AN EXAMINATION OF DIFFERENCES IN POSTURAL CONTROL IN INJURED ATHLETES AND UNINJURED ATHLETES

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Miranda June Osgood

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Approved by:

Marjorie A. King
Marjorie A. King, PhD, PT, ATC

Irene M. Cucina
Irene M. Cucina, D.P.E, ATC

Julie N B
Julie N. Bernier, Ed.D, ATC

Dedication

To Mom and Daddy,

for supporting me in every little thing

I wanted to be good at,

no matter how crazy it seems at the time!

Thank you!

Love, Miranda June

Acknowledgements

We ain't what we wanna be;
We ain't what we oughta be;
We ain't what we gonna be;
But thank God we ain't what we was.
-Martin Luther King, Jr.

Three years ago, I graduated summa cum laude from my undergraduate institution, ironically feeling lost and incapable. Now, three marathons, seven different jobs, six different living situations, about a thousand miles of running, a mountain of laughs, a small river of tears, and a whole bunch of amazing people later, I know I can do anything. Probably the best thing about having done this thesis is that I get to publicly and permanently thank the people that have gotten me here today.

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I am astounded by the number of incredible people I know. It takes my breath away every day and I can't imagine how I got so lucky. I am excited to start a new chapter in my life—one where I routinely get a full night's sleep and get paid on a regular basis! Some may sigh and say it's finally over, but I believe it has just begun.

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An Examination of
Differences in Postural Control
In Injured Athletes and Uninjured Athletes

Miranda June Osgood

Plymouth State University

Abstract

Objective: To determine whether there is a difference in translation of center of force between injured and uninjured individuals while doing a double-legged, right-legged, and left-legged squat with eyes open and eyes closed. ***Design and Setting:*** A repeated measures, counter-balanced, one session design was used. Five 2 x 2 ((injury status x eye condition) analyses of variance were calculated for both double-legged and single-legged squat data. Five 2 x 2 (dominance x eye condition) analyses of variance were calculated to determine whether dominance played a role in postural control. ***Subjects:*** College-age males and females who were self-reported as physically active participated in the study, with fifteen injured and fifteen uninjured subjects (*n* = 30). Injured was defined as having a minimum injury of one lateral ankle sprain 1 - 12 months ago; uninjured was defined as having no history of lower extremity injury. ***Measurements:*** The *Matscan*® from Tekscan, Inc. was used to assess translation of center of force. Subjects performed double-legged squats, right-legged squats, and left-legged squats with eyes open and eyes closed; three trials of each condition were recorded for a total of 18 per subject. The squat depth was 60° of knee flexion. Between squat conditions, subjects were allowed to rest briefly. ***Results:*** Injured and uninjured subjects displayed similar mean values of translation of COF in all variables in all squat conditions regardless of eye condition. However, as was expected, the mean values of translation of COF were significantly different in the main effect eye condition, with the translation being greater with eyes closed. ***Conclusions:*** Postural control was not significantly affected by musculoskeletal injury. Further research with attention to subject history and a larger subject group are recommended.

Differences in Postural Control
Between Injured Versus Uninjured Athletes

Musculoskeletal injury is thought to damage afferent nerves contained in muscles and ligaments that help maintain postural control (Bernier & Perrin, 1998; Forkin, Koczur, Battle, & Newton, 1996; Freeman, Dean, & Hanham, 1965). While postural control is obviously important in everyday life, it is especially so in athletics. Poor control of posture can lead to injury (Goldie, Evans & Bach, 1994; Lephart, Pincivero, Giraldo, & Fu, 1997; Tropp, Ekstrand, & Gillquist, 1984a), decreased athletic performance, and increased reaction time of muscles (Irrgang, Whitney, & Cox, 1994; Konradsen & Bohsen Ravn, 1991).

Physical rehabilitation clinicians generally agree that improving postural control is an essential component of a successful rehab program (Abfall & Bruce, 1998; Diamond, 1989; Hoffman & Payne, 1995; Houglum, 2001; Irrgang et al., 1994; Milch, 1986). However, there is a great deal of contradiction in this area in terms of research (Riemann, 2002). The issues include whether there is an actual loss of postural control following injury (Riemann, 2002). For example, Freeman et al. (1965), Lentell et al., (1990), and Cornwall and Murrell (1991) found a difference in postural stability in the injured limb while several other researchers (Bernier, Perrin, & Rijke, 1994; Tropp, Ekstrand, & Gillquist, 1984a) concluded that there was no loss. Riemann (2002) suggested that damage to lateral ankle-ligament mechanoreceptors is likely not the sole source of observable postural control deficits. Whether humans can improve postural control after or even before injury occurs has also been questioned (Ashton-Miller, Wojtys, Huston, & Fry-Welch, 2001, Tropp et al., 1985).

Much of the information available is reported in a qualitative manner (Forkin et al., 1996,; Freeman et al., 1965; Garn & Newton, 1988, Lentell et al., 1990), which is a less objective measurement than quantitative. Force platform tests are a form of quantitative measurement. A force platform measures the translation of the center of pressure (COP) of the subject and is widely accepted as accurate methods of postural control assessment (Ekdahl, Jarnlo, & Andersson, 1989; Goldie, Bach, & Evans, 1989; Tropp et al., 1984a & 1984b). Cornwall & Murrell, 1991; Jansen, Larsen, & Olesen, 1982). This device, however, can be costly and complex for clinical use or screening. The forceplate studies available, Tropp et al. (1984a & 1984b) and Cornwall and Murrell (1991), contradict one another. According to Tropp et al. (1984a & 1984b), there were no significant differences between injured and uninjured, while Cornwall and Murrell (1991) reported that there was a significant difference between the groups.

Subjects in postural control research are very often tested while standing in a static, one-legged stance (Ekdahl et al., 1989; Forkin et al., 1996; Freeman et al., 1965; Garn & Newton, 1988; Hoffman & Payne, 1995; Tropp et al., 1984a; Tropp et al., 1984b). The static stance is clearly not a functional test for athletes, particularly since most injuries occur while in motion, such as running or jumping.

The current study was conducted in an attempt to identify a method of assessing dynamic control of posture that is quantitative as well as quick and easy for a clinician to implement in a clinical setting. The research will add to the existing body of knowledge surrounding postural control and its effect on injury. The researchers expected that postural control would be worse in the injured subjects when their eyes were closed in a dynamic squat.

Method

The research project was designed to determine whether there is a significant difference in the translation of the center of force during a functional task between injured and uninjured individuals. The research measured a dynamic, functional movement in order that it may easily be generalized. The method section is divided into the following categories: subjects; testing instruments; procedure; and statistical analysis.

Subjects

Subjects for this research study were physically active, college-age male and female volunteers, from a University in northern New England. A power calculation was performed with the data of the first five subjects to determine the number of subjects needed. The result of this calculation was over 30 subjects per group. Due to the time constraints of the project, 15 subjects were chosen to be a part of the study. There was one group of uninjured athletes with no history of injury, and one group of athletes one to 12 months post injury with no pain. The injury was defined as a lateral ankle sprain; subjects were allowed to have an additional injury history as long as the injury was over a month prior and no longer caused pain or loss of function. Each subject was required to sign an informed consent document (Appendix C) before participation in the data collection process.

Testing instruments

The testing instrument used in the research was the *Matscan®* system provided by Tekscan of Boston, MA, a force-sensing floor mat measuring pressures and forces under the foot (Tekscan)(n.d.). Data were collected at a rate of 40 Hz for four seconds during the dynamic squats, and 32 seconds in a static position. A metronome set in one second intervals was used to time the squats. The *Matscan®* was connected to a Compaq laptop computer installed with *Windows®* software (Tekscan) (n.d.).

An apparatus consisting of two adjustable horizontal bars supported by two vertical bars was placed behind and in front of the subject. The horizontal bars were placed at a height specific to each subjects so that they would touch one bar with the buttocks and the other bar with a point on the lower legs when they flexed their knees to 60°. This device was tested for accuracy using a *Motion Monitor®* system and was found to measure 60° within ±3°.

Procedure

Approval for the study was received from the Institutional Review Board (IRB) before testing began. Subjects were recruited primarily from a Division III collegiate setting. The researcher assigned subjects to groups according to their injury status, injured or uninjured. The injured group had at least one lateral ankle sprain in the past 1-12 months. The uninjured group had no history of lower extremity injury.

The basis of the testing procedures was to perform a squat to 60° of knee flexion in six conditions: 1) double-legged with eyes open; 2) double-legged with eyes closed; 3) single-legged right with eyes open; 4) single-legged right with eyes closed; 5) single-legged left with eyes open; and 6) single-legged left with eyes closed. Knee flexion to 60° was determined by a goniometer operated by the researcher. In this position, the adjustable bar was placed behind the subject so that s/he felt it each time 60° knee flexion was met. Each subject was first instructed by the researcher in how to perform the squat, and was given as much time as needed to practice. Then the subject stood on the *Matscan*® in a foot position that was comfortable for him/her. The feet were traced on the mat to ensure consistency in foot placement if the subject stepped off the mat for any reason.

Each subject performed a total of 18 squats on the *Matscan*® in a counter-balanced order. Three trials of each squat condition were recorded, and the mean of the three trials was used in data analysis. A trial set was defined as all three trials of a particular squat condition.

The subjects were instructed to perform the squats with their hands on their hips, looking at a pre-marked point on the wall at eye-level, and with an upright trunk. Subjects received verbal cues from the researcher as to the timing of the squats, as well as the visual and audio aid of a metronome set at one-second intervals. The researcher gave verbal cues: "ready, set, down, up" in time with the metronome. Data were recorded beginning at "set," as triggered by the researcher. The subject squatted to 60° knee flexion at "down," touched the bar, and returned to an extended knee position at "up." Data were recorded for one additional second; however, the first and last seconds of data were discarded. In this way, the two remaining seconds of data represent the functional squat.

Statistical Analysis

There were three independent variables in this study: injury status (two levels, injured and uninjured, measured independently), eye condition (two levels, eyes open and eyes closed, repeated measures), and foot condition (three levels, double-legged, right-legged, and left-legged, repeated measures). Statistical analyses were performed using *SPSS*® for Windows® version 11.0 was used for all statistical analyses. To assess the translation of center of force, the dependent variables were area, distance, variability, and total displacement. These calculations are further explained in Appendix D.

For the double-legged squat data, five 2 x 2 mixed factorial analyses of variance (ANOVAs) were calculated (injury status x eye condition). For the single-legged squat data, five 2 x 2 mixed factorial ANOVAs were performed (injury status x eye condition). To find whether dominance played a role in postural control, five 2 x 2 (dominance x eye condition) mixed factorial ANOVAs were calculated using the uninjured subject data only. The alpha level was set at .05.

Results

The dependent variables were the area, distance, variability, mediolateral total displacement, and anteroposterior total displacement of the translation of the center of pressure, calculated using the x, y coordinates of the translation. The independent variable was college-aged, physically active individuals who either had a recent lower extremity injury or no history of lower extremity injury. There were two within factors: eye condition (eyes open and eyes closed) and foot condition (double-legged, right-legged, and left-legged).

Descriptive Statistics

A total of 15 recently injured, physically active individuals (mean age = 21.13, ± 1.96 years; mean height = 171.73, ± 8.48 cm; mean weight = 75.78, ± 11.84 kg) and 15 uninjured, physically active individuals (mean age = 21.4, ± 2.67 years; mean height = 164.74, ± 7.29 cm; mean weight = 65.27, ± 10.65 kg) participated in the current study. In the uninjured group, there were 12 females and 3 males who partook in the tests. In the injured group, there were eight females and seven males. Translation of center of pressure during each squat was recorded. The variables area, distance, variability, and total displacement were calculated. The descriptive statistics for each of these variables are presented in Tables 1 - 6.

Severity was rated using the method used by Cornwall and Murrell (1991), which classified a grade 1, 2, or 3 lateral ankle sprain as follows: (1) mild: no formal medical care sought, no immobilization or assistive device; (2) moderate: medical care sought, no immobilization, used assistive device for any length of time; (3) severe: as moderate, with some type of immobilization of the ankle. In the current study, there were seven grade 1 sprains (47%), six grade 2 sprains (40%), and three grade 3 sprains (13%). In the current study, 11 subjects in the injured group had multiple sprains on the limb in question, and nine subjects (60%) had over 5 sprains on the limb in question; two (13%) had over two sprains; and four (27%) had one sprain.

A total of 12 subjects had a history of bilateral sprains, and eight subjects had a history of lower extremity injury other than an ankle sprain in one or both lower limbs. These injuries included a torn meniscus, Achilles tendonitis, MCL sprain, quadriceps strain, sacro-iliac joint sprain, plantar fascitis, and fractured foot bones. Average time since the most recent sprain was 5.07 months, ranging from 1 - 10 months.

Trial Reliability

Three trials of each condition were collected from each subject. Tester reliability was analyzed by calculating intra-class coefficients (ICC) using repeated measures ANOVAs. The results of these analyses are presented in Appendix F, Tables 7 - 36.

The results were analyzed using a 2 x 2 mixed factorial ANOVA (eye condition x injury status). A total of five ANOVAs were computed (area, distance, variability, total displacement mediolateral, and total displacement anteroposterior). The inferential statistics are separated into the following sections: double-leg, single-leg, and dominance.

Double-Legged Squat Data

Subjects performed double-legged squats with eyes open and eyes closed. A total of five dependent variables were measured and will be presented in this section. The section is divided into the following subsections: area; distance; variability; and total displacement. The results of these ANOVAs are presented in Tables 37 - 41 of Appendix F.

Area. No significant (p = .291) interaction was found between injury status and eye condition for area. A significant (p = .002) main effect was identified between eyes open and eyes closed. No significant (p = .103) main effect was found between injured and uninjured individuals.

Distance. No significant (p = .205) interaction was found between injury status and eye condition for distance. A significant (p = .001) main effect was identified between eyes open and eyes closed. No significant (p = .152) main effect was found between injured and uninjured individuals.

Variability. No significant (p = .768) interaction was found between injury status and eye condition for variability. A significant (p = .017) main effect was identified between eyes open and eyes closed. No significant (p = .072) main effect was found between injured and uninjured individuals.

