EFFECTS OF A 4-WEEK BALANCE TRAINING AND COGNITIVE LOADING PROGRAM IN SUBJECTS WITH CHRONIC ANKLE INSTABILITY

by

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ABSTRACT

JOHN M. GONZALES. Effects of a 4-week balance training and cognitive loading program in subjects with chronic ankle instability. (Under the direction of Dr. TRICIA HUBBARD-TURNER)

Introduction: Previous research has suggested that dynamic balance training can improve both static and dynamic postural control in subjects with chronic ankle instability (CAI). Additionally, several studies have observed that performing various cognitive tasks may improve static balance. However, combining a traditional balance-training program with cognitive loading has not yet been investigated.

Objective: The purpose of this study was to assess the effectiveness of a 4-week rehabilitation program combining balance training and cognitive tasks in subjects with CAI compared to balance training alone.

Methods: Twenty-three subjects, (5 males and 18 females, height = 166.25±8.41 cm, weight = 74.56±14.6 kg, age = 20.4±1.12yrs), with CAI completed this study. Prior to the start of the study, all subjects performed baseline measurements consisting of static balance measures on a force plate, and the Star Excursion Balance Test (SEBT). Subjects were then randomly assigned to either the dual task group or the traditional balance-training group. The traditional balance training protocol was one established by McKeon. The dual task group completed the same balance training; however, they also performed various cognitive tasks. The cognitive tasks included backwards counting by 3s and 7s from a random three-digit number; as well as random number generation. For

each group, training consisted of 3 times per week for a total of 4 weeks. After the 4-week training period, follow up testing was the same as baseline testing. A repeated measures ANOVA (group x time) was performed with an alpha level of $p \leq 0.05$ set prior to testing.

Results: There were no significant group by time interactions for any of the time to boundary (TTB) dependent variables. There were significant main effects for time. Both group had a significant increase in medial lateral (ML) TTB mean (p = .002), in anterior posterior (AP) TTB mean (p = .003), in ML TTB standard deviation (StDev) (p = .048), and in AP TTB StDev (p = .041) at posttest compared to pretest. There was no significant interaction (p = .331) for the anterior direction of the SEBT. There was a significant main effect for time (p = .012). Both groups reached significantly further in the anterior direction at posttest compared to the baseline testing. There was no significant interaction (p = .396) for the posterior lateral direction of the SEBT. There was a significant main effect for time (p = .0001). Both groups reached significantly further in the posterior lateral direction at posttest compared to the baseline testing. There was also no significant interaction (p = .099) for the posterior medial direction of the SEBT. There was a significant main effect for time (p = .003). Both groups reached significantly further in the posterior medial direction at posttest compared to the baseline testing.

Conclusions: A 4-week balance training program under both a traditional balance training program and dual task paradigm significantly improves static and dynamic postural control. As this study was one of the first of its kind in looking at dual task interference over a 4-week balance training program, it is unclear if dual task interference truly impacts training. What is clear is the dual task has the potential to influence training as demonstrated by the moderate to strong effects it had on TTB and SEBT outcomes. However, more research must be conducted in order to better understand this.

DEDICATION

To my family and to my fiancé Caroline to whom without her constant love and support I would not have been able to finish this project. Thank you for your advice, love and support throughout this process.

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CHAPTER 1: INTRODUCTION

Each year, within the United States, there are an estimated 2 million cases of acute ankle sprains [1-3]. Of these cases, an estimated 40-60% will go on to develop Chronic Ankle Instability (CAI), a condition characterized by a reoccurring subjective feeling of "giving way" at the ankle joint [4,5]. This condition increases one's risk of future sprains as well as fear of reinjury [5]. These combined immediate effects decrease one's activity level and could increase one's risk for cardiovascular disease[5,6].

CAI is a complicated and multifaceted orthopedic injury that develops as a result of many interrelated deficits observed following an ankle sprain. Mechanical deficits include: pathologic joint laxity arising from ligament damage, arthrokinematic impairment, synovial hypertrophy, and development of degenerative joint lesions [5,7]. Neuromuscular deficits include: impaired proprioception and sensation, impaired neuromuscular-firing patterns, impaired postural control, and strength deficits [5,8,9]. It is hypothesized that many of the neuromuscular deficits are caused by alterations in muscle-spindle activation as well as slowed nerve-conduction velocity in the peroneal muscles. Even though these are unilateral impairments affecting local nerves, they often occur bilaterally. The presence of these bilateral deficits are likely indicative of alterations to balancing strategies and muscle synergies which are controlled by the central nervous system (CNS) [8,10,11]. Therefore, the role of CNS integration must be addressed when discussing neuromuscular deficits observed in individuals with CAI.

Balance training has been reported as an effective treatment for CAI and many studies have shown that it can greatly reduce the risk of recurrent ankle sprains in those with CAI [12,13]. Recent research has shown that the original balance training protocols that utilized only single leg static balance activities might not have been challenging enough to elicit adaptations in the sensorimotor system [14]. Additionally, the vast majority of sprains occur during dynamic not static activities. Therefore, in order to provide a more suitable stimulus to elicit favorable adaptations following ankle sprains, it is essential that training programs be structured to include dynamic stabilization after perturbations as well as both predictable and unpredictable tasks.

The ability to maintain a favorable degree of mobility and balance throughout daily activities requires constant integration of new information from the environment. For example, a basketball player would need to be able to determine where they need to be on defense as well as observe and react to whatever the other team is doing. The ability to perform more than one task simultaneously is referred to as dual tasking[15,16]. The effect of dual tasking on integration and response to multiple tasks usually results in a reduced ability to perform either task well. Some studies claim that due to neural limitations, the performance of one task will suffer in relation to the more important task; this is referred to as the limited capacity theory [17]. This phenomenon occurs because the two tasks compete for limited resources and the more "important" task is prioritized at the expense of the other. Another theory is the bottleneck theory which claims that no two tasks can be processed simultaneously [17,18]. Therefore, one task must complete integration before the next task can, thus there is a delay in response times of each task [17,18]. Whether or not this effect can be reduced with training has yet to be studied but is a topic of interest [19,20].

Current research indicates a lot of controversy regarding the impact dual tasking has on balance [21]. Some studies report dual tasking leads to a reduced ability to maintain postural stability [22-24]. Other studies report the opposite [19,25-27]. These studies have shown that when administering challenging cognitive tasks during a single-leg balance test, there have been improvements to postural stability compared to a single-leg balance test alone [25,26]. Generally, these studies reported that the cognitive task might require the subject to be more stable in order to perform it better, thus making the tasks mutually beneficial. Another possibility is that the cognitive task served as an external focus of attention, which has been shown to improve postural stability compared to internal focal points [23,28]. However, all of these studies looked at the effect of dual tasking on balance during one or two sessions. Additionally, these studies only utilized single-limb and static balance exercises, which do not fully address deficits associated with CAI. Since ankle sprains typically occur following sudden agitations of the joint, it would be more realistic to incorporate multiple forms of tests and exercises that challenge the ankle dynamically.

Thus, the purpose of this study will be to assess the effectiveness of a 4-week rehabilitation program combining balance training and cognitive tasks in subjects with CAI compared to balance training alone. We hypothesize that a 4-week program will show more improved postural stability in the subjects undergoing the combined therapy compared to the group practicing only the traditional balance training regimen.

CHAPTER 2: LITERATURE REVIEW

Introduction

Ankle sprains are one of the most common injuries that occur during athletic events and activities of daily living [29,30]. As stated previously an estimated 40-60% of these sprains go on to develop into Chronic Ankle Instability (CAI) [4,5]. The development of CAI has been tied to a multitude of risks and health issues including joint degeneration leading to the development of osteoarthritis [31-33]. As these issues develop, activity level may decrease due to fear of reinjury and pain during activities [5,34]. Due to these issues, CAI and the factors leading to the development of CAI have been studied closely.

Chronic Ankle Instability Pathology

Following an ankle sprain and development of CAI, the ankle joint suffers both mechanical and neuromuscular deficits [5]. Mechanical deficits are primarily due to structural damage following the injury. Joint laxity can occur due to ligament damage. The most common ligament tears in ankle sprains are the Anterior Talofibular Ligament (ATFL) and the Calcaneofibular Ligament (CFL) [5,7,8]. When damage occurs to these ligaments, the joint can become "loose". Both the ATFL and CFL prevent the ankle joint from excessive inversion and internal rotation, but when they are torn or injured their ability to resist these motions decreases. This can result in impaired arthrokinematics due to altered positioning of the joint during gait which in turn can lead to a risk of reinjury since most ankle sprains occur during a sudden inversion [5,35]. Additionally, the altered arthrokinematics can lead to synovial changes due to degeneration [5,36]. Inflammation of the injured ligaments and articular cartilage leads to the development of degenerative joint lesions which are painful and can result in a decrease in activity in an attempt to avoid pain [5,7].

