DUAL-TASK INTERFERENCE EFFECTS ON GAIT IN THOSE WITH CHRONIC ANKLE INSTABILITY

by

Ashley Duncan

A thesis submitted to the faculty of
The University of North Carolina at Charlotte
in partial fulfillment of the requirements
for the degree of Master of Science in
Kinesiology

Charlotte

2016

Approved by:

____
Dr. Erik Wikstrom

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Dr. Abbey Thomas

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Dr. Tricia Turner

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Dr. Mike Turner

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ABSTRACT

ASHLEY DUNCAN. Dual-task interference effects on gait in those with chronic ankle instability. (Under the direction of DR. ERIK WIKSTROM AND DR. ABBEY THOMAS)

Introduction: Clear postural deficits and impairments throughout the gait cycle have been shown in chronic ankle instability (CAI) patients. The potential causes for these deficits remain unknown but both centrally or peripherally mediated mechanisms have been hypothesized. A dual task interference (DTI) paradigm, such as walking with an additional cognitive task, may provide a better understanding of central influences contributing to the gait impairments observed in CAI patients. Objective: The purpose of this study was to identify if DTI during gait effects individuals with CAI differently compared to healthy uninjured controls. Methods: Seventeen participants volunteered for this investigation (9 CAI, 7 healthy). First, participants practiced the cognitive task, backwards counting by 7s. Participants the performed 6 walking trials (3 baseline, 3 DTI) at a set speed of 3.86 kph. All walking trials were 60-seconds in length and delivered in a random order. Each trial was separated by a 20-second transition period which required participants continue walking on the treadmill without any cognitive load. During the DTI trials, participants counted backwards by 7s from a pseudo-random threedigit number (e.g. 683) as quickly and accurately as possible. Gait parameters were collected using an OptoGait (Microgate, Bolzano, Italy) floor-based photocell system and included the proportion of gait cycle spent in double limb stance (%), step length (cm), and step time (sec). Participants wore noise cancelling head phones during all walking trials to minimize distractions. Separate repeated measures ANOVA were used to examine the effects of Group x Task on walking gait parameters. An alpha level of $p<0.05$ was used for all statistical analyses. Results: No significant differences between healthy and CAI participants were made in double limb support percentage at baseline (Healthy Baseline: 0.44+0.057; CAI:0.49 ±0.059) and (Healthy CT:0.44+0.064; CAI:0.49+0.059). Step times for each group were equal in both baseline and cognitive task (Healthy:0.58+0.03s; CAI:0.61+0.05s). No significant difference reported in step length (Healthy Baseline 56.52+5.18cm; CAI:52.74+4.71cm) and (Healthy CT:56.43+5.30cm; CAI:52.63+4.67cm). Conclusions: Preliminary data suggest there are no differences between healthy and CAI participants based on the means and standard deviations.

DEDICATION

To my parents, Karen and Will Duncan, for all of the motivation, support, and freezer food throughout this journey. And to Tim Azzarello for his constant love and support through this journey. You stuck by my side every 'step' of the way these past two years. I truly appreciate everything you have done for me.

ACKNOWLEDGMENTS

I would first like to thank Dr. Erik Wikstrom for his devout mentorship and patience the past three years. Your guidance has helped mold me into the researcher and student I have become. I would also like to thank my co-committee chair Dr. Abbey Thomas for her meticulous guidance and continuous support, I greatly appreciate all the guidance along the way. This project would not have been possible without help and guidance from you two. I would also like to thank Dr. Tricia Turner, Dr. Mike Turner, and Chris Burcal for all the help and support as my entire thesis committee. Lastly, I would like to thank the Department of Kinesiology for providing me with a quality education for 6 years!

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CHAPTER 1: INTRODUCTION

Ankle sprains are the most common type of acute sports injury.[1] An estimated 28,000 ankle injuries occur daily in the United States and over 3 million emergency room visits for foot/ankle injuries are reported annually[2, 3] and over $3 billion in US annual healthcare cost is the product of chronic joint injury and degeneration.[4] Due to quick return to full activity with minimal activity limits, ankle sprains are thought of as a minor injury.[5] For this reason, approximately 55% of those who sustain a lateral ankle sprain(LAS) never seek evaluation or treatment from a healthcare professional.[6, 7] Hertel found patients who did not undergo rehabilitation were more than twice as likely to experience recurrent sprains[5], thus creating a vicious cycle of recurrent injury caused by untreated symptoms from an inaccurate perception of the severity of LAS.

This vicious cycle is further supported by the fact that a history of ankle sprains is the most common predisposing factor for a future ankle sprain.[5] Indeed, a study examining acute injuries in volleyball players found that 4 out of 5 players with ankle sprains had previously injured their ankle and half of all players reported a second ankle sprain 6-12 month's post the initial injury.[8] Further, Gerber et al. conducted physical examinations on all cadets who sought medical attention after an acute ankle ligament injury. Of the 96 sprains, 63% of military cadets reported at least one previous ankle sprain prior to the current ankle sprain for which they were being treated.[9]

In reference to the International Ankle Consortium (Table 1), history of at least one repeated/recurrent ankle sprain has been defined as a condition called chronic ankle instability (CAI).[10] The most common symptom reported in CAI is the feeling of “giving way”.[11] Chronically unstable ankles result from repetitive bouts of instability.[7, 8, 12] However, the underlying neurophysiologic mechanism of CAI has yet to be determined.

Previous research suggests a combination of mechanical and functional instabilities may contribute to the decreased function observed in patients with CAI.[6] For example, joint laxity and alterations in articular mechanoreceptors may contribute to mechanical instability and sensorimotor deficits, respectively. Reduced stimulation to mechanoreceptors are believed to inhibit action potentials and ultimately decrease neuromuscular control and sensation.[13] As a result, patients would have deficits in strength, ankle proprioception, cutaneous sensation, nerve-conduction velocity, neuromuscular response times, and postural control.[6] These deficits may predispose individuals to an increased risk of recurrent sprains. Therefore, further research is needed to better understand the cause of and impact on the development and/or progression of CAI to develop improved treatments and/or prevention programs. A well-known paradigm, dual task interference (DTI), [14-17] has not yet been systematically explored in patients with CAI and may provide broader insight on inefficient adaptations in postural control and gait variability possibly leading to recurrent sprains.

Dual task interference[18] paradigms illustrate an individual’s ability to perform multiple tasks concurrently.[14] In addition, DTI paradigms provide researchers an opportunity to better understand performance limitations and cognitive prioritization when simultaneously completing multiple tasks.[17] Many ankle sprains occur during physical activity when individuals are performing cognitive tasks (e.g. determining how a defender might react or thinking about errands to complete later in the day) while completing different types of dynamic motor tasks. Therefore, DTI may provide additional information about the sensorimotor adaptations associated with and/or causing CAI.

During DTI testing protocols, three possible outcomes can occur. First, both tasks (cognitive and motor [19]) can improve. Second, one task (cognitive or motor) improves while the other is impaired. Or third, both the cognitive and motor tasks are impaired.[20] Multiple theories such as capacity sharing, the bottleneck model, and the cross-talk model are commonly accepted to explain some of the previously mentioned results, however no one theory at this time can fully explain DTI. The lack of a universal theory may be due to the wide variety of motor and cognitive tasks used during DTI testing protocols.

DTI test protocols have used visual, auditory, and verbal cognitive tasks which influence different areas of the brain.[21] The effects of DTI on static postural control performance have been evaluated in several different patient populations such as those with neurologic diseases, older adults, those with a history of falls, and healthy young adults.[22-26] However, very little research on the influences of DTI on those with CAI has been done.[19, 27] The limited CAI research has focused on static postural control with mixed results. While informative because poor postural control is associated with CAI and is a risk factor for future LAS, the task is not representative of the mechanism of injury. Therefore, the purpose of this investigation is to examine the effects of DTI in those with CAI and healthy controls during a dynamic motor task, gait. To determine if those with CAI respond differently to DTI relative to uninjured healthy controls, participants will be tested under a cognitive load and different levels of motor task difficulty.

Based on the existing literature, we hypothesize:

- Patients with CAI, compared to healthy controls, will demonstrate significantly greater detriments during dual task interference in set-speed gait for means and standard deviations during stance phase, swing phase, single support percentage, double limb support percentage, step time, and step length.
- Correct Response Rate in cognitive tasks will have less accuracy during all walking trials, respectively, compared to baseline.
- No significant differences will be demonstrated in correct response rate between CAI and healthy control participants during baseline, self-select and pre-selected walking speeds.

CHAPTER 2: LITERATURE REVIEW

2.1 Epidemiology

A LAS [28] is frequently caused by hypersupination of the ankle joint beyond the joint's normal range of motion. Hypersupination involves inversion and plantar flexion while unintentionally twisting the foot.[12] In sports and activities of daily living, incorrect foot positioning during a variety of tasks can result in LAS. It is estimated that 80% of LAS are caused by inversion or supination at the subtalar joint.[29] The anterior talofibular ligament (ATFL) is the first ligament damaged. With further rotation, the calcaneal fibular ligament (CFL) can become injured. A total rupture of the lateral ligaments includes the ATFL, CFL, and posterior talofibular ligament.[30]

Several factors have been reported to increase an individual's susceptibility for a LAS. Extrinsic factors include sport type, training errors, competition level/increased intensity, time played, environmental conditions, and equipment.[31] Intrinsic risk factors include history of sprain, foot width/size, height, body mass, generalized joint laxity, lower extremity strength, and extremity dominance.[32] Specific population groups have also been reported for pre-exposure for LAS risks. Populations with a history of ankle sprains and those who did not stretch were 4.9 and 2.6 times more likely at risk for injury.[33] Tyler et al. reported the overweight population was 3.9 times more likely[28] and people with inferior balance have a 2.4 increase risk of injury.[34]

Symptoms of an ankle sprain include various amounts of pain, edema, ecchymosis, reduced range of motion, and functional instability.[11] These symptoms can last a few days, up to six months, or even a year.[11] Ankle sprains are often graded as a I,II, or III (mild to severe) depending on the degree of damage to the lateral ligaments including the ATFL, CFL, and posterior talofibular ligament.[30] Most common assessments for an ankle sprain include ankle ligament stability testing and ankle strength testing; consequently, subjective clinical evaluation is often inconsistent and can lead to misdiagnosis. In addition, each injury is unique resulting in symptoms specific to each individual and sprain, making diagnosis and the development of treatment plans difficult.

Classically in a mild to moderate sprain, two weeks rest is prescribed. Research has lead us to believe that this may return patients to activity too soon. For example, a systematic review of ankle sprain patients reported 5-33% pain after one year.[35] Gerber et al.[8] collected data at the US Military academy on cadets who sought medical attention for acute ankle injuries. By 6 weeks 95% of participants returned to activity even though 39% reported residual symptoms. At 6 months post injury only 40% of participants had normal ankle examinations.[9] With improper assessment and neglect of proper healing it has been hypothesized that an initial LAS may go through a cascade of events eventually leading to long term consequences for the remainder of an individual's life.

