therefore, people are unable to detect the sequence or extent of body segment movement (Shumway-Cook & Woollacott).

Motor responses to a perturbation may include correction with simple ankle strategy activation, adjusting the base of support, taking a step, muscle co-activation, or reaching for an object. The individual may react using one or more of these motor responses, but an outside observer may only note the individual's final motor response. Ideally, aging adults would activate the most appropriate strategy when their postural control is disturbed to prevent loss of balance; however, this includes the limiting of over-reaction and under-reaction, potentially leading to a loss of balance and a fall. The majority of falls among the elderly are thought to be a result of inadequate and less efficient responses to a perturbation (Horak et al., 1997; Tang & Woollacott, 1998).

Just as any other motor skill, balance and strategy activation can be learned (Pollock et al., 2000). Physical therapists have the skills to teach such strategies and reinforce the CNS pathway. Just as infants develop these skills to interact with their environment, and older adults must maintain these skills to continue interacting with their environment without falling (Shumway-Cook & Woollacott, 1985). Viewing the reactive responses of postural control as a "motor skill" implies that physical therapists can target these strategies to improve balance and reduce the number of falls among older adults (Pollock et al.).

Assessment of Reactive Postural Control and Balance

The methods for assessing reactive postural responses in research compared to clinical settings differs. Research methods are by design more controlled in comparison to clinical methods, resulting in reliable and valid outcomes (Portney & Watkins, 2009). Clinical methods are patient-centered and performed in complex, uncontrolled environments. The methods used to examine reactive postural control within the realm of research are not feasible for clinic use; however, the methods for assessing these strategies in the clinic are not sufficient for research use, secondary to lack of control and increased variability.

Typically, the methods used to measure perturbation and postural control systems in research settings are cost prohibited and innately complex, make them impractical for clinical application (Chandler et al., 1990). The current research methods have placed participants in harness systems and provided a perturbation through contact from a moving object or by moving the surface beneath them (Bair et al., 2016; Chandler et al., 1990; Lurie et al., 2013; Mansfield et al., 2010). Although these methods appear to be reliable, their clinical utility is limited.

Barriers to implementing these techniques in a clinical setting include lack of financial resources to purchase the needed equipment and the cost of support staff to ensure safety. Therefore, clinicians use observation and general outcome measures to assess motor strategies in the clinic, which are subjective and not reliable, valid, or replicable enough to be used in research. To carry out the vision of evidence-based practice we need to bridge the gap between the research lab and the clinic. For the above stated reasons, reactive postural control is not routinely assessed in a clinical setting (Sibley et al., 2011).

In addition to limited access to equipment, there are likely two other reasons that physical therapists are not routinely examining and documenting motor strategies: a) clinicians do not think they can measure and alter motor strategies. Clinicians do not have a means to appropriately measure motor strategies; hence they do not think they can change them. Currently, there are limited objective outcome measures to analyze motor strategies and postural responses within a clinical setting. Nevertheless, a variety of current strategies have been investigated as a means to bridge the gap between the research lab and clinic when measuring motor strategies. Descriptions of each are as follows.

Examination of Postural Control and Balance

The most common way to assess motor strategies in the clinic is through visual examination. Clinicians visually assess how their patients respond to an applied perturbation and can assess predictive or reactive responses (Pollock et al., 2000). This may include the use of an outcome measure like the pull test, push and release test, or a portion of the BEST and Mini-BESTest (Sibley et al., 2011). These measures ask the clinicians to classify motor strategies based on a provided list or scale. For example descriptors such as: “independently took a step,” “took more than one step,” “no step taken,” or “unable to recover” (Horak et al., 2009; Jacobs et al., 2006; King & Horak, 2013). While not exhaustive, these scales are variable. If individuals are not activating motor strategies when their COM is threatened, they have the potential to lose their ability to prevent or recover from a loss of balance (Maki & McIlroy, 1996; Sibley et al.). Clinicians not routinely examining motor strategies could be a result of many different factors. These include: lack of knowledge about the importance of assessing these strategies, decreased comfort and experience, lack of objective reliable outcome measures, and lack of objective tools for clinicians to assess motor strategies use.

Sibley et al. conducted a study to assess balance examination practices and standardized balance measures among physical therapists. A total of 369 clinicians completed a survey questionnaire (Sibley et al., 2011). They found only 41.2% of clinicians reported assessing reactive control, 3% reported using the push and release test, and 0.3% reported using the BESTest (Sibley et al.); a total of 58.8% of clinicians sampled were not assessing reactive control (Sibley et al.). The lack of assessing patients reactive control in the clinic is concerning; the ability to successfully react to a loss of balance can determine whether a fall will occur.

Sibley et al. stated that clinicians reported regularly assessing functional activity, postural alignment, static and dynamic stability, motor components to balance, and overall functional balance on a routine basis. These clinicians suggested they assess these components regularly because they felt comfortable and they found them more feasible for clinical use. However, 20% to 25% of these same clinicians reported not regularly assessing sensory, cognitive, and reactive components to balance. The Berg Balance Scale (BBS), single-leg stance test (SLS), and the Timed "Up & Go" Test (TUG) were the three most frequently used, standardized methods reported in the study. (Sibley et al., 2011)

Literature supports the BBS, SLS, and TUG as efficient, well-established, and reliable outcome measures (Brooks et al., 2006; Van Iersel et al., 2008). The BBS is commonly used in multiple clinic settings to assess balance and fall risk. Clinicians support the use of the BBS to assess fall risk in older adults secondary to the short time necessary to complete (typically 15 to 20 minutes), minimal space and equipment requirements, and clear directions (Thorbahn & Newton, 1996). The TUG and SLS test can also be completed in a relatively short time frame of fewer than three minutes with minimal equipment requirements (Bohannon, 2012; Brooks et al.; Van Iersel et al.). Validity and reliability of these three measures, the BBS, SLS, TUG, have been established for multiple patient populations, allowing clinicians to easily interpret the results (Bohannon; Brooks et al.; Van Iersel et al.).

The Postural Stress Test (PST) was reported to have clinical utility for measuring postural responses (Chandler et al., 1990). The PST is an inexpensive, clinically applicable, quantitative measure of an individual's ability to withstand a series of graded forces at waist level. The test is composed of a series of trials performed at various graded weights with the goal of providing a posteriorly destabilizing force at waist level. The PST indicated that elderly fallers score significantly lower on the PST in comparison to community-dwelling older adults. Investigators also concluded that poor performance on the PST was not attributed to age alone. (Chandler et al.)

While clinicians are not using the PST to specifically measure postural responses, they do use more global outcome measures (e.g. BBS, SLS, TUG) when treating a variety of patients in multiple treatment settings. However, these balance measures do not specifically assess reactive postural control and motor strategy use. The need for more specific and consistent assessment of reactive postural control and motor strategies is the central focus of this dissertation.

Training Postural Control and Balance

As mentioned earlier in this chapter, clinicians do not have a means to appropriately measure motor strategies; hence they do not think they can change these strategies. The development of a motor strategy examination has also been investigated through the use of training programs. Many trials have assessed the potential applicability of these methods to older adults. Mansfield et al. conducted a randomized controlled trial to evaluate a perturbation-based balance training program in older adults aimed at targeting specific age-related changes in recovery reactions. A total of 30 older adults, 64 to 80 years of age with a recent history of falling or a self-reported instability, were included. Each participant was assigned to one of two groups: a six-week perturbation-based balance training program or a six-week controlled program of traditional flexibility and relaxation training. The investigators stated that the ability to execute these compensatory reactions was found to be impaired in older adults. (Mansfield et al., 2010)

The perturbation-based group intervention was developed based on principles of motor learning; this included provoked stepping and grasping reactions in all directions based on surface translation and cable pull perturbations (Mansfield et al., 2010). The outcome measures included lateral step displacement, multi-step reactions, foot collisions, grasping reactions, and frequency of grasping errors all dependent on surface translation and cable pull. Investigators found that the perturbation-training group had fewer foot collisions and decreased multi-step reactions. They stated these findings support the potential for perturbation-based balance training to improve the ability to appropriately respond to balance perturbations. The investigators concluded that perturbation-based training demonstrated promising results as an effective intervention to improve older adults' ability to prevent falling from a loss of balance. (Mansfield et al.)

Lurie et al. (2013) conducted a pilot study investigating the effectiveness of surface perturbation treadmill training as a prevention method for falls in older adults. Due to the common contribution of tripping and slipping on falls in older adults, the investigator developed a surface perturbation treadmill training (SPTT) intervention. The SPTT evoked postural disturbances to simulate tripping and slipping while the participant was safely supported in a harness over the treadmill. A total of 73 participants were randomized into two groups: the SPTT group or a "standard" physical therapy (PT) group. The standard PT group performed multidimensional exercise alone without the use of the treadmill training. The researchers' results revealed fewer falls and fewer injuries from falls in the SPTT group assessed through phone interviews 3 months following enrollment in the study. (Lurie et al., 2013)

In summary, although these studies presented valuable findings and support for the implementation of training motor strategy use, these methods may not be appropriate to perform in a clinical setting due to the cost and time associated with them; limited resources prevent the clinical applicability of such methods. Currently, reactive postural control is not being routinely assessed in the clinical setting (Sibley et al., 2011). In the case that reactive postural control is examined, clinicians are most often using their visual own observations in the assessment with may not be sensitive to detect change over time or to identify persons at risk for falls.

Activities-Specific Balance Confidence Scale

The Activities-specific Balance Confidence (ABC) scale is a quick and easy outcome measure to quantify an individual's confidence in their ability to maintain balance during functional activities and can be used to identify persons at risk of falling. The ABC scale is a 16-item self-reported measure of an individual's confidence in their balance while performing specific activities (Powell & Myers, 1995). The rating scale for each item is 0 to 100, 0 indicating no confidence and 100 indicating complete confidence in one's ability to perform the stated task without losing their balance. The score for each item is added, and the total is divided by the total number of items in determining the final score. For best results on this outcome measure, researchers recommend face-to-face test administration. Test-retest reliability on a group of 21 older adults (age 65 to 95) assessed in two-week intervals was excellent ($r = 0.92$, $p<0.001$). The ABC scale was reported to have an excellent relationship ($r= -0.068$, $p<0.01$) with the Fear of Falling Avoidance Behavior Questionnaire. (Powell & Myers)

The ABC scale is considered an efficient and appropriate outcome measure for assessing various functional levels (Powell & Myers, 1995) used across physical therapy settings for older adults. The ABC Scale has also been characterized as more suitable for moderate to high-functioning older adults in comparison to the Falls Efficacy Scale (Powell & Myers; Myers et al., 1996). A score between 50 and 80 indicates a moderate physical function level, and a score of above 80 indicates higher physical function in a sample of community-dwelling older adults (Myers et al.). A score of 67 or less indicates a fall risk (Lajoie & Gallagher, 2004). Most conditions represented on the ABC scale are a part of everyday situations faced by older adults that require them to use available balance and postural control systems.

Role of Dartfish

Dartfish was founded in 1999 at the Swiss Institute of Technology in Switzerland (V. Bergonzoli, personal communication, April 12, 2016). This software is a 2D video analysis software with capabilities to quantify time, distance, angle, and position through measurement (Bergonzoli, 2016). Since 1999, Dartfish has developed multiple products including the Dartfish Express app available for download on smart devices (Bergonzoli). The app is designed to record video clips, upload clips and images for analysis, create slow-motion playbacks, and quantify movements for analysis by drawing angles directly on a still image (Bergonzoli).

The Dartfish Express app is a potential tool for clinicians to measure motor strategies. The 2D simple motion analysis program can be downloaded on a laptop or conveniently downloaded as an app on a portable smart phone or tablet. The Dartfish software was developed to offer professionals a more user-friendly and cost-efficient software tool to analyze body movement. In contrast, the Dartfish ProSuite software is commonly used in research to capture a biomechanical analysis of a task using markers on appropriate landmarks (Khadilkar et al., 2014; Norris & Olson, 2011).