Neuromuscular deficits observed in those with CAI include: impaired proprioception, altered muscle-spindle activity, altered neuromuscular-recruitment patterns, and postural control deficits [5,7,8,37]. In 2006, van Cingel et al, found that individuals with CAI had a prolonged isokinetic dynamometer acceleration time (ACC-time) for ankle evertor muscles compared to uninjured controls and the contralateral limb. They speculated that this was due to injury to the fibular nerve following CAI that resulted in a lower motor nerve conduction velocity [9,38]. This reduced velocity would lead to poor recruitment patterns of the peroneal muscles making it harder for them to dynamically stabilize the joint during sudden inversion moments. Additionally, injury to the fibular nerve may also explain the impaired cutaneous sensation observed in some CAI subjects as well as poorer reflexive response times of evertor muscles to a sudden inversion [5,38]. Collectively, these alterations along with structural damage to mechanoreceptors reduce proprioception at the ankle.

The last major neuromuscular deficit observed is a decreased postural control [5,10,37]. Overall length of the path of center of pressure (COP) and the velocity of COP deviations/excursions throughout a balance test on a force plate are traditional ways to measure postural control [5,37]. Increases in both the length of the path and the velocity of COP are associated with decreased postural control and many studies have found such associations in CAI subjects [5]. Another measure of COP is time-to-boundary (TTB). TTB is a more sensitive COP outcome measure that uses COP data to determine how long it would take the COP to reach the boundary of the base of support as well as how quickly it can be "pulled back"[39]. Unlike the COP are and velocity, and increase in TTB is indicative of greater stability. Additionally, due to the inherent degree of variability in this measure it can be regarded as a better indication of how well the sensorimotor system can control COP [10]. Tracking these variables and manipulating them have enabled researchers to notice several strategies utilized in postural control. Anteroposterior stability is primarily controlled at the ankle joint with some assistance from the hips. Mediolateral stability is controlled at the hip joints. These stability strategies can therefore be referred to as an ankle or hip strategy. In the ankle strategy, pronation and supination at the ankle allow the individual to "sway" in an effort to keep their center of gravity within their base of support [5]. Muscles such as the gastrocnemius are recruited first followed by more distal muscles at the hip and knee to aid in stability [38,40]. This activation of muscles is referred to as a synergy and is hypothesized to be a part of a centrally mediated program that receives input from visual and vestibular inputs [40]. In the hip strategy, hip muscles such as the rectus femoris and tensor fascia latae are recruited in an effort to minimize mediolateral sway at the hip during a single leg balance task [38]. Hip strategies are often employed when perturbations to balance are larger, faster and more severe. In a healthy individual, both strategies are utilized on a continuum based on the perturbation, support surface, and task. However, due to the diminished mobility, strength, and proprioception at the ankle following a sprain it is likely that hip strategies are utilized more often in subjects with CAI [37,38]. This modification in balance strategies results an increase in COP area and velocity leading to overall stability decreases [37,38]. Additionally, the shifts in balance strategy may lead to a change in muscle synergies at the hip and ankle [40]. The main difference observed is an alteration in the order of muscle recruitment. Hip musculature will be recruited prior to ankle musculature. This might also be indicative of central nervous system alteration [37]. These combined deficits indicate the complicated nature of CAI and highlight the necessity for a multifaceted approach to rehabilitation.

Balance Training

Balance training has been shown to improve multiple deficits associated with CAI including postural control, strength, and joint proprioception [5,12,14,36,41-48]. However, methodology utilized during rehabilitation is varied and it is unclear as to what the optimal program structure is. Currently, most studies conduct rehabilitation for 4, 6, or 8 week time periods [5,12,14,36,41-48]. Based on these studies it appears that some improvements in postural control from balance training can be observed as early as 4 weeks [42] with additional improvements at 6 and 8 weeks[36,47,49]. Thus, longer interventions are ideal. However, previous studies[12,14] have suggested that 4 weeks is sufficient time to improve postural control measures. Since retention rate can at times be a factor during rehabilitation [48] it would be ideal to create an effective balance training program that is 4 weeks long. In addition to this, it appears that 3 days a week is the minimum amount of training during this time as it is commonly number of days prescribed in training programs[12,14].

Exercises conducted during balance training can include single or double-limb stance exercises, static or dynamic exercises, and exercises with eyes open or closed. Even though some significant changes have been observed following balance training, the literature is not clear about what the best balance training protocol is. In a study conducted by Rozzi et al. [46] individuals with functional ankle instability participated in a 4 week balance training program. During this study two groups consisting of an experimental group of unilateral CAI subjects and a control group of healthy individuals participated in a balance training protocol 3 days a week. The experimental group trained only their involved limb and the control trained a random limb. The training utilized the Biodex stability system which consisted of a movable platform that could tilt up to 20^0 in any direction. The system was interfaced with a screen that provided visual feedback in the form of a cursor that moved about a target as the subject swayed. Balance training consisted of both static and dynamic balance tasks using this system. Static balance training consisted of three 30 second trials in which subjects were instructed to balance on one leg at a predetermined stability setting. During that trial, they were instructed to focus on the cursor on the screen and try to keep it at the center of the bullseye. Dynamic balance training had two components. The first required the subjects to tilt the platform in all different directions but keep the cursor within the defined boundaries on the screen. Each subject performed 3 sets of 6 repetitions in both the anterior/posterior and medial/lateral directions. The second task required subjects to move about in a circle in either a clockwise or counterclockwise direction while tracing the boundaries on the screen with the cursor which they controlled with their movement. One set of 10 revolutions in both directions were completed. At baseline, both groups completed a single leg balance assessment on the Biodex Stability System at multiple stability levels. These included a stable and unstable platform on both the involved and uninvolved limb. Upon completion of the intervention, the subjects performed this assessment again. The results indicated that there was a significant improvement in balance ability of individuals with functional ankle instability. Interestingly at the start of the study, the experimental group presented bilateral deficits in balance ability. Yet, even though they only trained one limb, balance ability improved in the untrained limb as well. These results suggest that only one limb might need to be trained as it seems to effectively stimulate neuromuscular control mechanisms for bilateral stability. However, even though this training study utilized a form of dynamic balance, it did not address how dynamic stabilization is necessary upon impact from stepping, jump landing, or falling when many inversion sprains occur [50,51].

In a study conducted by Cruz-Diaz et al. athletes with CAI participated in a 6 week multi-station balance training program [36]. This study was a randomized controlled trial in which subjects were randomly assigned to a control group that received no rehab or an experimental group where subjects participated in a multi-station balance training program 3 times per week. The balance training consisted of a 5-10-minute warm-up and then a circuit of 7 different tasks. Each task was completed for 45 seconds with 30 seconds of rest in-between. The circuit was completed twice with a rest period of two minutes between. The tasks included use of resistance bands as well as balancing on: exercise mats, dynair, bosu ball, mini trampoline, foam roller, and ankle disc. Progressions on each included: dual stance to single leg stance; and dual stance catching a ball to single leg stance catching a ball. Subjects were tested before and after the program via the Cumberland Ankle Instability Tool (CAIT) and the Star Excursion Balance Test (SEBT). The CAIT is a valid and reliable 9-item questionnaire scored between 0 (severe instability) to 30 (normal stability) with a score of ≤27 indicating functional instability [52]. The SEBT is a valid and reliable dynamic balance task in which the subject balances in the center of a grid with 8 lines extending in different directions [53-55]. Subjects are instructed to balance on one leg and then reach as far as they can along each line and tap their foot. Distances are measured in cm and then the mean of each direction is divided over the leg length. Upon completion of the study, post-test measures indicated significant improvements in both SEBT and CAIT scores in the experimental group. These results suggest that balance training can improve dynamic postural control. Additionally, the authors speculated that balance training could potentially enhance the ability of the sensorimotor system to overcome the constraints related to CAI. However, this study did not utilize dynamic balancing tasks that stressed the joint in a similar fashion to jump landing or impact. As mentioned previously, due to the high incidence of ankle sprains during such instances, balance training should attempt to address this.