Individuals with a previous history of ankle sprain, a reported 32-74% show signs of residual and chronic symptoms, recurrent ankle sprains, and/or perceived instability.[36] Episodes of chronic lateral instability and repetitive ankle sprains has been defined as chronic ankle instability (CAI).[37] Symptoms associated with CAI often include pain, swelling, self-reported disability, recurrent sprains, and most commonly feelings of “giving way”.[3] In addition, patients with CAI are highly susceptible to ankle osteoarthritis.[2] Saltzman et al. determined 4 in 5 cases of ankle joint OA resulted from previous musculoskeletal trauma. He also found patients experienced ankle OA, on average, a decade younger than patients with primary ankle joint OA.[38] Many factors stemming from LAS’s and CAI contribute to degenerative OA. For example, a lateral ankle trauma disrupts the surrounding muscles, nerves, tendons, and ligaments.[39] Stretched ligaments lead to joint instability which subsequently allows excess translation and rotation of the talus within the ankle mortise. This excess motion creates shear forces on the cartilage contributing to premature degeneration and osteoarthritis.[40] Lingering swelling may also lead to inhibition in surrounding muscles and ultimately cause joint damage. All of these implications contribute to altered static postural control, joint moments and loading.[37] On a financial scale, $3 billion in US annual healthcare cost is the product of chronic joint injury and degeneration.[4]

Residual symptoms resulting from a LAS, CAI, and OA lead to decreased physical activity, interfere with activities of daily living, negatively impact health issues, and risk factors for mortality. All of which contribute to a decreased quality of life and morbidity.[37] Given the frequency of LAS’s and the high percentage of individuals who go on to develop CAI and/or post-traumatic ankle OA, it is clear that better treatment paradigms are needed. However, before treatments can be improved, a better understanding of the consequences associated with LAS and CAI is necessary.

2.2 Clinical Implications

Lateral ankle sprains (LAS) occur most commonly in sports including field hockey, volleyball, football, basketball, cheerleading, ice hockey, lacrosse, soccer, rugby, track and field, gymnastics, and softball.[29] Some estimate around 45% of all sports related injuries occur from ankle sprains.[3] With initial injury, ankle trauma causes damage to the surrounding muscles, nerves, tendons, and ligaments.[39] Due to quick return to full activity with minimal activity limits, ankle sprains are thought of as a minor injury.[5] Conversely, residual symptoms from a LAS can lead to decreased physical activity, interference with daily living, and health issues including risk factors for mortality contributing to additional health care system costs.[37] Furthermore, not all LAS are created equal and not all patients with CAI should be treated the same.

LAS results in a variety of impairments, post ankle sprain, a continuum of alterations occur mechanically and/or functionally.[37] As CAI develops, damaged somatosensory receptors fire a misinterpretation for sensations of pain, temperature, touch, and pressure;[41] damaged afferent pathways and loss of ankle sensori-motor control may contribute to strength deficits, impaired neuromuscular control, postural control, and proprioception;[42] and impaired proprioception, may contribute to an impairment in joint position sense, kinesthesia, and reflexive joint stabilization, all potentially exposing the ankle joint to further injury.[41] Basketball players with multiple LAS>2 year, compared to healthy players demonstrated increased sway during stance which is thought to increase errors in passive ankle repositioning.[42]

Patients with CAI, compared to healthy individuals, typically demonstrate a more rigid postural control as a coping mechanism[43] and are significantly inverted in sections of the gait cycle which can lead to potential rolling of the ankle.[44, 45] Up until about a decade ago, gait was thought of as an automatic task.[46, 47] Recent research provides evidence to suggest greater attentional demands are required to carry out a successful biomechanical task such as walking.[48, 49] An overload in the system during gait may provide better insight in central input, the brain, and postural deficits, the limb, which are not as apparent in normal gait.[17] Research to further look at attentional demands use a DTI paradigm together with a secondary task such as gait.[50] However, to this day, gait experiments performed on CAI individuals has solely looked at a single walking test and has neglected the cognitive aspect of gait. This might not be a sensitive enough test to investigate central impairments in patients with CAI. By performing a cognitive task during a gait trial, an active test, this may identify greater differences in CAI individuals compared to a passive gait test. And potentially provide a broader distinction in CAI deficits which have not yet been explored.

To maintain an efficient gait pattern, an individual must adapt and utilize proper control strategies via the central nervous system to control intra-limb coordination (ILC). To produce a functional movement he/she must assemble and preserve proper relations between joints within a limb for organized time and sequence.[51, 52] An individual whom has recently disrupted this ILC from an ankle sprain, it may be pertinent to not only rehabilitate the peripherial (limb) but as well as the central input. Chronic stroke survivors improve gait after virtual dual-task treadmill training.[53]

In the future, DTI interventions could be implemented with the rehabilitation for ankle sprains and for CAI individuals. DTI interventions could train the cognitive requirements and provide a greater improvement when individuals are cleared for return to play. Respectively, in an athletic setting cognitive tasks are being performed unconsciously, the athlete runs while communicating with teammates to pass the ball or predict where an opponent is going to run. If attentional demands are higher in the gait cycle of CAI individuals, they will have less capacity to carry out unconscious tasks and may suffer in performance. By rehabilitation of athletes both physically and cognitively there may be a closer margin in return to play as a healthy athlete that solely physical rehabilitation alone. However further identification of what types of DTI test are most successful would need to be researched.

The visual system in a main feedback for postural adjustment for gait.[54] In a clinical setting, gait can be trained by a visual cognitive task such as Stroop, n-back attneave shapes, or Mankin tests via a treadmill monitor. As a patient is warming up for rehabilitation, he/she could also ‘warm up’ the visual feedback system without the monitoring of the therapist. By increasing the cognitive demands with rehabilitation, this may exemplify a more ‘real world’ environment. Furthermore, this may provide prevention for further injuries by training the brain to free up attentional capacity devoted to injured gait mechanics[55] and return central resources to baseline.

2.3 Purpose of Gait Analysis/Assessment

Gait assessment is a tool for identifying potential declines in the quality of life and can be indicative of a pathology in individuals;[56-58] in addition, gait assessment may reveal deficits that can be improved upon to enhance sport performance during games and competitions. [5, 59, 60] Gait interpretation is utilized in two main areas, research and clinical assessment.[61] The research field strives for a better understanding of differences in pathological and healthy gait through gait analysis to help develop new, successful interventions for pathology treatments.[62, 63] Clinical relevance is to assess gait and identify deviations from normal patterns and give direct feedback to the patients to help improve activities of daily living.[61] During gait analysis, precise measurements of sub-phases may be useful for detection of normal or impaired gait[5] as well as the formulation an appropriate treatment plans and markers of rehabilitation progress.[5] Although gait analysis approaches are well utilized for several pathologies (i.e. lower limb amputation, stroke, osteoarthritis, etc.) minimal research has looked at gait assessment in CAI individuals.[63-65]

Normal Gait Cycle and Terminology

A complete gait cycle (GC) (Figure 1), a stride, involves heel strike to heel strike of the same foot or two consecutive steps, one step with each foot.[61, 66, 67] When walking or running, gait is considered to have bilateral symmetry; the left arm and right leg interchanges swing during a phase shift.[56, 68] Each leg experiences two major gait portions: stance phase, when the foot is in contact with the floor which makes up 60% of the GC, and swing phase. Swing phase is when the foot is moving forward to make the next step and comprises about 40% of the cycle.[66-68]

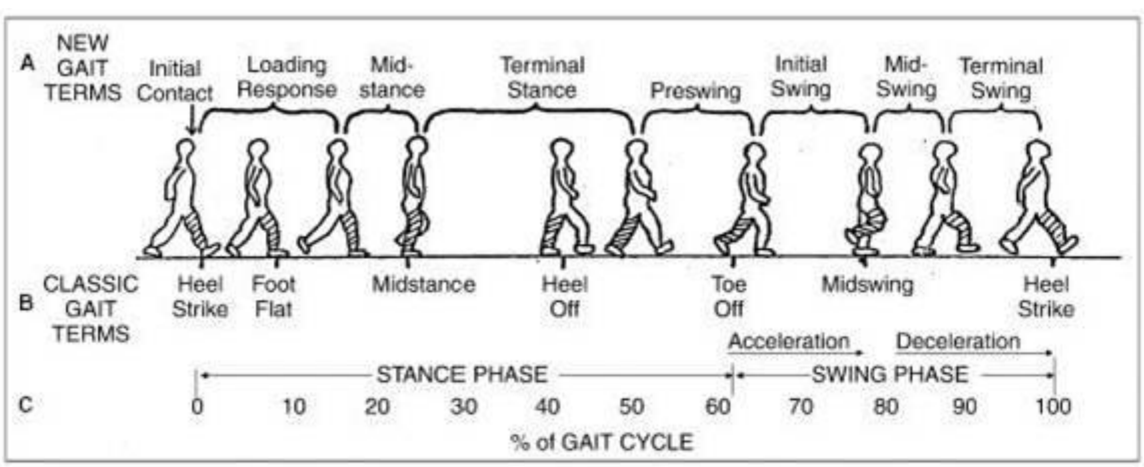

Figure 1: Breakdown of one complete gait cycle.

Stance Phase

Stance phase begins when the forward foot (heel strike) contacts the ground and terminates when the same foot leaves the ground (toe off).[66, 69] Heel strike begins the GC, and the body's weight begins to transfer to the standing leg.[68] The goal of stance phase is to maintain postural control by supporting the body against gravitational forces while propelling the body in continued motion.[56, 67] Stance phase is composed of five detailed sub-phases that allow for stabilization of the leg for weight acceptance, energy absorption, and forward propulsion of the body into the next step.[69] A more detailed breakdown, in sequential order, of stance phase includes initial contact, loading response, midstance, terminal stance, and pre-swing.[61]Also known as heel strike, or foot strike, initial contact comprises the first 0-2 percent of the GC. During initial contact, the foot touches the ground and decelerates the body.

At initial contact, the hip is in approximately 20 degrees of flexion. The hip extensors (e.g., hamstrings and gluteus maximus) contract concentrically. This generates an internal extensor moment at the hip and allows the hip to extend and generate power.

The knee joint is near full extension, with both quadriceps and hamstrings muscle contraction. At the end of swing phase, however, the knee shows an internal flexor moment from contraction of hamstrings.

The foot is slightly supinated at initial contact and the ankle is close to a neutral position in plantarflexion/dorsiflexion. The tibialis anterior muscle reaches its peak activation during initial contact, which allows the heel to contact the ground and the heel's soft tissue and footwear to absorb energy from the ground. At the ankle, little moment or power exchange occurs until after initial contact.

Loading response:

Loading response comprises of the next 2-12 percent of the GC. This is the initial double support period as the foot is lowered to the ground and the contralateral limb is lifted for swing, which helps assist with shock absorption and provide weight-bearing stability.