Total Displacement. No significant (p = .734) interaction was found between injury status and eye condition for total displacement in the mediolateral direction. A significant (p = .028;) main effect was identified between eyes open and eyes closed. No significant (p = .287) main effect was found between injured and uninjured individuals.

No significant (p = .456) interaction was found between injury status and eye condition for total displacement in the anteroposterior direction. A significant (p = .007) main effect was identified between eyes open and eyes closed. No significant (p = .074) main effect was found between injured and uninjured individuals.

Single-Legged Data

Subjects also performed single-legged squats with eyes open and eyes closed. In this analysis, the injured leg of the injured group was compared to the dominant leg of the uninjured group; this was due to the non-significant result of an ANOVA comparing dominant and non-dominant legs of the uninjured group. A total of five dependent variables were measured and will be presented in this section. The section is divided into the following subsections: area; distance variability; and total displacement. The results of these ANOVAs are presented in Tables 42 - 46 of Appendix F.

Area. No significant (p = .190) interaction was found between injury status and eye condition for area. A significant (p = .001) main effect was identified between eyes open and eyes closed. No significant (p = .945) main effect was found between injured and uninjured individuals.

Distance. No significant (p = .365) interaction was found between injury status and eye condition for distance. A significant (p = .001) main effect was identified between eyes open and eyes closed. No significant (*p* = .930) main effect was found between injured and uninjured individuals.

Variability. No significant (*p* = .173) interaction between injury status and eye condition for variability. A significant (*p* = .001) main effect was identified between eyes open and eyes closed. No significant (*p* = .968) main effect was found between injured and uninjured individuals.

Total Displacement. No significant (*p* = .255) interaction was found between injury status and eye condition for total displacement in the mediolateral direction. A significant (*p* = .001) main effect was identified between eyes open and eyes closed. No significant (*p* = .001) main effect was found between injured and uninjured individuals.

No significant (*p* = .904) interaction was found between injury status and eye condition for total displacement in the anteroposterior direction. A significant (*p* = .163) main effect was identified between eyes open and eyes closed. No significant (*p* = .354) main effect was found between injured and uninjured individuals.

Dominance

The results of the mixed model ANOVA comparing the dominant to the nondominant leg in the uninjured group are presented in Tables 47 - 51 of Appendix F. For the variable area in the eyes open and eyes closed condition, no significant ($p = .708$; $p = .205$, respectively) mean difference was found between the dominant and non-dominant legs. For the variable distance in the eyes open and eyes closed condition, no significant ($p = .140$; $p = .888$) mean difference was found between the dominant and non-dominant legs. For the variable variability in the eyes open and eyes closed condition, no significant ($p = .402$; p = .242) mean difference was found between the dominant and non-dominant legs. For the variable total displacement in the mediolateral direction in the eyes open and eyes closed condition, no significant ($p = .659$; $p = .093$) mean difference was found between the dominant and non-dominant legs. For the variable total displacement in the antero-posterior direction in the eyes open and eyes closed condition, no significant ($p = .467$; $p = .738$) mean difference was found between the dominant and non-dominant legs.

Discussion

The purpose of the current research was to examine the translation of the center of force during a dynamic motion, a squat, and determine whether a difference exists between a group of recently injured individuals and those who have never sustained a significant lower extremity injury. Squats were performed by all subjects on the right leg, left leg, and on both legs. Each subject performed the squats with his/her eyes open, and then with eyes closed. Translation of center of pressure was collected and the variables area, variability, distance, and total displacement were calculated using the x, y coordinates of this translation.

In all conditions, injured and uninjured results were similar, suggesting that injury did not effect the postural control systems of the body during a dynamic squat maneuver in these subjects. In all conditions, there was a difference in eye condition, with postural sway being greater in the eyes closed condition. It was expected that subjects would have increased postural sway with eyes closed, as several previous researchers have resulted in similar findings (Cornwall & Murrell; Garn & Newton,1988; Forkin et al., 1996; Freeman et al., 1965; Tropp et al., 1984a). However, the results were similar regardless of injury status. Nashner and Peters (1990) stated that when one of the three systems involved in postural control (visual, proprioceptive, and vestibular) is compromised, the other two may compensate. Forkin et al. (1996) found this to be true in their qualitative postural control study. The current study resulted in a different conclusion. When eyes were closed in the uninjured condition (i.e proprioceptive and vestibular systems assumed to be intact), these healthy systems were unable to compensate for the lost visual control. One might wonder if a blind individual would have similar postural control problems; or perhaps the body must learn to compensate for the loss and closing the eyes is too abrupt a loss. Likewise, perhaps the body learns to adapt to a loss in proprioception following a musculoskeletal injury. In the current study, injury occurred an average of 5.07 (±2.85 months) prior to testing. Following subjects through the recovery process of an injury may help to determine when, and if, loss of postural control occurs.

Although the current and other quantitative postural control studies (Tropp et al., 1984a and 1984b) do not support the idea that orthopedic injury necessarily disrupts postural control, this idea persists in the clinical setting (Abfall & Bruce, 1998; Diamond, 1989; Hoffman & Payne, 1995; Houglum, 2001; Irrgang et al., 1994; Milch, 1986). Forkin et al. (1996) gave several explanations regarding the varied results of studies that explore postural control and joint injury. The explanations included whether or not the mechanism of injury was considered, the type of athlete, whether an athlete has had a single or multiple injuries to the joint, and the time of the testing (Forkin et al., 1996).

Possible factors that may have influenced the outcome of this study include the testing procedures themselves. For several subjects, the single-legged squat was particularly difficult; these subjects often required additional trials to obtain three that could be used in analysis. However, for some subjects, the test was easier and a successful trial was recorded on the first attempt. The number of times subjects committed a mistrials was not recorded, but every subject needed to repeat at least one trial, regardless of injury status. Although a one-legged squat may be considered a functional task, even in activities of daily living such as walking up a flight of stairs, self-selected physical activity must be considered. For example, in society of today, many individuals choose to take an elevator rather than climb four flights of stairs. As a result, a one-legged squat may not be such a familiar motor pattern as might be expected.

The physical fitness regimen of a particular individual may have affected his/her ability to perform the tests. In the current study, the type of athlete was not taken into account, as the ambiguity of past activities, current recreational activities, and current competitive activities would be too great to analyze. Perhaps activities that rely on balance, such as skiing or squatting with weights, allow for a subject to perform the tests of the current study with greater ease. Future research should try to identify the activities that a subject does on a regular basis, as well as those s/he has done in the past.

Subjects were not grouped separately according to the severity of their injury; however, this question was included on the preliminary questionnaire. Subjects were intentionally placed in one group because Glencross and Thornton (1981) stated that neither severity of injury nor number of injuries on the same limb had an impact on the outcome of research. However, future research may wish to exclude those injuries that may not sufficiently disrupt the nervous system and result in a detectable loss of postural control.

Further research may find differences in postural control of subjects who are at specific stages of an injury or the recovery of an injury. More extensive questioning may be appropriate, particularly the type and amount of rehabilitation already accomplished. Researchers may also be interested in specifically searching for unilaterally injured individuals in order that this limb may be compared to the uninjured limb. Comparing a healthy limb to an injured limb of the same subject may help provide insight into the initial state of postural control.

From the recently injured group, it was impossible to compare the single-footed data of the injured limb to the single-footed data of the uninjured limb. This would have helped to explore whether there was an underlying postural control problem that predisposed the individual to an ankle sprain. However, 11 of the 15 injured subjects had a history of bilateral injury; thus they did not fit the description of "uninjured" as defined by the researcher. To make this comparison, the injured group would be required to have a unilateral injury. For this reason, this comparison was not made and provides a suggestion for further research.

The relatively low number of subjects in each group may have had an affect on the outcome of the study. Had the sample size matched the power calculation, the outcome of the study may have been different. Increasing sample size would also increase the external validity of the study.

Cornwall and Murrell (1991) found no statistical difference in the postural sway measurements of the dominant versus non-dominant leg of the control (i.e. healthy) group. This finding supports the current research. In the uninjured group, translation of center of pressure of the dominant leg was compared to that of the nondominant leg. The results of the two groups were similar, suggesting that dominance does not play a role in postural control.

The current research failed to identify a significant difference between injured and uninjured physically active individuals. There are several factors that may have contributed to this result, including physical activity level, severity of injury, and the relatively small sample size. The current research is supported by the force platform study by Tropp et al. (1984a & 1984b) that joint injury may not necessarily lead to postural instability as measured by the variable area, distance, variability, and total displacement used in the current research. However, it is contradicted by several researchers (Bernier & Perrin, 1998; Cornwall & Murrell,1991; Forkin, Koczur, Battle, & Newton, 1996; Freeman, Dean, & Hanham, 1965). Further research is recommended wit closer attention to subject history and a larger subject population to better understand the effects of musculoskeletal injury on postural control.

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Appendix A

Research Design

Postrual control is important to the performance of an athlete (Goldie Evan & Bach, 1994; Irrgang, Whitney, & Cox, 1994; Konradsen & Bohsen Ravn, 1991; Lephart, Pincivero, Giraldo, & Fu, 1997; Tropp, Ekstrand, & Gillquist, 1984b). There is evidence that postural control is negatively affected by injury (Forkin, Koczur, Battle, & Newton, 1996; Freeman, Dean, Hanham, 1965; Garn & Newton, 1988) and some evidence that it is not affected at all (Cornwall & Murrell 1991; Tropp, Odenrick, & Gillquist, 1984a & 1984b).

Statement of the Problem

The purpose of the study is to determine whether there is a measurable difference in postural sway and asymmetry scores between injured and uninjured athletes during a dynamic movement with the eyes open and eyes closed.

Definition of Terms

The following definitions will be used within the context of the research study:

Uninjured Athletes

Subjects in the "uninjured athletes" group will be defined as college-aged athletes who have never had a significant lower extremity injury, and who can perform the requirements of the experiment without pain.

Injured Athletes

Subjects in the "injured athletes" group will be defined as those who have sustained an acute ankle injury within the last one to twelve months and who can perform the requirements of the experiment without pain.

Area of Center of Force Translation

Area (A) will be defined as the ground that was covered by the center of force (COF) translation during the static and dynamic movements. The X and Y coordinates of each measurement of COF will be used to determine the radii of the covered ground, whereupon area will be calculated by using the formula for the area of an ellipse ($\pi ab = A$).

Variability of Center of Force Translation

Variability (V) is the variation in distance the COF travels from one x, y coordinate to the next. The variable will be calculated by taking the standard deviation of the distances.

Distance of Center of Force Translation

Distance (D) will be defined as the total linear distance from one point of COF to the next. This will be calculated from one point of COF to the next. This will be calculated using the Pythagorean theorem for determining the length of the hypotenuse of a triangle: ($a^2 + b^2 = c^2$), where c = distance of COF translation, a = height, and b = width.

Total Displacement of Center of Force Translation

Total displacement (TD) of COF will be determined by taking the antero-posterior (AP) maximum and minimum point difference, as well as that of the medio-lateral (ML) maximum and minimum. The formulas that will be used follow: $TD_{AP} = AP_{max} - AP_{min}$; $TD_{ML} = ML_{max} - ML_{min}$.

Dynamic Tests

Dynamic tests are those that require a deliberate movement of the center of force outside the normal base of support (Irrgang et al., 1994). The dynamic tests that will be used in the research will be a one-footed squat and a two-footed squat.

One-footed squat

The one-footed squat will be defined as a squat performed on only one leg (right or left) to 60° of knee flexion according to the weight-bearing leg. The squat will be performed with hands on hips, looking straight ahead, and an upright upper body position.

Two-footed squat

A two-footed squat will be defined as a squat performed on two legs, feet in a natural standing position to 60° of knee flexion. The squat will be performed with hands on hips, looking straight ahead, and an upright upper body position.

Postural Control and Postural Sway

Postural control will be defined as the maintenance of a state of postural equilibrium that is maintained through three sensory systems: oculomotor, vestibular, and proprioceptive (Golomer, Dupui, & Bessou, 1994; Houglum, 2001; Lepers, Bigard, Diard, Gouteyron, & Guezennec, 1997; Nashner & McCollum, 1985). Postural sway will be defined as any deviation of the center of gravity and the resulting attempt of the body to stabilizing it through muscular contractions (Nashner & McCollum, 1985).

Center of Pressure

Center of pressure, according to Thomas and Whitney (1959), is the point from the center of gravity to the ground in a vertical line perpendicular to the ground while no acceleration is occurring.

Center of Force

The term "center of force" refers to the measurement that relates to the center of gravity in acceleration

(Goldie, Bach, & Evans, 1989). This measurement is a more functional one and so will be used in this experiment.

Proprioception

Proprioception was described by Grigg (1994) as the sense of position and movement of the limbs. Sense of position and movement is initiated by afferent neurons (mechanoreceptors) in skin, muscles, tendons, fascia, joint capsules, and ligaments (Grigg, 1994; Lehmkuhl & Smith, 1983). When a joint moves, these afferent (sensory) neurons are deformed, causing an action potential and in turn sending a signal to the central nervous system. The signals give the brain a sense of position, i.e., proprioception (Grigg, 1994).

Delimitations

The research may be delimited by the following factors:

1. The subjects will be college-aged volunteers from a small university in the Northeastern United States.

2. The subjects will all perform the squats using a standard protocol to 60° of knee flexion.

3. The *Matscan*® will be the only hardware used in the experiment.

4. A total of three trials of each movement condition will be performed.

5. Subjects will self-report being pain-free.

6. The calculated dependent variables will be used to reflect overall postural control.

Limitations

The following will be considered during interpretation of the results of the research study:

1. Knee flexion to 60° may not be functional for all types of athletes.

2. Continuous squatting may cause fatigue.

3. Continuous squatting may cause a learning effect in postural control.

4. Center of force translation measurements will be calculated using standard geometric equations.

Hypotheses

1. No significant mean difference in center of force translation will exist between injured and uninjured individuals in the dynamic squat.

2. No significant mean difference in center of force translation will exist between tests with eyes open and tests with eyes closed in the dynamic squat.

3. No significant mean difference in center of force will exist between tests on two legs, right leg, and left leg in the dynamic squat.