Currently, the Dartfish ProSuite software use includes measurements of flexibility and joint motion with reliable results (Mier, 2011; Norris & Olson, 2011). The technology is consistently utilized to easily capture body mechanics and precise movements (Khadilkar et al., 2014; Melton et al., 2011). Regardless of the utility in the research realm, its use in clinical settings outside of the domain of sports is limited. The use of the Dartfish software as a clinic tool to measure motor strategies and assist in the evaluation process has not been formally investigated. It is unclear if postural reactions can be captured and classified using this methodology.

While the clinical use of the Dartfish ProSuite software is unlikely, the recent availability of the Dartfish Express app for smart devices may expand its clinical utility. Clinicians can easily incorporate the use of the Dartfish Express app as a tool for their evaluations and treatments without a significant cost or loss of valuable time. Currently, the Dartfish Express app costs approximately $4.99 to purchase or a small monthly fee, which can be downloaded on a smart device, while the Dartfish ProSuite software retails for approximately $3,200.00. The convenience and availability of the app eliminates the travel time and special arrangements for a visit to a motion analysis laboratory and the expense of the Dartfish ProSuite software. The Dartfish products have the potential to provide a more specific tool that can provide objective measurements regarding patient's reactive postural control and motor strategies use. (Bergonzoli, 2016)

Eltoukhy et al., compared the Dartfish 2D analysis with the 3D motion analysis to determine the magnitude of difference between the marker trajectories during a squat (Eltoukhy et al., 2012). Analysis showed approximately a ±5 mm overall difference between the two systems when assessing the motion during a squat. Although validity and reliability were not established, researchers concluded that the use of the Dartfish as a method of measurement has "serious potential." (Eltoukhy et al.)

The concurrent validity, intra-rater reliability, inter-rater reliability, and between-day test-retest reliability of lower extremity joint range of motion measured with Dartfish ProSuite software as compared to goniometry measurement was also investigated (Norris & Olson, 2011). Concurrent validity of the 2D angle analysis with Dartfish compared to the use of a goniometer for the measurement of hip and knee motion in the sagittal plane demonstrated a high correlation (r >95). Interclass correlations (ICCs) for test-retest reliability reported were reported to be 0.79 and 0.91 for hip and knee flexion, respectively. Inter-rater and intra-rater reliability for both hip and knee flexion were excellent, with hip flexion at 0.99 and knee flexion at 0.98 (Norris & Olson). The authors concluded that the study's findings support the "clinical utility" of the 2D video analysis Dartfish system. (Norris & Olson)

Although these studies support the use of Dartfish ProSuite software, their findings and conclusions are limited. There are no current studies that have addressed the use of the Dartfish Express app in a clinical setting. There is a significant gap in the literature regarding the validity and clinical utility of the Dartfish systems, especially within the field of physical therapy. Such lack of data highlights the need for further investigation. Furthermore, there is no current evidence for the use of the Dartfish tools to measure balance and postural control. The studies carried out in this dissertation investigate the use of Dartfish software as a tool to measure motor strategies in a physical therapy setting and reinforce the clinical utility of the software.

Summary

Falls in the older adult population are a major concern across healthcare disciplines. The rising concern drives expenses and resources to be used in the field to determine best practices for addressing the increasing incidence of falls in the older adult population (Ambrose et al., 2013; CDCa, 2016). To address healthcare providers, as care plans are developed, a physical therapist must have a firm understanding of balance and means to examine balance in order to guide treatment in clinical practice.

Maintaining balance incorporates motor strategies (ankle, hip, and stepping) where the most appropriate strategy varies based on direction and magnitude of the force applied (Shumway-Cook & Woollacott, 1989, 2012). However, fallers use motor strategies differently and less efficiently (Chandler et al., 1990; Lajoie & Gallagher, 2004; Melzer et al., 2004) as compared to non-fallers (Bair et al., 2016).

There is ample evidence in the current literature to indicate that aging has a profound effect on the use of motor strategies and postural responses (Chandler et al.; Lajoie & Gallagher; Melzer et al.). There are also several well-designed studies measuring the effects of perturbation and postural reaction training in older adults within a lab setting (Bair et al., 2016; Chandler et al.; Mansfield et al., 2010; Pai, Yang, Bhatt, & Wang, 2014; Pai, Bhatt, Yang, & Wang, 2014), but no studies to date have measured these effects in the clinical setting. The challenge is how to incorporate these laboratory findings and directly apply these methods within a clinical or community setting.

Dartfish technology offers innovative measurement tools that can be easily incorporated by clinicians into their clinical practice. Dartfish products have not been previously studied with the purpose of measuring motor strategies use, warranting further investigation for this purpose within the field of physical therapy. The proposed studies sought to provide methods integrating the research laboratory and community setting with more affordable equipment and feasible methods of examining motor strategies.

CHAPTER III

STUDY ONE: CONCURRENT VALIDITY OF DARTFISH PRODUCTS TO ASSESS MOTOR STRATEGY USE IN YOUNGER ADULTS

Background

Motor strategies are used across the lifespan to prevent individuals from losing their balance (Shumway-Cook & Woollacott, 2012). Activation of a motor strategy when a disturbance occurs aids an individual in maintaining postural control (Kuo & Zajac, 1993). Motor strategies typically occur distal to proximal and include various muscle synergies appropriate for responding to a balance threat (Shumway-Cook & Woollacott, 1985). Motor strategies have been categorized as ankle, hip, and stepping (Horak & Nashner, 1986; Shumway-Cook & Woollacott, 2012). An ankle strategy is described as a means to “recover from a small displacement at the hips”; a hip strategy is a means to recover from “a larger displacement” (Horak & Nashner; Shumway-Cook & Woollacott, 2012). A stepping strategy is a response to in-place strategies no longer controlling center of mass with respect to base of support resulting in a step to widen the base of support (Horak & Nashner; Shumway-Cook & Woollacott, 2012). While current literature highlights the importance of motor strategy activation for fall prevention, physical therapists are not routinely assessing motor strategy activation in clinical practice (Sibley et al., 2011).

The most common way to assess motor strategy use in the physical therapy clinic is through visual examination. Limitations to visual observation may include validity and reliability. There is little evidence to conclude whether or not clinicians can visualize the activation of a motor strategy quickly enough to determine what strategy was used and in what progression the strategy was activated. Outcome measures may also be used, including the pull test, push and release test, or a portion of the BESTest and Mini-BESTest (Sibley et al., 2011). These measures ask the clinician to classify motor strategies based on a provided list or scale. For example, descriptors such as: “independently took a step,” “took more than one step,” “no step taken,” or “unable to recover” (Horak et al., 2009; Jacobs et al., 2006). These scales provide a general overview of the participant’s response to a balance threat, but do not provide specific information concerning which strategy and how the strategy was used.

Researchers use cable-pull systems with a support harness to apply and measure the response to a standardized perturbation (Bair et al., 2016; Lurie et al., 2013; Mansfield et al., 2011; Martinez et al., 2013); however, this is typically not feasible to perform outside of a research laboratory. Researchers use electromyography (EMG) to evaluate muscle activation prior to, during, and following a reactive response (Gatev et al., 1999). However, EMG is an expensive form of measurement that requires special equipment and training which raises the question of how to measure the activation of motor strategies and apply the information in a clinical setting.

Physical therapy practice relies on specific outcome measures to guide the clinician’s plan of care and to measure improvements in clinical practice. Clinicians are driven by regulators and third party payers to provide outcome measures. They’re driven to demonstrate objective improvements in order to justify their patient’s need for skilled physical therapy. The Dartfish Express application (app) is a possible solution that provides a tool to objectivity measure motor strategies. The Dartfish software is highly specific and able to capture small changes that are visually undetectable or appreciable to clinicians.

Dartfish products are simple two-dimensional (2D) motion analysis software programs that can be downloaded on a laptop or conveniently downloaded as an app on a smart phone or tablet. The retail price of the Dartfish Express app on an iOS device is approximately $4.99 or a small monthly fee (Bergonzoli, 2016), which makes this tool very cost-effective for a therapist in any setting. The Dartfish software can pick up small, high-velocity movements missed by the human eye (Bergonzoli). Clinicians can incorporate the Dartfish Express app in their examination and treatment without significant cost or loss of valuable time. The app has the potential to provide clinicians with a more specific tool that provides objective measurements regarding patient's responses to perturbations and motor strategy use. Additionally, the convenience and availability of the app eliminates the need to travel to a motion analysis laboratory for a more in-depth assessment.

Reliability and validity questions remain regarding the use of 2D motion analysis. Assessing motion from a 2D standpoint condenses and limits the amount of information obtained, providing less room for calculation errors (Eltoukhy et al., 2012). This study investigates the concurrent validity of the Dartfish app in comparison to the Dartfish

ProSuite software as a tool to capture and measure motor strategy use in young adults in a forward and backward direction outside of a research laboratory.

The purpose of this methodological study was to establish the concurrent validity between the Dartfish Express app on an iPad 2 and the Dartfish ProSuite 7.0 software to measure motor strategy use during a compensatory stepping correction in a young adult population age 20 to 45 years old. Investigators hypothesized that there would be a strong relationship between the Dartfish ProSuite 7.0 software and the Dartfish Express app in mean angle (degree) of the start position and stop position (initiation of motor strategy) in young adults. Investigators also hypothesized that there would be no significant difference between the Dartfish ProSuite software and the Dartfish Express app in mean angle (degree) of the start position and stop position (initiation of motor strategy) in young adults.

Methods

Participants

This study included 30 participants who are apparently healthy adults, age 22 to 40 years old, ambulatory with or without an assistive device (walker/ cane/ orthotic), and with or without the presence of any chronic medical conditions. Participants were excluded if they had current acute medical conditions or major surgery, within the past year. Participants were also excluded if they required the assistance of another person to safely walk. Prior to study acceptance, each participant completed a health screen form to evaluate their past medical history, co-morbidities, and health conditions. The form also provided the investigator with demographic information and the participation's eligibility in the study (Appendix A). Participants were recruited from Texas Woman's University (TWU) located in Dallas, Texas as well as the surrounding geographic areas in person or by email, telephone, or flyer announcement (Appendix B).

Measurements and Instrumentation

Dartfish was founded in 1999 at Switzerland's Swiss Institute of Technology. Dartfish is a 2D video analysis software with capabilities to quantify time, distance, angle, and position through measurement (V. Bergonzoli, personal communication, April 12, 2016). Since 1999 Dartfish has developed multiple products, including the Dartfish app available on iOS and Android devices that are primarily used by athletes and their coaches. The app is designed to record video clips, upload video clips and images for analysis, create slow-motion playbacks, and quantify movements for analysis by drawing angles directly on a still image. (Bergonzoli, 2016)

The Dartfish software was developed to offer professionals a more user-friendly and cost-effective software tool to analyze movement outside of motion analysis laboratories. Eltoukhy et al. compared the Dartfish 2D analysis with the three-dimensional (3D) motion analysis to determine the magnitude of difference between the marker trajectories during a squat (Eltoukhy et al., 2012). The authors reported there was approximately a ±5 mm difference between the two systems when assessing the motion (Eltoukhy et al.). Although they did not establish specific validity or reliability, the researchers concluded that the Dartfish had "serious potential" (Eltoukhy et al.).

Concurrent validity of the 2D angle analysis with Dartfish compared to the use of a goniometer for the measure of hip and knee motion in the sagittal plane demonstrated a high correlation (r >95) (Norris & Olson, 2011). Interclass correlations for test-retest reliability reported were 0.79 and 0.91 for hip and knee flexion. Inter-rater and intra-rater reliability for both knee and hip flexion were found to be excellent, (0.98 to 0.99). The authors concluded that the study's findings support the "clinical utility" of the 2D video analysis and the Dartfish ProSuite software (Norris & Olson).