Hip extensors continue to contract during the loading response to contract hip extension, which provides postural stability and control of forward motion from the head, arm, and trunk (HAT) segments. Hip and knee moments are the same as at initial contact.

Eccentric contraction of knee extensors (quadriceps) in the loading response helps to control speed and magnitude of knee flexion used to initiate stance phase flexion and absorb the impact of foot strike.

Eccentric contraction of the ankle dorsiflexors (tibialis anterior) controls plantar flexion. Furthermore, pronation of the foot and internal rotation of the tibia decelerate the foot on touchdown. Ankle dorsiflexors generate an internal dorsiflexor moment resisted by an external plantar flexor moment.

Midstance:

Also known as feet adjacent, during 12-31 percent of the GC, midstance is the first half of single limb support (SLS). Midstance provides limb and trunk stability as the swing leg passes the standing leg. The swing leg makes progression over the stationary foot.

In midstance, the hip moves from a flexed to an extended position which is achieved by inertia and gravity as concentric contraction of the hip extensors (e.g. gluteus maximus and hamstrings) ceases and the internal extensor moment disappears. At the hip, the quadriceps and pretibial muscles are predominately inactive in this phase.

The knee during midstance switches from flexion to extension by concentric contraction of the quadriceps (vasti).

The foot remains flat on the floor as forward rotation of the tibia about the ankle joint moves from plantar flexion to dorsiflexion. Eccentric contraction of the triceps surae generates an internal plantar flexor moment as force vector moves into the forefoot.

Terminal stance:

Also known as heel off, terminal stance represents 31-50 percent GC interval and completes SLS. Terminal stance begins with heel rise progression of the body beyond the supporting foot and ends when the contralateral foot strikes the ground.

At terminal stance, peak hip extension is reached and hip abductor activity stabilizes the pelvis which then terminates with initial contact of the contralateral limb. The tibia slows down forward motion and the femur moves forward.

Peak knee extension moves from extension to flexion as the quadriceps contraction disappears which brings the joint in front of the force vector, hence the internal moment changes from flexor to extensor.

The foot becomes supinated and reaches peak ankle dorsiflexion at terminal stance as the tibia externally rotates. As the heel rises, the toes remain on the ground and extend at the metatarsophalangeal (MTP) joint, known as toe break, which tightens the plantar fascia. Triceps surae continuously generate an internal plantar flexor movement as eccentric contraction continues with power absorption.

Pre-swing:

Also known as opposite initial contact, consists of 50-62 percent interval of the GC. Pre-swing is the end of stance phase as weight begins to transfer to the contralateral limb. This phase must generate a large amount of power to position the limb and accelerate progression from the demands of swing initiation.

During pre-swing, hip motion reverses from extension (power absorption) to flexion (power generation). The adductor longus acts as the primary hip flexor with assistance from in stretched hip ligaments producing tension due to gravity.

Hip flexors (iliacus and psoas) and biceps femoris generates knee flexion, eccentric contraction of rectus femoris limits the rate of knee flexion and results in power absorption. Muscle forces produce most flexion acceleration before toe off which determines knee flexion velocity at toe off and correlated to peak knee flexion.

Concentric contraction of triceps surae (gastrocnemius and soleus) moves the ankle into plantar flexion, which brings the center of mass forward which draws ground reaction force with it, moving it into the forefoot and in front of the knee joint. This creates a high external dorsiflexor moment opposed by a correspondingly high internal plantar flexor moment. In addition, the foot reaches maximal supination with hindfoot inversion (adduction) and coupled external tibial rotation resulting in stability of the foot for loadbearing.

Swing Phase

While stance phase is ongoing in one limb, the contralateral limb is carrying out swing phase. Swing phase begins at toe off and is completed at heel strike.[66, 69] The goal of swing phase is to reposition the limb and make sure the toe is clear from the ground. After swing phase is initiated, it often is sustained by momentum. Swing phase is broken down into three sub-phases, in sequential order, and includes initial swing, midswing, and terminal swing.[61, 66, 67]

Initial swing:

Also known as toe off, includes the 62-75 percent portion of the GC. Initial swing begins as the foot lifts and clears from the floor while the swinging foot advances to become adjacent to the stance foot.

Prior to toe off, triceps surae contraction ceases and an internal plantar flexor moment rapidly declines. After toe off, rectus femoris and adductor longus, along with tension in the hip ligaments, continues to flex the hip while the ankle reaches peak dorsiflexion due to tibialis anterior activation.

The leg acts as a 'double pendulum' in that the knee flexes as a result of hip flexion. With increased gait speed, the rectus femoris may eccentrically contract to control the speed of knee flexion; however, no muscular contraction is needed to control the knee. An extensor moment slows knee-joint flexion. Gravity reduces the need for a large hip flexor joint moment, which contributes to flexion of the knee.

Midswing:

Comprised of 75-87 percent GC interval, midswing advances the stance limb past the swinging limb until the stance limb is beside the tibia of the swing leg.

During midswing quadriceps activate hip flexion. The knee is passively at peak flexion, accomplished due to rapid acceleration of the thigh. Transition from initial to terminal swing requires the leg to achieve 'toe clearance' to prepare for the next foot fall. The foot remains slightly supinated, until the following initial contact, with minimal clearance ~14mm from the ground.

Contraction of the tibialis anterior moves the foot out of plantar flexion and late in the swing pretibial muscles dorsiflex the ankle to ensure toe clearance. Since only the weight of contralateral limb is involved, very small moments and power exchanges are seen at the ankle. After initiation, momentum sustains swing phase and the quadriceps become mostly inactive. Iliopsoas contracts to aid forward motion creating peak power generation at hip to accelerate swinging leg forward.

Terminal swing:

Terminal swing comprises of the last 87-100 percent of the GC and ends when the foot strikes the floor. Terminal swing completes limb advancement and prepares the limb for stance.

At the end of swing, hip extension terminates and the hamstrings eccentrically contract to limit knee hyperextension, maintain the hip joint in flexed position, and slow forward rotation of the thigh. This generates an internal extensor joint moment to prepare for power absorption at heel strike.

Rapid knee extension in terminal swing moves from passive non-muscular forces to prepare the limb for loading and proper foot placement during stance phase. In addition, a flexor knee-joint moment slows knee extension.

At the ankle, the tibialis anterior contraction continues to plantar flex the foot and hold the ankle in place to prepare for a controlled landing at heel strike, thus generating a dorsiflexion moment, making the ankle moment negligible.

Speed Changes Influence Walking Cycle

Variations in walking speed influence several patterns in the gait cycle (GC). For example, the faster one walks, the shorter the step length.[62] With increased walking speed, stance to swing phase proportions shift in correlation to the speed increase. As previously mentioned in the GC, while walking there is a 60/40 distribution.[66-68] An inversely proportional transition to a 40/60 distribution is met as running velocity is reached.[62, 66, 67] As speed continues to increase, double limb support decreases to zero (flight phase), and running begins.[70] Stride duration will also decrease with increased speed of walking attributed predominately by a decrease in stance time. Interestingly, swing phase does not vary as much with a change in gait speed.[69]

Jordan et al.[71] investigated step interval and length as well as stride interval and length at 80%, 90%, 100%, 110%, and 120% of preferred walking speed (self-selected speed) in eleven healthy young adult females. Subjects walked on a Kistler Gaitway treadmill, which included two embedded force plates, and successfully completed a twelve minute interval for each randomized condition. Figure 2 illustrates that with increasing speed intervals, stride and step intervals decrease while step and stride lengths increase.[71]

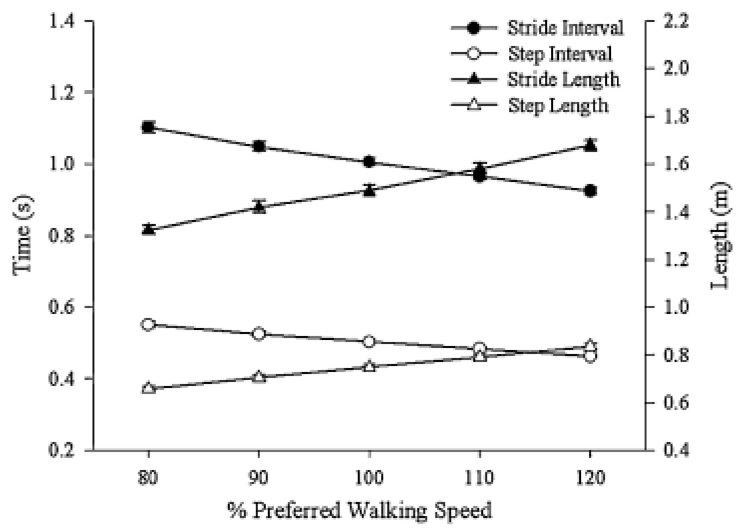

Figure 2: Comparison of group mean values at walking speeds for stride interval, step interval, stride length, and step length.

Though some suggest there are stride pattern differences in treadmill walking compared to overground walking, Murray et al.[72] found similar findings as Jordan et al.[71] Murray et al.[72] collected kinetic and EMG activity in seven young healthy women while walking at their own comfortable speed, a slow stroll, and as fast as possible. Subjects completed at least six trials of each speed by walking on an elliptical pathway. Strategically placed reflective targets were used to record outcome measures by interrupted-light photography. As seen in the table below, decreases from one speed to another resulted in decreased stride length, cadence, and swing time as a percent of the cycle, meaning healthy individuals reduce walking speed by taking shorter steps in a longer period of time.[72]

Table 1: Average stride dimensions and temporal components.

Gait components	No.	Slow	Free	Fast
Velocity (m/min)	14	49.9 ± 2.5	85.0 ± 3.1	115.0 ± 3.6
Cycle duration (s)	14	1.38 ± 0.04	1.03 ± 0.02	0.90 ± 0.02
Cadence (steps/min)	14	87.5 ± 2.4	116.9 ± 2.2	134.3 ± 3.0
Stride length (cm)	14	111.4 ± 3.0	140.7 ± 2.8	165.9 ± 3.7
Stride length (% of body height)	14	65	85	100
Stride width (cm)	14	6.4 ± 1.0	7.6 ± 0.6	8.4 ± 1.3
Foot angle (°)	14	4.8 ± 1.0	4.7 ± 0.9	3.7 ± 1.0
Stance (s)	28	0.90 ± 0.03	0.62 ± 0.02	0.50 ± 0.02
Swing (s)	28	0.48 ± 0.01	0.41 ± 0.01	0.40 ± 0.01
Stance (% cycle)	28	65	60	56
Swing (% cycle)	28	35	40	44
Double-limb support (s)	28	0.21 ± 0.02	0.10 ± 0.01	0.05 ± 0.01

Mean ± SE.