4. No significant interaction will exist between injury status and eye condition in the dynamic squat.

5. No significant interaction will exist between injury status and foot condition in the dynamic squat.

6. No significant interaction will exist between eye condition and foot condition in the dynamic squat.

7. No significant mean difference in center of force will exist between injured and uninjured individuals in the static stance.

Appendix B

Review of Literature

Maintaining and improving postural control is a focus of rehabilitative medicine (Abfall & Bruce, 1998; Diamond, 1989; Hoffman & Payne, 1995; Houglum, 2001; Irrgang, Whitney, & Cox, 1994; Milch, 1986). Successful control of posture is a complex combination of several mechanisms that can be grouped into three general systems: oculomotor (the eyes); vestibular (the inner ear organs); and somatosensory (the sensory receptors in ligaments, muscles, and tendons called proprioceptors) (Golomer, Dupui, & Bessou, 1994; Lepers, Bigard, Diard, Gouteyron, & Guezennec, 1997; Nashner & McCollum, 1985). When any one of these mechanisms is inhibited, there is a decrease in postural stability (Lepers et al., 1997; Nashner & McCollum, 1985). However, Nashner and Peters (1990) suggested that two of the systems may compensate for any one system that is disrupted. Fitzpatrick, Rogers, and McCloskey (1994) demonstrated that the somatosensory system may be the most important of the three, as posture has been shown to be controlled even in the absence of visual, vestibular, and cutaneous sensation from the lower extremity. Compensation for any one defective mechanism may especially be important during high-speed activities such as sports, when visual feedback cannot be relied on to orient oneself in the environment due to rapid changes in the environment (Goldie, Evans, & Bach, 1994).

Posture is maintained when the body correctly senses changes in the position of the center of gravity using these visual, vestibular, and somatosensory systems (Horak & Nashner, 1986). The brain sends signals to muscles to contract or relax in an attempt to oppose the movement of the center of gravity, reorienting it to a more stable position. The changes in muscles may be minute and cause small movements in all joints of the body (Thomas & Whitney, 1959), particularly at the ankle and hip (Bernier & Perrin, 1998; Horak & Nashner, 1986; Nashner & McCollum, 1985). Researchers have theorized that injury to the supporting structures of a joint (ligaments and tendons) can reduce the function of proprioceptors (Bernier & Perrin, 1998; Forkin, Koczur, Battle, & Newton, 1996; Freeman, Dean, & Hanham, 1965) and thus disrupt postural control. Decreased control of posture could potentially lead to further injury (Goldie et al., 1994; Lephart et al., 1997; Tropp, Ekstrand, & Gillquist, 1984b), decreased athletic performance, and increased reaction times of muscles associated with the affected proprioceptors (Irrgang et al., 1994; Konradsen & Bohsen Ravn, 1991).

Individuals with a history of joint injury often complain of a functional instability, or the feeling of the joint "giving way", for several months or even years following the initial injury (Bernier & Perrin, 1998; Konradsen & Bohsen Ravn, 1991; Tropp, Odenrick, & Gillquist, 1985). Functional instability has been shown to be directly correlated to an increase in postural sway (Tropp et al., 1985). Individuals with functional instability also may have a higher risk of sustaining an ankle injury than those with adequate stability (Tropp et al., 1984b). Therapists have attempted to find effective methods of reducing re-injury and other lasting consequences of joint trauma for years (Abfall & Bruce, 1998; Diamond, 1989; Hoffman & Payne, 1995; Houglum, 2001; Irrgang et al., 1994; Milch, 1986). There is a need to reduce causes of postural control problems, yet there is not a clear understanding of how this should be done, for how long, and even if it works (Riemann, 2002).

The practice of enhancing proprioceptor response and regaining postural control following injury is a widely accepted rehabilitation protocol (Abfall & Bruce, 1998;

Diamond, 1984; Hoffman & Payne, 1995; Houglum, 2001; Irrgang et al., 1994). Yet, there is conflicting evidence that might justify the need for possibly time-consuming and even costly practices in the clinical setting (Riemann, 2002). There is little to no evidence that rehabilitation of proprioception is effective (Lephart et al., 1997), and the research that surrounds postural control is so varied in terms of methods and subject parameters (such as age, gender, and injury status) that results tend to vary as well (Riemann, 2002). Examples of variations in methods include qualitative (Freeman et al., 1965; Forkin et al., 1996; Riemann, Guskiewicz, & Shields, 1999) versus quantitative tests (Goldie, Bach, and Evans, 1989; Konradsen & Bohsen Ravn, 1991; Tropp, Ekstrand, & Gillquist, 1984a). Subject parameters vary in the interval of time between injury and testing (Bernier & Perrin, 1998; Brunt et al., 1992; Forkin et al., 1996; Tropp et al., 1984a), in the specific injury sustained, and in the specific mechanism of injury (Forkin et al., 1996). All of these factors and more can lead to lack of agreement within the available research (Forkin et al., 1996; Riemann, 2002). Due to the present variations in research design, researchers continue to seek the best conclusion as well as the best methods of assessing postural control.

To better understand the literature surrounding postural control and injury of lower extremity joint structures, this review of the literature will explore: (1) definitions and terms surrounding control of posture; (2) postural control of injured and uninjured individuals; (3) how neurological damage affects postural control; (4) methods of assessment of postural control; (5) subject parameters in postural control research; (6) rehabilitation of postural control; (7) designing a comparative research study; and (8) summary.

Definitions and Terms Surrounding Control of Posture

The section will acquaint the reader with terms commonly found in research pertaining to postural control. Any misuse of terms will be addressed and a pathway will be created for the reader to understand more clearly this review of literature. The section is divided into the following subsections: proprioception vs. balance; joint position sense; center of gravity; center of pressure; center of force; stabilometry; postural sway; and conclusion.

Proprioception vs. Balance

The current literature in postural control is often confusing, as some terms are used interchangeably, such as the use of the terms *proprioception* and *balance*. Ashton-Miller, Wojtys, Huston, and Fry-Welch (2001) attempted to dispel the tendency of clinicians to use the words *balance* and *proprioception* synonymously. They stated that "…the use of the term 'ankle prorioception'…has most often been allowed to include measurement of skill in motor tasks such as balancing, not really true tests of proprioception" (Ashton-Miller et al., 2001, p. 129). Indeed, in a study conducted by Freeman et al. (1965), the term *proprioceptive deficits* was used to indicate the times when a subject had difficulty remaining in a one-legged stance, i.e., had decreased *balancing* capabilities. The reader should note, however, that *proprioception* is just one of the three mechanisms that humans use to maintain *balance* (Golomer et al., 1994; Gutierrez, Helber, Dealva, Ashton-Miller, & Richardson, 2001; Lepers et al., 1997; Nashner & McCollum, 1985); therefore, the two are clearly not synonyms. As a result of the long-standing misuse of terms, the attempt of humans to maintain an upright posture will be hereby referred to in this review of literature and resulting research study as *postural control*. Any loss of postural control will be referred to as simply *loss of postural control*.

Proprioception was described by Grigg (1994) as the sense of position and movement of the limbs. Sense of position and movement is initiated by afferent neurons (mechanoreceptors) in skin, muscles, tendons, fascia, joint capsules, and ligaments (Grigg, 1994; Lehmkuhl & Smith, 1983). When a joint moves, these afferent (sensory) neurons are deformed, causing an action potential and in turn sending a signal to the central nervous system. The signals give the brain a sense of position, i.e., proprioception (Grigg, 1994). Proprioception is sometimes termed "kinesthesia". Lehmkuhl and Smith (1983), however, pointed out that it is important to remember that the terms are not synonyms. While kinesthesia refers to awareness of position of limbs and the body in motion (Garn & Newton, 1988; Lemkuhl & Smith, 1983), proprioception is awareness of limbs and the body in static position (Lehmkuhl & Smith, 1983).

Two proprioceptors that have been purported to contribute to postural control are muscle spindles and Golgi tendon organs, found in muscles and tendons, respectively (Edin & Vallbo, 1988; Fitzpatrick et al., 1994;

Lehmkuhl & Smith, 1983). Fitzpatrick et al. (1994) conducted a study that successfully eliminated other systems used in control of posture (visual, vestibular, and somatosenses of the lower extremity), and found that subjects were still able to maintain control well above the point where a loss of postural stability or a stumble might occur. They attributed this to proprioceptors in the lower extremity, particularly muscle spindles and Golgi tendon organs (Fitzpatrick et al., 1994).

The muscle spindle is an afferent receptor found in a muscle that is sensitive to that muscle being stretched (Burke & Eklund, 1977; Edin & Vallbo, 1988). The muscle spindle sends a signal to the brain, which triggers a "sway-stabilizing reflex contraction" (Burke & Eklund, 1977, p. 187) of the muscle within which it is contained (Burke & Eklund, 1977).

The Golgi tendon organ is connected to 10 to 15 muscle fibers, which stimulate the receptor when tension is produced by the bundle of fibers (Lehmkuhl & Smith, 1983). The receptor then sends signals back to the central nervous system, which in turn excites inhibitory interneurons. The chain reaction that ensues causes a muscle force to be limited as the motor neuron is inhibited (Lehmkuhl & Smith, 1983).

Joint Position Sense

Joint position sense is one component of proprioception, and is one that can be measured in order to assess proprioception (Bernier & Perrin, 1998). Joint position sense is, in essence, exactly that – the ability of an individual to sense, or be aware of, the position of a joint (Lemkuhl & Smith, 1983). Joint position sense is important in a discussion of postural control because it is related to the function of proprioceptors as well. Glencross and Thornton (1981) stated that "if the total number of [proprioceptors] is reduced through injury, then fewer cells are available for activation when terminal joint positions are reached, resulting in increased degree of error in joint position sense" (p. 26). If the position of a joint cannot be sensed by an individual, especially at an extreme degree, compensation by musculoskeletal structures cannot be activated, and loss of postural control, a possible fall, and further injury are imminent (Richardson & Ashton-Miller, 1996).

Center of Gravity

Center of gravity was defined by Kendall, McCreary, and Provance (1993) as a given point at which the weight of the body is considered to be concentrated. Kendall et al. (1993) stated that at this point, if one applied a single, vertical force that is equal in magnitude to the weight of the body, the body will remain in equilibrium. This point will vary according to the position of the body in question; however, in the "ideally aligned posture" (Kendall et al., 1993, p. 12) of an average adult, the center of gravity would be slightly anterior to the first or second sacral vertebra (Kendall et al., 1993). That is, as a human sways in response to postural disturbances, the center of gravity will also slightly shift.

Center of Pressure

The center of pressure is the point from the center of gravity of the body to the ground in a vertical line perpendicular to the ground while no acceleration is occurring (Spaepen, Vranken, & Willems, 1977; Thomas & Whitney, 1959). The center of pressure has also been called the line of gravity (Kendall et al., 1993). Goldie et al. (1989) stated that while the displacement of the center of pressure itself is not directly proportionate to that of the center of gravity, the mean position of the center of pressure accurately reflects the mean position of the vertical projection of the center of gravity of the body. Thus, the center of pressure is a valid measure of postural control (Goldie et al., 1989).

Center of force

Center of force, according to Goldie et al. (1989), is the measurement that relates to the center of gravity in acceleration. In other words, the center of force is a more functional measurement. The center of force will be the measurement of choice in the dynamic test of this experiment.

Stabilometry

Stabilometry is a quantitative method of measuring the center of pressure of an individual during particular postures (Cornwall & Murrell, 1991; Tropp et al., 1984b). When an individual moves, his/her center of gravity and thus pressure moves as well (Kendall et al., 1993). The movement of the center of pressure is measured and is represented by x, y coordinates (Cornwall & Murrell, 1991; Tropp et al., 1984b). Stabilometry is typically performed using a force platform (Bernier & Perrin, 1998; Bhattacharya, Succop, Kincl, & Bagchee, 2002/2003; Cornwall

& Murrell, 1991; Hoffman & Payne, 1995; Riemann et al., 1999; Tropp et al., 1984a & 1984b). In this experiment, the *Matscan®* will measure the center of pressure

Postural Sway

Postural sway (Nashner & McCollum, 1985) is any deviation of the center of gravity and the resulting attempt of the body to stabilize it through muscular contractions. The postural sway of an individual is inversely related to his/her postural control (Cornwall & Murrell, 1991). That is, the greater the postural sway, the worse the postural control.

All of these terms relate to postural control in some way. The following is how all the defined terms interact. Postural control is regulated by muscle length variations (Nashner & McCollum, 1985) and changes in the center of gravity (Horak & Nashner, 1986). When a change is sensed by the vestibular system and proprioception, which can be quantified by measuring joint position sense, the body adjusts for the resulting change in center of gravity by activating antagonistic and synergistic muscles and thus maintaining postural control (Nashner & McCollum, 1985). The changes in muscle length result in movements that occur at every joint in the body (Thomas & Whitney, 1959), especially at the ankle and hip during weight-bearing, with minimal involvement of the knee (Bernier & Perrin, 1998; Horak & Nashner, 1986; Nashner & McCollum, 1985). Stabilometry is an effective method of measuring center of pressure, which can be translated into values of postural sway (Goldie et al., 1989). Postural sway indicates the degree of postural control one has (Cornwall & Murrell, 1991).

Postural Control of Injured And Uninjured Individuals

Exercises designed to improve postural control are widely included in the protocols of rehabilitation of musculoskeletal injury (Abfall & Bruce, 1998; Diamond, 1989; Hoffman & Payne, 1995; Houglum, 2001; Irrgang et al., 1994; Milch, 1986). A common belief is that injured individuals will have a loss of postural control to some degree. However, there is much conflicting qualitative and quantitative evidence on the subject (Goldie et al., 1994). The section will review the existing literature on postural control; studies on injured and healthy subjects will be included, as well as athletes and non-athletes.

Injured vs. Uninjured

Research in postural control that involves injured subjects most often uses subjects who have sustained an ankle injury, whether it is an acute injury or a chronic functional instability (Bernier & Perrin, 1998; Cornwall & Murrell, 1991; Forkin et al., 1996; Freeman et al., 1965; Garn & Newton, 1988; Konradsen & Bohsen Ravn, 1991; Tropp et al., 1984a; Tropp et al., 1985). The frequent use of subjects with ankle injuries by researchers is due to the high incidence of ankle injuries in athletics (Garrick, 1977) and the important role of the ankle in postural stability (Bernier & Perrin, 1998; Horak & Nashner, 1986; Nashner & McCollum, 1985). Therefore, much of the research presented here will deal with individuals who have sustained a lateral ankle injury.