Procedure

Researchers obtained informed consent (Appendix C) at the start of the initial meeting time approved by TWU's Institutional Review Board. Testers followed a script to ensure accuracy and consistency between testing (Appendix D). Participants were asked to wear form-fitting clothing for proper marker placement. A Sony video camera and iPad 2 were positioned to obtain a full vertical sagittal plane image of the participant. Markers were placed on the following three bony prominences on participant's left side for accuracy of measurement: lateral axis of knee, lateral malleolus, and lateral base of the fifth metatarsal. Standardized methods were used to palpate landmarks for marker placement (Biel, 2010). Recording devices were positioned at an equal height and appropriate distance based on the height of the participant (Figure 1). Both devices recorded at the same time in order to capture the same movement.

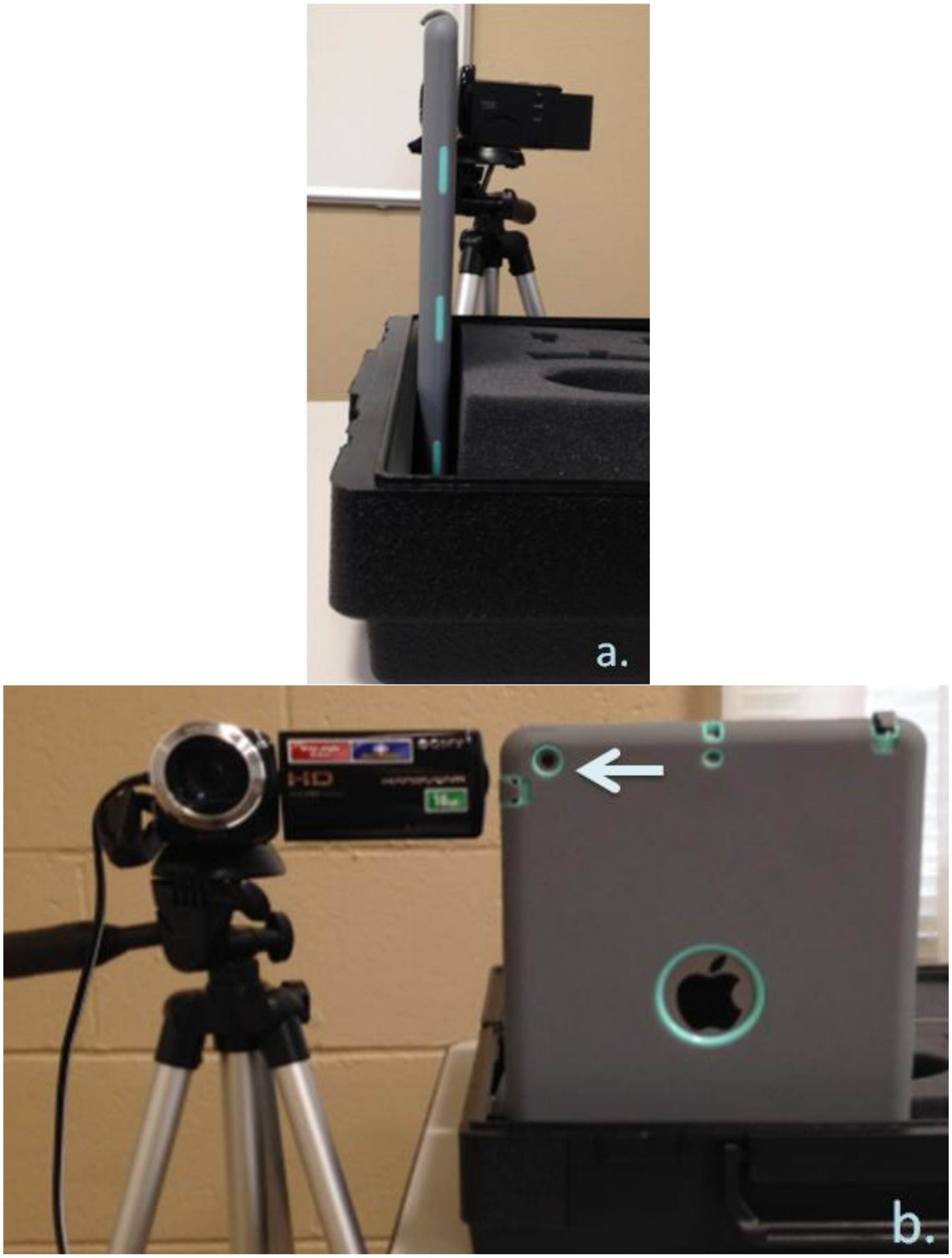

Figure 3.1: Sagittal view (a) and frontal view (b) of camera lens setup including the Sony camera and iPad. Arrow indicates position of the iPad 2 lens.

A gait belt with loops (Figure 2) was placed securely around the participant's abdomen over their approximate center of mass. Participants were asked to position themselves in an upright standing position with heel on a piece of tape and feet shoulder-width apart. Once the participant was in place, they were read the instructions, “Lean forward into my hands as far as you can go. Once you feel like you are losing your balance, do whatever you feel is necessary to regain your balance, including taking a step.” This statement was adapted from the Mini-BESTest compensatory stepping correction for forward and backwards motion (Franchignoni et al., 2010) to evoke an internal perturbation as participants reached their self-selected cone of stability limits. Participants did not receive an external perturbation; instead, their response to this internal perturbation was measured.

Figure 3.2: Gait belt with loops

One tester was positioned in front of or behind the participant maintaining a reading of zero Newton’s on a flat handheld dynamometer placed in the tester’s left hand (Figure 3). The handheld dynamometer was placed inferior to the clavicle for forward testing and on the spine of the scapula for backward testing. This tester’s right hand was in direct contact with the participant in the same location on the opposite side of the body and applied no force on the participant. The use of a flat handheld dynamometer was to endure the investigators exerted no force on the participant. A second tester was positioned behind or in front of the participant for safety purposes, guarding the participant with hands placed in the gait belt loops (Figure 4). The use of a gait belt with loops minimized the possibility of providing unwanted tactile feedback leading to a false sense of security for the participant, thus affecting their performance. Lastly, a third investigator was responsible for starting the recording devices.

Figure 3.3: MicroFET 2 Handheld Dynamometer

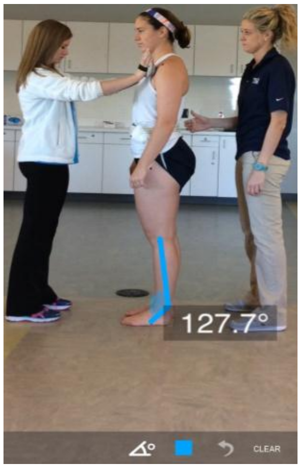

Figure 3.4: Younger Adult Testing Procedure

The trial was repeated if any force was applied. During the data collection only one trial was repeated secondary to not maintaining a reading of zero Newton's on the handheld dynamometer. The procedure took approximately ten minutes for each participant over a single session.

Data Collection

Each video clip taken on the iPad 2 was uploaded into the Dartfish Express app for analysis. Each video clip captured by the Sony camera was uploaded into the Dartfish ProSuite 7.0 software on a laptop. Once the video clips were uploaded ankle angles for each position was determined. This process took about two minutes per device for an experienced Dartfish user.

The axis was aligned on the lateral malleolus marker; the Dartfish app drawing tool was used with a stylist to draw a line from the lateral malleolus to the lateral axis of the knee marker and the base of the fifth metatarsal marker (Biel, 2010). The use of markers to determine start and stop angles provided a standard measurement across participants rather than using standard goniometric measurements (Figure 5). Ankle start angle for forward and backward directions was defined as the participant’s starting position prior to the initiation of an ankle strategy. Ankle stop angle for forward and backward directions was defined as the participant’s position prior to their heel rising from the ground to initiate a step. Each video clip was measured at the same time stamp on both devices within a 0.3 second window due to differences in software formatting. Sound cues were also used to capture the closest video clip for each device.

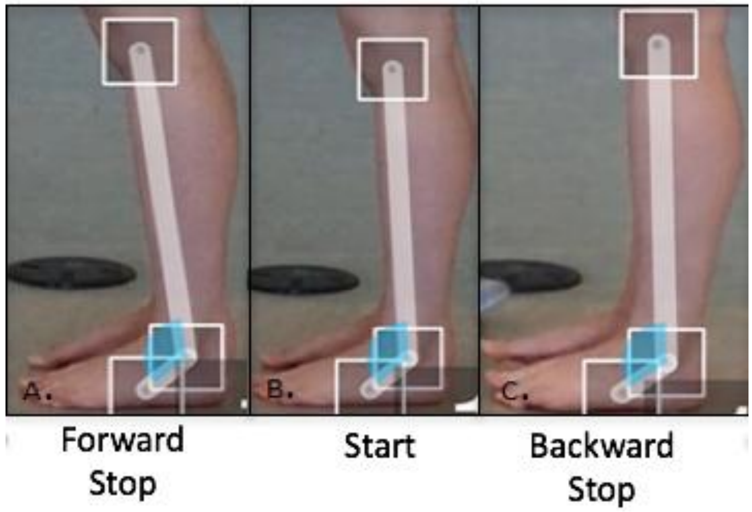

Fig. 3.5: Positions for Forward Stop Angle (A), Start Angle (B), and Backward Stop Angle (C). Note: standard goniometric landmarks are not represented, arrows represent the direction of movement and the time stamp captured for forward and backward stepping response time.

Data Analysis

Data analysis was completed with SPSS 19. Descriptive statistics were used to analyze participant characteristics of age and gender. The relationship between the Dartfish ProSuite 7.0 software and the Dartfish Express app on an iPad 2 was analyzed with SPSS using Pearson's product moment correlation coefficient. Criteria used for Pearson’s correlation are as follows: 0 to 0.25 no relationship, 0.25 to 0.50 fair relationship, 0.50 to 0.75 good relationship, and above 0.75 an excellent relationship (Portney & Watkins, 2009).

Dependent t-tests compared the between software differences on forward start, forward stop, backward start, and backward stop angles. Mean values for each position were calculated to provide a standard measurement at which a motor strategy was initiated and terminated prior to taking a compensatory step in young adults. Calculated mean values may indicate an individual's limit of stability in the anterior and posterior direction under these specific conditions. Means values may also serve as a baseline measurement for comparisons in subsequent studies with another population of individuals comparing the initiation and completion of an ankle motor strategy.

Results

Thirty participants completed the study (21 female and 9 male) ranging from 22 to 40 years old (M=26.5 ±4.5 years). Self-reported physical activity was assessed by the question, "Do you participate in regular physical activity?" with a total of 29 participants responding "yes." Self-reported fear of falling was assessed by the question "are you concerned about falling?" with 30 participants reporting "no." Participants were asked these questions to provide the investigators a description of the sample. All participants were successful in responding to the anticipatory balance threat and preventing loss of balance.

Differences between devices for all four positions were compared using dependent t-tests. Positions included forward start, forward stop, backward start, and backward stop angles. There was no significant difference noted between the Dartfish Express app and Dartfish ProSuite 7.0 software for all positions (Table 1). Pearson's product moment correlation coefficient statistic showed an excellent relationship (>0.75) (Portney & Watkins, 2009) between the Dartfish ProSuite 7.0 software and the Dartfish Express app, for all positions (Table 2). The ankle means (measured in degrees) for each position and standard deviation between software were similar with only small differences less than one degree noted (Table 3 and Figure 6).