These observations (Table 1) are supported by Andriacchi et al.[62] who looked at slow, normal, and fast walking speeds across a 10 m walkway in seventeen normal adults age 22-59 (average 28 years old).[62] Both swing and support time were inversely proportional to walking speed, while step length and cadence varied linearly with gait speed.[62] Many speed-related appear to adjust the step length due to changes in amplitudes of lower limb motion which are found at heel-strike positions.[62] As walking speed progressively increased, there was an increase in knee flexion at initial contact, possibly to increase shock absorption.[72] Murray et al. observed faster walking speeds corresponded with an increase in EMG activity. In addition, increased walking speed caused most limb segments to move through a greater arc of motion in a shorter period of time which may suggest a greater acceleration and deceleration demand in muscle forces.[72] However, other studies show that individual EMG activity data vary significantly.[73]

Sex Differences

In addition to variations in the gait pattern based on fluctuations in walking speed, the gait pattern naturally varies between males and females. More specifically, men typically have more shoulder swing and women typically have more hip swing.[68] In addition, women typically have lower gait velocity and step length but higher step frequency than men.[74-76] Murray found sex differences were statistically significant except in step frequency at slow gait.[74] Oberg et al.[75] measured the gait in 200 normal healthy individuals ages 10-79. Subjects walked along a 10 m walkway as two 5.5 m photocells, in the middle of the walkway, collected data. The centered photocells allowed for omission of interference from acceleration and deceleration times. Self-selected walking speed in men averaged 1.18-1.34 m/s (2.6-3.0 mph) and in women 1.10-1.29 m/s (2.5-3.0 mph).[75] Murray et al. found the self-selected gait speed to be 1.51 m/s (3.4 mph) for men and 1.30 m/s (2.0 mph) for women.[74, 76] With several factors such as walking speed and gender differences influencing gait pattern, distinguishing normal and pathological gait becomes complex.

2.4 Postural Control and Gait

Chronic ankle instability (CAI) most commonly results in motor and sensory impairments. Sequentially, reoccurring instability leads to deficits in postural control.[11] When compared to healthy controls, individuals with functional ankle instability had higher levels of impairments in static and dynamic balance tests.[77] Though clear postural deficits have been shown in patients with CAI, studies show inconsistent findings due to a variety of instrumented measures.[37] Altered input from lateral ankle joint receptors may contribute to sensorimotor impairments associated with significant deficits on postural control and gait mechanics in patients with CAI.[6, 78, 79]

Sensory reweighting has been suggested in the presence of this pathology. McKeon et al.[43] assessed the effects of textured insoles on postural control in an attempt to potentially disrupt plantar cutaneous receptors.[43] Patients with CAI showed significantly less time to boundary (TTB) magnitude and variability.[78, 80] In individuals with CAI compared to controls, textured insoles demonstrated a significant decrease in the main effect in the mean of TTB minima in AP (14.2±3.7 versus 12.2±3.1) and ML (4.6±1.6 s versus 4.0±1.0) directions respectively.[43] This suggests disrupted plantar cutaneous receptors, due to textured insoles, exhibits a detrimental effect on the sensorimotor system and the ability to control single-limb stance. Similar to pathological populations, patients with CAI demonstrate a more rigid postural control strategy which is known as a coping mechanism. CAI population may not have enough relevant input to execute movements, thus demonstrating greater reliance on other available inputs such as plantar surface receptors on the bottom of the foot.[43]

The Dynamical System Theory states a healthy sensorimotor system adapts to organismic, environmental, and task constraints to efficiently achieve movement goals.[81] “Optimal movement variability” of a healthy system demonstrates greater flexibility and adaptability to stresses on the body from increased task or environmental demands.[82, 83] As constraints on the somatosensory system increase, there is a switch to a more stable movement strategy.[81] Damaged joint mechanoreceptors from a sprain might cause altered movement patterns in the kinetic chain[84] triggering inappropriate adaptations in somatosensory control.[12] With a diminished ability to properly reorganize movement strategies from increased task constraints, patients with CAI may result in an inflexible movement pattern and potentially contribute to future degenerative pathologies.[37, 82] Therefore, DTI paradigms on individuals with CAI may reveal similar postural control influences compared to similar lower extremity impaired populations.[50, 54]

Patients with CAI have shown impairments throughout the gait cycle in overground and treadmill and barefoot and shod gait.[44, 85, 86] Hiller et al.[87] suggest a decreased detection of inversion movements and delayed motor response of peroneal muscles is influenced by the redistribution of the sensorimotor system associated with CAI. Drewes et al. [45] found, throughout the entire gait cycle, patients with CAI were more inverted while walking and jogging immediately prior to heel strike, at heel strike, and immediately post-heel strike. Patients with CAI demonstrated less travel time-to-boundary due to a greater lateral COP and overall pressure distribution.[55, 88]

Decreased detection of inversion position may make the ankle more vulnerable to turning on the lateral border contributing to reoccurring LAS.

Monahan, Delahunt, and Caulfield[44] used 3D motion analysis to assess kinematic and kinetic pattern differences while barefoot walking in patients with CAI compared to controls.[44] Individuals with CAI displayed 6-7^{o} greater inversion than healthy individuals throughout 100-200 ms (pre- to post-heel strike (HS)). Changes throughout the entire gait cycle in angular velocity demonstrated altered pattern and magnitude. Throughout the 200 ms post-HS, individuals with CAI demonstrated eversion, however, controls demonstrated inversion resulting in increased stress and loading response to ankle joint structures in CAI.[44] In early stance phase, there were differences in magnitude of time averaged angular displacement, angular rotations, joint moments, and joint powers, potentially leading to increased stress and continuous damage to ankle joint structures.[89, 90]

Baur et al.[91] observed differences between barefoot and shod running in individuals with chronic Achilles tendonitis, suggesting the need to assess discrepancies between walking while wearing shoes and barefoot walking in patients with CAI. Chinn et al.[85] evaluated walking and jogging on a treadmill at preselected speeds. In both walking and jogging trials, kinematic differences existed between CAI and heathy control groups. During walking gait cycles, unlike Monahan's[44] barefoot walking study, no significant differences were reported in rearfoot inversion-eversion between CAI and controls with shoes. Similarly, Drewes et al.[92] observed during mid to late stance 42-51% of the gait cycle CAI group showed 3^{o} less dorsiflexion.[85, 92] In conjunction, Ryan[93] found patients with CAI were less dorisflexed at the point of peak dorsiflexion during the entire jogging gait cycle. In jogging trials, individuals with CAI, compared to controls, were inverted 4-96% of the gait cycle. Furthermore, patients with CAI, compared to healthy controls, were significantly more inverted in three increments 11-18% (mean difference:3.9°±0.3°), 33-39% (mean difference:4.8°±0.1°), 79-84% (mean difference:4.8°±0.1°) of the gait cycle. In addition, the CAI group was more plantar flexed in mid-swing phase 54-68% (mean difference = 7.2°±0.5°) of the gait cycle. Increased eversion muscle activity was demonstrated in walking and jogging[85] which may be used as a protective mechanism in preventing ankle sprains.[94] Demonstrating differences in gait kinematics between CAI and healthy control individuals.

Terada et al.[86] observed that individuals with CAI demonstrated decreased walking pattern variability compared to controls. Similarly, those with CAI showed less variability in frontal plane ankle kinematics.[86] Lack of optimal gait variability of frontal plane ankle kinematics may be due to sensorimotor control inhibition in the fibularis longus in patients with CAI.[95] Deficits in feedback and feedforward control strategies may also influence inaccurate foot position and muscle activation timing potentially leading to repeated injury.[96, 97]

Recent literature demonstrates postural control and gait deficits in patients with CAI.[44, 55, 78, 80, 88] However, what is less known are the potential causes for these deficits and if consequences are centrally or peripherally mediated. Troop et al.[98] saw postural deficits occur equally in the bilateral limb even after unilateral ankle traumas.[98] Examining movement variability and compromised neuromuscular control in unilateral and bilateral patients with CAI may provide a better understanding of kinematic and kinetic pattern differences during activities. In addition, insight into potential mechanisms of bilateral ankle impairments may reveal how individuals with CAI utilize altered muscular activation coordination in effort to prevent future injury. Future research investigating the uninvolved or bilateral limb may provide definitive insight to determine the extent of centrally mediated sensorimotor dysfunction in patients with CAI. Additionally, experiments such as walking with an additional cognitive task, are needed to assess the influences mediated by central mechanisms. DTI interventions and kinetic and kinematic pattern differences may provide a better understanding of central influences contributing to postural deficits and gait impairments in patients with CAI.

2.5 Theories of DTI

Dual task interference (DTI) paradigms illustrate an individual's ability to perform multiple tasks concurrently and have been studied by theorists and psychologists for over 100 years.[14] DTI interventions provide a window to understand the capacity of attentional limitations and working memory. By overloading cognitive performance, functional insights provide answers to simple questions on human performance limitations during tasks such as postural control.[17] DTI interventions provide researchers an opportunity to better understand performance limitations and cognitive prioritization when completing multiple tasks simultaneously.[17] In general, DTI interventions cause lower performance compared to performing a single task alone; unless one or multiple tasks being performed are automatic.[99]

Multiple theories such as Capacity Sharing, the Bottleneck Model, and the Cross-Talk Model provide framework for research, which are validated through several types of tasks.[20] These are commonly accepted as to explain some of the above mentioned results, however no one theory at this time can fully identify the overall process. The lack of a universal theory may be due to the wide variety of motor and cognitive tasks used during DTI testing protocols.

Capacity Sharing "Limited Attentional Resources Model" is the most widely[21] accepted theory of DTI. The model suggests that every task utilizes different quantities of processing resources. The efficiency of a task depends on the capacity available to the task.[14] When more than one task is carried out, a capacity limit will eventually be approached. This is also known as capacity overload. For example, if someone has a capacity limit of 10 and performs two tasks both requiring process quantities of 6, performance in one or both tasks will be impaired due to the greater processing demands relative to supply.

Bottleneck Theory "Single-Channel Model" states certain critical mental operations occur sequentially and must be carried out sequentially.[14] It is used most often when describing simple two task interference which can be explained as a task delay or impairment in task performance when two tasks require the same mechanism or operational space.[14] For example, a response of one task can only be carried out by the central response and then the second process can begin.[100] The analogy of traffic slowing when two lanes merge into a single lane represents how mental capacity slows down when different tasks require the same space or control pathway.[101] Pashler and Johnston[17] explain the brain utilizes individual neurons for massive parallel processing. These neurons, with several cortical areas, perform a variety of interconnected cognitive functions and when multiple operations occur, an inhibitory interaction results and prevents parallel processing.[17]

Cross-talk Theory proposes the idea that it is the informational content being processed that causes the delay/interference as opposed to the operation itself.[17] Simultaneously performing two similar mental tasks contributes to a larger impairment versus two very different tasks simultaneously performed.[14, 17] Furthermore, the theory postulates processing is directly affected by the specific content. Huestegge and Koch[100] explains, tasks require “left” or “right” brain decisions. During dual tasking, if both processes require “left” decisions, overlapping signals contribute to conflicting information and higher interference on performance will result.[100]

2.6 Postural Control and the Effects of DTI

The influence of secondary tasks on postural sway depends on several factors. The available perceptual information, precision required to control postural and suprapostural components, difficulty to acquire necessary information, and quantity of attentional load.[20] Complex interactions result in three possible outcome measures: 1) both the cognitive (suprapostural) and motor (balance) tasks improve, 2) one task improves while the other becomes worse, and 3) both tasks become worse.[20] The wide array of outcomes make it difficult to evaluate ongoing higher level processes while dual-tasking. One thought is that diverse secondary tasks utilize cognitive load and attentional capacity differently.