Konradsen and Bohsen Ravn (1991) conducted a study to determine the relationship between functional instability of the ankle and peroneal muscle reaction time when exposed to sudden ankle inversion. The correlation between reaction time, functional instability, and postural sway was also examined. Peroneal reaction time was measured using surface electrodes on the peroneal muscles. Subjects stood on two feet with one foot on a trapdoor that periodically caused the ankle to invert and the peroneals to react and protect the ankle. Postural sway was measured according to the amplitude of variation of the center of pressure on a force plate during a single limb stance. The average position of the center of pressure for each 60-second trial was calculated and used for data. Thirty athletes, all with functional instability in a least one ankle and without joint laxity, were used in the study (Konradsen & Bohsen Ravn, 1991).

In subjects with functionally stable ankles, the median sway of center of pressure was 5.4mm (Konradsen & Bohsen Ravn, 1991). In the unstable ankle group, the median sway was 6.8mm. The researchers found that sway was highly correlated with peroneal reaction time (Spearman's rho = .92). As time increased, sway increased. The investigators suggested that stability during a single leg stance is at least in part dependant on the ability of the peroneals to react effectively to stresses (Konradsen & Bohsen Ravn, 1991). The conclusions of Konradsen and Bohsen Ravn (1991) support the theory that afferent nerve fibers are damaged in ligamentous injuries (Freeman et al., 1965), which may in turn have an affect of increased postural sway.

Tropp et al. (1984a) attempted to determine whether an acute ankle sprain had a significant negative effect on stabilometry readings. Subjects were 25 male soccer players (17-34 years old) who were tested as soon as pain, swelling, and decreased range of motion were gone. The tests were done one to three weeks post injury. Values of the injured limb were compared to the uninjured limb during a single-legged stance. Postural sway was measured with a force plate. Coordinates in an X, Y plane were used to calculate a confidence ellipse, representing total sway amplitude in mm^2. Subjects stood on the force plate with arms crossed at the chest and the non-weight-bearing leg flexed at the knee for 60 s for each trial. There was a two-min rest period between each trial. The tests were done in a darkened room to exclude distracting visual stimuli, and a light five meters away from the subject was used as a fixation point for subjects (Tropp et al., 1984a).

No significant difference was found between the stabilometric readings of the injured versus uninjured legs (Tropp et al., 1984a). The researchers speculated that this lack of increased postural sway, which is contrary to the current belief that postural control *is* decreased by injury, was due to the length of time after injury. They suggested that previous results showing increased postural sway were influenced by secondary muscle atrophy and loss of coordination, perhaps due to a much longer interval between time of injury and time of testing (Tropp et al., 1984a).

However, Forkin et al. (1996) offered a different explanation of their results. These researchers pointed to the fact that Tropp et al. (1984a) did not exclude visual feedback in any of their trials. In fact, they even provided a focal point for the subjects (Tropp et al., 1984a). According to Nashner and Peters (1990), when one sensory mechanism of balance is disrupted, the other two may compensate. So, in the study produced by Tropp et al. (1984a), the underlying proprioceptive deficit could have been compensated for by the vestibular and oculomotor systems. Cornwall and Murrell (1991) also questioned the validity of the dependent variables in this study, stating that the area that the center of pressure traverses is not a sensitive enough measure of postural stability. In the current study, area of the center of pressure will be calculated along with several other variables. A comparison of the variables will help determine whether the suggestion of Cornwall and Murrell is correct.

The same researchers (Tropp et al., 1984b) conducted another study, this time with two intentions: to determine whether there is increased postural sway after ankle injuries; and whether a decrease in postural control results in an increased risk of ankle injuries in athletes.

A control group of 30 males (21-35 years old), described as normally active, were tested. None of this group had a history of functional instability of either ankle and no history of injury to either lower extremity. The test group consisted of 180 soccer players from a senior soccer division (17-38 years old). The soccer players were examined for persistent signs and symptoms of old ankle injuries. Tropp et al. (1984b) defined an old injury as one having occurred while playing sports and resulted in the subject either seeking medical advice or missing practices or games. The length of time from the injury to the time of testing was not mentioned. All subjects were tested in the same manner as in Tropp et al., 1984a). Again, no control for visual compensation was included, and a confidence ellipse was calculated from x,y coordinates on the force plate. The soccer players were followed throughout 1980, and all ankle injuries were examined by the same orthopaedic surgeon (Tropp et al., 1984b).

One hundred twenty-seven of the test group were re-examined after the season (Tropp et al., 1984b). The rest were excluded due to recent severe injury or insufficient participation on the soccer team. There was no statistically significant difference between decreased postural stability and history of ankle injury. However, there was a significant increase in ankle injury occurrence if postural control was increased at the beginning of the study. Of the 71 players who had no history of injury, those with original pathologic stabilometry values sustained more ankle injuries than those with normal stabilometric values. Of the 57 normal players, only five (9%) suffered an ankle injury. Of the 14 pathological results, eight (57%) ($p < 0.001$) were injured by the end of the season. The researchers suggested that individuals with abnormal stabilometry values may also have an abnormal way of controlling posture (Tropp et al., 1984b).

Forkin et al. (1996) attempted to determine if collegiate level gymnasts with multiple lateral ankle sprains had a decrease in maintenance of postural control and reduced proprioception on their injured versus uninjured side. Subjects were 11 high school and collegiate gymnasts (two male and nine female) with a history of more than one lateral ankle sprain one to 12 months previously with no pain or edema at the time of testing (Forkin et al., 1996). Due to difficulty in finding subjects with unilateral sprains as originally planned, gymnasts with a contralateral ankle sprain over two years old (Forkin et al., 1996).

Proprioception was measured by placing the foot of each subject in five degrees of plantar flexion or no movement at all (Forkin et al., 1996). A curtain was placed so that the subject could not see his/her own ankle. The subject was asked to state whether or not s/he felt that the ankle was moved.

The test for postural control was subjective and involved the subjects themselves in judging on which side they felt it was easier to maintain their posture (Forkin et al., 1996). Two observers, who were blinded as to which ankle was injured, judged the postural control of the subjects. The criteria for judging postural control were (1) the number of times the non-weight-bearing foot touched the ground, and (2) the amount of upper body motion required to maintain an upright stance. Upper body motion was specifically determined by how often flexion or extension of the trunk was used, and the position of the arms (low or high guard). Subjects stood for 30 s on one leg and then 30 s on the other, first with eyes open and secondly with eyes closed (Forkin et al., 1996).

In the proprioception tests, subjects detected slight movements of the ankle statistically more consistently on the uninjured ankle than on the injured ankle (Forkin et al., 1996). In the postural control tests, 63% (seven of 11) of the subjects had a deficit in postural control while standing on the injured limb with the eyes closed, as reported by both of the observers. In contrast, only 36% (four of 11) and 45% (five of 11) of the same subjects had this deficit when the eyes were open, as reported by the first and second observers, respectively (Forkin et al., 1996). Along with a small subject group, the researchers realized that the study is limited due to the use of only gymnasts and the fact that the mechanism of injury was not taken into account. However, the researchers concluded that there was a trend toward a decrease in postural control when eyes are closed. The theory of Nashner and Peters (1990) that while one system is not functioning properly, the other two may compensate is supported by the finding by Forkin et al. (1996).

Forkin et al. (1996) gave several explanations regarding the varied results of other studies that explore postural control and joint injury. The explanations included whether or not the mechanism of injury was considered, the type of athlete, whether an athlete has had a single or multiple injuries to the joint, and the time of the testing. Forkin et al. (1996) also mention that perhaps gymnasts are especially able to compensate for the sensory deficits due to the nature of their sport. For example, not only do they routinely rely on the visual and vestibular contributions to postural control, but they also effectively rely on other body segments to orient themselves in space. The researchers (Forkin et al., 1996) concluded that a sensory malfunction at one joint has the ability to affect the postural control of the entire body. Because of these conclusions, in the current study, trials will be performed once with the eyes closed, and once with the eyes open.

Freeman et al. (1965) conducted a study intended to (1) determine the presence or absence of a loss of postural control following injury and (2) determine the most appropriate treatment for regaining a stable joint. Treatment methods of this study will be discussed in a later section. Subjects recruited were 85 patients who were zero to three days post injury, and had a foot or ankle sprain with the possibility of a fracture ruled out by x-ray. Of these 85 patients, only approximately 35 were tested for postural deviations in the initial testing period due to the fact that the remaining patients still had significant pain, in completing the test, decreased range of motion, and/or abnormal calf muscle power. The researchers (Freeman et al., 1965) stated that these factors would cause the test to be invalid. The test consisted of a modified Romberg's test (Freeman et al., 1965): subjects stood on the uninjured foot with the eyes open, then with the eyes closed, each for an unspecified amount of time. The procedure was then repeated standing on the injured foot. An examiner observed the testing, blinded to which limb was injured. Of the patients in the preliminary test, approximately 60% (51 out of 85) objectively (as noted by the examiner) or subjectively (as reported by the subject) had decreased postural control. The results are different from those of the study of Tropp et al. (1984a), who tested patients one to three weeks post injury. While Tropp et al. (1984a) did not find significant differences in the postural control of injured limbs versus the uninjured limbs, Freeman et al. (1965) did. Both groups of authors controlled for pain and decreased range of motion; only the study of Freeman et al. (1965) controlled for visual compensation.

Garn and Newton (1988) attempted to replicate the study of Freeman et al. (1965). Active men (*n* = 24) and women (*n* = 6) from a naval academy participated in the study if they had one injured lower limb and one uninjured lower limb. The injured limb requirement consisted of having a history of two or more lateral ankle sprains, the most recent incident being one to 60 months before testing. Subjects were excluded if they had any pain or swelling, and if an injury occurred in the last 30 days (Garn & Newton, 1988).

Subjects stood on the injured leg for 30 s, then on the uninjured for the same time (Garn & Newton, 1988). The test was done once with the eyes open, and again with the eyes closed. Postural control was rated subjectively by the subject him/herself as well as by an objective, blinded observer. The criteria used by the observer to judge postural control were (1) the number of times the subject required the touch-down of the non-weight-bearing foot to steady him/herself, and (2) the amount of upper extremity and trunk movement required to maintain postural control with both criterion being comparative of the injured foot to the uninjured foot (Garn & Newton, 1988).

For the subjective tests, 43% (13 out of 30) of the subjects perceived their postural control to be worse when on the injured side, 23% (seven out of 30) when on the uninjured side, and 33% (ten out of 30) felt no difference (Garn & Newton, 1988). The objective observers rated 53% of the subjects to have decreased postural control on the injured side, 23% worse on the uninjured side, and for the rest, no difference was found. The authors of this study concluded that their results showed a high incidence of increased postural sway while standing on the injured leg as opposed to the uninjured (Garn & Newton, 1988).

In an effort to pinpoint the exact effect of inversion ankle sprains on postural control, Cornwall and Murrell (1991) designed a stabilometry study. The experimental group was screened to exclude volunteers who had a history of bilateral ankle sprains, those unilateral sprains occurring over two years prior to time of testing, and any other musculoskeletal or neurological conditions that might affect standing postural sway. The resulting control group consisted of 20 individuals, 12 male and eight female, with a mean age of 24.90 (5.06 yrs). The mean time of injury prior to testing was 12.35 (2.09 months). Subjects were questioned as to the severity of their injuries, and were rated as follows: (1) mild: no formal medical care sought, no immobilization or assistive device; (2) moderate: medical care sought, no immobilization, used assistive device for any length of time; (3) severe: as moderate, with some type of immobilization of the ankle (Cornwall & Murrell, 1991).

The control group consisted of 30 individuals (eight male, 22 female) with no history of ankle sprains. The mean age of this group was 22.63 (SD = 3.14 years old) (Cornwall & Murrell, 1991). The two groups were different with respect to height and weight. However, when the authors analyzed the effects of these two factors, it was determined that height and weight would not have a significant effect on the outcome of the study because of a low correlation with the dependent variables ($r < 0.25$) (Cornwall & Murrell, 1991).

All subjects performed a one-legged stance on a force platform on each leg, once with eyes open, and once with eyes closed, in a random order while data were recorded for 12.8 seconds (Cornwall & Murrell, 1991). From the resulting center of pressure coordinates, linear distance (mm) traveled in both mediolateral and anteroposterior directions were calculated. The mean power frequencies of postural sway in both of these directions were calculated using an algorithm (Cornwall & Murrell, 1991).

Analysis of variance tests showed that postural sway amplitude was significantly greater in the experimental group than in the control group (Cornwall & Murrell, 1991). There was no significant difference in the direction (mediolateral versus anteroposterior) of sway for the injured subjects. With eyes closed, postural sway significantly increased regardless of the injury condition. The researchers concluded that inversion ankle sprains do indeed alter postural control, even those injuries up to two years old. They raised the question and suggested further research on whether the increase in postural sway is due to increased joint laxity or to damaged nerve fibers within the joint capsule and ligaments (Cornwall & Murrell, 1991).

Variance in Research

From this discussion, it is clear that conflicting evidence exists in regard to whether a musculoskeletal injury necessarily leads to postural control deficits and/or loss of proprioception. Interestingly, one of the two quantitative research studies presented here that intended to compare injured and uninjured individuals

(Tropp et al., 1984a) resulted in a lack of evidence that postural sway is increased due to injury. Unfortunately, the experimental methods of Tropp et al. (1984a) are limited due to the fact that visual compensation was not controlled for (Forkin et al, 1996). Every qualitative comparison between injured and uninjured, however, displayed a significant difference in postural sway, with the injured groups having the greater sway (Forkin et al., 1996; Freeman et al., 1965; Garn & Newton, 1988). Even though quantitative research is generally accepted as more accurate than qualitative (Friden, Zatterstrom, Lindstrand, & Moritz, 1989; Jansen, Larsen, & Olesen, 1982; Nashner & Peters, 1990), the notion that postural control is negatively affected by injury prevails. Quantitative, reliable research is needed that directly compares postural control of injured persons to uninjured.