A study that did address this was conducted by McKeon et al. 31 subjects with CAI participated in a 12 session 4 week progressive balance training rehabilitation program [14]. This balance program emphasized recovery of single-limb balance following a dynamic perturbation. Balance training for this study included a progressive training regimen with 5 different tasks. These tasks included 3 hopping tasks and 2 static balancing tasks. At baseline, all subjects performed both the SEBT as well as static balance on a force plate. The force plate data allowed the researchers to calculate TTB measures (mean TTB ML and AP), and traditional COP measures (COP area, SD of COP excursions, range of COP excursions, mean COP velocity in both AP and ML directions). This study lead to two important conclusions. The first is that exercises that place the subject in situations more similar to daily activities, such as stabilizations after dynamic perturbations, are challenging enough to elicit detectable changes in postural control.

Additionally, traditional quite single leg stance training does not reflect the situations that an average individual will be placed in throughout a given day. However, sudden perturbations followed by stabilization occurs all the time from jump landing to cutting in a sport and gait patterns. Therefore, this style of movement needs to be emphasized and included in a balance training program. The second important conclusion is that manipulating both task and environmental constraints in those with CAI during a progressive balance training regime was more challenging to the sensorimotor system. Therefore, this might serve as an adequate stimulus for necessary adaptation and thus allow an individual to overcome more sensorimotor deficits associated with CAI compared to other forms of balance training.

Using the same population as McKeon et al., a separate study conducted by Mettler et al. demonstrated that a progressive balance training program that emphasizes stabilization following a hop can alter the COP location in subjects with CAI [45]. COP location provides information about the spatial distribution of force application under the foot. Changes in COP location from anterolateral to posteromedial have been hypothesized to represent a less constrained sensorimotor system [12,45]. A less constrained sensorimotor system would allow the subject to have more degrees of freedom and movement about the ankle. This change would enable the subject to have more movement strategies when put in a potentially harmful situation and thus allow them to better adapt to potentially harmful situations. Following completion of the progressive balance training program subjects had a more posterior shift in COP location compared to no change in the control group. These results suggest that a progressive balance training program that emphasizes stabilizations following dynamic perturbations help to free up the sensorimotor system and provide more degrees of freedom at the ankle.

Due to the role that the sensorimotor system plays in postural control and balance, it is important to understand how balance training influences it. A study conducted by Sefton et al. looked at how 4 sensorimotor constructs changed in response to a 6 week balance training program in order to better understand this [47]. These constructs included: static balance, dynamic balance, joint position sense, and motorneuron pool excitability. Static balance was measured using traditional COP measures such as: total COP path length and RMS average COP displacement. Dynamic balance was measured using the SEBT. Joint position sense was measured using a Biodex System 3 exercise dynamometer, and motorneuron pool excitability by measuring the soleus Hoffmann reflex (H-reflex). The results of the study suggested that balance training may improve sensorimotor control at the ankle. CAI subjects had significantly better dynamic balance following the balance training as well as improved joint position sense. Comparison between pre-and post-test measures also showed an increased in Hmax/Mmax ratio in the CAI group indicating greater motorneuron pool excitability and ability to recruit motor units. Interestingly the balance training incorporated an external focus of attention by utilizing a cognitive task. The cognitive task was a balance board that had a marble maze on it. Subjects were required to move the marble through the maze by shifting their balance and COP about. This was included because it has been hypothesized that including a cognitive task may have a greater influence on changes in motorneuron pool excitability [47]. Since the results showed exactly that, it would be interesting to follow up on this finding and include cognitive tasks in future balance studies.

While each study has shown improvements in postural control have contributed a new piece of information on how to potentially improve postural control, ankle sprains and CAI remain very prevalent. Thus, improvements to balance training are still necessary. Additionally, every study discussed above has neglected a major factor in their design. That is that in everyday life athletes, workers, individuals, etc. are required to balance without thought and in situations where they are multitasking. Thus, balance training needs to focus on training individuals for situations as these. An ideal balance training program would therefore result in not just improvements in postural control, but also in ability to dual task. Therefore, this program must include a challenging progressive program that emphasizes dynamic stabilization and cognitive elements over a minimum of 4 weeks.

Cognitive Loading

As indicated in previous sections, numerous neuromuscular deficits result from CAI and play a large role in the development of future deficits and diseases associated with CAI. Of these deficits the most pronounced is decreased postural control indicating a highly constrained sensorimotor system [12,45]. Within the last section, balance training was assessed as a method to improve postural control and free up the sensorimotor system. Based upon current literature, balance training has been effective in improving postural control yet it still neglects to address an important factor. That factor is that in day to day activity, no individual will simply be standing or balancing on one foot. Instead, they will be continuously moving, interacting, and reacting to their environment. Typically, this will occur simultaneously with movement. Thus, most times an individual will need to balance they will be doing so under divided attention. This act of performing two tasks simultaneously is referred to as dual tasking.

Whenever an individual dual tasks, typically there has been an improvement in one task followed by a reduced performance of the other task [56,57]. There are two possible explanations for this. First there could competition for limited processing resources. This theory is referred to as the limited capacity theory [15,16,58]. In this theory, two stimuli compete for priority and resources. They both arrive at a processing center ready for integration; but the one that is deemed more important utilizes more of the available resources for processing. Thus, that task is integrated faster leading to a quick response in one but a delayed response in the other [15,16,58]. Another possibility is the presence of a "traffic jam". This is referred to as the bottleneck theory [16]. This theory claims that simultaneous processing of two tasks is not possible. Therefore one task is integrated completely before the second task can begin being processed [15,16,18].

There are conflicting findings throughout literature about the effect that dual task has on balance [25,26,58, 59, 60,67,69-72]. Based on the bottleneck theory, when an individual is balancing, moving, or performing any activity of daily living, they will only be able to process one thing at a time[16]. Recent research has indicated that the cognitive task will be prioritized in younger healthier populations because balance and movement can be mediated subconsciously via an increased amount of subcortical integration [59,60]. But following the development of CAI and a constrained sensorimotor system, more focus is required to balance and respond to sudden perturbations. This results in balance becoming a more conscious rather than subconscious task and thus requires more cortical activation. Yet due to the presence of a bottleneck there is interference and the result is diminished balance as well as a greater amount of attention directed at staying upright. Thus, the goal of balance training should be to retrain the sensorimotor system to be more automatic and require less integration thereby reducing the bottleneck.

The effects of dual task interference on a balance training program have yet to be studied. But the effect of dual tasking in the form of cognitive loading during a quite single limb balancing stance is better understood. In a study, conducted by Dault MC et al. postural stability decreased as novelty and difficulty of stance and cognitive tasks were increased [61]. In other words, as the tasks became less familiar and harder, postural stability decreased. But when the task was easier the subjects became comfortable and little changes to postural control were observed. However, when the subject was stressed by new and difficult tasks, they were forced to adapt and thus postural sway worsened. This suggests a potential mechanism for retraining the sensorimotor system through progressive cognitive loading [62]. As subjects adapt to the required workload, the impact of dual task interference appears to influence postural sway in a less obvious and negative manner.

In another study conducted by Burcal et al. performance during a single leg static balance test improved while a simultaneous cognitive task was administered [25]. The cognitive tasks included: random number generation, manikin test, and backwards counting. Each test was chosen to “stress” a different aspect of working memory to cover more cognitive domains and their effects on postural control. During each task, subjects were instructed to either focus on the balance or cognitive task. While focusing on either task improved postural control compared to the control group, focusing on the cognitive task resulted in better TTB outcomes compared to baseline. This could again emphasis a retraining of the sensorimotor system to become more automatic. Additionally, this study highlights how providing an explicit instruction to focus on one task over the other may serve as a stimulus to shift focus externally.

Some research has suggested that performing a cognitive task might help improve balance by shifting focus away from the balance task [27,63]. For example, Siu et al. observed an increase in postural control under dual task conditions and attributed this to a shift in focus [27]. In their study, subjects had to perform a visual spatial task while balancing on one leg. The authors hypothesized that his task required subjects to focus on the presentation of the cognitive task thus helping them to shift their focus away from the postural task. This conclusion was also reached by Stoffregen et al. [63]. When performing a dual task protocol, postural sway decreased indicating improvements in postural stability. Like Siu et al. they also hypothesized that this occurred due to an external shift in focus in order to perform the cognitive task better.

In a study done by Rahnama et al. an experimental CAI group and a matched healthy control group underwent a dual task protocol in which their postural stability and cognitive performance were studied [23]. Based on a comparison to baseline measurements and between groups, it was concluded that CAI subjects had decreased postural stability under a dual task paradigm. Interestingly, the healthy group showed no changes in postural stability when asked to dual task. The authors hypothesized that the changes in the CAI group must be due attributed to those subjects devoting more attentional resources towards regulating balance [23]. They further hypothesized that this could have therapeutic applications. As previously stated, it is known providing an external focus of attention improves stability[26,28]. Thus, presenting a cognitive task during balance training might help shift the focus externally and, therefore, help improve the automaticity of postural control. However, more research is needed before this can be implemented.