Table 1

Dartfish Express App and Dartfish ProSuite 7.0 Software Comparison Using Dependent t-test

Position	Mean Difference (Degrees)	t-value	p-value
FW Start app vs Software	-0.04	-0.44	0.66
FW Stop app vs Software	0.13	1.31	0.20
BW Start app vs Software	0.13	1.79	0.08
BW Stop app vs Software	-0.02	-0.16	0.88

Note: App= application, FW= forward, BW= backward, vs= versus, *= significant ≤ 0.05. Measurements taken from markers placed on lateral axis of knee, lateral malleolus, and base of the fifth metatarsal. Note: standard goniometric landmarks are not represented. (n=30)

Table 2

Relationship Between Dartfish Express App and ProSuite 7.0 Software

Position	r	p-Value
FW Start	0.996	0.00
FW Stop	0.996	0.00
BW Start	0.998	0.00
BW Stop	0.995	0.00

Note: app= application, FW= forward, BW= backward. Measurements taken from markers placed on lateral axis of knee, lateral malleolus, and base of the fifth metatarsal. Note: standard goniometric landmarks are not represented. (n=30)

Table 3

Ankle Means in Younger Adults

Position	iPad Mean Degrees (±SD)	Camera Mean Degrees (±SD)
FW Start	131.25±5.43	131.24±5.68
FW Stop	128.39±6.48	128.26± 6.42
BW Start	131.38±6.32	131.21± 6.29
BW Stop	132.60± 7.45	132.63± 7.68

Note: FW= forward, BW= backward, SD= standard deviation. Measurements taken from markers placed on lateral axis of knee, lateral malleolus, and base of the fifth metatarsal. Note: standard goniometric landmarks are not represented. (n=30)

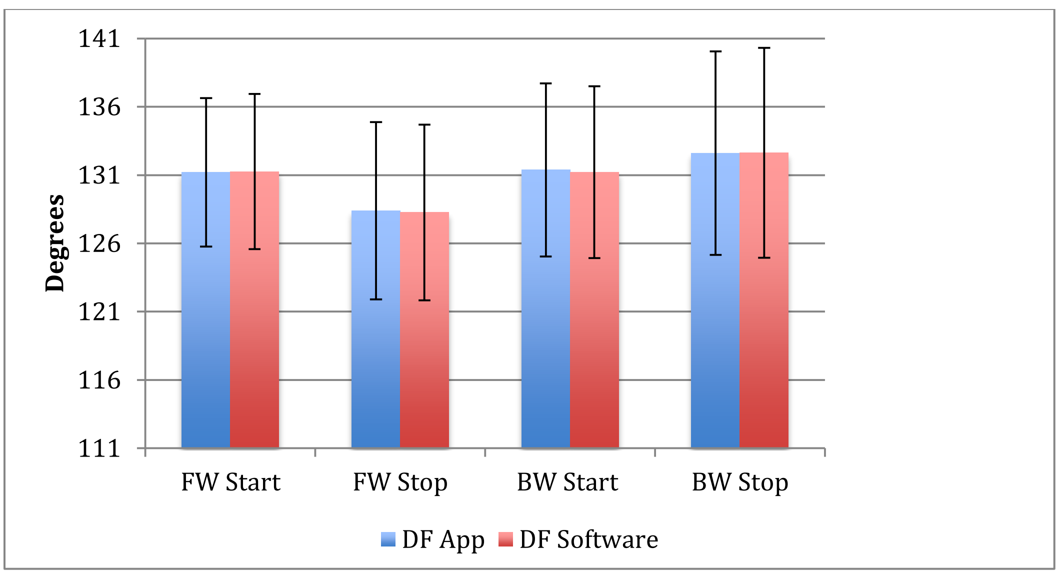

Fig. 6. Ankle Mean Comparisons in Younger Adults. N*ote*: DF= Dartfish, App= application, FW= forward, BW= backward. Measurements taken from markers placed on lateral axis of knee, lateral malleolus, and base of the fifth metatarsal. Note: standard goniometric landmarks are not represented. (n=30)

Discussion

Motor strategies are essential to maintain balance and prevent falls at any age across the lifespan (Woollacoot & Shumway-Cook, 1990). The clinical setting should reinforce frequent assessments of motor strategy use as a fall prevention tool. There is a gap in the literature on valid clinical outcome measures to objectively measure motor strategy use. Currently, clinicians use visual assessment or general balance measures to assess motor strategy use. These measurements do not consistently provide detail on initiation, time taken, and the sequence of motor strategies. Inadequate use of motor strategies can result in a fall secondary to a slow or inappropriate reaction or recovery from the balance disturbance. The profession of physical therapy faces great challenges in the practice setting; outcome measures are essential for reimbursement and to demonstrate the positive impact on individual's mobility. This study sought to bridge the gap by investigating the concurrent validity between the Dartfish Express app on an iPad 2 and the Dartfish ProSuite 7.0 software. Furthermore, this study sought to measure the motor strategy use during a compensatory stepping correction in a young adult population.

Our study defined start and stop angles as the measurement in degrees prior to the initiation of a motor strategy and the measurement immediately following a motor strategy, respectively. These angles are helpful in determining the subject's displacement from a normal state of balance. They provided an objective measure for comparison and were easy to locate with the use of the Dartfish Express app. The use of the angle drawing tool on the app made it easy to quickly capture an angle and measure the change over a given time period.

Currently, there is not a feasible way to measure force exerted during a perturbation without the use of a harness system, something that is not readily available in physical therapy clinics. Investigators used a handheld dynamometer as a means to standardize the testing procedures. A standard applied force for each participant was not used in this investigation due to the lack of a tool to measure an applied force in a community setting. Therefore, the handheld dynamometer was used to ensure no force was exerted. As a result, participants did not experience an external perturbation, but rather an internal perturbation in response to an anticipatory balance reaction.

The Dartfish Express app and the Dartfish ProSuite 7.0 software are highly correlated in mean angle (degrees) of the start position and stop position (initiation of a motor strategy) in young adults leaning in a forward and backward direction. No significant differences were found between the app and software, and less than one-degree difference between measurements across the app and software was noted. The less than one-degree difference noted between devices could be due to variable postural sway observed across participants. The angle measured immediately prior to a compensatory step may also be representative of an approximation of an individual's limit of stability. This study concluded that the Dartfish Express app is a valid measurement tool for a forward and backward motor strategy use in a lateral view in a young adult population.

Dartfish Express app has great potential to be used as an initial evaluation tool for physical therapists to establish motor strategy use and to measure progress following a balance intervention targeting motor strategy use. The Dartfish Express app represents a more cost-effective and more accessible alternative to Dartfish ProSuite 7.0 software. Many therapists have easy access to a smart device, including tablets and phones, providing the opportunity to incorporate Dartfish Express app analysis into their clinical practice. Further investigations with the Dartfish Express app should consider the clinical utility and inter- and intra- reliability when used as a tool to measure motor strategy use.

Limitations

There are a few notable limitations to this study, yet means to avoid bias and to expand the applicability of this study were implemented. This study was limited by the variance in participant interpretation of the instructions "lean forward (backward) into my hands as far as you can go. Once you feel like you are losing your balance, do whatever you feel is necessary to regain your balance including taking a step." In response to multiple participants going into forward trunk flexion centered at their hips, the participants were instructed "please do not bend at your hips and keep your trunk upright." Despite strong instructions, some participants still demonstrated difficulty with the task. Inter-participant variability is present regardless of setting and is not limited to this study design. Although modified mini-BESTest instructions were used in this study, participants did not receive an external perturbation. Instead, participants responded to an internal perturbation when they reached their self-selected cone of stability limits.

Participants were collected from a convenience sample primary consisting of young adults in their twenties who were involved in regular physical activity. As a result, the sample means may not be generalizable to the young adult population. In order to ensure appropriate app functioning, the Dartfish Express app continuously updates to improve the functionality, fix bugs, and change tool options among other facets. Minimal changes in data results over the analysis period could result from updates in the app software. The investigators did not track the documented changes of the app. However, it was noted that the investigators were unable to detect or monitor major changes in app functionality.

Conclusion

The Dartfish Express app is a valid tool to use when measuring ankle strategy position in younger adults leaning in a forward and backwards direction. There is high clinical utility of the Dartfish Express app, as it proves to be a useful, time-saving tool to evaluating or measuring progress of motor strategy use. In this study, there was a strong correlation between the Dartfish Express app and the Dartfish ProSuite software. Further investigation is warranted to establish the reliability and clinical utility of the Dartfish Express app as a tool to measure motor strategy use.

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CHAPTER IV

STUDY TWO: MOTOR STRATEGY USE IN OLDER VERSUS YOUNGER ADULTS AS ASSESSED BY THE DARTFISH APPLICATION

Background

Adults 65 years and older account for approximately 46.2 million of the U.S. population as of 2014, a 28% increase growth since 2004 (U.S. Department of Health and Human Services, 2015). The rapid expansion of this population subset has resulted in an increased number of falls, reported as one of the most frequent causes of injury to older adults in the United States (Center of Disease Control and Prevention [CDCa], 2016; Cigolle et al., 2015). It is estimated that 30% of community-dwelling adults over the age of 65 fall at least once per year (CDCa). The significant rise in the number of falls in the older adult population is also associated with health comorbidities and considerable healthcare expenses (CDCa; Shumway-Cook et al., 2009). In 2013, the direct medical cost for falls in older adults totaled $34 billion in the United States (CDCa). It is apparent that there is great need to reexamine means in which we can address falls within the healthcare setting.

The degenerative changes in all major body systems during the aging process increase the risk of falls in older adults (Ambrose et al., 2013). Falls also frequently lead to a decline in general health and mobility in older adults (Stoeckel & Porell, 2009). This decline in health and mobility can result in increased financial burden, mortality, a housing relocation, increased fear of falling, psychological and social anxiety, and decreased ability to perform activities of daily living (Denkinger et al., 2015; Scheffer et al., 2008; Stoeckel & Porell). Fear of falling, defined as the level of concern an individual has about falling, is often increased after a fall has occurred (Enderlin et al., 2015). This fear may also result in decreased balance confidence, which is a validated predictor of falling (Landers et al., 2016).

As a result of an increased number of falls, disciplines across the healthcare spectrum continue to investigate how to reduce the number and severity of falls occurring in the older adult population (Ambrose et al., 2013; CDCa, 2016; Ramsey et al., 2015). These efforts include task forces developed to design fall prevention guidelines across multidisciplinary centers (Choi & Hector, 2012; Miake-Lye et al., 2013) and have contributed to a 12% reduction in falls noted with the utilization of initial and follow-up design interventions (Choi & Hector). Providing an appropriate fall intervention includes assessing each individual's risk factors, predisposing factors, fall history, psychological factors, and current disease process. Even with proper intervention strategies, not all falls can be prevented; however, a multiple-intervention approach should be utilized to maximize fall prevention (Choi & Hector).

Physical therapists, as movement specialists, play a vital role in multidisciplinary fall prevention including the assessment and training of motor strategies. Activating a motor strategy when a disturbance occurs assists in maintaining postural control (Kuo & Zajac, 1993). Motor strategies are used differently across the lifespan (Shumway-Cook & Woollacott, 2012) resulting in an increased risk for falling in older adults (Lajoie & Gallagher, 2004; Melzer et al., 2004). Ideally, aging adults would activate the most appropriate motor strategy in a given situation to prevent loss of balance. Available motor strategies include ankle, hip, and stepping (Horak & Nashner, 1986; Shumway-Cook & Woollacott, 2012). An ankle strategy is defined a method used to recover from a small displacement at the hips through activation of muscles centered on the ankle joint and is typically the first motor pattern used for controlling upright sway (Horak & Nashner, 1986; Shumway-Cook & Horak, 1989). A hip strategy is defined as the means to recover from a larger, fast-displacement producing a rapid motion at the hip joint to restore the center of mass within the base of support (Horak & Nashner; Shumway-Cook & Horak). A stepping strategy is defined by the result of in-place strategies no longer being able to control the center of mass with respect to base of support (Horak & Nashner; Shumway-Cook & Horak). Motor strategy also can be understood as various muscle synergies occurring distal to proximal, as appropriate, in response to a balance threat (Shumway-Cook & Woollacott, 1985).

There are marked differences in the use of motor strategies in older adult fallers compared to older adult non-fallers (Bair et al., 2016; Chandler et al., 1990; Lajoie & Gallagher, 2004; Melzer et al., 2004). Differences cited include reduced reaction times and inadequate somatosensory and motor responses to a perturbation (Horak et al., 1997; Lajoie & Gallagher). Reactive stepping behavior in community dwelling older adults is an independent predictor of a future fall (Carty et al., 2014). Additionally, failure to activate motor strategies appropriately when the center of mass (COM) is threatened outside limits of stability may result in a loss of the ability to prevent or recover from a loss of balance (Maki & McIlroy, 1996; Sibley et al., 2011). While current literature highlights the importance of motor strategy activation in fall prevention, physical therapists are not routinely assessing this aspect of balance in clinical practice (Sibley et al.). Inconsistencies between current literature and physical therapy practice may result in the neglect of assessing and training appropriate motor strategy activation the older adult population.