As it can also be seen from this discussion, and as Irrgang et al. (1994) stated, research studies often do not include data on normal, healthy subjects to which pathological results can be compared. Because of this, the current study will be conducted using both injured and uninjured subjects.

Research in stabilometry is often conducted with the subject in a one-legged stance (Cornwall & Murrell, 1991; Forkin et al., 1996; Freeman et al., 1965; Garn & Newton, 1988; Hoffman & Payne, 1995; Tropp et al., 1984a; Tropp et al., 1984b; Tropp et al., 1985). While this adequately assesses postural control in a static condition, it is not indicative of a functional task, especially in sports activities, when injuries are likely to occur. Attempts should be made to improve the generalizability of the postural control research by including a dynamic movement in stabilometry studies.

How Neurological Damage Affects Postural Control

The somatosensory system plays a large role in balance (Golomer et al., 1994; Lepers et al., 1997; Nashner & McCollum, 1985), and some have even said that it is the most important system in postural stability (Fitzpatrick et al., 1994; Gutierrez et al., 2001). Since this system involves afferent and efferent nerves, or those that deliver messages to and from the central nervous system, respectively, it follows that any disruption, including diseases such as stroke, Parkinson's disease, and dementia (Van den Bosch, Gilsing, Lee, Richardson, & Ashton-Miller,

1995) of the neurological system would affect postural control (Richardson & Ashton-Miller, 1996).

Peripheral Neuropathy

One such neurological condition is peripheral neuropathy (Richardson & Ashton-Miller, 1996). Peripheral neuropathy is characterized by the loss of sensation and motor function in the distal extremities due to nerve damage (Richardson & Ashton-Miller, 1996). The condition is most often caused over time by diabetes mellitus, but can also result from alcohol abuse, chronic obstructive pulmonary disease, renal disease, or vitamin B_{12} deficiency, among others (Richardson & Ashton-Miller, 1996).

Van den Bosch et al. (1995) had subjects stand in an apparatus that put the ankle into inversion, eversion, or neutral. The experimental group ($n = 7$) were those diagnosed with peripheral neuropathy, and the control group had no neurological deficits. Subjects were asked to indicate when and if they felt the ankle being moved in either direction. The investigators found that the controls were able to detect movement in inversion and eversion as little as 0.3° from neutral. The researchers did not report the measurement error of the apparatus. Thus, it is difficult to identify the clinical significance of 0.3°. In contrast, the experimental group were, as a whole, not able to detect movement until 1.4° from neutral. Richardson and Ashton-Miller (1996) surmised that this amount of decreased proprioception at the ankle, an important joint in postural control (Bernier & Perrin, 1998; Fitzpatrick et al., 1994; Horak & Nashner, 1986; Nashner & McCollum, 1985; Thomas & Whitney, 1959), would cause the center of gravity, being approximately one meter above the foot, of the patient, who is in a unipedal stance to exceed 2.3 cm before s/he even perceived it (Richardson & Ashton-Miller, 1996). The distance, being a significant fraction of the width of the foot of the patient, is one that can cause the center of gravity to move dangerously close to the edge of the base of support without the awareness of the patient (Richardson & Ashton-Miller, 1996). The movement of the center of gravity may result in a fall or, at the least, a stumble. Peripheral neuropathy patients also have been found to rely heavily on vision to compensate for somatosensory deficits. The authors pointed to peripheral neuropathy as a significant yet overlooked cause of falls in the elderly (Richardson & Ashton-Miller, 1996).

Joint Injuries

Neurological damage clearly can lead to deficits in postural control. Not only can systemic disease lead to neurological damage, but also localized injury such as a sprain or strain of the structures surrounding a joint. Nitz, Dobner, and Kersey (1985) held that nerve damage in athletic injuries may be more prevalent than previously thought. The researchers found that the peroneal, tibial, and posterior tibial nerves were damaged in some ankle sprains when a lateral ankle sprain was combined with a deltoid (medial) complex injury. Freeman et al. (1965) argued that since the nerve fibers in ligaments and capsules actually have a lower tensile strength than the soft tissues that contain them, it follows that an injury to a ligament or capsule would also lead to injury of its nerve fibers. The researchers also stated that these nerves probably do not regenerate. The resultant decrease in functioning afferent and efferent nerves leads to lasting instability of that joint (Freeman et al., 1965). Since joints of the lower extremity, especially the ankle and the hip, largely contribute to postural control (Bernier & Perrin, 1998; Horak & Nashner, 1986; Nashner & McCollum, 1985), it follows that injuries to these joints will lead to a decrease in postural control.

Methods of Assessment of Postural Control

Postural control is actually measured by assessing postural sway and inversely relating it to how well the combined oculomotor, vestibular, and somatosensory systems are functioning to maintain a posture (Lephart et al., 1997). For example, an increased postural sway would indicate a decreased postural control. There are several ways of measuring postural sway, and they can generally be divided into two categories: quantitative and qualitative measurements (Riemann et al., 1999). Both methods have advantages and disadvantages. The main disadvantage of qualitative measures is that of decreased reliability (Friden et al., 1989; Jansen et al., 1982; Nashner & Peters, 1990), and the main limitation of quantitative is that of the cost of equipment (Riemann et al., 1999).

Qualitative tests often rely on complete loss of balance and/or a gross compensatory movement, such as the touch-down of a foot that is detected and recorded by an observer (Jansen et al., 1982). For this reason, qualitative tests are often criticized for their insensitivity to unobservable postural sway that can only be analyzed by objective, or quantitative tests (Cornwall & Murrell, 1991; Jansen et al., 1982; Nashner & Peters, 1990). Forceplates have been shown to be reliable and valid in their measurements of balance (Goldie et al., 1989; Goldie, Evans, & Bach, 1992). The section is divided into the following two subsections: qualitative; quantitative.

Qualitative

Riemann et al. (1999) have shown that there is a correlation between the subjective Balance Error Scoring System (BESS) and objective force platform measurements. The BESS is a method of scoring postural control in which subjects are given an error point for committing each of the following errors: lifting hands off the iliac crests; opening the eyes, stepping, stumbling, or falling; remaining out of the test position for more than five seconds; moving the hip into more than 30° of flexion or abduction; and/or lifting the forefoot or heel. The researchers found a high intertester reliability rate (.78- .96) when single-leg and tandem stances were performed on a firm surface, and all stances on a foam surface. They concluded that the subjective BESS method of postural control measurement and the object force platform are comparable forms of assessing postural control and that they are both accurate and reliable (Riemann et al., 1999).

Freeman et al. (1965) conducted their assessment of postural control using the subjective modified Romberg's test. Subjects were to stand on the uninjured foot first with eyes open, then with eyes closed. The sequence was then repeated on the injured foot, provided that the test did not cause pain. An examiner, blinded as to which foot was injured, judged on which side postural control was better. The subject her/himself also reported on which limb s/he felt more stable (Freeman et al., 1965).

Quantitative

Force platforms are a widely accepted way of quantitatively (objectively) measuring postural control (Bhattacharya et al., 2002/2003; Ekdahl, Jarnlo, & Andersson, 1989; Goldie et al., 1989; Tropp et al., 1984a & 1984b). Goldie et al. (1989) explained that this is accomplished by measuring the vertical ground reaction force and computing the center of pressure by measuring force at three or more points on the force platform or by measuring torque around the horizontal axes. Goldie et al. (1989) conducted a reliability and validity study to determine how accurate force platforms are in measuring balance and postural sway. They named two measuring units that can be used from a force plate: center of pressure (COP) and center of force, both expressed in x,y coordinates in the two horizontal axes of a force platform. Center of pressure was defined in the work of Thomas and Whitney (1959) as the point from the center of gravity of an individual to the ground in a vertical line perpendicular to the ground while no acceleration is occurring. Force, as stated by Goldie et al. (1989), is the measurement that relates to the center of gravity in acceleration.

Two purposes of the study of Goldie et al. (1989) was to explore the correlations between the force and center of pressure measures of postural steadiness, and to determine the sensitivity of force and center of pressure measurements in detecting even minute changes in posture. The researchers showed that there was a poor correlation ($r < .31$) between force and COP measurements. The researchers suggested that "either the measures are evaluating different aspects of postural control, or that the measures contain proportionately different amounts of random error, or that the relationship between the two measures is nonlinear" (Goldie et al., 1989, p. 515). The research presented in this review of literature concerning forceplate measurements are all reported as "center of pressure" (Cornwall & Murrell, 1991; Tropp et al., 1984a; Tropp et al., 1984b). The current study will by conducted using a *Matscan*®, which collects data and reports it as center of force (Tekscan, n.d.).

Bernier and Perrin (1998) recommended that when measuring postural sway, several measures should be considered, such as center of balance (COB), COB distance, modified equilibrium score, and maximum sway in both the anteroposterior direction and the mediolateral direction. Tropp et al. (1984a) also calculated the area (A) of postural sway using a confidence ellipse formula and x,y coordinates from a force plate.

Bhattacharya et al. (2002/2003) measured postural sway in laborers using a force platform and calculated four variables from the movement of the center of pressure (COP) of the body. The variables were named and defined as (1) sway area: the area of the projection of the COP on the horizontal (x,y) plane; (2) sway length: the distance traveled by the COP; (3) mediolateral (ML) (x) excursion, calculated as the net deviation of the COP in the ML direction; and (4) anteroposterior (AP) (y) excursion

(Bhattacharya et al., 2002/2003). Ekdahl et al. (1989) argued that measuring the length (i.e. distance of the sway path of the center of pressure is more accurate than measuring the area. The researchers stated that a large amount of sway may occur within a restricted area; a calculation of the area may not be an adequate description of how far the center of pressure has traveled (Ekdahl et al., 1989).

Irrgang et al. (1994) warned against attempting to use static postural control tests to predict how well one will do with a dynamic test. They stated, "static and dynamic tests appear to examine different aspects of the complex 'balance system'" (p. 74). Postural control should be tested in a way that is functional to the individual (Goldie et al., 1989; Irrgang et al., 1994; Richie, 2001). Few researchers, however, have followed this advice.

Ekdahl et al. (1989) and Bhattacharya et al. (2002/2003) are two groups of researchers that have tested individuals for functional balance. Ekdahl et al. (1989) attempted to determine whether age and gender had a significant effect on measurements of postural sway. They utilized 152 subjects who had no self-reported problems maintaining standing postural control. The functional tests consisted of walking as fast as possible for 30 meters, standing on each leg for 30 s with the eyes closed and open, and a coordination test: simultaneous flexion of one arm and the opposite leg as fast as possible for 15 s. Results were based on how fast a subject could walk the 30 meters, how long the single leg stance could be maintained, and how many arm/leg flexion rotations could be accomplished in 15 seconds. While the specific results of the study are not particularly relevant here, the use of every-day activities as functional postural control tests is rare and notable. One result from the study by Ekdahl et al. (1989) that is important to the current research is that as age increased, particularly past 50 years of age, there was a significant difference in the ability to perform the tasks of blindfolded one-legged stance and the walking test. No significant difference was found between genders (Ekdahl et al., 1989). The limit of college-age athletes will control for any age effects in the current research. Both age and gender will be recorded.

Bhattacharya et al. (2002/2003) incorporated functionally appropriate tasks in their study as well. The researchers attempted to determine whether variables common in a labor setting (elevation, inclination, poor lighting, and noise distraction) would increase postural sway. While the specific results of the study are not particularly relevant to this review, it should be noted that three different functional tasks were performed while postural sway data was being recorded on a force plate: bending to the point that the upper trunk touched the knees, standing stationary with the hands on the hips for 30 seconds, and reaching to pick up a weight and put it on a shelf. In general, results showed that postural control was poorer in the reach task than bending, as well as in bending compared with standing still (Bhattacharya et al., 2002/2003). The researchers concluded that it is apparent that functional testing may be important in postural control research. If postural control is progressively worse in healthy individuals according to the difficulty of the task, it follows that an injured individual may have deficits that, while undetectable in a static (stationary) condition, are evident in a dynamic (functional) condition. The idea that postural control is more difficult during a functional task becomes especially important when dealing with athletes, where functional tasks are often difficult and are those that cause injury.

As already mentioned, force plate systems can be rather expensive (Riemann et al., 1999). They may not be practical for most clinical situations. Fortunately, there is another option for quantitative analysis that is less expensive and much more portable. The instrument is the *Matscan®* system developed by Tekscan of Boston, MA. The system consists of a force-sensing floor mat designed to lie on a flat surface. The device measures pressures and forces under the foot; force is represented by an x,y coordinate. Data is collected at a rate of 40 Hz. The size of the *Matscan®* is 432mm x 368mm (17″ x 14.5″), and each cell has a pressure range of one to 150 PSI (Tekscan, n.d.). The *Matscan®* is connected to a laptop computer installed with *Windows®* software (Tekscan, n.d.).

There are several ways to interpret the data. Five of these are in finding the area, distance, variability, total displacement, and asymmetry scores. The five variables will be described in detail below.

Area is defined as the ground that was covered by the center of force (COF) translation and is calculated using the formula for the area of an ellipse (Bernier & Perrin, 1998. Area was used in several studies already mentioned, (Bernier & Perrin, 1998; Cornwall & Murrell, 1991; Tropp et al., 1984a; Tropp et al., 1984b).

Distance is defined as the total linear distance from one point of COF to the next. This is calculated using the Pythagorean theorem for determining the length of the hypotenuse of a triangle.

Variability is the variation in distance the COF travels from on X,Y coordinate to the next. It is calculated by taking the standard deviation of the distances.

Total displacement (TD) of COF is determined by taking the antero-posterior (AP) maximum and minimum point difference, as well as that of the medio-lateral (ML) maximum and minimum point difference. Cornwall and Murrell (1991) used a similar variable.

Force plate systems can be expensive (Riemann et al., 1999) and complex. For this reason, sports and rehabilitative programs may not have access to them and may rely on less accurate, qualitative measures to assess postural control. The qualitative assessment tools (Romberg's test, BESS) however, are not sensitive to minute yet significant defects in postural control (Cornwall & Murrell, 1991; Jansen et al., 1982; Nashner & Peters, 1990).