Conclusion

Chronic ankle instability is a significant problem that increases the risk for multiple disorders and detriments. Due to the increasing prevalence and occurrence of CAI, optimal rehabilitation programs must be constructed. Combining an established program (balance training) with a novel concept (cognitive loading) that might further improve results is a logical step. Therefore we plan to build from the study conducted by McKeon et al. [14] by repeating the balance training program and adjust its layout by adding progressive cognitive loading tasks throughout the program.

CHAPTER 3: METHODS

Participants

Subjects were recruited from the University of North Carolina at Charlotte. A total of 23 male and female participated in the study. Twelve (4males, 8 females, age = 20.20±1.11 years, height =165.46±10.82 cm, weight =75.09±17.47 kg) were randomly assigned to the experimental group, and 11 (1 male, 10 females, age = 20.73±1.1 years, height =167.11±5.04 cm, weight = 73.97±11.55 kg) were randomly assigned to the control group. Subjects were identified as having CAI based off a score of 90% or less on the Foot and Ankle Ability Measure (FAAM) and 80% or less on the FAAM Sport surveys [52,54]. Inclusion criteria included: age between 18 and 35 years, history of at least one ankle sprain occurring more than 3 months prior to the study, a history of the previously injured ankle joint "giving way" as well as the presence of recurring sprains and/or a feeling of instability, and a score of 90% or less on the FAAM and 80% on the FAAM Sport [52]. Exclusion criteria included: history of concussion or brain trauma, lower limb fractures, acute musculoskeletal injury in the lower limbs in the previous 3 months, any lower limb surgery, and any history or current neural impairments [52]. All subjects provided written informed consent before participation, and the testing procedures used in the investigation were approved by our University's Institutional Review Board.

Study Design

This was a randomized controlled trial examining the effects of cognitive loading tasks and balance training in those with CAI. There were two groups, an experimental and control group. The control group consisted of subjects with CAI who underwent a traditional balance training rehabilitation exercise program. The experimental group consisted of subjects with CAI who underwent a dual task protocol consisting of the same balance training as the control group with the addition of a cognitive task.

Procedure

In total, this study consisted of 14 sessions each lasting between 20 and 30 minutes over the course of 4 weeks. At the first session, all subjects filled out an informed consent form and were given an overview of the intervention protocol. If they wished to still participate then they continued through all baseline tests conducted during the first session. Upon completion of the baseline session the subject was randomly assigned to either the control or experimental group via excel. Demographic information was recorded and measured (Table 1).

Table 1: Participant demographic data (mean ± standard deviation)

Group	Age (years)	Height (cm)	Weight (kg)	FAAM (%)	FAAM-Sport (%)
DT	20.20±1.1	165.46±10.82	75.09±17.47	87.67±4.96	73.78±12.49
Control	20.73±1.1	166.93±4.84	72.72±11.84	83.5±9.65	66.6±12.53

After all paperwork was completed baseline testing began. This consisted of a baseline cognitive task evaluation, static balance and dynamic balance evaluation, and evaluation of their ability to dual task during a static balance task.

The baseline cognitive task evaluation tested the individual's ability to perform 3 different cognitive tasks while seated. These tasks included: backwards counting by 3s, backwards counting by 7s, and random number generation. For both of the backwards counting tasks, the individual was given a random three-digit number and instructed to count backwards at their own pace, in increments of 3 or 7, for 30 seconds. For the random number generation task, a metronome was set to 60 beats per minute and participants were instructed to randomly recite a digit between 0 and 9. Counting serially for 3 responses or in any sort of repeating pattern (i.e. 0010034005001) was considered an error. For each task, subjects were given several practice trails until they felt comfortable with the task. Then three trials of each task were conducted where the researcher recorded the participant's responses. The responses were graded later for accuracy and a percentage score was determined for each trial.

For static postural control, subjects stood on an ATMI force plate and performed three 30 second trials on one leg with their eyes open [14]. During these trials participants were instructed to follow a previously established protocol in which they must balance and stay as still as possible with their hands on their hips while lifting their opposite leg with approximately 45^0 knee flexion and 30^0 hip flexion (figure 1) [14]. Center of pressure (COP) variables including COPXvelocity, COPYvelocity, COP 95% confidence ellipse area, TTBX, and TTBY were determined using a custom MATLAB algorithm. The average of all three trials were calculated and used for comparison later. Only the affected limb was tested.

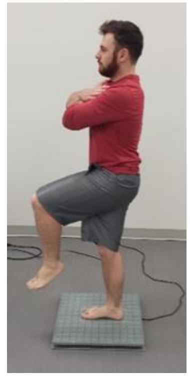

Figure 1: Static postural control

For dynamic postural control, subjects performed the Star Excursion Balance Test (SEBT) since this test has been shown to be both reliable and valid in detecting dynamic postural deficits related to CAI [31,37,55]. Subjects conducted this test following previously established protocol recommended by Gribble et al.[37]. During the test, subjects balanced on the affected leg with hands on hips in the center of three tape measures pointing straight ahead (anterior), back to the left/right (posterior medial and posterior lateral depending on the limb). Subjects then were instructed to reach their opposite leg as far as they can in each direction then tap the tape measure with their foot (figure 2).

Figure 2: Star Excursion Balance Test

Subjects had six practice trials in each direction before testing began. The reach distances for each direction were recorded and normalized to leg length. Any trial in which the subject lost balance or removed their hands from their hips was discarded and repeated. A total of three trials was conducted for each subject and mean distances were calculated and used for comparison later.

Finally, subjects performed the same cognitive tasks they did earlier (see above) during 9 dual task static balance trials on the forceplate. Three trials of each dual task combination were performed. If a participant broke the designated posture or put their foot down the trial was discarded and repeated. Responses to the cognitive tasks were recorded and scored for accuracy later. Following completion of the first session subjects were then scheduled for the next session.

Balance Training

Starting with the second session, participants in both the experimental and control group attended twelve 20-30 minute sessions over the course of 4 weeks. During this time both groups underwent a balance training program. The balance training rehabilitation exercise program consisted of a progressive regimen based off of the study done by McKeon et al. [14]. These exercises included hop to stabilization (figure 3), hop to stabilization and reach (figure 3), unanticipated hop to stabilization (figure 4), and single-limb stance activities. In each session subjects completed a given number of sets of each of these exercises at varying difficulty levels.

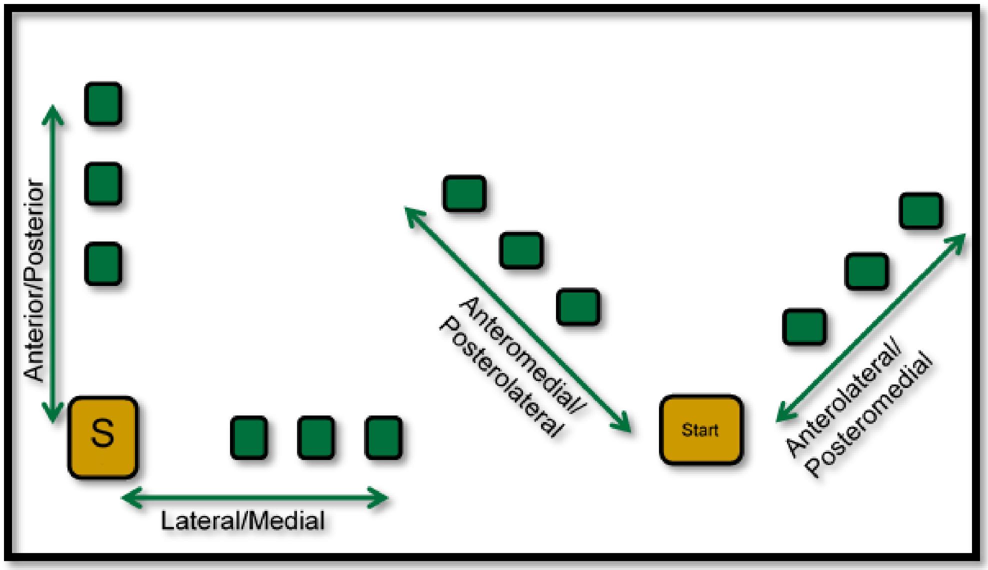

Figure 3: Hop and stabilization. Hop and reach.