For example, alternative visual secondary tasks (i.e. Spatial or Objective working memory) may generate alternative findings due to the influences on different locations of the brain. As mentioned in the Cross-Talk Theory, simultaneously performing two similar mental tasks (influencing one hemisphere of the brain) contributes to a larger impairment versus two very different tasks simultaneously performed.[14, 17]

VanderVelde et al. compared visual n- back tasks utilizing object working memory (OWM) (same or different attneave shapes) to spatial working memory (SWM) (visual-spatial shapes location).[102] OWM strictly activates the left-hemisphere of the brain while SWM primarily activates the right-hemisphere.[103] Thus allowing researchers to separate the influences of OWM and SWM visual systems.

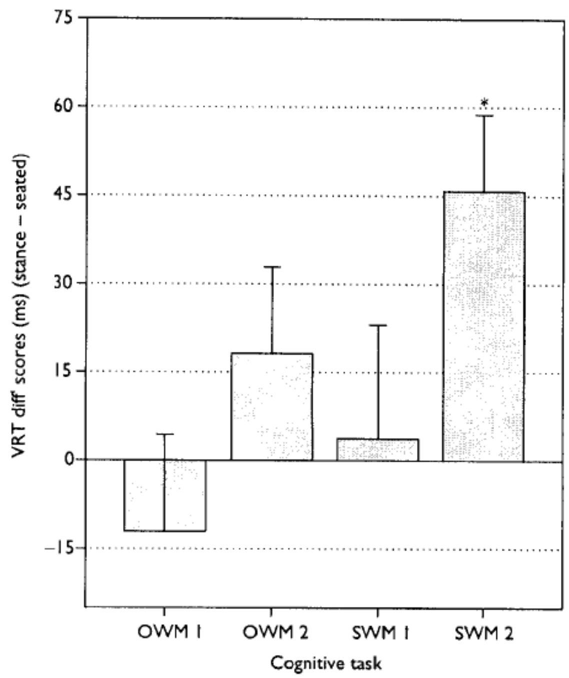

Figure 3: Cognitive task verbal response times in ms (mean and standard error) plotted as difference scores contrasting seated and tandem Romberg postural conditions.

As seen in Figure 3, SWM demonstrated impaired postural performance and significantly delayed verbal response times. OWM showed no significant influence on postural control.[102] Though both tasks influence the visual system, cognitive processing is executed in separate areas of the brain, thus it is hard to compare posture-cognition task outcomes to one another. In addition, incongruent levels of task difficulty and individualized cognitive task influences on the brain make comparisons among various paradigms unreliable.[104,101]

Stance control of posture has been thought to be guided by higher cognitive systems.[47] DTI test protocols influence visual, auditory, and verbal cognitive tasks which influence different areas of the brain.[21] These three postural control systems, play a direct role in postural control and are individually limited in their capabilities. Sensory information modulates the generation and output of movement[101] thus potentially furthering postural impairments in DTI interventions in postural and gait tasks for individuals with CAI.

Visual aids provide assistance for postural stability and spatial positioning but accuracy of visual input declines with self-motion causing a misinterpretation of visual cues. During movement, signal displacement of the head provides information for postural adjustment.[102] Visual capacities are stressed by tasks such as optic flow or eyes open versus eyes closed.

The somatosensory system references supporting structures to provide information on position and motion as well as the correlation of body segments to one another. However, the somatosensory system is disrupted with any non-horizontal surface. Proprioceptive receptors in healthy individuals become impaired by uneven ramps or vibration perturbations. As previously mentioned, patients with CAI suffer from proprioceptor deficits. Thus signifying, individuals with CAI potentially may have additional detriments, compared to healthy controls, in proprioceptive tasks.

Lastly, the vestibular system detects movement of the head in reference to gravity and inertial forces. The limitation is that head movement (e.g. flexion) cannot be distinguished from a flexed trunk with no additional neck motion.[101] When one or more of these systems are removed postural adjustments must be altered to compensate however, patients with CAI whom suffer from functional and/or mechanical postural impairments, may demonstrate greater task difficulty.

Increased cognitive demands could directly influence additional postural control deficits in sensory information exhibited by those with CAI. For example, when a cognitive task requires attention, postural sway adjustments are demonstrated. It has been shown that during postural control tasks, balance is prioritized over secondary cognitive tasks in both quiet stance and perturbed stance.[22, 105]

One limitation of DTI experiments, however, is the manner in which instructions are given to participants. Muller suggested that when directions and timing of experimental protocols are pre-explained, participants demonstrate anticipatory postural control contributing to postural preparation which effects both cognitive task and postural control performance.[106] Anticipatory postural adjustments (APA) are a proactive strategy to improve stability and posture prior to voluntary movement. Burcal and Wikstrom[101] examined the effects of varied working memory tasks (backwards counting, random number generation, and the manikin test) under different sets of instructions (no instructions, focus on the postural control task, and focus on the suprapostural task). Though all postural outcomes improved, measurements showed greatest improvements in visuo-spatial tasks compared to phonological loop tasks.[19]

Several DTI protocols, utilizing the previously mentioned systems, have been used to evaluate postural control in a variety of samples such as those with neurological diseases, older age (healthy or history of falling), and healthy young adult. Some of the DTI protocols include simple reaction time tasks involving the visual and auditory systems, verbal memory tasks, the Stroop test, mathematical subtraction (counting down by threes or sevens), random number generation, and sentence completions.[21]

In addition to simple reaction time tasks, the influences of postural control in mechanical tasks (i.e. talking or button pressing) may directly influence postural control alone. Task stresses may produce enough mechanical demands to effect sway not associated with cognitive load. Articulatory versus non-articulatory tasks might influence altered breathing rates and contribute to changes in standing postural control from a mechanical perspective in addition to DTI. Jeong observed postural sway increased with increased respiration rate in able-bodied individuals.[107] Dault[108] further examined the effects of articulation on the amplitude and frequency of postural sway while performing a secondary task.

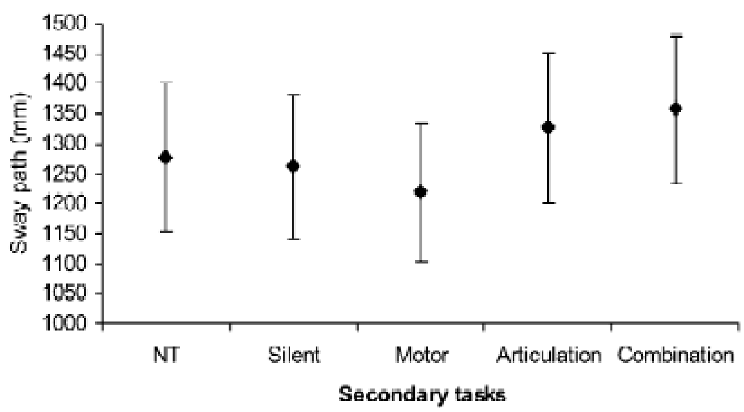

Figure 4: Average sway path (±standard error) for each secondary task condition for vision and postural tasks combined.

Outcomes revealed with a secondary task alone, sway amplitude decreased; conversely, when articulation was added to a cognitive task, the frequency of sway increased (Figure 4).[108] In addition, increased sway was found in participants only while performing articulation tasks and not during tasks performed silently.[108, 109]

Yardley[109] suggests the changes in sway during articulation tasks may be a result between a central interference between motor programs for articulation and for posture.

Increased sway frequency and decreased sway amplitude can be interpreted as increased postural stiffness.[110] Dault[111] suggests postural control can be adjusted to allow for better performance of a visual or hepatic task. In his study, he examined the effects of three postural stances (shoulder width, seesaw shoulder width, tandem seesaw) while performing three levels of Stroop cognitive tasks (word card, color card, color-word card).

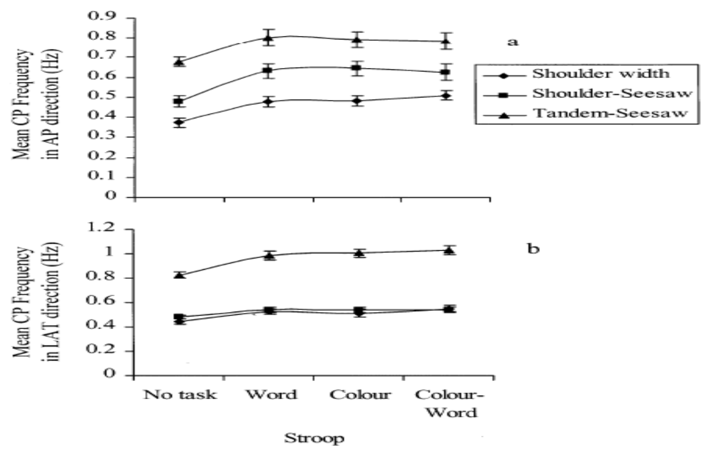

Figure 5: Mean CP frequency in AP (a) and lateral directions (b) for all postural stances and Stroop conditions.

A more rigid stance with increased cognitive task difficulty was demonstrated. The most difficult cognitive task consistently performed the worst and showed significantly reduced speed, which can be explained to increased task difficulty (Figure 5). Tandem seesaw revealed a larger amplitude, frequency, and velocity of the Center of pressure (COP)-fluctuations Anterior Posterior direction. COP frequency increased while COP amplitude decreased. The trade-off can be explained as utilizing a “more critical stabilization of posture" to facilitate the additional visual information from the cognitive task.[111]

Posture first hypothesis can help explain these results. Shumway-Cook suggests that during increased threat of injury, postural control and gait stability are prioritized over secondary task in order to reduce risk of injury or falling and to preserve balance.[101, 112] The influence of secondary tasks on postural sway depends on several factors. The available perceptual information, precision required to control postural and suprapostural components, difficulty to acquire necessary information, and quantity of attentional load.[20] These secondary tasks potentially cause a greater or lesser variance of static postural sway on a population such as CAI, however limited research has examined the interference of dual task effects.[19, 50, 113]

2.7 Gait and Effects of DTI

Some researchers have suggested gait should be viewed as a complex motor skill that utilizes executive function, especially when other tasks are performed at the same time. [26, 114] Executive function tasks on Alzheimers patients predicted the dual tasking effect on gait variability. Gait variability, while walking, reflects balance control. Increased variability has been associated with gait unsteadiness and fall risk of the stepping pattern.[112, 115] Though shown to have influences on neuromuscular diseases and old age populations, the influence of executive function and dual task influences, potentially linking a pathway to gait impairments, to patients with CAI has not yet been studied.