Research has shown postural deficits in individuals with injuries as much as 60 months old (Garn & Newton, 1988), which could contribute to re-injury (Goldie et al., 1994; Lephart et al., 1997) and/or decreased athletic performance (Irrgang et al., 1994; Konradsen & Bohsen Ravn, 1991). If these lasting postural control problems are detected early in the clinical setting, rehabilitation may begin and time lost to injury and future injury may be decreased. Less expensive, quantitative means of assessing postural control needs to become available to rehabilitation clinics.

Subject Parameters in Postural Control Research

Subjects in any type of research must be clearly defined. The main characteristic in research involved with balance that must be noted is whether the subject is injured or uninjured. Next, if the subject is injured, the specific injury should be noted as well. Timing of the testing should also be mentioned. The interval between time of injury and time of testing is potentially very important to the outcome of the study. Yet another subject parameter is how many times the individual may have experienced the injury in question. Choices of previous researchers in postural control will be discussed here.

Injured vs. Uninjured

As previously mentioned, postural control research is done with healthy subjects (Hoffman & Payne, 1995; Riemann et al., 1999), injured subjects (Bernier & Perrin, 1998; Forkin et al., 1996; Freeman et al., 1965; Konradsen & Bohsen Ravn, 1991; Tropp et al., 1984a; Tropp et al, 1984b; Tropp et al., 1985), or both (Brunt et al., 1992; Cornwall & Murrell, 1991; Garn & Newton, 1988). Most researchers that have studied balance with injured subjects, including all the researchers listed above, have dealt with individuals with lateral ankle sprains, either acute (Freeman et al., 1965; Tropp et al., 1984a) or chronically unstable (Bernier & Perrin, 1998; Forkin et al., 1996). The reason for this is most likely that for athletes, the lateral ligament complex of the ankle is the most frequently injured structure in the body (Garrick, 1977). Since balance is maintained at least in part by movements of the joints of the lower extremity, including, of course, the ankle joint (Bernier & Perrin, 1998; Fitzpatrick et al., 1994; Horak & Nashner, 1986; Nashner & McCollum, 1985; Thomas & Whitney, 1959), it is therefore appropriate and clinically applicable to choose subjects with ankle injuries in the study of postural control as it pertains to injured athletes.

Interval Between Injury and Testing

Much less consistent across the current research than the injury of subjects is the interval between the time of injury and the time of the research testing (Bernier & Perrin, 1998; Brunt et al, 1992; Cornwall & Murrell, 1991; Forkin et al., 1996; Freeman et al.,1965; Garn & Newton, 1988; Riemann et al., 1999; Tropp et al., 1984a). Brunt et al. (1992) used ankle-sprain patients whose injuries were less than 12 months old. Tropp et al. (1984a) used injured subjects with sprains greater than three months old and found no proprioceptive defects. Another study by the same authors Tropp et al. (1984a) included subjects who were tested as soon as their pain, swelling, and decreased range of motion had subsided, which resulted in a range of one to three weeks. The researchers in the study of Tropp et al. (1984a) produced no significant difference in postural control measures between healthy and unhealthy limbs of the same subject. Forkin et al. (1996) found that 63% of the participants in their study had decreased postural control on the injured side. They used multiple ankle-sprain patients whose sprains occurred from one to 12 months prior to testing. Bernier and Perrin (1998) conducted their study with patients selected on the criteria that they had greater than or equal to two lateral ankle sprains in the 12 months prior to testing. Garn and Newton (1988) used subjects with a history of two or more lateral ankle sprains, ranging from two to 20 sprains with a mean of 5.7 (± 4.3) sprains. The most recent sprain occurred from one to 60 months [*M* = 7.8 (± 12.2)] prior to testing. Freeman et al. (1965) utilized subjects who had foot or ankle sprains from zero to three days old. Pain and decreased range of motion was controlled for, as well as was visual feedback as a compensatory mechanism. Of the 35 patients who could be tested, 60% of these had a noticeable decrease in postural control in a modified Romberg's test on the injured leg (Freeman et al., 1965). Cornwall and Murrell (1991) included injured subjects with an ankle sprain occurring up to two years prior to testing, with a mean time elapsed of 12.35 months (SD = 2.09). They found a significant increase in postural sway on the injured ankles as compared to the uninjured control group.

Riemann et al. (1999) used healthy subjects who had no musculoskeletal injuries within the past six months for their forceplate reliability study. The stipulation of the healthy subject of the Garn and Newton (1988) research was that there was no history of neuromuscular or neurological damage. Cornwall and Murrell (1991) used healthy subjects in their control group; these individuals simply had no history of ankle sprains. Hoffman and Payne (1995) excluded subjects if they had any history of lower extremity injury, or if their initial postural sway measurement indicated any sort of underlying postural control disorder. In their control group, Tropp et al. (1984b) included only subjects with no history of functional instability of either ankle and no history of injury to either lower extremity.

Research in postural control that is conducted with injured subjects varies in the time of testing compared to time of injury (Bernier & Perrin, 1998; Brunt et al, 1992; Cornwall & Murrell, 1991; Forkin et al., 1996; Freeman et al.,1965; Garn & Newton, 1988; Riemann et al., 1999; Tropp et al., 1984a). Currently, there seems to be no speculation as to what stage of injury an individual will experience increased postural sway; how many injuries have occurred; how severe injuries may have been; what stage of injury an individual will, or should, regain adequate postural control if at all; or at what stage of injury one should be tested. The shortest allowed time presented here was zero to three days after injury (Freeman et al., 1965); the longest was 60 months (Garn & Newton, 1988). Both groups of researchers found similar results: a high incidence of postural control deficits with a history of injury. In sharp contrast, Tropp et al. (1984a) used subjects one week following injury and found no such deficits. Confounding factors, such as mechanism of injury and details of the study must be taken into account.

Number of Injuries

Research also varies widely in terms of the number of ankle sprains sustained (Bernier & Perrin, 1998; Cornwall & Murrell, 1991; Forkin et al., 1996; Freeman et al., 1965; Garn & Newton, 1988; Konradsen & Bohsen Ravn, 1991; Tropp et al., 1984a.). The research presented here ranges from one ankle sprain (Cornwall & Murrell, 1991; Freeman et al., 1965; Konradsen & Bohsen Ravn, 1991; Tropp et al., 1984a) to multiple ankle sprains (Bernier & Perrin, 1998; Forkin et al., 1996; Garn & Newton, 1988). All of these authors with the exception of Tropp et al. (1984a) found a significant increase in the postural sway of injured individuals compared with uninjured individuals, regardless of how many injuries subjects had sustained. Tropp et al. (1984a), it should be remembered, did not control for visual system compensation. Perhaps it is not the number of injuries a subject has had, but rather the methods chosen by the researcher. As a result of this conclusion, subjects in the current research will not be excluded based on frequency of injury, and visual compensation will be controlled for. However, the information will be included in subject questionnaire.

Research is needed in this area to determine the point at which an individual might experience losses in postural control. The current study will be conducted with injured subjects having sustained a lateral ankle injury one to 12 months prior to testing, based on the significant findings of Forkin et al. (1996) as long as the subjects have no pain, swelling, or loss of range of motion in the injured ankle. Healthy subjects will have no history of known neuromuscular damage, based on the findings of Garn and Newton (1988), who found a significant decrease in postural control in subjects with injuries up to 60 months old.

Rehabilitation of Postural Control

General rehabilitation protocols follow the three-step pattern of re-establishing (1) range of motion and flexibility, (2) muscular strength and endurance, and (3) postural control and proprioception (Houglum, 2001). The protocols are widely accepted in the clinical setting to attempt to regain proprioception in an effort to return a patient to activities of daily living as well as to an athletic setting, and many recommendations for exercises exist (Abfall & Bruce, 1998; Diamond, 1989; Hoffman & Payne, 1995; Houglum, 2001; Irrgang et al., 1994; Milch, 1986). In spite of the conflicting research concerning the necessity and efficacy for such exercises, these practices persist.

One group of authors (Ashton-Miller et al., 2001) questioned whether proprioception can actually be improved in either a healthy individual or an injured individual. They suggested that any increase in performance is probably in fact due simply to refined motor function as a result of exercise rather than improved function of muscle spindles or Golgi tendon organs. Ashton-Miller et al. (2001) and several other groups of authors have said that even if the proprioceptive system itself *could* be improved, it is probably impossible to prevent injury this way, as the window of time needed for a protective musculoskeletal reaction is too short in an instance of sudden joint displacement (Ashton-Miller et al., 2001; Konradsen & Bohsen Ravn, 1991; Konradsen, Voigt, & Hojsgaard, 1997). The following section will review the literature as it pertains to the need for postural control rehabilitation and its functional effects on patients.

Necessity of Rehabilitation

Konradsen et al. (1997) conducted an experiment to determine the role of the peroneal muscles in an ankle inversion stress situation and to measure the electromechanical delay in the peroneal muscles. The electromechanical delay was defined as the time from the beginning of electrical activity (as measured by electromyograph (EMG)) from the peroneal muscles to the beginning of a subtalar eversion movement; that is, one that would protect the lateral ankle structures.

Ten subjects (23-36 years old) who had no history of severe ankle injury were tested (Konradsen et al., 1997). They stood on a trap door that was able to tilt to 30 degrees. Surface electrodes were attached over the muscle bodies of the peroneus longus, the peroneus brevis, the rectus femoris, and the biceps femoris. Electromechanical delay was measured by placing the foot of the subject in a position of 30°. On a given signal, the subject was instructed to contract the peroneal muscles. EMG activity was recorded from the time signals exceeded 10% of the peak background noise, thus eliminating background noise as a confounding factor (Konradsen et al., 1997).

The researchers discovered that the electromechanical delay in these healthy subjects was approximately 54 msec (Konradsen et al., 1997). Combined with the reaction time between the start of the inversion to the start of muscle activity and the time it takes to generate substantial peroneal tendon tension to perform a protective mechanism, the reaction would occur 126 msec after the start of the inversion. The subtalar joint reached 30° of inversion in 80 msec. The researchers reported that an inversion of 40° can cause damage to the lateral ligaments, and that this could occur in 100 msec. If an athlete is walking or running, the ankle would reach this angle even faster. When compared to the 126 msec needed for a protective peroneal muscle reaction, it is clear that the feedback reaction is too slow to prevent injury (Konradsen et al., 1997).

Treatment Programs

As briefly mentioned, Bernier and Perrin (1998) investigated whether ankle joint position sense in subjects with chronic ankle instability could be improved through six weeks of training. Postural sway was measured under static (standing on a stable platform) and dynamic (standing on a tilting platform) conditions with eyes open and with eyes closed. A force plate was used to assess postural stability. Subjects assumed a single-legged stance with the non-weight-bearing leg flexed at the knee and the arms crossed over their chests. Two trials were conducted in each test condition. Test conditions consisted of the single-legged stance on a stable platform with eyes open and closed, and the same stance on a tilting (inversion and eversion) platform with eyes open and closed (Bernier & Perrin, 1998). Postural stability was calculated by finding "sway index", and modified equilibrium score (MES). Sway index was defined as the standard deviation of the distance the subject spent away from his/her center of balance, or the point where a person is in equilibrium. Modified equilibrium score was defined as a measure of the actual anteroposterior or mediolateral sway in relation to the theoretical limits of stability, in this case, the maximum sway possible in a given direction as determined by the force plate manufacturer (Bernier & Perrin, 1998).

Joint position sense was assessed using an isokinetic dynamometer (Bernier & Perrin, 1998). The foot of the subject was placed on the dynamometer in the neutral position. The ankle of the subject was then passively moved into seven different test positions. When each test position was achieved, the ankle was moved in the opposite direction to the end range of motion. At this point, the ankle was once again passively moved into the original test position; when the subject felt that the test position had been reached, the subject was instructed to contract the antagonistic muscles. The muscle contraction resulted in a recording of a force curve, which was translated into degrees of error for each test position (Bernier & Perrin, 1998).

Subjects were 48 males and females, ages 18-32 with a self-reported history of functional instability (FI) (Bernier & Perrin, 1998). FI was defined by Bernier and Perrin (1998) as one or more significant lateral ankle sprains that caused the subject to be non-weight-bearing, and was followed by a repeat injury and/or feeling of instability or giving way. The subjects had at least two episodes of this instability in the 12 months prior to testing (Bernier & Perrin, 1998).

The researchers concluded that there was a significant effect of the six-week rehabilitative training on equilibrium scores of postural control, but not in sway index or joint position sense at the ankle (Bernier &

Perrin, 1998). The investigators suggested that this could be due to the possibility that ten minutes per day, three day per week for six weeks is simply not enough to cause changes in peripheral afferents involved in proprioception, or that the exercises needed to be more specific to the tasks required for testing (Bernier & Perrin, 1998).

Goldie et al., (1994) also found that postural control training was beneficial in controlling postural sway in subjects with a lateral ankle sprain. The researchers hypothesized that subjects who had sustained an inversion ankle sprain and participated in specific "[postural control] training" exercises would have less postural sway than those who did not participate in these training activities. Goldie et al. (1994) collected 48 injured subjects, one-half of whom were trained and one-half of whom were untrained. The criteria for these subjects were as follows: (1) being two to 24 months post injury; (2) having already resumed full activity; (3) having a mechanism of injury that had been a weight-bearing inversion of the ankle; (4) having had pain for at least 24 hours over the lateral aspect of the ankle; (5) weight-bearing must have been impaired for at least 24 hours; (6) the injury must have caused the individual to seek medical attention; and (7) external support must have been applied to the ankle following the injury (Goldie et al., 1994).

The training of the subjects in this group varied greatly, ranging in treatment sessions from two to 140 sessions (Goldie et al., 1994). The investigators reported that 83% of the trained subjects attended at least ten sessions. All of the subjects performed some type of one-footed balance exercise, and most were trained using a "rocker board," described as a circular board mounted on a hemisphere with the round surface in contact with the floor. Some of the untrained subjects did participate in rehabilitation for the injured ankle, but none of these programs included specific balance exercises (Goldie et al., 1994).