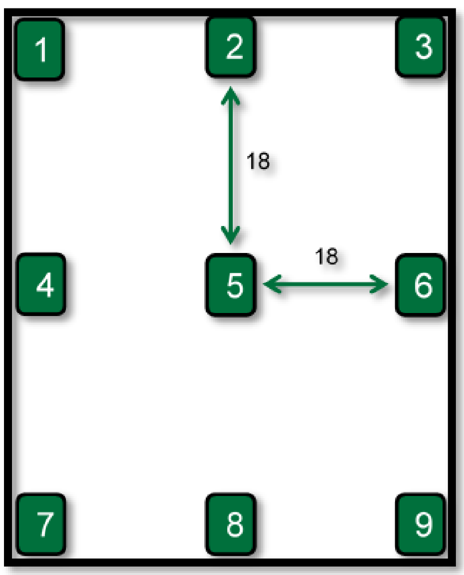

Figure 4: Unanticipated Hop.

There were six levels of difficulty for the hop to stabilization task. These included 1). Marker 18 inches away, participant could use their arms to help stabilize any mediolateral sway 2). Marker 18 inches away, participants had to keep their hands on their hips. 3). Marker 27 inches away, participant could use their arms to help stabilize any mediolateral sway. 4). Maker 27 inches away, participants had to keep their hands on their hips. 5). Marker 36 inches away, participant could use their arms to help stabilize any mediolateral sway. 6). Marker 36 inches away, participants had to keep their hands on their hips. For this protocol subjects began in the center of the setup seen in figure 3. At the start of the trial, the researcher told the subject the level for the first hop (for example: level 2, first marker hands on hips). The subject then balanced on one leg with their hands on their hips. They then moved through a sequence of hops to the first marker where they stabilized momentarily and then hopped back before moving to the next marker in the sequence. The sequence was the same for every subject each session and never changed. The sequence went as follows: anterolateral, anteromedial, mediolateral, anteroposterior, lateromedial. Throughout the session, a total of 10 sequences such as this were completed for a total of 10 hops in each direction. In order to advance in difficulty subjects had to perform all 10 jumps throughout the session without any errors. Errors included: removing hands from hips for levels that required them to keep their hands there, excessive trunk flexion/motion, tapping/putting their foot down at any point during the sequence, missing the marker, jumping short of the marker.

The hop to stabilization and reach task had six levels of difficulty. These included: 1). Marker 18 inches away, participant could use their arms to help stabilize any mediolateral sway 2). Marker 18 inches away, participants had to keep their hands on their hips. 3). Marker 27 inches away, participant could use their arms to help stabilize any mediolateral sway. 4). Maker 27 inches away, participants had to keep their hands on their hips. 5). Marker 36 inches away, participant could use their arms to help stabilize any mediolateral sway. 6). Marker 36 inches away, participants had to keep their hands on their hips. The protocol for the hop to stabilization and reach task was identical to the first task with one addition. After the subject performed their hop to the designated marker and stabilized, they were then instructed to reach back towards the starting position with their opposite foot. After reaching they held this position briefly then moved their leg back, hoped back to the starting point and stabilized before moving on to the next hop in the sequence. The sequence was the same for every subject each session and never changed. The sequence went as follows: anterolateral, anteromedial, mediolateral, anteroposterior, lateromedial. A total of 5 sequences such as this were completed throughout a session for a total of 5 hop and reach movements in each direction.

There were five levels of difficulty for the unanticipated hop to stabilization task. These included: 1). Jump distance 18 inches (one square away). 2). At least one jump of 36 inches was included in the sequence (two squares away). 3). Single foam pad added so one landing surface was uneven 4). Two foam pads added. 5). Three foam pads added. In the unanticipated hop to stabilization protocol, subjects began by balancing on one leg on a designated numbered square (figure 2). Once they stabilized they were given a number of another square and instructed to hop to that square. The participant was then required to hop to that square and stabilize in the center of that square. This pattern was repeated until the subject had performed 5 jumps.

For the single-limb stance activities the subjects were instructed to perform a single-limb stance for 30-90 seconds in two different conditions, eyes open and eyes closed. There were six levels of difficulty for each condition. These levels include: 1).

Hands on hip 30 seconds’ firm flat surface. 2). Hands on hips 45 seconds’ firm flat surface. 3). Hands on hips 60 seconds’ firm flat surface 4). Hands on hips 30 seconds on foam pad. 5) Hands on hips 45 seconds on foam pad 6). Hands on hips 60 seconds on foam pad. Subjects will perform each condition twice. Rest was given throughout the session as needed.

While the order of these exercises and level of difficulty could have been manipulated per session, a subject was not able to move past the level of difficulty in a task without demonstrating mastery of that level. To demonstrate mastery of a given level subjects could not perform any errors during that given set. Errors included: touching down on the opposite limb at any point during that given set, excessive trunk motion, removal of hands from hips during levels that required them to keep their hands there, bracing of any kind, and missing the target. An example of a session can be seen in Figure 5 below:

Hop to stabilization											
Direction	Trial #										Difficulty level
Diagonal L	1	2	3	4	5	6	7	8	9	10	
Diagonal R	1	2	3	4	5	6	7	8	9	10	
Left/Right	1	2	3	4	5	6	7	8	9	10	
Front/Back	1	2	3	4	5	6	7	8	9	10	
Right/Left	1	2	3	4	5	6	7	8	9	10	

Hop to stabilization and reach						
Direction	Trial #					Difficulty level
Diagonal L	1	2	3	4	5	
Diagonal R	1	2	3	4	5	
Left/Right	1	2	3	4	5	
Front/Back	1	2	3	4	5	
Right/Left	1	2	3	4	5	

Static balance				
Condition	Trial #		Balance Errors	Difficulty level
Eyes open	1	2		
Eyes closed	1	2		

Unanticipated hop to stabilization			
Trial #	Sequence	Balance errors	Difficulty level
1	5 → 6 → 9 → 8 → 4		
2	5 → 1 → 2 → 4 → 7		

Hop to stabilization											
Direction	Trial #										Difficulty level
Diagonal L	1	2	3	4	5	6	7	8	9	10	
Diagonal R	1	2	3	4	5	6	7	8	9	10	
Left/Right	1	2	3	4	5	6	7	8	9	10	
Front/Back	1	2	3	4	5	6	7	8	9	10	
Right/Left	1	2	3	4	5	6	7	8	9	10	

Hop to stabilization and reach						
Direction	Trial #					Difficulty level
Diagonal L	1	2	3	4	5	
Diagonal R	1	2	3	4	5	
Left/Right	1	2	3	4	5	
Front/Back	1	2	3	4	5	
Right/Left	1	2	3	4	5	

Static balance				
Condition	Trial #		Balance Errors	Difficulty level
Eyes open	1	2		
Eyes closed	1	2		

Unanticipated hop to stabilization			
Trial #	Sequence	Balance errors	Difficulty level
1	5 → 6 → 9 → 8 → 4		
2	5 → 1 → 2 → 4 → 7		

Figure 5: Balance training data sheet

Dual Task Intervention Protocol

The balance training protocol for both groups was identical. However, the experimental group performed cognitive tasks simultaneously with their balance tasks. These tasks included random number generation, and backwards counting variations. These tasks have been shown to improve postural control during dual task protocols [56].