The Dartfish Express application (app) is an innovative two-dimensional (2D) measurement tool clinicians can easily incorporate into physical therapy clinical practice as a tool to assess and measure motor strategies. The retail price of the Dartfish Express app, downloadable on any iOS or Android device, is approximately $4.99 or a small monthly fee (Bergonzoli, 2016), proving it to be a time- and money-saving option for physical therapists in a variety of settings. This study utilized the iOS Dartfish Express app on an iPad 2. The Dartfish Express app has previously been validated with the Dartfish ProSuite software in a younger adult population as a tool to measure motor strategy use (Criminger et al., 2016). Although the Dartfish Express app was validated with the software in a young adult population, questions remain about using this software for a more clinically appropriate older adult population. This study investigated whether the Dartfish Express app can be used as a tool to measure motor strategy use in older adults.

The purpose of this study was to investigate whether motor strategy use during an anticipatory stepping correction in an older adult sample (age 65 years and older) measured with the Dartfish Express app, was comparable with a younger adult sample (age 20 to 45). The time taken to initiate and complete a stepping strategy in a forward and backward direction was also investigated. Investigators hypothesized there would be no difference in the mean start angle (degrees) and a significant difference in mean stop angle leaning forward and backward, in older adults compared to younger adults. Investigators also hypothesized there would be a difference in the mean-time (seconds) from initiation to completion of a step, forward and backward, in older adults compared to younger adults.

Methods

Participants

This study included a total of 60 adults: 30 older adults (age 66 to 81) and 30 younger adults (age 22 to 40). Eligible participants were deemed to be ambulatory and able to maintain their balance in an upright position with or without an assistive device (walker/ cane/orthotic). Participants were excluded if they had current acute medical conditions, major surgery within the past year, or required the assistance of another person to safely walk. Each participant completed a health screen form for inclusion/exclusion criteria and provided the investigator with demographic information regarding various co-morbidities, health conditions, fear of falling, and current physical activity level (Appendix A). Older adult participants completed an Activities-Specific Balance Confidence (ABC) scale prior to testing (Appendix E) as a means of assessing confidence in their ability to perform activities of daily living without falling. Investigators used answers on the intake questionnaire to describe the study sample. Participants were recruited from Texas Woman's University (TWU) as well as local senior community church groups (Appendix

B). Each participant provided informed consent approved by TWU's Institutional Review Board (Appendix C).

Measurements and Instrumentation

Dartfish, founded in 1999 at Switzerland's Swiss Institute of Technology, developed a two-dimensional (2D) video analysis app that captures time, distance, angle, and position through recorded video clips (Bergonzoli, 2016). App capabilities include creating slow-motion playbacks and quantifying movements for analysis by drawing angles directly on a screen shot (Bergonzoli). Dartfish was developed to offer a user-friendly and cost-efficient tool to quantify and analyze movement outside of motion analysis laboratories (Bergonzoli) that are primarily used by athletes and coaches. Dartfish 2D analysis software and three-dimensional (3D) motion analysis software was previously investigated to determine the magnitude of difference between the marker trajectories during a squat position (Eltoukhy, Asfour, Thompson, & Latta, 2012). The authors reported there was approximately a ± 5 mm difference between the two systems when assessing the motion (Eltoukhy et al.).

Dartfish ProSuite software and Dartfish Express app concurrent validity was previously investigated as a tool to measure motor strategy use in a forward and backward direction in a young adult sample (Criminger et al., 2016). No between-device differences were found, and an excellent relationship ($r = 0.995$ to 0.998) between the Dartfish software and app was reported (Criminger et al.). These results indicate that the Dartfish Express app is a valid tool in comparison to the Dartfish ProSuite software to measure motor strategy use in a young adult population.

The ABC scale is a quick and easy outcome measure to quantify confidence in ones ability to maintain balance during functional activities. Most conditions represented on the ABC scale are a part of everyday situations older adults may face requiring them to use balance and postural control systems. The ABC scale is a 16-item self-report measure of balance confidence while performing specific activities (Powell & Myers, 1995). The rating scale for each item is 0 to 100, with 0 indicating no confidence and 100 indicating complete confidence in the individual's ability to perform the stated task without losing their balance (Powell & Myers). The score for each item are added together and then divided by the total number of items for the final score (Powell & Myers). In a sample of community dwelling older adults, a score of 50 to 80 indicated a moderate physical function level, while a score greater than 80 indicated a higher physical function level (Myers, Fletcher, Myers, & Sherk, 1998). A score 67 or below indicates a fall risk (Lajoie & Gallagher, 2004).

Procedure

The primary investigator and testers followed a script for all data collection to ensure accuracy and consistency between tests (Appendix D). Participants were asked to wear formed-fitting clothing for marker placement. Markers were placed on three bony prominences on participants left side for accuracy: lateral axis of knee, lateral malleolus, and lateral base of the fifth metatarsal. Standardized methods were used to palpate body landmarks for marker placement (Biel, 2010). The iPad 2 was positioned on a height adjustable table so that the lens view included a full vertical image of the participant based on their height (Figure 7).

Figure 4.1: iPad Lens Setup. Arrow Signifying Camera Lens.

A gait belt with loops (Figure 2) was placed securely around the participant's abdomen over their approximate center of mass. Participants were asked to position themselves in an upright standing position, heels on a piece of tape, with feet shoulder width apart. Once the participant was in place, they were read the instructions, "Lean forward/ backward into my hands as far as you can go. Once you feel like you are losing your balance, do whatever you feel is necessary to regain your balance, including taking a step." This statement was adapted from the Mini-BESTest (Franchignoni et al, 2010) instructions for compensatory stepping correction for forward and backward direction.

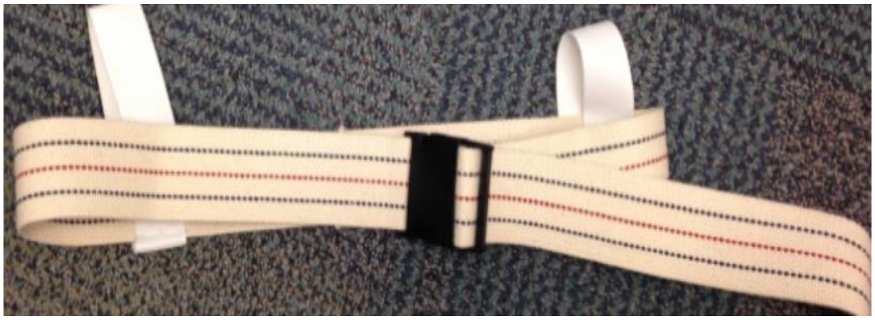

Figure 4.2: Gait Belt with Loops

Three investigators were present for testing procedures. The first tester was responsible for starting and stopping the iPad recording. A second tester was positioned behind or in front of the participant for safety purposes. The second tester guarded the participant with the gait belt loops to minimize the possibility of providing unwanted tactile feedback that might cause a false sense of security for the participant, thus affecting their performance (Figure 8.). Lastly, a third investigator was positioned in front of or behind the participant maintaining a reading of 0 Newtons on a flat handheld dynamometer placed in the investigator's left hand (Figure 3). The handheld dynamometer was placed inferior to the clavicle for forward testing and on the spine of the scapula for backward testing.

Figure 4.3: MicroFET 2 Handheld Dynamometer

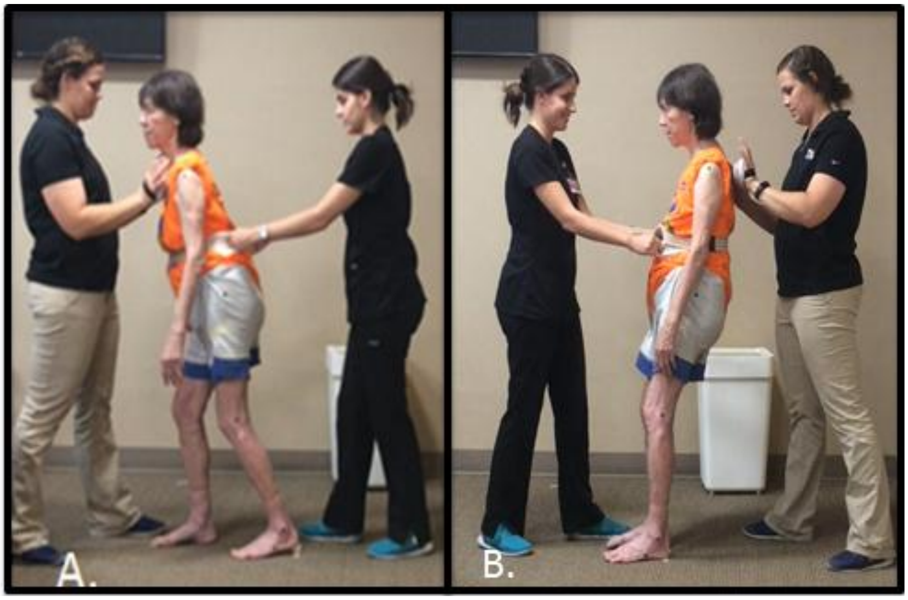

Figure 4.4: Participant Positions for Forward (A) and Backward (B) Testing.

This tester's right hand was in direct contact with the participant in the same location on the opposite side of the body and applied no force on the participant. The use of a flat handheld dynamometer was to ensure the investigators exerted no force on the participant. The trial was repeated if any force was applied as measured with the handheld dynamometer. One participant needed to be repeated in this study secondary to "0" not being maintained during forward testing procedures. The procedure took approximately fifteen minutes for each participant over a single session.

Data Collection

Investigators measured ankle strategy with the use of kinematic measurement tools available on the Dartfish app based on foundational literature finding that the execution of motor strategies is a combination of muscle synergies and kinematics including joint motion (Horak et al., 1997). Each video clip of this procedure was analyzed with the Dartfish Express app on an iPad 2. Using a stylus, this process took about two minutes for an experienced Dartfish user. Ankle measurements were determined by the participants start position prior to initiation of a motor strategy and stop position immediately following the use of an ankle strategy. The axis was aligned on the lateral malleolus marker and the drawing tool was used to draw a line from the axis to the lateral axis of the knee marker, and the marker placed over the base of the fifth metatarsal (Biel, 2010). Based on a protocol established in an unpublished study, markers were used to provide a standardized measurement for start and stop angles across participants rather than using standard goniometric measurements (Criminger et al., 2016). The time (seconds) it took an individual to initiate and complete a stepping strategy was measured with the Dartfish Express app's time stamp. (Figure 9)

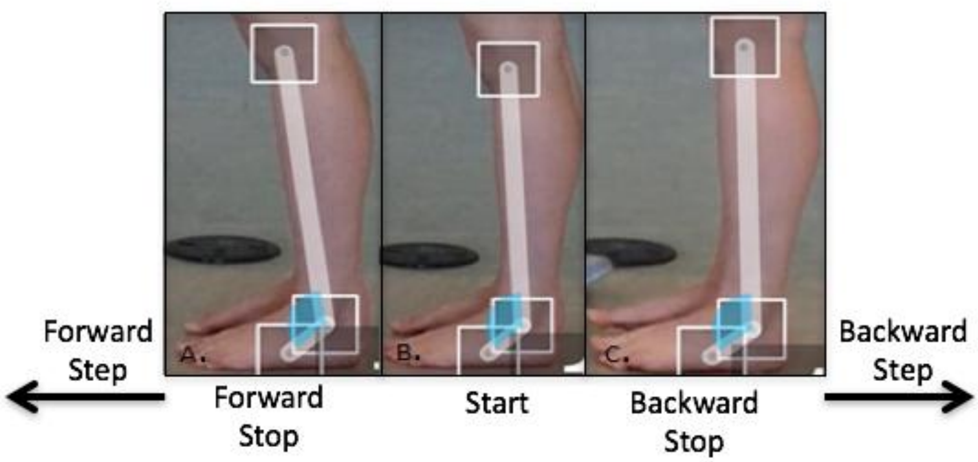

Figure 4.5: Positions for Forward Stop Angle (A), Forward Step, Start Angle (B), Backward Stop Angle (C) and Backward Step. Note: standard goniometric landmarks are not represented, arrows represent the direction of movement and the time stamp captured for forward and backward stepping response time.