The testing procedure for this study was similar to one developed in a previous study by the same authors (Goldie et al., 1992). All subjects performed a single-legged stance with their hands on their hips in four conditions: (1) uninjured leg, eyes open; (2) uninjured leg, eyes closed; (3) injured leg, eyes open; (4) injured leg, eyes closed. Subjects completed four consecutive five-second trials of the same condition; between conditions, subjects rested in a chair for one minute. The examiners stated that the opportunity to practice the test over the four trials would improve retest reliability. Subjects were informed that the purpose of the study was to stand as still as possible. A target was placed at eye level five meters away from the subject for visual orientation. If the subject lost postural control and touched the ground with the non-weight-bearing foot, the trial was included in the data as long as the touchdown occurred within the boundaries of the force plate. If the touchdown occurred outside these boundaries, the trial was labeled a mistrial. The trial was not repeated, as the researchers felt that this would introduce a learning bias. Rather, the worst scores for the subject were repeated in place of the mistrial and the mean of the resulting four trials was used in the final analysis (Goldie et al., 1994).

Of the several findings of the researchers (Goldie et al., 1994), four are important in this discussion. Overall, postural control deteriorated significantly ($p < .05$) with eye closure. In the trained subjects, there was no significant difference between the injured and uninjured legs in either the eyes open or eyes closed conditions. In the untrained subjects, however, postural sway was significantly increased on the injured leg in both the eyes open and eyes closed conditions. For the untrained subjects, the difference between the injured and uninjured legs in the eyes closed condition was not significantly greater than the difference between the two legs in the eyes closed condition. The authors (Goldie et al., 1994) concluded from these findings that the trained/untrained variable was the most important of the variables in this study, and that balance training improves postural control following lateral ankle sprains.

Goldie et al. (1994) speculated about causes of increased postural sway following ankle injuries; they suggested a combination of factors, including muscle atrophy, since postural sway in the eyes closed condition was no more increased in the injured limbs versus the uninjured limbs. The theory agrees with that of Tropp et al. (1984a), who, as already discussed, conducted their stabilometry study with relatively new injuries (one to three weeks old). Tropp et al. (1984a) conjectured that their own findings of no significant difference in postural sway of healthy limbs were due to the fact that muscle atrophy had not yet set in the injured limbs.

Freeman et al. (1965), as mentioned in an earlier section, conducted a study with 85 original patients. Only approximately 35 were tested for postural control deficits, but all were randomly placed into one of three treatment groups. The first group consisted of 21 subjects who were immobilized in a walking cast for three weeks. Following cast removal, subjects wore a compression bandage with no other treatment. The second group of 32 subjects received an average of three to four treatments of ice, compression bandages, resistive range of motion and stabilization exercises, and walking re-education. The third group, with 31 subjects, received the same treatment as group two as well as an average of five treatments of exercises designed to develop coordination of calf muscles. The coordination of the calf muscles consisted of exercises on a flat board with a block on the bottom that was curved in one plane, creating a see-saw, much like the rocker board used in the study of Goldie et al. (1994). Subjects were required to stand with one foot on this board so that the edges of the board did not touch the floor. When this became easy for the subjects to do, the board was replaced with one that had a half-sphere on the bottom. The same requirements were made for this piece of equipment as the see-saw board. The researchers (Freeman et al., 1965) held that this exercise was functional because it simulated walking on uneven surfaces by creating the same passive displacements of the foot to which the calf muscles must adapt. While all patients found it harder to balance on the injured foot, all improved in performance with treatment; and once the task was learned, the ability to perform it was retained (Freeman et al., 1965). Indeed, this mirrors the concept of motor learning that the performance of a practiced skill should improve over time (Magill, 1989).

Only 46 subjects in the study by Freeman et al. (1965) were tested six to 14 months after the initial assessment, and an additional ten completed a questionnaire sent through the postal service 12-13 months following the initial assessment. The low re-test rate of the subjects was a shortcoming of the study as admitted by the authors (Freeman et al., 1965). None of these subjects had a mechanically unstable ankle as clinically measured with a talar tilt test. The same modified Romberg's test was used at the follow-up visit (Freeman et al., 1965).

Of treatment group number three, which performed calf-coordination exercises, only seven percent (one patient) complained of the foot having a tendency to give way (Freeman et al., 1965). In the other two groups, 46% (12 patients) reported this. The researchers concluded that coordination exercises significantly ($p = 0.0088$) decreased the incidence of functional instability. Of the 31 patients who regained full range of motion, 42% (13 patients) had decreased postural control as assessed by Romberg's test. Of these 13, two subjects (15% of the 13; 6% of the 31) were treated with coordination exercises. Coordination exercises were found to significantly ($p = 0.0132$) decrease the incidence of a lasting loss of postural control as measured by the same Romberg's test. There was a statistically significant ($p = 0.0013$) association between the presence of a clinically detectable loss of postural control and the subject reporting functional instability in subjects who had no previous history of foot or ankle injury and who had regained full range of motion at the time of re-test. The investigators attributed the increased postural control to the calf muscle coordination exercises (Freeman et al., 1965). While this is a logical conclusion, it must not be overlooked that group number three had an average of five treatments in addition to those of group number two. As Bernier and Perrin (1998) stated in their study, perhaps the duration of the treatment is the important factor. As Ashton-Miller et al. (2001) may have commented, perhaps the motor function of the muscles that affect ankle joint position was significantly improved by the simple fact that five extra treatments were implemented, and not necessarily the specific exercises performed.

In a slightly different study, Hoffman and Payne (1995) recruited all healthy subjects to determine whether a training program designed to increase proprioception can decrease postural sway. Their total sample size was 28 with a mean age of 16.4 (± 1.1). Volunteers for the study were screened and excluded if they had any reported history of lower extremity injury, or if their initial postural sway measurement indicated any sort of postural control disorder, the limits of which were unspecified by the researchers. The subjects were randomly placed in either the control or experimental group; each group numbered 14 (Hoffman & Payne, 1995).

Leg dominance of each of the subjects was determined by a series of functional tests, and this leg was used throughout the course of testing and training (Hoffman & Payne, 1995). For the pre-test, each subject stood barefooted in a one-legged stance on the dominant leg on a Kistler force platform with the opposite leg in a position of subject preference. Hand/arm placement was not specified, and there was a visual focal point three meters in front of the subject. Data was recorded for 26 s, the first and last three s of which were discarded to decrease the sampling error (Hoffman & Payne, 1995).

The training of the experimental group was ten weeks long, each section lasting approximately ten min, three times per week (Hoffman & Payne, 1995). The Biomechanical Ankle Platform System (BAPS) was used. Each subject started on the lowest of five weight-bearing progressions and moved to a higher level once the task could be performed without upper body stabilization for 20 s. After ten weeks of training, both the experiment and control groups were retested on the force platform (Hoffman & Payne, 1995).

Postural sway was calculated by finding the standard deviation of x and y coordinates, which was termed *sway variability* (Hoffman & Payne, 1995). The sway variability of each trial was averaged to find the mean sway variability for x and y for each subject. The values of pre-test and post-test were compared: a positive score indicated an improvement in postural control; a negative score indicated a decrease in postural control. A single factor ANOVA was used to determine the significance of the findings between the experimental and control groups (Hoffman & Payne, 1995).

The results of the ANOVA indicated a significant difference between the groups (X parameter, $p = 0.033$; Y parameter, $p = 0.019$). Hoffman and Payne (1995) concluded that their training program did indeed decrease postural sway in healthy subjects. They suggested that proprioceptive training may be an important injury prevention tool that should be implemented in physical training programs (Hoffman & Payne, 1995). They did point out, however, that more research needs to be done on this topic with healthy subjects. They acknowledged that factors such as age, height, gender, and weight may be important in control of postural sway because of the position of the center of gravity of the subject (Hoffman & Payne, 1995). Also, there seems to be at present no long-term studies that indicate an actual decrease in injury occurrence with a training program such as this.

Several studies have shown that postural control is negatively affected by joint injury (Cornwall & Murrell, 1991; Forkin et al., 1996; Freeman et al., 1965; Garn & Newton, 1988). Decreased postural control may result in further injury (Goldie et al., 1994; Lephart et al., 1997; Tropp et al., 1984b), and decreased athletic performance (Irrgang et al., 1994; Konradsen & Bohsen Ravn, 1991).

Rehabilitation of postural control is generally accepted as necessary (Abfall & Bruce, 1998; Diamond, 1989; Hoffman & Payne, 1995), and several researchers have recommended that rehabilitation of an athlete be specific to the functional activities of the respective sport (Abfall & Bruce, 1998; Freeman et al., 1965; Garn & Newton, 1988; Irrgang et al., 1994). Yet, as is apparent from this discussion, there is little evidence that such rehabilitation is effective in preventing re-injury. More research is needed to determine if current rehabilitative exercises are effective in producing long-term, preventative effects.

Designing a Comparative Research Study

Throughout this review of literature on postural control, several comments and suggestions have been made in regards to future research. The section will review these comments that will be relevant to a research study attempting to compare the postural control of injured versus uninjured athletes in a static and dynamic test. Procedures that will be used in the current research will be indicated, and any ideas that will be included in the research design that have not already been discussed in this review will be discussed here.

Subject Parameters

Comparing an injured subject to him/herself in terms of postural sway may be as important as comparing an injured subject with an uninjured control group. The uninjured limb of a subject can be compared to the injured limb to determine a baseline for that subject (Goldie et al., 1994). Tropp et al. (1985), pointed out that a pre-existing postural control deficit may already exist in the injured subjects, which theoretically could have led the individual to sprain the ankle in the first place. The data of the subjects in this research who are injured will be analyzed to compare the uninjured leg to the injured leg, as well as the uninjured leg to the uninjured, control group.

Studies that have included injured subjects have stipulated that the injury be anywhere from one week (Tropp et al., 1984a) to 60 months old (Garn & Newton, 1988). Those that used healthy subjects generally held that these individuals could have no history of injury to the lower extremity and no neurological diseases that might disrupt postural control (Cornwall & Murrell, 1991; Garn & Newton, 1988; Hoffman & Payne, 1995; Riemann et al., 1999; Tropp et al., 1984b). In the current study, injured subjects will be one to 12 months post injury, as long as pain, decreased range of motion, and swelling are gone. Uninjured subjects will have no history of injury to the lower extremity for which they sought medical advice.

Ekdahl et al. (1989) found postural sway to be influenced by age; there was a significant gender difference only in the force platform tests. Postural control was worse in older individuals, especially those over 50 years old; women showed significantly better postural control than men. Height, weight, and leisure activities had no effect on sway results (Ekdahl et al., 1989). In the current research, subjects will not be screened according to age or gender in the interest of acquiring a larger sample size. However, the information will be collected and considered when interpreting the results. By limiting subjects to college-age, no subjects older than 35 years will be tested.

Glencross and Thornton (1981) found that subjects were significantly worse in replicating joint positions as the severity of their injury also increased. The decreased joint position sense occurred, however, only at extreme positions, namely 140º and 130º. Joint angles of 120º and 105º showed no difference in joint position sense according to the severity of the injury (Glencross & Thornton, 1981). Because no joint angles will be extreme in the present study, subjects will not be selected according to their injury severity. Severity, however, will be noted in subject history forms. As in the study of Cornwall and Murrell (1991), severity will be rated as follows: (1) mild: no formal medical care sought, no immobilization, or assistive device; (2) moderate: medical care sought, no immobilization, used assistive device for any length of time; (3) severe: as moderate, with some type of immobilization of the ankle.

Testing Procedures

While Tropp et al. (1984a & 1984b) found no significant difference between the postural sway of injured versus uninjured individuals, Freeman et al. (1965) did. Tropp et al. (1984a & 1984b) conducted a quantitative study using a force plate; Freeman et al. (1965) conducted a qualitative study using a modified Romberg's test. While a quantitative study is typically more accurate (Friden et al., 1989; Jansen et al., 1982; Nashner & Peters, 1990), it must be remembered that Tropp et al. (1984a) did not control for compensation of postural control by the visual system. Freeman et al. (1965) found that postural sway was significantly greater with eyes closed than with eyes open for all subjects, and significantly greater for injured subjects versus uninjured subjects. For this reason, all three trials of each condition in the current study will be performed with eyes open, and with eyes closed. For the eyes open trials, a target will be placed at eye level approximately five meters away from the subject to provide visual orientation (Goldie et al., 1994).

As mentioned in an earlier section, few studies have included a dynamic or functional movement in the assessment of postural control. Rather, it is common for tests to be done in a one-legged static stance (Ekdahl et al., 1989; Forkin et al., 1996; Freeman et al., 1965; Garn & Newton, 1988; Hoffman & Payne, 1995; Tropp et al., 1984a; Tropp et al., 1984b). A few groups of researchers have included a functional postural control test (Bhattacharya et al., 2002/2003; Ekdahl et al., 1989). Ekdahl et al. (1989), however, used a qualitative assessment tool that may not be a precise or sensitive measurement of postural control. Bhattacharya et al. (2002/2003) tested subjects in a very specific functional test that, while quite applicable to the group being studied, may not be relevant to other populations. A two-legged and one-legged squat will be performed to 60 degrees, which is functional in that one needs 60 degrees of knee flexion for normal gait on level ground (Rancho Los Amigos Hospital, 1989).

Standing on one leg with no visual orientation available has been shown to be difficult (Ekdahl et al., 1989). Riemann et al. (1999) said that the degree to which a person can perform a given postural control task will provide valuable insight into his or her postural stability. Therefore, during this test of the study, the length of time the subject remains in the stance will be recorded and normalized by time.

A mistrial will be defined as by Goldie et al. (1994). If a subject falls, steps off the mat, or touches the non-weight-bearing foot to the mat, the trial will be labeled a mistrial. Goldie et al. (1994) chose not to repeat these trials, as a learning bias may be introduced. Instead, the worst scores were repeated (i.e. used twice) in place of the mistrial and the mean was calculated from the resulting trials. Instead of taking the worst trial, in the current study, three trials will be taken and the single best trial (i.e. the one with the longest time) will be normalized by time. The reasoning behind this decision is that the worst trial may in fact be zero to very few seconds in the given stance.