There were several levels of difficulty for each cognitive task. For the random number generation task, there were three levels of difficulty. These included: 1). Metronome set to 60 beats per minute, 2). Metronome set to 72 beats per minute, and 3). Metronome set to 80 beats per minute. For the backwards counting task, there will be 4 levels of difficulty. These included: 1). Counting backwards in increments of 3 from a provided three-digit number, 2). Counting backwards in increments of 7, 3). Counting backwards by 3 three times then forwards by 7 once (-3 -3 -3 +7, i.e. 345 – 342 – 339 – 336 – 344); 4). Counting backwards by 7 twice and then forwards by 3 once (-7 -7 +3). At the beginning of each session a subject was instructed on which task they would be performing and the level of difficulty (for example hop to stabilization level 2). They then were told the cognitive task they would doing for that trial (for example backwards counting by 3s from 465). Prior to the start of the session the cognitive tasks that were to be completed during each balance trial were determined with an equal number of random number generation and backwards counting tasks being completed. An example of the data collection sheet can be seen below in Figure 6:

Hop to stabilization											
Direction	Trial #										Difficulty level
Diagonal L	1	2	3	4	5	6	7	8	9	10	2
Diagonal R	1	2	3	4	5	6	7	8	9	10	2
Left/Right	1	2	3	4	5	6	7	8	9	10	2
Front/Back	1	2	3	4	5	6	7	8	9	10	2
Right/Left	1	2	3	4	5	6	7	8	9	10	2

Cognitive Task for hop to stabilization		
Trial #	Task	Cognitive Errors
1	BC3 (875)	
2	BC3 (746)	
3	RN	
4	RN	
5	RN	
6	BC3 (223)	
7	RN	
8	BC3 (463)	
9	RN	
10	BC3 (875)	

Figure 6: Dual Task training sheet example

In order to accurately score performance of the dual task condition, balance and cognitive errors were counted during each trial. Balance errors include: touching down on the opposite limb at any point during that given set, excessive trunk motion, removal of hands from hips during levels that required them to keep their hands there, bracing of any kind, and missing the target. Cognitive responses were recorded during the session and scored later. Errors for the backwards counting cognitive tasks include: repeating a number multiple times before counting, incorrect responses, or forgetting the number. Errors for the random number generation task include: repeated 3 of the same digit in a row, counting serially after 2 responses (etc. *12*3/983/167 but not *12*6/493), stating any digit other than those between 0 and 9, and forming obvious patterns (001500470091). To demonstrate mastery of the protocol and move on to the next balance difficulty level, subjects had to perform all movements in that task without error (same previously defined) in 2 consecutive sets. To demonstrate mastery of the cognitive task and move on to the next level of difficulty, subjects had to complete the entire session with an overall accuracy score (error free) of at least 90%. Advancements were made based off performance in each task individually. Thus, if a subject successfully completed the balance trials but does not score over 90% in the cognitive tasks they would progress only in the balance task at that time.

Post-Test

After 4 weeks, subjects returned for their 14th and final session which served as a follow up session. This session was scheduled for at least a week after completing training. During this session, subjects performed the same balance and cognitive tests they did at baseline (static balance on a force plate, the SEBT for dynamic balance, and counting while sitting and during balancing). They were also instructed to fill out the FAAM and FAAM Sport questionnaire in order to provide feedback on their perceived level of function during activities of daily living and sports.

Data Analysis

Data was collected and organized into an excel spreadsheet. The independent variables were group (traditional balance training and dual task) and time (pretest and posttest). Separate 2 x 2 repeated-measures ANOVA were used to assess differences in the outcome measures due to the different training approaches. Repeated-measures ANOVAs were run for a total of 5 different conditions. These included: static single leg balance with no cognitive task; static single leg balance while backwards counting by 3s;

static single leg balance while backwards counting by 7s; static single leg balance while performing a random number generation task; and performing the SEBT. An alpha level of $P < 0.05$ was set prior to these tests. Cohen's D measures of effect sizes were calculated to determine the magnitude of the effect of each training paradigm. The strength of effect sizes was determined as small (≤0.4), moderate (0.41-0.7), and large effects (≥0.71)[14].

CHAPTER 4: RESULTS

The purpose of this study was to assess the effectiveness of a 4-week rehabilitation program combining balance training and cognitive tasks in subjects with CAI compared to balance training alone. Descriptive data for all dependent variables can be found in tables 2-6.

Static Postural Control with no cognitive task

Means and standard deviations for all static balance dependent variables can be found in table 2. There were no significant group by time interactions for any of the time to boundary (TTB) dependent variables. There were significant main effects for time. Both group had a significant increase in medial lateral (ML) TTB mean ($p = .002$), in anterior posterior (AP) TTB mean ($p = .003$), in ML TTB standard deviation (StDev) ($p = .048$), and in AP TTB StDev ($p = .041$) at posttest compared to pretest.

Table 2: Static Balance Measurements (mean ± standard deviation

	Traditional Balance		Dual Task			
	Pretest	Posttest	Pretest	Posttest	Group Effect	Time Effect
Mean TTBML	1.73±0.35	1.90±0.44	1.74±0.51	2.06±0.50	0.301	0.002
Mean TTBAP	4.52±0.95	5.18±1.33	4.53±1.32	5.39±1.13	0.664	0.003
SD Min TTBML	1.34±0.4	1.49±0.49	1.53±0.69	1.76±0.58	0.685	0.048
SD Min TTBAP	2.99±0.85	3.25±0.82	3.09±0.99	3.71±0.95	0.383	0.041
Velocity COP ML	2.44±0.39	2.21±0.49	2.51±0.52	2.11±0.32	0.291	0.001
Velocity COP AP	2.24±0.57	1.92±0.43	2.34±0.58	1.89±0.29	0.492	0.001
COP 95% area mean	8.46±1.37	6.99±1.36	8.89±1.61	8.11±1.47	0.506	0.041

Dynamic Balance Measurements

Means and standard deviations for all dynamic balance dependent variables can be found in table 3. There was no significant interaction (p = .331) for the anterior direction of the SEBT. There was a significant main effect for time (p = .012). Both groups reached significantly further in the anterior direction at posttest compared to the baseline testing. There was no significant interaction (p = .396) for the posterior lateral direction of the SEBT. There was a significant main effect for time (p = .0001). Both groups reached significantly further in the posterior lateral direction at posttest compared to the baseline testing. There was also no significant interaction (p = .099) for the posterior medial direction of the SEBT. There was a significant main effect for time (p = .003). Both groups reached significantly further in the posterior medial direction at posttest compared to the baseline testing.

Table 3: Star Excursion Balance Test (mean ± standard deviation

	Traditional Balance		Dual Task			
	Pretest	Posttest	Pretest	Posttest	Group Effect	Time Effect
SEBT A	0.77±0.11	0.81±0.14	0.78±0.12	0.86±0.13	0.331	0.012
SEBT PL	0.89±0.13	1.00±0.12	0.90±0.13	1.01±0.09	0.396	0.0001
SEBT PM	0.90±0.14	0.95±0.09	0.95±0.08	1.04±0.11	0.099	0.003

Effect sizes

Table 4: Effect sizes for Dual Task Training Group (pre-to posttest)							
	Dual Task Post			Dual Task Pre			
	mean	n	SD	mean	n	SD	effect size
TTB ML	2.06	12	0.5	1.74	12	0.51	0.61
TTB AP	5.39	12	1.13	4.53	12	1.32	0.68
SD TTB ML	1.76	12	0.58	1.53	12	0.69	0.35
SD TTB AP	3.71	12	0.95	3.09	12	0.99	0.62
COPv ML	2.11	12	0.32	2.51	12	0.52	-0.89
COPv AP	1.89	12	0.29	2.34	12	0.58	-0.95
COP 95% area	8.11	12	1.47	8.89	12	1.61	-0.49
SEBT A	0.86	12	0.13	0.78	12	0.12	0.62
SEBT PL	1.01	12	0.09	0.9	12	0.13	0.95
SEBT PM	1.01	12	0.11	0.95	12	0.08	0.60

Table 5: Effect sizes for Traditional Balance Training Group (pre-to posttest)							
	Traditional Balance Post			Traditional Balance Pre			
	mean	n	SD	mean	n	SD	effect size
TTB ML	1.9	11	0.44	1.73	11	0.35	0.41
TTB AP	5.18	11	1.33	4.52	11	0.95	0.55
SD TTB ML	1.49	11	0.49	1.34	11	0.4	0.32
SD TTB AP	3.25	11	0.82	2.99	11	0.85	0.30
COPv ML	2.21	11	0.49	2.44	11	0.39	-0.50
COPv AP	1.92	11	0.43	2.24	11	0.57	-0.61
COP 95% area	6.99	11	1.36	8.46	11	1.37	-1.04
SEBT A	0.81	11	0.14	0.77	11	0.11	0.31
SEBT PL	1	11	0.12	0.89	11	0.13	0.85
SEBT PM	0.95	11	0.09	0.9	11	0.14	0.41

Table 6: Effect sizes for between group comparison							
	Dual Task Post			Traditional Balance Post			
	mean	n	SD	mean	n	SD	Effect size
TTB ML	2.06	12	0.5	1.9	11	0.44	0.33
TTB AP	5.39	12	1.13	5.18	11	1.33	0.16
SD TTB ML	1.76	12	0.58	1.49	11	0.49	0.48
SD TTB AP	3.71	12	0.95	3.25	11	0.82	0.50
COPv ML	2.11	12	0.32	2.21	11	0.49	-0.24
COPv AP	1.89	12	0.29	1.92	11	0.43	-0.08
COP 95% area	8.11	12	1.47	6.99	11	1.36	0.76
SEBT A	0.86	12	0.13	0.81	11	0.14	0.36
SEBT PL	1.01	12	0.09	1	11	0.12	0.09
SEBT PM	1.01	12	0.11	0.95	11	0.09	0.57

CHAPTER 5: DISCUSSION

Summary

We found that 4 weeks of balance training resulted in improved static postural control and dynamic postural control in both a traditional balance training group and dual task paradigm. In all static postural control outcomes (COP and TTB measures) subjects in both training groups improved from pre-to-post measures. In all dynamic postural control outcomes (SEBT) subjects in both training groups improved from pre-to-post measures. This study adds to the mounting literature that balance training is a necessity for patients with CAI to help improve balance, and a program of 4 weeks in length is adequate to demonstrate improvements in balance. Based on the results of this study, adding a cognitive task to balance activities did not show significant improvement over the balance training alone, and thus may not be critical to rehabilitation programs aimed at improving postural control.