Data Analysis

Data analysis was completed with SPSS 19. Descriptive statistics were used to analyze participant characteristics of age, gender, mean ABC scale score, and self-reported physical activity. Stem-and-leaf plots were used to determine the distribution of the data. An independent t-test was used to determine the difference between the older and younger adult means of the start and stop angles, when a motor strategy was initiated (start) and completed (stop) at the ankle joint. Standard goniometric measurement was not used for this analysis. The mean-time it took for older and younger adults to initiate and complete a stepping strategy was measured in seconds and was compared between older and younger adults using an independent t-test. A power analysis was used to determine our sample size of 30 participants in each group generated a medium effect size ($f^2 = 0.606$).

Results

A total of 60 participants completed the study (30 older adults [OA] and 30 younger adults [YA] including 42 females [21 OA, 21 YA] and 18 males [9 OA, 9YA]). The mean age of young adults was 26.5 years (SD ±4.5); the mean age for older adults was 72.6 years (SD= ±4.0). Twenty older adult participants reported they were concerned about falling on the participant intake form. Self-reported physical activity was assessed on the intake form by the question, "Do you participate in regular physical activity?" with a total of 49 out of 60 (20 OA, 29 YA) participants responding they are physically active. All older adult participants completed the ABC scale with an average score of 85.22%

(SD= ±15.93) out of 100% (Powell & Myers, 1995). All participants were successful in responding to the anticipatory balance threat and preventing loss of balance.

Forward start and stop angles (measured in degrees) between the older and younger adult groups were compared with independent t-test. There was a significant difference noted in the forward stop angle between older and younger adults (p= 0.012) (Figure 10). There were no other significant differences between older and younger adults. The mean-time (measured in seconds) it took for participants to initiate and complete a stepping strategy, in both the forward and backward direction, was compared with independent t-test (Table 4, Figure 11). No significant differences were noted.

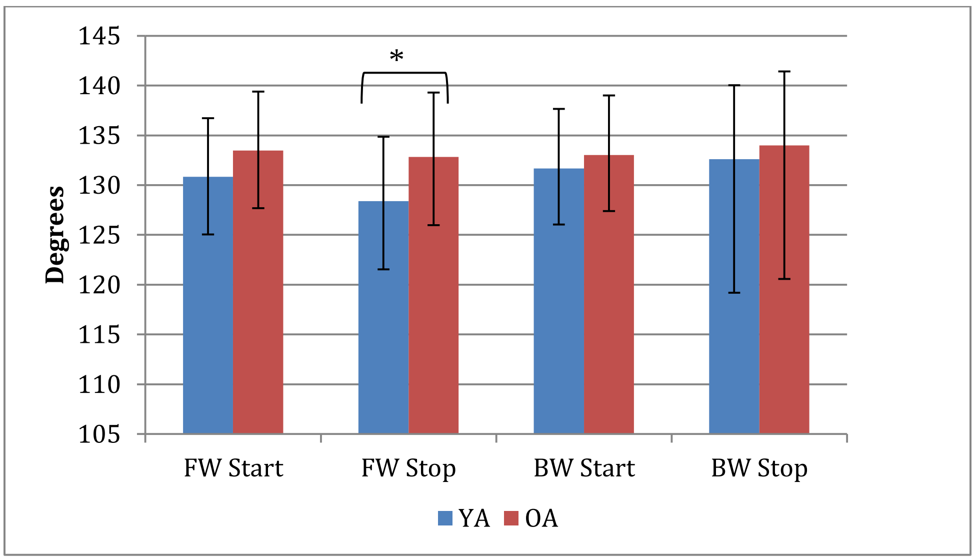

Fig. 4.6. Younger and Older Adult Ankle Means. *Note*: FW= forward, BW= backward, YA=young adult, OA=older adult, *= p<0.05. Measurements taken from markers placed on lateral axis of knee, lateral malleolus, and base of the fifth metatarsal. Note standard goniometric landmarks are not represented. (n=60)

Table 4

Younger vs Older Adult Mean Stepping Reaction Time Using Independent t-test

Time	Young Adult Mean (Seconds)	Older Adult Mean (Seconds)	t-value	p-value
Forward	1.62 (SD= ±0.90)	2.27 (SD= ±1.80)	-1.77	0.08
Backwards	0.57 (SD= ±0.18)	0.53 (SD= ±0.12)	1.07	0.29

Note: *= significant ≤ 0.05. (n=60), SD= standard deviation

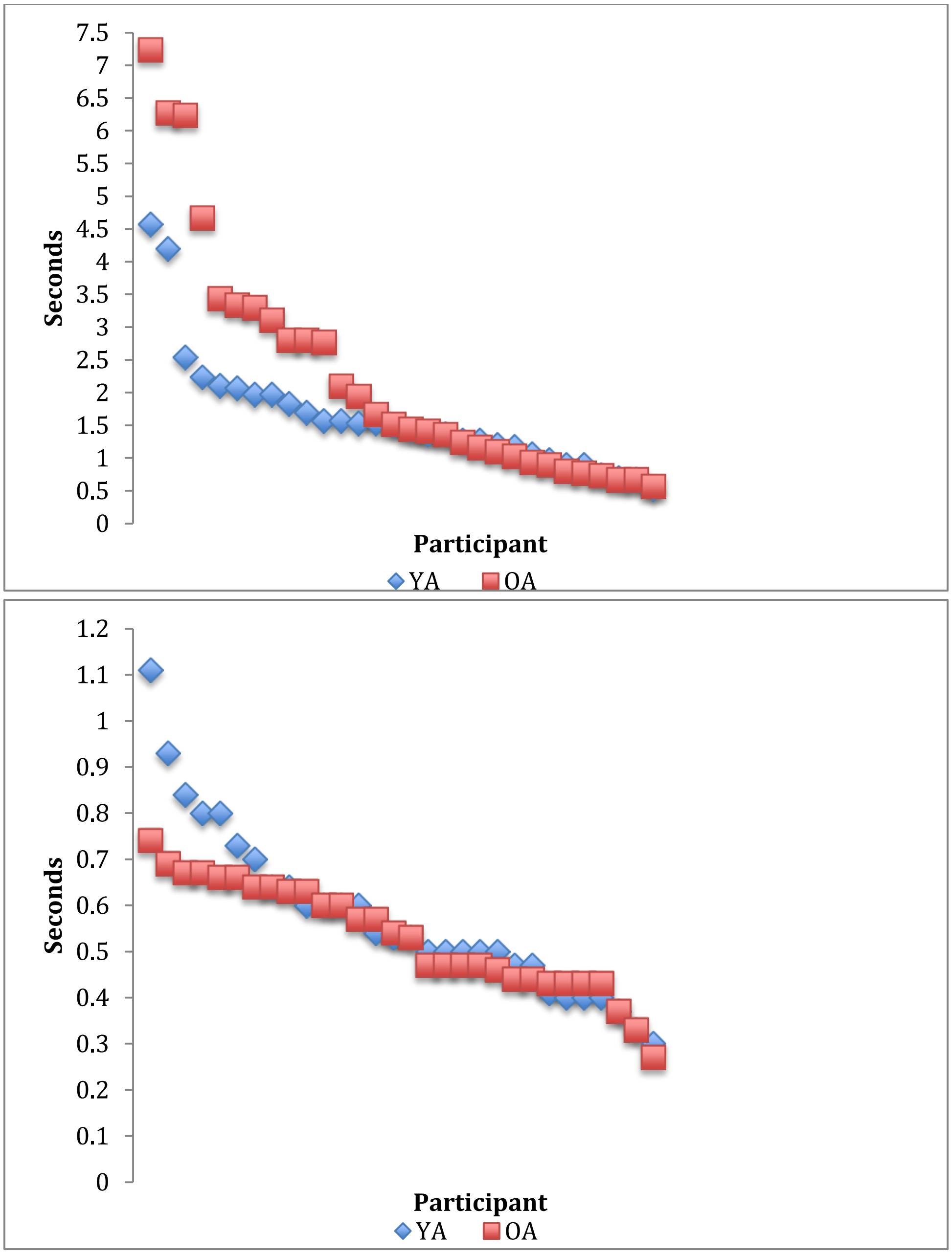

Fig. 4.7: Younger and Older Adult Stepping Reaction by Participant. *Note*: YA= young adult, OA= older adult. Measurements taken from markers placed on lateral axis of knee, lateral malleolus, and base of the fifth metatarsal. Note standard goniometric landmarks are not represented. (n=60)

Discussion

Objectively measuring motor strategy use is an ongoing challenge for therapists in the clinical setting (Sibley et al., 2011) due to the lack of available objective measurement tools. The Dartfish app is an affordable tool that can be easily accessed through smart phone technology across multiple physical therapy settings as an objective measurement of motor strategy use. Therefore, the goal of this investigation was to use the Dartfish app as a tool to measure motor strategy use in younger and older adults in a community-based setting.

In general, community dwelling young adults are confident in their ability to maintain balance, and none of the 30 younger participants were concerned about falling or had a history of falls. That is not the case for many older adults, even those living in the community. Therefore, to better describe the older participants, they completed the ABC scale. The average older adult ABC scale score was 85.22%, indicating a higher physically functioning community dwelling sample of older adults (Myers et al., 1996) not at risk for falling (Lajoie & Gallagher, 2004). Nevertheless, as reported on the intake questionnaire, 20 out of the 30 older adults (66.7%) reported a concern about falling. Determining fall risk is complex and is often multidimensional. Conflict between scores on the ABC scale and participants' report of fear of falling suggest that multiple tools may be needed to provide a clear picture of both internal and external fall risk factors. The ABC scale is a self-efficacy scale; therefore, the scale is limited to the participants' subjective view of their balance confidence on the 16 questionnaire items rather than their fear of falling. Further assessment beyond completion of the ABC scale is necessary to establish an individual's fall risk including reported fear of falling and history of falling.

Results from this study indicated a significant difference in forward stop angle. The younger adults demonstrated increase ankle excursion between forward start and stop positions before taking a step. These findings may indicate a more reserved reactive postural response in older adults. Potential causes of this difference include increased fear of falling, decreased confidence in their ability to regain their balance beyond that point, and an avoidance bias from previous experiences of episodes of loss of balance. Current literature has addressed these variables as factors that influence falls in the older adult population (Bair et al., 2016; Landers et al., 2016). There was no significant difference noted between older and younger adults in backward measurements. Both younger and older participants' responses appeared to be more reserved in the backward direction. This difference may be associated with a psychological component such as anxiety or fear of falling in a backward direction or in any direction where they have partial visual information. Psychological components of balance were not evaluated in the scope of this study.

We measured and compared differences in forward and backward stepping reaction times. No significant differences in forward or backward stepping reaction times were found. This result could be attributed to our sample including only community-dwelling older adults whose ABC scores classified them as higher physically functioning community dwelling older adults (Myers et al., 1996). Although more than half of the older adult participants reported that they were concerned about falling, they still maintained a community-level active lifestyle, as reflected in their study intake questionnaire.

The average age of our older adult sample was 72.6 years, with a range from age 66 to 81. Our sample study population could further be classified as primary young-old adults (age 65-74) and middle-old adults (age 75-84) (Spirduso et al., 1995). A lack of a difference in reaction times between older and younger adults may have resulted from generational differences and variations in the individuals' value placed on health and mobility (Spirduso et al.). The results obtained could also be attributed to study methods used, most specifically the definition of start and stop positions measured by the position prior to the heel rising. This measurement was used to isolate ankle strategy use. This measurement did not account for the toe-off time, the time at which the participant's toe rose from the ground, which could have represented a combination of motor strategies. Further investigation is warranted to explore the generational differences that may contribute to balance reaction times as well as the appropriate methods to measure reaction time.