Increased gait variability and walking speed, associated with risks of falls, act as an indicator for functional capacity.[116, 117] In addition, stepping consistency act as indicators for balance control during walking.[115] Spatio-temporal DTI has been shown to significantly slow gait parameters in frail, prefrail, and nonfrail community dwelling individuals.[117] Springer[115] examined the effects of several dual task interventions on gait in young, healthy, adults, elderly non-fallers, and elderly fallers. The simple and complex task were an auditory response task the difference being the complex included an additional phoneme-monitoring task. Serial 7's, participants subtracted by 7's starting at 500. Successfully demonstrating the influences of cognitive tasks on postural control in multiple populations.

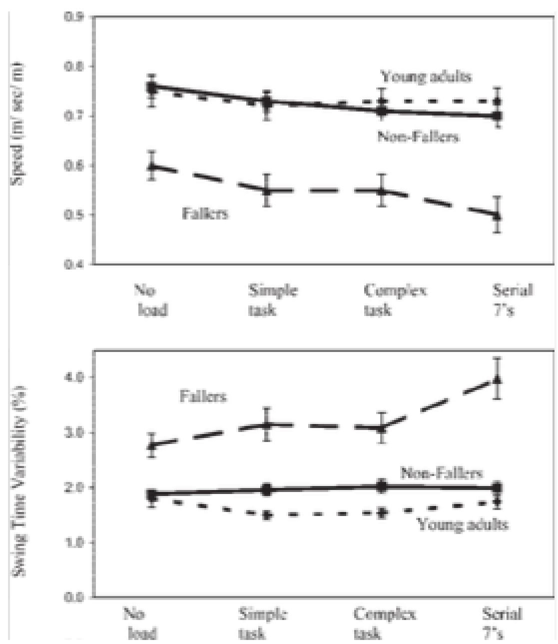

Figure 6: Effects of dual task on gait speed and swing time variability.

As seen in Figure 6, to compensate for dual task influences, young adults reduced gait speed and elderly non-fallers reduced their gait speed and swing time. Only in elderly fallers did dual tasking effects on gait detrimentally cause unsuccessful maintenance of a stable gait pattern.[115] Serial 7's in all three groups showed the most significant influences on gait speed and swing time variability. Springer[115] concluded dual task tests with gait increases variability between faller and non-fallers making it an identifier for risks of falls.

Fundamental influences in postural control may be used to understand population limitations. In one study, Faulkner et al.[24] examined a visual-spatial reaction time decision task while walking in an older population. They demonstrated increased distractors resulting in increased response time, decreased accuracy, slower walking pace and higher levels of recurrent falls.[24] These findings provide insight to age-related changes in attentional capacity and suggest adding additional gait impairments may help identify individuals at risk of falling.[24] Similar to the falling population, interaction between postural control and cognitive tasks in individuals with CAI may show similar detriments in gait variability and walking speed.

CHAPTER 3: METHODOLOGY

3.1 Research Design:

A cross-sectional design was used to identify if dual task interference during gait eaffects individuals with CAI differently compared to healthy uninjured controls. Independent variables include Cognitive task difficulty (baseline, counting backwards by 7s) and motor task difficulty (self-selected and pre-selected walk). Dependent variables include stance phase, swing phase, single support percentage, double limb support percentage, step time, and step length.

3.2 Participants:

Participants included in the study were a total of 38 individuals (nineteen normal healthy young adults and nineteen young adult individuals with CAI). All participants were recreationally active (i.e. three aerobic exercise sessions for a total of 90 minutes a week) between the ages of 18-35 years. Uninjured controls were free from acute lower extremity injuries and concussions for the past 3 months and have not had any major lower extremity surgeries. Similarly, uninjured controls were within +/- 10% of the age, body mass, and height and sex matched to those with CAI. Exclusion criteria for all participants include: a history of previous surgeries to the musculoskeletal structures of the lower limbs, a history of a fracture in either lower extremity requiring realignment, and acute injury to musculoskeletal structures of other joints of the lower extremity that may impact joint integrity and function. Participants with CAI met the recommended inclusion/exclusion criteria set by the International Ankle Consortium. [2] Those with CAI met the following criteria: 1) at least one episode of giving way within the past year, 2) at least one recurrent ankle sprain prior to study participation, 3) answering 5 or more questions of "yes" on the Ankle Instability Instrument (AII), 4) report pain, instability, and/or weakness in the involved ankle, 5) previous sprain created at least one interrupted day of desired physical activity, 6) attribute these signs to their initial ankle injury, 7) failure to resume all pre-injury level of activities, 8)no previous ankle fractures, and 9) no previous head and acute lower extremity injury within the past three months. Participants had a minimum level of self-reported disability as measured by the Foot and Ankle Ability Measure (FAAM) Activities of Daily Living subscale (<90%, the FAAM Sports (FAAM-S) subscale (<80%).[118] Individuals with a history of bilateral ankle sprains will be automatically excluded. All participants read and signed the informed consent before participating in the study.

3.3 Instruments

Questionnaires of self-assessed disability: A total of 4 questionnaires were completed for each limb. Completion of questionnaires takes no more than 10 minutes. These questionnaires include: NASA Physical Activity Scale, Ankle Instability Instrument, Foot Ankle Ability Measure (FAAM) and the FAAM-Sport. These questionnaires determine the amount of disability and pain that an individual currently has and examples of these documents can be seen in the attached pages.

NASA Physical Activity Scale (Table 2) was designed by the Johnson Space Center to examine physical activity levels in prior month prior to assessment. [119]

FAAM/FAAM-Sport (Table 3) recommended by the International Ankle Consortium[118]. These are reliable and valid measures for self-reported physical function in individuals with a range of leg, ankle, and foot musculoskeletal disorders. They assess test content, internal structure, score stability, and responsiveness. FAAM consists of 21-items of activities of daily living (ADL). FAAM-Sport is an 8 item sub-scale measurement. ADL and Sport showed a 0.89 and 0.87 test retest reliability respectively.[120] Higher FAAM and FAAM-Sport scores are indicative of better ankle function.

Ankle Instability Instrument (Table 4), compared to subjective evaluation by a health care provider, is a more objective way to identify patients with CAI or functional instability and help determine the range of severity.[121]

Treadmill. Precor C956i (PreCor Corp, Woodinville, WA) is a purpose-built treadmill for high-use environments with impact control system to provide a natural feel when walking and jogging. Due to the slanted nature of the side panels of this treadmill 4 Irwin Quick Grip clamps (Irwin Tools, Huntersville, NC) are used to prevent sliding of the Optogait.

Optogait. (Microgate USA, Mahopac, NY) Optogait is a movement analysis system for functional assessment on patients with normal and pathological conditions with capabilities to assess spatio-temporal aspects of gait. Despite systematic differences in speed, cadence, step length, step width, and stride length, the Optogait system has been found to have strong concurrent validity in overground walking with relative and absolute test-retest reliability to the Gaitrite system to capture spatial-temporal parameters.[122, 123] During treadmill walking, Optogait demonstrated strong test-retest reliability compared to the Zebris treadmill system; nonetheless, demonstrated systematic differences in single limb stance phase, stance phase duration, and total double limb stance phase.[123, 124]

The system can range from one to 100 meter in length. The device is comprised of adjacent transmitting and receiving bars containing infrared LEDs. Optogait and Zebris and Gaitrite systems revealed systematic differences in both overground and treadmill walking, due to the infrared LED lights on the Optogait that are raised 3mm above ground which captures stance time a couple of milliseconds before heel-strike.[124] It has the accuracy of measuring up to one-thousandth of a second. The system detects contact and flight times of participant's movements to measure duration and establish position during gait. It allows for objective assessment of physical conditions as well as identify postural asymmetries. The customizable software allows for individualized patient plans with easy re-call storage capabilities to assess validity. Though not a limitation in the present study, for future studies with patients whom may drag his/her feet while walking, or walks with step length shorter[125] than his/her foot length this can disrupt data recording from the infrared light beams.[123]

Audio Recorder. Olympus DR-1000 Dictation Kit. To ensure participants accurate responses an audio recorder was used during all dual task responses and later analyzed. The recorder was connected to a laptop where audio recordings were be digitally saved and later assessed. During walking trials, the audio recorder will be place in the water bottle holder area of the treadmill.Skullcandy Proletariat Noise Cancelling wore noise cancelling headphones set at a low level to still be able to hear directions from the investigator.

3.4 Procedures:

Interested individuals were given an eligibility screening questionnaire which included the Ankle Instability Instrument, FAAM, FAAM-Sport, and NASA Physical Activity scale. Once a participant was deemed eligible, he/she reported to the Biodynamics Research Lab for a single test session. Participants were asked to wear comfortable walking shoes and clothes for all testing procedures. At the test session, a verbal script was used to keep testing consistent and prevent any discrepancies in directions. First, participants read and sign the informed consent document and had general information regarding age, height, and body mass collected. Participants next assessed his/her self-mathematic skills on a visual analog scale (VAS). In addition to the VAS, participants completed one additional questionnaires about ankle function, and then went through a basic ankle history and physical exam to capture information recommended by the International Ankle Consortium. This information included an ankle drawer and talar tilt test to assess ligament laxity as well as additional questions about their ankle injury and treatment history. For both CAI and healthy matches, both left and right ankles will be tested.

Next, participants underwent baseline cognitive task testing. To do this, the participant were seated comfortably, wearing noise-cancelling head phones to block distracting sounds, and given instructions and a demonstration by the investigator. Next, the participant completed a series of seven practice trials of backwards counting task by seven. Extensive practices trials were designed to help prevent a learning curve that may occur during testing trials. The cognitive test stresses the phonological loop component of working memory.[14] Participants were given a three-digit number by the investigator and was required to count backward in steps of seven as quickly and accurately as possible. This was followed by three seated baseline cognitive trials. All practice and test trials were 60 seconds in length. An audio recording during each of the baseline and dual-task trials to allow accurate responses records under cognitive conditions. Similarly, a visual analog scale was used to assess participant's perception of task difficulty after completion of each baseline, and walking trials. During all test trials, a clipboard covered the treadmill console, to prevent number distractions from treadmill console, and participants were reminded to hold their gaze straight ahead.