Static Postural Control Outcomes

After undergoing a 4-week intervention, individuals in both groups had significantly improved static postural control. These findings are consistent with other balance training interventions [12-14,45,47]. While baseline values for all static outcomes (COP area, velocity COPX, velocity COPY, TTB ML, TTB AP, SD TTB AP, and SD TTB ML) were higher than those observed in McKeon's study [14]; they are still below what would be considered healthy or uninjured scores [64]. Additionally, other studies have collected static postural control variables for only 10 seconds on a forceplate [65] however, this study collected for 30 seconds. While 10 seconds is considered enough time to evaluate single leg quiet stance, more time is necessary under dual task conditions. Other studies that have sought to evaluate the effect of dual tasking during single leg balance tasks have typically collected data for 30 seconds [25] as this will allow time for adaptations to the task as well as a more longer window to determine an efficiently scale for the cognitive task [66-68]. Using the data collected, it would be interesting to see if data taken from only the middle 10 seconds would yield different results.

Time to Boundary Outcomes

TTB is considered a more sensitive [39] outcome measure as it can offer an estimation of the coordination of the sensorimotor system[39]. Increases in TTB mean minima and SD can indicate a greater degree of stability as well as a less constrained sensorimotor system[39]. At baseline, both groups showed a low TTB mean minima and SD compared to the data presented on healthy individuals in other studies [14,64]. This implies that both groups had poor balance, as is expected in a CAI population.

After training, both the traditional balance training group and dual task training group had significantly increased TTB mean minima and SD in both the ML and AP directions. The mean minima TTB in both the ML and AP directions improved in both groups from pre-to posttest. The effect sizes for these changes in the dual task group were 0.61 and 0.68 for the ML and AP directions respectively. Comparatively, the effect sizes for the changes in the traditional balance training group were 0.41 and 0.55 for the ML and AP directions respectively. So, although there was no statistical difference between the groups, effect sizes were slightly greater for the dual task group compared to the balance training alone. This indication is strengthened when comparing these results to previous studies such as McKeon's balance training study[14]. McKeon et al., found that balance training also improved TTB mean minima in both the ML and AP direction with effect sizes of 0.6 and 0.41 in the ML and AP directions respectively[14]. Our results exhibited a nearly identical effect, confirming the effectiveness of this program as well as demonstrating a stronger effect in the dual task paradigm. However, when comparing between training programs, the effect sizes were 0.33 and 0.16 for TTB ML and AP respectively. This suggests that when directly comparing the two groups, the dual task program small effect size compared to the traditional balance training program.

Additionally, TTB SD in both the ML and AP directions improved in both groups. The effect sizes for the dual task group were 0.35 and 0.62 in the ML and AP directions respectively. In the traditional balance training group, the effect sizes were 0.34 and 0.31 in the ML and AP directions respectively. When comparing posttest data between the dual task and traditional balance training program the effect sizes were 0.48 and 0.50 for SD TTB ML and SD TTBAP respectively. This further strengthens the findings presented above as these moderate effect sizes between groups suggest that the dual task paradigm might have more clinical impact on improving SD TTB ML and SD TTB AP. Similarly, McKeon et al., found that TTB mean minima and SD magnitudes could be changed through rehabilitation [14]. Our results confirm these findings by demonstrating significant improvements in TTB mean minima and TTB SD in two different balance training programs. This indicates that balance training is effective in improving static postural control in subjects with CAI. Due to our findings and the findings of other studies, it appears that balance training is not only effective but a necessary intervention for those with CAI [14,36,45-47]. Additionally, it appears that dual task training may have the potential to induce changes to TTB measures when compared to traditional balance training.

Dynamic Postural Control Outcomes

Dynamic postural control, as assessed via the SEBT, improved in both groups from pre-to post but not between groups as well. The SEBT is valid measure of dynamic postural control and increases in reach distances with respect to leg length indicate an increased ability to control their own body while performing a more dynamic motion [53]. Improvements were observed in all three reach distances (anterior, posteromedial, and posterolateral). This is consistent with findings from other studies that have utilized the SEBT to measure dynamic balance in those with CAI following a balance training program [14,36,47]. The reach scores in each direction were larger than those observed in other balance training studies [14,36,47.] However, a previous literature review on the SEBT reach test determined that women tend to bend more at their knees than men which may influence their reach scores[53]. Due to the relatively low number of men in this study (18:5 women to men ratio compared to a 19:12 women to men ratio in McKeon's study), this may have influenced the reach scores. Since there was no significant difference between groups following training, effect sizes were calculated to determine the magnitude of change in each group and then compare that. In the dual task training group, from pre-to posttest, effect sizes were 0.64, 0.95, and 0.60 for SEBT A, SEBT PL, and SEBT PM respectively. These effects were moderate to strong suggesting that dual task training has a strong modifying effect on dynamic balance. Comparatively, the effect sizes from pre-to posttest in the traditional balance training group were 0.32, 0.85, and 0.41 for SEBT A, SEBT PL, and SEBT PM respectively. These effects are weaker than those in the dual task training group. However, when comparing between both groups the effect sizes for dual task posttest to traditional balance posttest were 0.36, 0.09, and 0.57 for SEBT A, SEBT PL, and SEBT PM respectively. Of all three-reach distance, only posteromedial exhibited a moderate effect within and between groups. This suggests that dual task training may have a greater effect on this reach than traditional balance training. The SEBT PM reach distance forces an individual to move their COP towards the posteromedial side of their foot which reaching with their other leg[69]. Studies that have looked at COP location have determined that those with CAI have a COP location that is more anterior and lateral [45,70]. Ideally, COP location would be more posterior and medial [45]. Thus, clinically speaking, reaching further in the PM direction may suggest an improved ability to maintain a posteromedial COP location during a dynamic balancing task. Combining this suggestion with the finding that dual task training had a moderate to strong effect on TTB SD in both the ML and AP directions suggest that dual task training may have influenced the sensorimotor system by freeing up more degrees of freedom [8,10,14,53]. However more research that determines the COP location following dual task balance training must be conducted in order to support this notion.

Between groups there was no significant difference in any of the balance outcome measures. There are several possibilities for this. The first is that the more time may be necessary to truly observe the effects of dual task on balance training. The training paradigm utilized in both groups during this study included 4 weeks of balance training as it is the minimal amount of time needed to observe improvements in balance [42]. However, a dual task training study may require longer. Previous studies have suggested that cognitive loading may improve static balance performance [25,26,58,65,68,71-73]. However, the improvements that were observed were over a single session. Due to the lack of follow-up there is no telling if these effects would continue to manifest following exposure to multiple sessions. In 2005, Pellecchia conducted a study in which healthy subjects were exposed to dual task conditions multiple times over a week[74]. Subjects were divided into three groups, one group simply did a baseline and follow-up study, the other groups received training of some kind 3 times throughout that week. One training group performed single task training in which they practiced the balance and the cognitive task separately. The other training group practiced the balance and cognitive task concurrently. At baseline, subjects were tested under two different conditions. The first was static balance on a forceplate and the second was static balance while performing a backwards counting task (dual task condition). Initially, performance of a cognitive task while balancing increased sway (decreased stability) in each of the three groups. However, after a week, the dual task training group exhibited a significantly reduced amount of sway under dual task conditions but not under static conditions which remained unchanged. The single task training group also showed a significant decrease in sway during the dual task conditions but not during the single task condition. The control group did not change. This suggests that dual task training can improve stability after several sessions exposure. However, this was a healthy population, with minimal COP outcome measures, doing a simple single leg balancing task. The single training group also improved relative to the no training group but not as much as the dual task group during a dual task condition. However, during the postural task only condition, the single training group had just as good of balance as the dual task group. Given the simplicity of the cognitive task, the single task group may have continued to improve given more time.