Current fall literature has highlighted the importance of measuring motor strategy use and the applicability of motor learning principles (Horak et al., 1997; Sibley et al., 2011). This study focused on using the Dartfish app to objectively measure ankle and stepping strategies. The results of this study demonstrate the ability of the Dartfish app to routinely measure motor strategy use in a community setting. The ability of the Dartfish app to quantify small changes in movement may make it a valuable addition to the current tools used to assess motor strategies; the app can be used in conjunction with outcome measures and postural control interventions to provide clinicians with a more comprehensive assessment of patient motor strategy use. The app involves a minimal investment of time and financial cost. However, current literature regarding the Dartfish app is limited and determination of clinical feasibility and applicability should further be investigated.

The accessibility of an objective clinical measurement tool can assist clinicians in developing the most appropriate plan of care to meet their patients' individual needs. Current literature highlights the relevance of the Dartfish software in physical therapy clinical practice, including sports medicine and orthopedics. Bergonzoli (2016) suggests the Dartfish serves as an injury prevention tool for athletes, as it provides objective feedback of biomechanical movement which can then be modified to prevent overuse and other injuries. To our knowledge, our study is the first to investigate the use of Dartfish as a tool to measure balance in an older adult sample. In applying the general principles of the app's utility and clinical reliability, there is great potential for the Dartfish to be used as a fall and injury prevention tool in the older adult population. The information and measurements collected by the app provides objective feedback that can be modified with specific cues and other clinical interventions. Furthermore, the Dartfish app provides clinicians with a resource by which motor strategies can be objectively measured. As a result, clinicians will then know how to address these deficits in their intervention, with the ultimate goal in reducing an individual's risk for falling and thus improving quality of life. The Dartfish app has the potential to serve as a vital tool for health and wellness programs across the adult lifespan.

More information is needed to assess the usefulness of the Dartfish app in other populations typically needing treatment to address falls and balance disorders. Future studies are needed to explore the differences between older adults who report falling and a fear of falling compared to those who do not. The utility of the Dartfish Express app in measuring motor strategy use before and after an intervention targeting motor strategy training should be considered in future studies. As such, task-specific principles applied within an intervention could also be explored to improve older adult's ability to appropriately respond to a balance threat.

Limitations

Several limitations must be noted when considering the findings of this study. This methodological study focused on the Dartfish app and did not include measurements beyond those captured by the app, such as center of mass, leg length or joint range of motion measurements. These potential variables may play important roles in balance strategy use, but were beyond the scope of this study. Furthermore, the Dartfish Express app software program continuously updates offering improvements including improving functionality, fixing bugs and updating tool options. This could have led to small changes in data analysis performed over a period of time that the investigators were unable to detect or control. However, it was noted that the investigators did not detect changes in app functionality.

Limitations to this study include the variance in participant interpretation and understanding of the instructions "lean forward (backward) into my hands as far as you can go. Once you feel like you are losing your balance, do whatever you feel is necessary to regain your balance including taking a step." The study focused on the ability of the Dartfish to measure an ankle strategy moving into a stepping strategy. Multiple participants responded to the instructions by moving into excessive forward trunk flexion centered at their hips (a hip strategy). The activation of hip strategy was not measured in these studies. Instead, participants further were instructed, "please do not bend at your hips and keep your trunk upright" and "take a step to prevent losing your balance when needed." Some participants still demonstrated difficulty with the task. The older adult sample demonstrated increased difficulty with the task compared to the younger adult sample, frequently requiring repeated instructions. Participants used a variety of a hip strategy motion in response to the instructions and additional study is required to determine if the Dartfish application is a valid tool for measuring hip strategy use. Nevertheless, the overuse of hip strategy may have affected the participants' use of ankle and stepping strategies as well as start and stop angles and as stop and start times.

Due to the lack of clinically applicable resources to produce and measure an applied perturbation, a modified version of the Min-BESTest was used in this study to provoke a motor strategy response. Although studies have reported positive findings administering and measuring a perturbation with harness systems and moveable force plates (Bair et al., 2016; Dijkstra et al., 2015; Sturnieks et al., 2013), these are not readily available in most clinics. A handheld dynamometer was used in this study to standardize the testing procedures ensuring no force was exerted by the tester during the procedures. Thus, participants did not experience an external perturbation, but rather an internal perturbation as they moved to the limits of their cone of stability.

A final study limitation is that participants were recruited from a convenience sample in the local community. While results regarding the validity of the Dartfish app can be generalized to similar community-based populations that may be the focus of health promotion and wellness programs, our results may not be generalizable to all older and younger adult populations. The ability of the Dartfish app to measure the balance strategies in persons with balance dysfunction has not been determined.

Conclusions

Older adults demonstrate a significant difference in ankle motor strategy use in comparison to younger adults when measured in a forward direction. Motor strategy use in a forward and backward direction across the adult life span can be effectively measured in a clinical setting with the Dartfish Express app. The Dartfish Express app can be a useful and time saving tool when evaluating or measuring progress of motor strategy use. Further investigation is warranted to establish the most appropriate clinically applicable way to assess motor strategy use with the Dartfish Express app as an outcome measurement tool.

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CHAPTER V

DISCUSSION

Introduction

While contemporary literature highlights the importance of motor strategy activation in fall prevention, physical therapists do not routinely assess motor strategies in clinical practice (Sibley et al., 2011). Measurement difficulties in non-research settings may contribute to this finding. Therefore, the goals of this dissertation were to identify an adequate tool to assess motor strategies, establish its validity, and use it as a tool in community-based settings. We used Dartfish, a two-dimensional (2D) motion analysis software, and designed two studies to achieve these goals.

The purpose of study one was to establish the concurrent validity of the Dartfish Express app on an iPad 2 compared to the Dartfish ProSuite 7.0 software to measure the motor strategy use during a compensatory stepping correction in a young adult population. After establishing the validity of the Dartfish Express app on an iPad 2, the purpose of the second study was to investigate whether motor strategy use measured with the Dartfish Express app in an older adult sample was comparable with a younger adult sample as well as stepping strategy reaction time in the forward and backward directions. This chapter will provide clinical implications and recommendations for future research. Relevant limitations in each section will be discussed.

Discussion of Findings

Clinical Implications

While there are many ways to evaluate motor strategy use in individuals, finding the most effective and clinically applicable tool to measure motor strategy use is undetermined. There is a well-established body of knowledge on the activation and training of motor strategies within a laboratory setting (Bair et al., 2016; Horak & Nashner, 1986; Lurie et al., 2013; Mansfield et al., 2011; Martinez et al., 2013; Shumway-Cook & Woollacott, 2012). However, they lack clinical utility due to limited financial, time, and staffing resources available in most clinical settings (Chandler et al., 1990).

The two studies in this dissertation sought to expand the knowledge on the use of the Dartfish Express app as a valid tool for objectively measuring motor strategies. Our results suggested that the Dartfish Express app can be used in conjunction with current outcome measures to provide a more comprehensive assessment of motor strategy use in community settings. The Dartfish app on an iPad2 is a portable tool, thus making it easily used by therapist in the clinic and community.

When considering the use of the Dartfish Express app in clinical settings, several practice concerns arise: methods used in these studies included three testers and the use of markers on boney prominences. Prior to initiation of the first study, investigators chose to use three testers providing each tester with one task to ensure safety of participants. As the studies were carried out, it became clear that it is not necessary to have three testers to use the Dartfish app. Clinicians can easily set up the camera device of their choice, start the recording, and then preform the testing. This would result in longer digital clips, but overall use of the Dartfish app would be unchanged. Based on the mobility level of the patient, clinicians may require a second person for safety purposes. For relatively mobile patients, only one tester is needed in the direction of the step. Although placing markers on boney prominences will require valuable clinic time (approximately 1 minute), pilot data suggest marker use increased accuracy when using the Dartfish drawling tool. Pilot data also supported using a stylus and a device with a larger screen size for increased accuracy when using the Dartfish app. While an iPhone was considered, the iPad was selected, as the Dartfish drawing tool was easier with the iPad's larger 9.7-inch (246.4-mm) screen. The results found in this dissertation are specific to the use of the Dartfish app on an iPad 2, therefore can-not be generalized to smaller or larger screen size. The Dartfish app on a similar-sized device has the potential to be used across physical therapy clinical settings for initial assessments, fall and injury prevention, as a means to measure progress and as a means to provide patient education using visual feedback. Use of the Dartfish app saves valuable time and financial resources for users.

Dartfish has been used by athletes and coaches ranging from high school to the Olympics to quantify and provide immediate feedback on performance and as an injury prevention tool (Bergonzoli, 2016). The use of Dartfish by healthcare professionals is on the rise providing movement assessments, injury prevention, and enhancing patient care (Bergonzoli, 2016) and has great potential to serve as a fall and injury prevention tool in the older adult population. The app is designed to be a condensed portable version of the software, making it user friendly by providing instructions and icons for the user to follow as a guide (Bergonzoli). The Dartfish app is available on iOS and Android devices, including smart phones and tablets, for an affordable price. This allows easy access of the Dartfish technology to a larger audience of practitioners increasing the potential for clinical utility. The app on each operating system may have variations, software updates, and fees outside of the user's control that may affect the outcomes of clinical use. To maintain reliability with the app's performance, users should use the same device for all testing procedures. Using the Dartfish app as a measurement tool to provide preventative knowledge and advance clinical practice in physical therapy is an innovative step to better understanding of movement in older adults.

While no single study can provide a complete validation of the one best tool across the adult lifespan, the two studies completed add to the body of knowledge providing evidence that the Dartfish Express app can be used as a tool to objectively measure motor strategy use following an internal perturbation in community-dwelling older and younger adults. The findings in these studies provide a way to seek answers to new questions regarding motor strategies use and training in patient populations.

Recommendation for Future Research

This investigation is the stepping stone for new approaches in balance and postural control in the clinical setting. It also opens the door to future directions and research lines that should be addressed. Further investigation is needed to establish the Dartfish app's reliability, clinical utility, responsiveness, and ability to further advance clinical research; the aforementioned facets should consider the app's utility in assessing and training motor strategies.

Future research should investigate the reliability of the Dartfish app as a tool to assess motor strategies across a lifespan, as the app currently shows strength in assessing motor strategies as evidenced by the domains in which the app is utilized. Once validity and reliability of the app have been established, investigators can continue exploring the best means to provide an internal or external perturbation, thus provoking the use of motor strategies in the individual patient. There is no one best means to provide an internal perturbation; looking at a functional reach task could be considered. Likewise, there is no best method to provide an external perturbation; however, using a treadmill to evoke an external perturbation could be considered. As such, upon gaining results from evaluations of Dartfish app measurements in the context of varied internal and external perturbations, researchers can apply the findings to a clinical setting.

Clinical utility of the Dartfish app is critical secondary to the limited time and resources of the clinician. Cost benefit should be invested to determine if the time needed to learn to use the device, set-up the device, and implement the use of it is worth the loss of clinic time. Also further investigation is needed to determine if the Dartfish app is user-friendly across provider networks and a valuable tool in the scope of their clinical practice. Once clinical utility is established, further research should explore remaining questions on motor strategy training interventions. Such findings can shed light on direct clinical application for patients with balance dysfunction and older adults who fall or who are at risk for falls.

Within the clinical setting, the Dartfish app's responsiveness as a tool to measure balance strategies in patients with balance problems is important to investigate. Further investigation in this area will guide clinical use of the Dartfish app as a measurement tool. The app has the potential to provide clinicians with valuable information otherwise unknown, as this information cannot be captured with the human eye.