Next, participants began baseline walking at a self-selected comfortable speed on the treadmill. The treadmill was increased in increments of 0.2 mph every 10 seconds until the participant reached a comfortable pace, as if they are leisurely walking down the street. To confirm speed and prevent a "quick trigger" response, speed was be increased two more increments and then be lowered down by 0.1 mph every 10 seconds until the participant reached a comfortable self-selected speed. If the participant did not match the first speed this procedure was repeated until participant confirmed a comfortable walking pace. After the investigator confirmed that the participant was at the desired speed, a total of three baseline (no cognitive task) and three cognitive dual-task trials were recorded while the participants continued to walk at the desired speed. Each trial was 60-seconds in length, delivered in a random order, determined by flipping of a coin, and separated by about 20-seconds of a transition period during which time the participant continued to walk at their self-selected speed. After each trial, participants completed a VAS assessing confidence in ability to complete the baseline or cognitive task. Participants then were required to take at least a 10-minutes rest.

Following the rest period, the same procedure was used at a pre-selected walking speed of 3.86kph (2.4 mph). Again, six 60-second test trials, a total of three baseline (no cognitive task) and three cognitive dual-task trials were recorded in an identical manner. Again, participants completed the VAS ranking the difficulty of tasks during the transition periods.

3.5 Outcomes Measures

A visual analog scale ranked 1-100 (1: not confident at all, 100: very confident) wasused to for participants to self-assess confidence in mathematical abilities as well as confidence in ability to rank the difficulty in completion of tasks. Cognitive outcomes included the total number of responses given and the percent correct. These data was used to calculate the Correct Response Rate [126] CRR=Response Rate per Second x Percent of Correct Responses. Higher CRR indicates better cognitive performance during dual task condition.

Gait outcomes included: pre-selected walking speed stance phase, swing phase, single support percentage, double limb support percentage, step time (sec), and step length (cm)

Gait speed (kph) is the speed in which the individual propels him/herself forward. Means (group average), Standard Deviations (extent of deviation for a group as a whole), Coefficient of Variation (dispersion of a probability distribution):

Support Stance phase (s) represents the support time during gait. It is represented by the first and last contact of a foot.

Swing phase (s) begins with the last foot contact to the ground and ends with the first contact to the ground in the same foot. Swing phase corresponds to single limb support of the other leg.

Single Support Stance phase (%) represents the support percentage during gait. It is represented by the first and last contact of a foot.

Double limb support phase (%) represents the support time during gait. It is represented by the contact of both feet to the ground.

Step time (s) represents the amount of time from to off of one foot to heel strike of the opposite limb.

Step length (cm) is the distance between two consecutive footprints, steps from the heel of one foot print to the heel of the consecutive footprint.

3.6 Data Analysis:

A sample size estimate looked at outcomes of interest in CAI to control differences in gait kinematics and single to dual task alterations in healthy adults. Average effect sizes ranged from 0.59-1.89. Using a conservative effect size estimate of 0.035 resulted in a total sample size of 38. This is consistent with other CAI related sample sizes.

Cognitive accuracy was assessed using separate Group [control, CAI] x Time [baseline, Dual-Task] ANOVAs for self-selected and pre-selected walking. Gait characteristics were assessed using separate Group [control, CAI] x Time [baseline, dual-task] repeated measures ANOVAs for pre-selected speed walking. For VAS data, percent change from baseline was determined. Change scores were analyzed via group by speed repeated measures ANOVAs. An alpha level of 0.05 will be used on all statistical analyses and post-hoc testing will be performed as needed to identify the exact location of differences.

Table 2: Inclusion Criteria, as a minimum by the International Ankle Consortium, for subjects within the condition of Chronic Ankle Instabilty.

Inclusion Criteria

1. A history of at least 1 significant ankle sprain
   - The initial sprain must have occurred at least 12 months prior to study enrollment
   - Was associated with inflammatory symptoms (pain, swelling, etc)
   - Created at least 1 interrupted day of desired physical activity
   - The most recent injury must have occurred more than 3 months prior to study enrollment
   - We endorse the definition of an ankle sprain as "an acute traumatic injury to the lateral ligament complex of the ankle joint as a result of excessive inversion of the rear foot or a combined plantar flexion and adduction of the foot. This usually results in some initial deficits of function and disability"[15]
2. A history of the previously injured ankle joint "giving way," and/or recurrent sprain, and/or "feelings of instability."
   - We endorse the definition of "giving way" as "the regular occurrence of uncontrolled and unpredictable episodes of excessive inversion of the rear foot (usually experienced during initial contact during walking or running), which do not result in an acute lateral ankle sprain"[15]
     - Specifically, participants should report at least 2 episodes of giving way in the 6 months prior to study enrollment
   - We endorse the definition of "recurrent sprain" as "two or more sprains to the same ankle"[15]
   - We endorse the definition of "feeling of ankle joint instability" as "the situation whereby during activities of daily living (ADL) and sporting activities the subject feels that the ankle joint is unstable and is usually associated with the fear of sustaining an acute ligament sprain"[15]
     - Specifically, self-reported ankle instability should be confirmed with a validated ankle instability–specific questionnaire using the associated cutoff score. Currently recommended questionnaires:
       - Ankle Instability Instrument[36]: answer "yes" to at least 5 yes/no questions (this should include question 1 plus 4 others)
       - Cumberland Ankle Instability Tool[26]: score of ≤24
       - Identification of Functional Ankle Instability[40]: score of ≥11
3. A general self-reported foot and ankle function questionnaire is recommended to describe the level of disability of the cohort, but should only be an inclusion criterion if the level of self-reported function is important to the research question. Currently endorsed questionnaires:
   - Foot and Ankle Ability Measure[11]: activities of daily living subscale <90%, sport subscale <80%
   - Foot and Ankle Outcome Score[32]: score of <75% in 3 or more categories

Table 3: NASA physical activity status scale.

Please check the box next to ONE of the following responses that best describes your exercise habits.	
0	No regular exercise, no physical activity outside of office work
1	No regular exercise, occasional walking or exertional activity
2	Rare regular exercise, some exertional activity, usually less than 30 minutes per week
3	Rare regular exercise, some exertional activity, usually more than 30 minutes per week but less than 1 hour per week
4	Occasional regular exercise, no more than 60 minutes of exercise per week
5	Regular exercise: weekly average of 30–60 minutes
6	Regular exercise: weekly average of >1–3 hours per week
7	Regular exercise: weekly average of >3–6 hours per week
8	Regular exercise: weekly average of >6–9 hours per week
9	Regular exercise: weekly average of >9–11 hours per week
10	Regular exercise: weekly average of >11 hours per week

Table 4: FAAM and FAAM Sport Subscale

Patient Name: ______________________ Date: ______________

FAAM Activities & Daily Living Subscale

Please answer **EVERY QUESTION** with **ONE** response that most clearly describes your condition within the past week. If the activity the question is limited by something other than your foot or ankle, mark **NOT APPLICABLE (N/A)**.

Because of your **foot & ankle**, how much **difficulty** do you have with:	No Difficulty	Slight Difficulty	Moderate Difficulty	Extreme Difficulty	Unable To Do	N/A
Standing	0	1	2	3	4	□
Walking on even ground	0	1	2	3	4	□
Walking on even ground without shoes	0	1	2	3	4	□
Walking up hills	0	1	2	3	4	□
Walking down hills	0	1	2	3	4	□
Going up stairs	0	1	2	3	4	□
Going down stairs	0	1	2	3	4	□
Walking on uneven ground	0	1	2	3	4	□
Stepping up and down curbs	0	1	2	3	4	□
Squatting	0	1	2	3	4	□
Coming up on your toes	0	1	2	3	4	□
Walking initially	0	1	2	3	4	□
Walking 5 minutes or less	0	1	2	3	4	□
Walking approximately 10 minutes	0	1	2	3	4	□
Walking 15 minutes or greater	0	1	2	3	4	□

Because of your **foot & ankle**, how much **difficulty** do you have with:	No Difficulty	Slight Difficulty	Moderate Difficulty	Extreme Difficulty	Unable To Do	N/A
Home responsibilities	0	1	2	3	4	□
Activities of daily living	0	1	2	3	4	□
Personal care	0	1	2	3	4	□
Light to moderate work (standing, walking)	0	1	2	3	4	□
Heavy work (push/pulling, climbing, carrying)	0	1	2	3	4	□
Recreational activities	0	1	2	3	4	□

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?

_______%

FAAM Sports Subscale

Because of your **foot & ankle**, how much **difficulty** do you have with:	No Difficulty	Slight Difficulty	Moderate Difficulty	Extreme Difficulty	Unable To Do	N/A
Running	0	1	2	3	4	□
Jumping	0	1	2	3	4	□
Landing	0	1	2	3	4	□
Starting & stopping quickly	0	1	2	3	4	□
Cutting/lateral movements	0	1	2	3	4	□
Low impact activities	0	1	2	3	4	□
Ability to perform activity with your normal technique	0	1	2	3	4	□
Ability to participate in your desired sport as long as you would like	0	1	2	3	4	□

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 sports related activities?

Table 5: Ankle Instability Instrument

Instructions
Please fill out the form completely. If you have any questions, please ask the administrator of the survey. Please mark the ○ completely. Thank you for your participation.

1. Have you ever sprained an ankle?		Right	○Yes	○ No
		Left	○ Yes	○ No
2. Have you ever seen a doctor for an ankle sprain?		Right	○ Yes	○ No
		Left	○ Yes	○ No
3. Did you ever use a device (such as crutches) because you could not bear weight due to an ankle sprain?		Right	○ Yes	○ No
		Left	○ Yes	○ No
If yes, 3a. In the most serious case, how long did you need the device?				
Right: ○ 1-3 days ○ 4-7 days ○ 1-2 weeks ○ 2-3 weeks ○ >3weeks				
Left: ○ 1-3 days ○ 4-7 days ○ 1-2 weeks ○ 2-3 weeks ○ >3weeks				
4. Have you ever experienced a sensation of your ankle "giving way"?		Right	○ Yes	○ No
If yes,		Left	○ Yes	○ No
4a. When was the last time your ankle "gave way"?				
Right: ○ <1 month ○ 1-6 months ago ○ 6-12 months ago ○ 1-2 years ago ○ >2 yrs				
Left: ○ <1 month ○ 1-6 months ago ○ 6-12 months ago ○ 1-2 years ago ○ >2 yrs				
5. Does your ankle ever feel unstable while walking on a flat surface?		Right	○ Yes	○ No
		Left	○ Yes	○ No
6. Does your ankle ever feel unstable while walking on uneven ground?		Right	○ Yes	○ No
		Left	○ Yes	○ No
7. Does your ankle ever feel unstable during recreational or sport activity?	Right	○ Yes	○ No	○ N/A
	Left	○ Yes	○ No	○ N/A
8. Does your ankle ever feel unstable going *up* stairs?		Right	○ Yes	○ No
		Left	○ Yes	○ No
9. Does your ankle ever feel unstable going *down* stairs?		Right	○ Yes	○ No
		Left	○ Yes	○ No

	Right	Left
How many times have you sprained your ankle in the past?	_____	_____
How long has it been since your last significant ankle sprain (in months)?	_____	_____
How many times in the past 6 months has your ankle felt like it "gives way"?	_____	_____

CHAPTER 4: RESULTS

Descriptive statistics of the participants are shown in Table 6 while injury characteristics are shown in Table 7; ($p<0.05$). Participants with CAI were similar to healthy controls, showing no significant difference in height, body mass, age, self-selected walking speed, or physical activity score. However, significant differences were found in FAAM, FAAM-Sport, AII, and injury characteristics. Higher FAAM and FAAM-Sport scores are indicative of better ankle function.