More studies that look at 6, 8 and even 10-week training programs must be attempted before more conclusions can be drawn.

The type of task utilized may not be difficult enough to elicit a noticeable response in training. Providing a difficult task during balance training was hypothesized to be similar to providing an external focus of attention[25]. However, the cognitive tasks selected for this study were chosen due to the ability to track them and progress an individual through a graded program. Thus, the initial task had to be simple enough for the subject to learn. But since all the tasks were pattern based, it is possible that many individuals caught on to the pattern early on and then did not focus on the cognitive task throughout the training, thus negating the potential external focus of attention. Comparatively, during a dual task study, Burcal et al., found that the most significant improvement that was observed was during a manikin task which stressed a visual-spatial form of working memory as opposed to the phonological loop utilized via backwards counting and random number generation tasks used in this study[25]. Additionally, Burcal et al., employed specific instruction on which task to focus on during testing[25]. In this study, no such direction was given during baseline or follow-up in order to observe a true dual task condition. In the future, more difficult tasks like fine motor skills or targeting tasks should be utilized in conjunction with a balance training program as well as specific instruction on focus of attention throughout to consider this limitation.

Dual task interference might not truly influence balance in the same way as an external focus of attention. Currently, research surrounding the effect of dual task interference on postural control is divided [25,26,58, 59, 60,67,69-72]. It is universally accepted that within older populations, dual task interference has a negative effect on balance

[26,66,75]. This is attributed to adopted balancing first mentality in older adults [26,66,75]. Balance worsens with age, so if an older adult is put under dual task conditions balance will worsen even more [75]. Yet, in younger populations many studies report improvements in postural control during dual task conditions [25,26,58,65,68-71]. The majority of these utilize a healthy populations [26,58,65,68-71] making it difficult to draw parallels to injured populations like those with CAI. Conversely, one study that utilized a multiple sclerosis (MS) population, found that 12 weeks of dual task balance and gait training is feasible as they saw improvements in the dual task group relative to a control group [76]. While this population is very different from the one utilized in this study, individuals with MS have altered balance as do individuals with CAI. The extent of those differences only make this comparison stronger as individuals with MS have far worse balance and gait kinematics [77]. Due to the findings of that study, the use of cognitive loading within a training program are still up for debate but certainly feasible.

It was hypothesized that dual task interference could be modified to act as a method to allow the sensorimotor system to become more automatic and thus perform its functions at a more subconscious level [74]. Due to the limited number of brain imaging studies, it is unclear if dual task interference would even have this effect. Therefore, more brain imaging studies must be conducted in order to better understand the true effect that dual task interference has on cortical functioning during a motor task.

Limitations

This study is not without limitations. First, retention rate was not ideal as almost 25% of recruited subjects dropped out after baseline due to time constraints. Secondly, the sample size was limited which makes drawing conclusions difficult. Finally, a lack of specific and consistent direction throughout the dual task training program makes drawing comparisons to other dual task studies difficult. According to Burcal et al. arousal may influence resource allocation during processing of tasks throughout postural control [25].

Conclusion

In conclusion, a 4-week balance training program under both a traditional balance training program and dual task paradigm significantly improves static and dynamic postural control. As this study was one of the first of its kind in looking at dual task interference over a 4-week balance training program, it is unclear if dual task interference truly impacts training. What is clear is the dual task has the potential to influence training as demonstrated by the moderate to strong effects it had on TTB and SEBT outcomes. However, more research must be conducted in order to better understand this.

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APPENDIX: PATIENT REPORTED OUTCOMES

Foot and Ankle Ability Measure (FAAM)

Please answer every question with one response that most closely describes to your condition **within the past week**. If the activity in question is limited by something other than your foot or ankle mark not applicable (N/A).

	Side	No difficulty	Slight Difficulty	Moderate Difficulty	Extreme Difficulty	Unable to do	N/A
Standing	Right	☐	☐	☐	☐	☐	☐
	Left	☐	☐	☐	☐	☐	☐
Walking on Even Ground	Right	☐	☐	☐	☐	☐	☐
	Left	☐	☐	☐	☐	☐	☐
Walking on even ground without shoes	Right	☐	☐	☐	☐	☐	☐
	Left	☐	☐	☐	☐	☐	☐
Walking up hills	Right	☐	☐	☐	☐	☐	☐
	Left	☐	☐	☐	☐	☐	☐
Walking down hills	Right	☐	☐	☐	☐	☐	☐
	Left	☐	☐	☐	☐	☐	☐
Going up stairs	Right	☐	☐	☐	☐	☐	☐
	Left	☐	☐	☐	☐	☐	☐
Going down stairs	Right	☐	☐	☐	☐	☐	☐
	Left	☐	☐	☐	☐	☐	☐
Walking on uneven ground	Right	☐	☐	☐	☐	☐	☐
	Left	☐	☐	☐	☐	☐	☐
Stepping up and down curbs	Right	☐	☐	☐	☐	☐	☐
	Left	☐	☐	☐	☐	☐	☐
Squatting	Right	☐	☐	☐	☐	☐	☐
	Left	☐	☐	☐	☐	☐	☐
Coming up on your toes	Right	☐	☐	☐	☐	☐	☐
	Left	☐	☐	☐	☐	☐	☐
Walking initially	Right	☐	☐	☐	☐	☐	☐
	Left	☐	☐	☐	☐	☐	☐
Walking 5 minutes or less	Right	☐	☐	☐	☐	☐	☐
	Left	☐	☐	☐	☐	☐	☐
	Right	☐	☐	☐	☐	☐	☐

Font Paragraph

Participant Number______________________ Date ____________________

Walking approximately 10 minutes	Left	☐	☐	☐	☐	☐	☐
Walking 15 minutes or greater	Right	☐	☐	☐	☐	☐	☐
	Left	☐	☐	☐	☐	☐	☐

Because of your **foot and ankle** how much difficulty do you have with:

	Side	No difficulty	Slight Difficulty	Moderate Difficulty	Extreme Difficulty	Unable to do	N/A
Home responsibilities	Right	☐	☐	☐	☐	☐	☐
	Left	☐	☐	☐	☐	☐	☐
Activities of daily living	Right	☐	☐	☐	☐	☐	☐
	Left	☐	☐	☐	☐	☐	☐
Personal Care	Right	☐	☐	☐	☐	☐	☐
	Left	☐	☐	☐	☐	☐	☐
Light to moderate work (standing, walking)	Right	☐	☐	☐	☐	☐	☐
	Left	☐	☐	☐	☐	☐	☐
Heavy work (push/pulling, climbing, carrying)	Right	☐	☐	☐	☐	☐	☐
	Left	☐	☐	☐	☐	☐	☐
Recreational activities	Right	☐	☐	☐	☐	☐	☐
	Left	☐	☐	☐	☐	☐	☐

How would you rate your current level of function during your usual activities of daily living from 0 to 100 with 100 being your level of function prior to your foot or ankle problem and 0 being the inability to perform any of your usual daily activities?

Right: .0 % Left: .0 %

Total FAAM ADL Score: Right: _________ Left: _________

FAAM Sports Scale

Because of your **foot and ankle** how much difficulty do you have with:

	Side	No difficulty	Slight Difficulty	Moderate Difficulty	Extreme Difficulty	Unable to do	N/A
Running	Right	☐	☐	☐	☐	☐	☐
	Left	☐	☐	☐	☐	☐	☐
Jumping	Right	☐	☐	☐	☐	☐	☐
	Left	☐	☐	☐	☐	☐	☐
Landing	Right	☐	☐	☐	☐	☐	☐
	Left	☐	☐	☐	☐	☐	☐
Starting and stopping quickly	Right	☐	☐	☐	☐	☐	☐
	Left	☐	☐	☐	☐	☐	☐
Cutting/lateral movements	Right	☐	☐	☐	☐	☐	☐
	Left	☐	☐	☐	☐	☐	☐
Low impact activities	Right	☐	☐	☐	☐	☐	☐
	Left	☐	☐	☐	☐	☐	☐
Ability to perform activity with your normal technique	Right	☐	☐	☐	☐	☐	☐
	Left	☐	☐	☐	☐	☐	☐
Ability to participate in your desired sport as long as you would like	Right	☐	☐	☐	☐	☐	☐
	Left	☐	☐	☐	☐	☐	☐

How would you rate your current level of function during your sports related activities from 0 to 100 with 100 being your level of function prior to your foot or ankle problem and 0 being the inability to perform any of your usual daily activities?

Right: .0 % Left: .0 %

Total FAAM Sport Score: Right: ________ Left: ________