The advancement of clinical research will ensue as the Dartfish app is utilized in assessments of motor strategy activation and fall prevention, especially within the older adult population. Current literature focuses on technical applications of induced force and perturbation: the use of induced forward, lateral, and backward perturbations coupled with the use of harness systems; the use of specialty designed technology that provides an external perturbation (Bair et al., 2016; Dijkstra et al., 2015; Sturnieks et al., 2013). Although these studies report positive findings supporting the need for further postural reaction assessment and training strategies in the older adult population, the equipment used is not readily available for clinicians. Alternative methods for assessing postural reactions and motor strategy use is needed in a form that is not cumbersome and not technical for the provider; the Dartfish app proves beneficial in overcoming this barrier, thus warranting future study.

Literature supports the idea that motor strategy training can be successful through task specific practice and repetition (Dijkstra et al., 2015); thus, further investigations should target the clinical utility of assessing and training motor strategies for fall prevention across physical therapy practice settings. In the older adult population, neuroplasticity also comes with repetition of tasks (Dijkstra et al.). The Dartfish app can be used as an assessment and training tool, with repeated use. Using the Dartfish app will provide clinicians a means to capture small changes in older adult’s motor strategies use.

Prior to full implementation of the Dartfish app into clinical practice when caring for older adults, additional research is needed in diverse realms; variations of this study's design and methods will encourage exploration in other areas for the app's use. While optimal methods for assessing motor strategy are not known, this study sought to expand current research in the realm of motor strategy activation using the Dartfish app in the older adult population. Varying methods would ensure a stronger understanding of the app's reliability, functionality and sensitivity as it relates to application in the clinical realm.

Expanding participant populations and making comparisons among groups would lead to greater insight into the validity of the Dartfish app. In future studies, assessment of patients in expanded age groups and those with a fall history should occur. In considering young older adults and middle older adults, researchers can establish validity of Dartfish across the human lifespan, and not solely in the older adult population. Furthermore, expanding participant age groups will also provide a greater understanding of age-related motor response changes within each subset. In turn, this will provide a stronger connection between Dartfish measurements and fall prevention strategies.

Once the remaining questions, as cited above, have been clarified, the Dartfish app can begin implementation in clinical practice and alter practice protocols. This may include further investigations focusing on best clinical practice guidelines for training motor strategies. Due to increasing rates of falls in the United States population (Centers for Disease Control and Prevention [CDC], 2016) it is necessary that such literature findings are established in motor strategy training protocols using established methods for testing. In conclusion, while the reliability, clinical utility, responsiveness, and ability to further advance clinical research still should be considered, we are confident that this study provides the initial steps to establish methods for using Dartfish as a measurement tool in healthy, younger and older adults.

Conclusion

The studies conducted in this dissertation indicate that the Dartfish app is a valid tool for clinicians to use in conjunction with current outcome measures for the clinical assessment of motor strategies across the adult lifespan in community settings. The app is more affordable than the Dartfish ProSuite software and is user friendly on multiple smart devices. The second study in this dissertation emphasizes the need to further investigate stepping reaction time differences between older and younger adults. Available literature and clinical practice would benefit from updated evidence for clinical application. The Dartfish app is an innovative measurement tool that can be used to assess motor strategy use.

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APPENDIX A

Participant Intake Forms

Participant ID ______ Date _____ / _____ / _____ Tester _____ Dartfish Study

Intake Form

1. Male _____ Female _____

2. Date of Birth: __________ Age: __________

3. Do you have a doctor that you see regularly? _____ NO _____ YES

4. How often do you visit your doctor? ______________________________

5. Has a doctor ever told you had any of the following conditions? (check all that apply)

_____ Cancer _____ Diabetes _____ Blood clots _____ Stroke (right or left side affected) _____ Blood Pressure (low or high) _____ Arthritis (osteo/ rheumatoid) _____ Seizures	_____ Parkinson's _____ Multiple Sclerosis _____ Heart Disease (please describe Below) _____ Renal Disease (Please describe Below) _____ Visual difficulties (Please describe Below) _____ All Other conditions

Please describe all other conditions here:

6. During the past year, have you had ANY surgical or medical procedures?
_____ NO _____ YES
a. If YES, what type?
____

7. Are you able to stand on your own without any help? _____ NO _____ YES

a. If NO, then who (such as family members, friends) or what (such as cane, wheelchair, walker) do you use?
____

8. Do you have ANY pain today? _____ NO _____ YES
a. If YES, where? ____

b. Is this typical or unusual for you? ______________________________________

9. Do you participate in regular physical activity? _____ NO _____ YES

a. If YES,

Typically how many days a week? (circle one)
1 2 3 4 5 6 7

On average how many minutes each day? (circle one)
0-15 15-30 30-45 45-60 60-75 75-90 90-105

What type of activity? (circle all that apply)
Cardiovascular (walking, running, swimming, dancing)
Strengthening (body weight, free weights, exercise machines)

10. Are you concerned about falling? _____ NO _____ YES

11. Are you afraid you might fall? _____ NO _____ YES
a. If YES, please describe when or under what circumstances you think you might fall:
____

12. Do you have any other comments or concerns? _____ NO _____ YES
a. If YES, please describe them:
____

This is the end of the Health Screening Questionnaire Thank you for your participation and we look forward to working with you!

Participant ID __________ Date _____ / _____ / _____ Tester ____ Dartfish Study

Contact Information

1. Name: ____

2. Phone: ____

3. Address: ____

   City: ______________________

   Zip: ______________________

4. Testing Date: ____

This information is collected on a separate page so the participant's identity is protected.

APPENDIX B

Recruitment Flyers

TEXAS WOMAN'S UNIVERSITY

Want to be a part of an innovative exciting study with new technology?

WE NEED YOU!

If you are age **22-45** and able to carry out your daily task without assistance we want you to be a part of our study investigating balance reactions!

This is a one time commitment lasting ~15 minutes.

If you are interested or have further questions please contact us by phone or email.

Thank You for YOUR help!

Email: Christina Criminger, PT

ccriminger@xxx.xxx

Phone: 214-xxx-xxxx

TEXAS WOMAN'S UNIVERSITY

<u>Want to be a part of an innovative exciting study with new technology?</u>

WE NEED YOU!

If you are age 65 or older and able to carry out your daily task without assistance we want you to be a part of our study investigating balance reactions!

This is a one time commitment lasting ~15 minutes.

If you are interested or have further questions please contact us by phone or email.

Thank You for YOUR help!

Email: Christina Criminger, PT

ccriminger@xxx.xxx

Phone: 214-xxx-xxxx

APPENDIX C

IRB Approval Letter

TEXAS WOMAN'S UNIVERSITY
DENTON DALLAS HOUSTON

Institutional Review Board
Office of Research and Sponsored Programs
P.O. Box 425619, Denton, TX 76204-5619
940-898-3378
email: IRB@twu.edu
http://www.twu.edu/irb.html

DATE: July 17, 2014

TO: Ms. Christina Criminger
School of Physical Therapy - Dallas

FROM: Institutional Review Board - Dallas

Re: Approval for Criterion Validity of the Dartfish Use During Compensatory Stepping Corrections in Adults: Methodological Considerations (Protocol #: 17680)

The above referenced study has been reviewed and approved by the Dallas Institutional Review Board (IRB) on 7/17/2014 using an expedited review procedure. This approval is valid for one year and expires on 7/17/2015. The IRB will send an email notification 45 days prior to the expiration date with instructions to extend or close the study. It is your responsibility to request an extension for the study if it is not yet complete, to close the protocol file when the study is complete, and to make certain that the study is not conducted beyond the expiration date.

If applicable, agency approval letters must be submitted to the IRB upon receipt prior to any data collection at that agency. A copy of the approved consent form with the IRB approval stamp is enclosed. Please use the consent form with the most recent approval date stamp when obtaining consent from your participants. A copy of the signed consent forms must be submitted with the request to close the study file at the completion of the study.

Any modifications to this study must be submitted for review to the IRB using the Modification Request Form. Additionally, the IRB must be notified immediately of any adverse events or unanticipated problems. All forms are located on the IRB website. If you have any questions, please contact the TWU IRB.

cc. Dr. Ann Medley, School of Physical Therapy - Dallas
Dr. Mary Thompson, School of Physical Therapy - Dallas
Graduate School

APPENDIX D

Procedure Script

Procedure Script

1. Informed consent:
a. "Welcome to our study. Please fill out this informed consent form and intake form. These forms will provide us with information about you and will be confidential. Please read over the forms carefully and let us know if you have any questions or would like anything clarified before we get started. Please note that this session will be videotaped. While we will present the results of this study at a scientific meeting or in a scientific paper, your identifiable information or image will not be shared with anyone outside of the research team."
b. Assign participant a research identification number prior to testing to maintain participant's privacy.
c. *Hand participant form and pen.* Participant completes forms
d. "Do you have any questions at this time?" *Answer any questions.*
e. "Remember, you can stop at any time."
f. "If you need to change into shorts and/or a t-shirt before we get started, there is a bathroom down the hall."
2. Participant set up:
a. "We are going to place markers on your shoulder, hip, knee, ankle and foot. These are simply to help us identify landmarks when we analyze the video.
b. Please take off your shoes and socks so we can see and place the markers on your ankle and foot.
c. We are going to place this gait belt around your waist for safety purposes.
d. Please stand with your heel at this line."
3. Testing Procedures for forward motion:
a. Tester #1 standing behind participant without contacting participant but prepared to prevent a fall from occurring. Tester #2 (primary tester) standing in front of participant with a flat hand held dynamometer in their left hand in contact with participant just inferior to the clavicle. Ask participant to lean towards tester #2 while maintaining a reading of 0 Newton's of force on the dynamometer. Tester #3 will start and stop recording of video camera and motion analysis cameras.
b. Instructions to participant for forward motion: "Lean forward into my hands as far as you can go. Once you feel like you are losing your balance, do whatever you feel is necessary to regain your balance."
4. Testing procedures for backward motion:
a. Tester #1 standing in front of participant without contacting participant but prepared to prevent a fall from occurring. Tester #2 (primary tester) standing behind participant with a flat hand held dynamometer in their right hand in contact with participant on the spine of scapula. Ask participant to lean towards tester #2 while maintaining a reading of 0 Newton's of force on the dynamometer. Tester #3 will start and stop recording of video camera and motion analysis cameras.

b. Instructions to participant for backward motion: **“**Lean backwards into my hands as far as you can go. Once you feel like you are losing your balance, do whatever you feel is necessary to regain your balance including taking a step.”

5. “We are now done with testing. Do you have any further questions for us?” Take markers off of participant if trial 2 used markers.
6. Testers will upload the video to the Dartfish software

APPENDIX E

Activities-Specific Balance Confidence Scale

The Activities-specific Balance Confidence (ABC) Scale*

Instructions to Participants: For each of the following activities, please indicate your level of confidence in doing the activity without losing your balance or becoming unsteady from choosing one of the percentage points on the scale from 0% to 100% If you do not currently do the activity in question, try and imagine how confident you would be if you had to do the activity. If you normally use a walking aid to do the activity or hold onto someone, rate your confidence as if you were using these supports.

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…

1. …walk around the house? _____%
2. …walk up or down stairs? _____%
3. …bend over and pick up a slipper from the front of a closet floor? _____%
4. …reach for a small can off a shelf at eye level? _____%
5. …stand on your tip toes and reach for something above your head? _____%
6. …stand on a chair and reach for something? _____%
7. …sweep the floor? _____%
8. …walk outside the house to a car parked in the driveway? _____%
9. …get into or out of a car? _____%
10. …walk across a parking lot to the mall? _____%
11. …walk up or down a ramp? _____%
12. …walk in a crowded mall where people rapidly walk past you? _____%
13. …are bumped into by people as you walk through the mall? _____%
14. …step onto or off of an escalator while you are holding onto a railing? _____%
15. …step onto or off an escalator while holding onto parcels such that you cannot hold onto the railing? _____%
16. …walk outside on icy sidewalks? _____%

*Powell LE & Myers AM. The Activities-specific Balance Confidence (ABC) Scale. Journal of Gerontology Med Sci 1995; 50(1):M28-34.

Total ABC Score: __________

Scoring: _____________ / 16 = | __________% of self confidence |

Total ABC Score