Table 6: Descriptive characteristics of demographical information.

	CAI (N=19)	Healthy (N=19)
Height (cm)	167.22±8.52	167.31±9.15
Mass (kg)	68.11±10.61	67.25±11.86
Age (years)	20.05±2.04	20.89±1.49
FAAM (%)*	84.00± 9.00	100±0.00
FAAM-S (%)*	71.00±14	100±0.00
Physical Activity	5.58±1.50	5.89±1.33
Math Confidence (mm)	71.37±15.23	67.63±20.51
Self-Selected gait speed (kph)	3.34±0.83	3.36±0.47

Table 7: Descriptive characteristics of AII and injury characteristics.

	Healthy Control	Patients with CAI
# Yes's	0±0.00	7.38±2.34
# Involved Sprains	0±0.00	4.88±6.82
#Uninvolved Sprains	0±0.00	0.44±0.63
# Months since last significant sprain	0±0.00	12.31±17.79
# Months since last uninvolved sprain	0±0.00	29.00±37.99
# Involved ankle givingway	0±0.00	6.93±7.24
Saw provider for initial sprain (Y/N)	N/A	Y(65%),N(35%)
Saw provider for most recent sprain (Y/N)	N/A	Y(22%),N(78%)
Initial grade sprain (I,II,III)	N/A	I(21%),II(57%),III(22%)
Recent grade sprain (I,II,III)	N/A	I(60%),II(40%),III(0%)
# Days initial sprain non-weight bearing	N/A	9.25±6.60
# Days most recent sprain non-weight bearing	N/A	3.79±3.66
Rehab(Y/N)	N/A	Y(33%),N(67%)
Average weeks of rehab	N/A	6.00±4.78
Months since last rehab visit	N/A	46.58±27.714

The repeated measures MANOVA for gait variables revealed no significant condition main effect [$F_{(6,31)}$=1.607, p<0.17 or condition x type interaction [$F_{(6,31)}$=1.096, p<0.397]. Table 3 contains the means and standard deviations of the included gait variables across the different conditions (baseline and cognitive) effect [$F_{(6, 31)}$=1.607, p<0.178] or type (healthy and patients with CAI.

Table 8: Means and Standard Deviations for Gait in Healthy Controls and Patients with CAI

	Healthy Controls			Patients with CAI		
	Baseline	Dual-Task	P-value	Baseline	Dual-Task	P-value
Stance phase (%)	82.20±2.00	82.30±2.00	0.066	87.40±2.00	83.30±2.00	0.07
Swing phase (%)	38.10±1.00	38.00±1.00	0.227	37.00±1.00	37.70±1.00	0.23
Single limb support (%)	38.10±2.00	38.00±1.00	0.296	35.20±2.00	37.70±1.00	0.30
Double limb support (%)	44.10±2.00	44.30±2.00	0.149	47.70±2.00	47.70±2.00	0.149
Step time (sec)	0.60±0.01	0.60±0.01	0.05	0.60±0.01	0.59±0.01	0.052
Step length (cm)	57.37±1.68	57.67±1.80	0.14	55.51±1.68	55.16±1.80	0.140

Descriptive characteristics of means and standard deviations for confidence in completing a task are shown in Table 9. The repeated measures ANOVA for perceived confidence in completing the baseline and cognitive tasks revealed a significant main effect of condition [$F_{(2,32)}$=24.54, p<0.001] without a significant condition x type interaction [$F_{(2,32)}$=0.917, p<0.409]. During self-selected speed walking, participants were more confident in their math skills following the baseline compared to the cognitive task (*P*<0.001; Table 9).

Table 9: Means and Standard Deviations for Perceived Confidence in Healthy Controls and Patients with CAI

	Healthy Controls (3.34±0.83 kph)		Patients with CAI (3.36±0.47 kph)	
	Baseline	Dual-Task	Baseline	Dual-Task
S-S Speed	26±14	25±12	48±99	46±76

Descriptive characteristics of means and standard deviations are shown in Table 10 for Correct Response Rate (CRR) in Verbal Tasks. Participants with CAI were similar to healthy controls, showing no significant difference in correct response rates among the baseline and pre-selected speed conditions. (P>0.05; Table 5).

Table 10: Descriptive characteristics of means and standard deviations for both accuracy and speed of responses.

	Healthy Controls*	Patients with CAI*
Baseline (at rest)	0.27±0.14	0.48±0.99
Pre-selected speed (kph)	0.29±0.12	0.30±0.16

*Higher CRR indicates better cognitive performance during dual task condition.

CHAPTER 5: DISCUSSION

5.1 Summary

Individuals with CAI often demonstrate gait impairments compared to healthy adults.[44, 45, 55, 85, 88] As few individuals walk without performing some sort of cognitive task at the same time, this study sought to determine if the addition of a cognitive task during walking would exacerbate gait differences between participants with CAI and healthy adults. Contrary to our hypothesis, there were no differences between patients with CAI and healthy adults for any gait variables or cognitive tasks. These findings were consistent across baseline and cognitive task conditions.

5.2 Gait

Both healthy controls and patients with CAI in the current study, compared to previous studies in healthy young adults for both treadmill and overground self-selected walking, demonstrated a faster self-selected walking speed in treadmill and overground gait.[115, 127] Participants with CAI, in the present study, match the CAI population used in a previous shod treadmill walking study reporting similar FAAM and FAAM-S percentages.[85] Previous studies in patients with CAI have evaluated gait, both overground and treadmill walking in barefoot and shod conditions with varying results.[44, 55, 85, 86, 88, 92] In previous studies, participants with CAI demonstrate kinematic differences compared to healthy controls while walking including detriments in dorsiflexion, a more lateral center of pressure while walking, and more inversion pre-heel strike to post-heel strike.[55, 78, 85, 88]But no study to date has looked at the influence of performing a cognitive task while walking on gait in patients with CAI.[55]

Patients with unilateral and bilateral CAI, compared to healthy controls, during barefoot overground walking demonstrated a slowing down of weight transfer from heel strike to toe off. Results showed significantly longer contact time in heel and midfoot areas, significant decrease in relative forces under heel and toes, and increased relative forces in midfoot and lateral forefoot compared to controls.[55] Furthermore, there were no differences between injured and uninjured limbs this may suggest an altered gait pattern is centrally mediated.[55] Despite these findings, the present study found no significant differences in stance time in both baseline walking and walking with a cognitive task at self-selected and pre-selected speeds. One reason for the contrary findings may be that the Optogait setup. More specifically, the system senses foot falls, 3mm above ground which results in heel-stike being captured stance time a couple milliseconds before heel-strike actually occurs.[122, 123]

5.3 Dual Task Interference

Adding a cognitive task to walking imposes additional cognitive load on the central processing system; furthermore, attention is a mediator for motor control. We chose to utilize a cognitive task of counting backward by 7's, a phoneme-monitoring task, because it demonstrated the largest influence on executive function in young, healthy, adults during overground walking at a self-selected pace.[115] However, it has been suggested that a greater impairment will take place when overlapping functions from the same area of the brain occur simultaneously.[14, 17] Concurrent to the present study, previous findings saw no significant difference in overground walking with a counting backwards task, serial 1's and 3's, at slow, preferred or fast walking speeds in young, healthy, adults.[128]

This is the first study to examine the effects of a cognitive task on gait in patients with CAI. However, previous studies have examined how gait is impacted by cognitive load in healthy adults.[21, 105, 115, 127, 128] During treadmill walking, Qu[127] reported no differences in step time or step length variability in healthy, young adults during a similar backward counting task to the one employed in the present investigation.[127] The present study, demonstrated faster self-selected speed; however, showed similar findings in that healthy, the cognitive task did not alter gait characteristics. Therefore, young adults show to have sufficient working memory to simultaneously complete a cognitive and motor task in both treadmill and overground walking.[21, 105, 127] Given the lack of differences in gait data in a dual-task paradigm between groups in our study, it appears that for patients with CAI either the cognitive load was not challenging enough, the spatio-temporal gait measures were not sensitive enough, or her/she demonstrates sufficient working memory, one can simultaneously walk and perform a cognitive task without disrupting spatio-temporal gait parameters.

Postural control strategies in healthy adults after perturbations provide adequate balance and step recovery in gait.[129] Visual input is a main contributor in postural control by providing continuous input on body orientation and movement[130] and swing limb trajectory.[131] Therefore, Serial 7's, a phoneme-monitoring task, may not have stressed the central area enough or was not significant enough of a stress to influence postural control. Future studies will need to stress other areas of working memory to broaden the interpretation of central influences on both postural control and gait in CAI patients. Examples of additional tasks include, both auditory and visual Stroop tests with verbal responses. In a previous virtual reality gait study, young healthy adults demonstrated increased failure rates in cognitive tasks during obstacle clearing during treadmill gait and compared to baseline walking.[132]

Differences in our findings and those of others may be due to variance in gait pattern in treadmill versus overground walking.[133-136] Overground walking can emphasize "freezing gait", stride variations, and changes in pace whereas on a treadmill, the brain will devote attention to prevent injury and falling off.[47, 129, 132] In treadmill walking, this can promote an increase in gait focus with a decrease in successful dual task trials.[21, 132] Conversely, in overground walking, young, healthy, adults successfully adapted to the dual task of counting backwards by 7's by decreasing gait speed and swing time to adapt to cognitive tasks.[115, 128] Diverse results and findings in treadmill compared to overground walking adversely impact the overall literature.

5.4 Limitations

Most previous studies assessing gait in patients with CAI collected data using motion capture system (3D) technology and assessed gait parameters that we were unable to capture using the Optogait (1D) system. For example, the Optogait cannot distinguish left or right foot gait patterns which hinders distinction in limb to limb gait asymmetries.

Additionally step width cannot be captured. A wider step width, reflects a more causes walking pattern,[137] which may be indicative of postural adjustments to task constraints. Central influences on gait in patients with CAI are not well understood; therefore, it may be pertinent to study differences in baseline gait compared to cognitive influences on gait with more sensitive parameters such as those recorded with motion capture technology.

CHAPTER 6: CONCLUSIONS

The main objective of this study was to determine how an additional cognitive load affected patients with CAI during treadmill walking. We observed that the addition of a cognitive task did not adversely influence patients with CAI relative to healthy controls with respect to gait parameters including stance phase, swing phase, single support percentage, double limb support percentage, step time, and step length. These results suggest that patients with CAI were able to successfully adapt to the additional constraints placed upon them. If a DTI intervention is to be used as a rehabilitation tool in patients with CAI, either a more influential or more demanding task may be necessary for training improvement.

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