Smith (1953) stated that standing for long periods of time in the same position is unnatural. Burke and Eklund (1977) stated that they found standing in the same position to be arduous for their subjects, and so in their study, subjects sat periodically. Several other researchers incorporated a rest period into their testing procedures (Bhattacharya et al., 2002/2003; Goldie et al., 1992; Tropp et al., 1984a & 1984b). As it seems this is a procedure accepted among researchers to reduce effects of fatigue, a rest period will be incorporated into the current research. After every two trial sets, there will be a one minute rest period during which subjects will sit in a chair.

Independent and Dependent Variables

Goldie et al. (1989) focused on three aspects of postural control: steadiness, symmetry, and dynamic stability. Steadiness was defined by these authors as the degree to which an individual could keep the body motionless. Symmetry was defined as the degree to which a subject could keep weight evenly distributed between the two feet in an upright stance. Dynamic stability was defined as the ability of a subject to transfer the vertical projection of the center of gravity around the base of support (Goldie et al., 1989). These variables were calculated from x, y coordinates produced by a force plate.

In their study, Cornwall and Murrell (1991) determined that there was no statistical difference in the postural sway measurements of the dominant versus non-dominant leg of the control (i.e. healthy) group. For this reason, leg dominance will not be a variable in this study. As leg dominance cannot be positively ruled out as a factor, however, dominance will be noted in subject history.

In conclusion, this study will address the differences in postural control of injured versus uninjured athletes in a static and dynamic movement. There will be one independent variable in this study: injury status, with two levels: injured and uninjured. There will be two within factors: foot condition (two-legged, right-legged, and left-legged), and eye condition (eyes open and eyes closed). Two mixed model analyses of variance (ANOVAs) will be calculated, one with static data, and one with dynamic data.

There will be six dependent variables that will be used to interpret the data of the translation of the center of force. They will be calculated using the x, y coordinates from the Tekscan. The variables are the area of the translation, the distance it travels, the variability in the distances it travels between two coördinates, its total displacement mediolaterally and anteroposteriorly, and asymmetry scores, or the degree to which the center of force sways from being between the right and left feet.

It is the attempt of this study to create an accurate (i.e. quantitative) screening tool that will identify potential postural control deficits. This review of literature has revealed that some researchers have found altered methods of controlling posture in patients with injuries over a year old (Forkin et al., 1996). If this finding can be considered a truth, it is possible that these patients will benefit from therapeutic intervention in the area of postural control. It is the belief of the researcher that this study will help develop a cost-effective method of assessing postural control and determine the most accurate variable to interpret the data.

Summary

Postural control is important to athletes for purposes of safety and for level of performance (Goldie et al., 1994; Irrgang et al., 1994; Konradsen & Bohsen Ravn, 1991; Lephart et al., 1997; Tropp et al., 1984b). Postural control may be affected by injury to musculoskeletal structures (Bernier & Perrin, 1998; Cornwall & Murrell, 1991; Forkin et al., 1996; Freeman et al., 1965; Garn & Newton, 1988). However, most of the research that assesses postural control of injured individuals is qualitative (Forkin et al., 1996; Freeman et al., 1965; Garn & Newton, 1988); these authors have found a significant difference in postural control of injured versus uninjured subjects. The results of the quantitative studies presented in this review (Tropp et al., 1984a & 1984b; Cornwall & Murrell, 1991) contradict one another, as in the review by Riemann (2002). The two studies of Tropp et al. (1984a & 1984b) indicated no significant difference between injured and uninjured individuals, whereas Cornwall & Murrell (1991) did find that injured subjects had significantly worse postural control. The conflicting results have been attributed to the specific methods used by Tropp et al. (1984a & 1984b), namely that the effect of visual compensation was not controlled for (Forkin et al., 1996).

While improving postural control is a recognized focus of rehabilitation of musculoskeletal injury (Abfall & Bruce, 1998; Diamond, 1989; Hoffman & Payne, 1995; Houglum, 2001; Irrgang et al., 1994; Milch, 1986), some have questioned that this can be done (Ashton-Miller et al., 2001). No research was found that might suggest that current rehabilitation protocols intending to improve postural control actually help prevent injury. Further quantitative research is needed in the field of comparing injured individuals with uninjured, and in long-term effects of rehabilitation aimed at improving postural control.

The current study will help develop a quick and easy method of assessing postural control, possible even to be used as a screening tool in preventative medicine. The method used will be relatively inexpensive and supply reliable, quantitative data.

Appendix C

INFORMED CONSENT

AGREEMENT TO PARTICIPATE IN

POSTURAL CONTROL OF INJURED ATHLETES VERSUS UNINJURED ATHLETES IN A DYNAMIC MOVEMENT AND STATIC STANCE

Miranda Osgood
Department of Health and Human Performance
Plymouth State University
Plymouth, NH
03264
mjosgood@mail.plymouth.edu

Purpose: The purpose of this research is to identify whether there are changes in postural control (i.e. balance) in an athlete with a history of a sprained ankle versus an athlete with no history of lower extremity injury when the athlete either stands still or squats.

Description: You will be asked to perform 18 squats, 6 on two legs, 6 on your right leg, and 6 on your left leg. You will also be asked to stand still for 30 seconds 18 times, again 6 on two legs, 6 on your right, and 6 on your left. You will rest in a nearby chair for one minute after each set (set = 3 squats and 3 static stance trials). The testing session will take approximately 45 minutes.

Procedures: After filling out a questionnaire regarding your injury history, you will be instructed to stand on the *Matscan*®, a thin pressure-sensing mat that has an on-line connection to a computer, in a self-selected, comfortable position, and the investigator will trace your feet on the mat for reference. You will then be asked to perform a squat during which the investigator will measure with a large protractor (goniometer) your knee bending (flexion) to a certain point. This point will be similar to sitting in a chair.

You will stand with your hands on your hips and be asked to do three trials of each of the following in an order that will vary per subject.

1. Standing quietly on two feet (static stance)
    a. Three 30 second intervals with eyes open
    b. Three 30 second intervals with eyes closed
2. Two-footed squat
    a. Three repetitions with eyes open
    b. Three repetitions with eyes closed

3. One-footed squat on both right and left sides
    a. Three repetitions with eyes open
    b. Three repetitions with eyes closed
4. Standing quietly on one foot (static stance), on both the right and left sides
    a. Three 30 second intervals with eyes open
    b. Three 30 second intervals with eyes closed

There will be a metronome (a pendulum-type device that keeps time by ticking) to help time the squats, and the investigator will give you verbal cues as well.

Risks: A risk exists for previously injured subjects only if that injury has not yet healed, as soreness may result from standing for a long period of time. In order to reduce this risk, subjects who have complaints of pain or who have not returned to normal daily activities will be excluded. No subjects will be tested less than one month following time of initial injury. This restriction will prevent the risk of re-injury during the testing procedures.

Benefits: Good postural control may help improve your performance in athletics as good control of posture leads to more efficient movement and energy conservation. This study will assess your level of postural control, and you may receive information on how to improve it upon request. You will also be adding to the scientific literature concerning how injury affects postural control.

Alternative Procedures: It has been determined that the procedures are those that offer the least amount of risk to the subject, while allowing for the collection of significant and relevant data. This investigation is strictly voluntary and you are not required in any way to participate.

Confidentiality: Your confidentiality will be maintained by assigning a number code to you. The informed consent documents will be seen only by the researcher, and kept for five years in a locked file cabinet.

Right to Withdraw: As a strictly voluntary participant, you will maintain the right throughout the study to withdraw your participation at anytime without prejudice, penalty, or loss of any care or benefits to which you are otherwise entitled.

Costs and Compensation: There will be no additional cost to you for your participation in this study. In the event you sustain an injury, emergency medical services will be notified. However, no compensation for medical care, hospitalization, loss of income, pain, suffering, or any other form of compensation will be provided as a result of such injury.

Contact Information: In the event that you have additional questions regarding the research, please contact any of the following individuals.

Miranda Osgood Principal Investigator 106 Main St Apt. 4 Andover, NH 03216	Marjorie King, PhD, ATC, PT Director of Graduate Athletic Training Plymouth State University 17 High Street, MSC 22 Plymouth, NH 03264 (603) 535-3108 Fax: (603) 535-2395 making1@mail.plymouth.edu

For questions regarding yours rights as a research subject, please direct your questions to:

Brian Healy
Associate Professor of Psychology
Chair of Institutional Review Board
Plymouth State University
(603) 535-2369
bhealy@plymouth.edu

I CERTIFY THAT I HAVE READ AND FULLY UNDERSTAND THE ABOVE PROJECT, THAT I HAVE BEEN GIVEN SATISFACTORY ANSWERS TO ALL MY QUESTIONS, AND THAT I HAVE BEEN ADVISED THAT I AM FREE TO WITHDRAW MY CONSENT AND TO DISCONTINUE PARTICIPATION IN THE PROJECT OR ACTIVITY AT ANY TIME WITHOUT PREJUDICE. I WILLINGLY CONSENT TO PARTICIPATE.

______________________________ ______________________________

Signature of Subject **Date**

(If you cannot obtain satisfactory answers to your questions or have comments or complaints about your treatment in this study, contact: Institutional Review Board, Plymouth State University: Brian Healy (603) 535-2369 or bhealy@plymouth.edu.)

Appendix D

TEKSCAN POSTURAL CONTROL STUDY

Name:______________________________ **Subject ID#:**______________

Contact information: Email:____________________Phone#_______________

Date: ________ **HT:** ________(in)_______(cm) **Wt:** ______(lbs)_______(kg)

DOB: ________________ **Gender:** M F

I am INJURED NOT INJURED

Please list any past injuries: ____________________________

I work out: 1-3 days per week 3-5 days per week 5-7 days per week

Injury history:

Are you currently under the care of a sports medicine specialist for this injury? Y N

Are you currently limited in your daily activity as a result of injury? Y N

Ankle sprained: R L

Number of sprains on this ankle: _________

Have you ever sprained the opposite ankle: Y N

What was the date of your last injury? (month and year) _________

Did you…	yes	no	
Seek medical care?	☐	☐	If yes, where? ____________
Wear a cast or brace?	☐	☐	
Use crutches?	☐	☐	

For researcher only:
Injury rank:
_____

Approximate length of time before returning to normal activity level ____________

Does it feel unstable or give out on you? Y N

Dominance

Upper Quarter/Hand: which hand to you write with? ____________________

Lower Quarter/Leg: Which leg do you kick a ball with? ____________________

Past Orthopedic History

Location: Foot, ankle, knee, hip, low back, upper back, shoulder, elbow, wrists, hand

Current Outcome:

0. not injured
1. no restrictions
2. occasional flare up; symptomatic treatment
3. active but requires support treatment
4. restriction of activity but remains active
5. not active

Location	**Side (R/L)**	**Surgery/Injury**	
		Date:	
		Diagnosis	
		Current Outcome (#1)	
Location	**Side (R/L)**	**Surgery/Injury**	
		Date:	
		Diagnosis	
		Current Outcome (#1)	
Location	**Side (R/L)**	**Surgery/Injury**	
		Date:	
		Diagnosis	
		Current Outcome (#1)	
Location	**Side (R/L)**	**Surgery/Injury**	
		Date:	
		Diagnosis	
		Current Outcome (#1)	

TEST	A	D	V	TD	AS	
DSEO2L1						**MEANS** A: D: V: TD: AS:
DSEO2L2						
DSEO2L3						
SSEO2L1						**MEANS** A: D: V: TD: AS:
SSEO2L2						
SSEO2L3						

(REST)

	A	D	V	TD	AS	
DSEORL1						**MEANS** A: D: V: TD: AS:
DSEORL2						
DSEORL3						
SSEORL1						**MEANS** A: D: V: TD: AS:
SSEORL2						
SSEORL3						

(REST)

	A	D	V	TD	AS	
DSEOLL1						**MEANS** A: D: V: TD: AS:
DSEOLL2						
DSEOLL3						
SSEOLL1						**MEANS** A: D: V: TD: AS:
SSEOLL2						
SSEOLL3						

(REST)

	A	D	V	TD	AS	
DSEC2L1						**MEANS** A: D: V: TD: AS:
DSEC2L2						
DSEC2L3						
SSEC2L1						**MEANS** A: D: V: TD: AS:
SSEC2L2						
SSEC2L3						

(REST)

	A	D	V	TD	AS	
DSECRL1						**MEANS** A: D: V: TD: AS:
DSECRL2						
DSECRL3						
SSECRL1						**MEANS** A: D: V: TD: AS:
SSECRL2						
SSECRL3						

(REST)

	A	D	V	TD	AS	
DSECLL1						**MEANS** A: D: V: TD: AS:
DSECLL2						
DSECLL3						
SSECLL1						**MEANS** A: D: V: TD: AS:
SSECLL2						
SSECLL3						

COMMENTS:

Appendix E

ADDITIONAL TABLES

Table 1

Descriptive Statistics for Variables Computed from X, Y Coordinates Reflecting Translation of Center of Pressure for Eyes Open, Double-Legged Stance

Variables	Mean	*s*	Min	Max	*N*
Area	10.66	5.43	4.33	29.15	30
Distance	18.02	4.18	9.42	27.80	30
Variability	0.17	0.05	0.10	0.33	30
Total Displacement (ML)	9.97	0.86	1.64	4.70	30
Total Displacement (AP)	4.51	1.38	2.87	10.22	30

Table 2

Descriptive Statistics for Variables Computed from X, Y Coordinates Reflecting Translation of Center of Pressure for Eyes Open, Right-Legged Stance

Variables	Mean	*s*	Min	Max	*N*
Area	8.34	3.89	4.36	21.06	30
Distance	16.26	3.68	10.60	27.73	30
Variability	0.14	0.05	0.10	0.36	30
Total Displacement (ML)	2.51	0.80	1.55	5.84	30
Total Displacement (AP)	4.44	2.14	2.86	14.64	30

Table 3

Descriptive Statistics for Variables Computed from X, Y Coordinates Reflecting Translation of Center of Pressure for Eyes Open, Left-Legged Stance

Variables	Mean	*s*	Min	Max	*N*
Area	8.89	3.22	2.43	15.31	30
Distance	16.73	3.48	10.46	28.31	30
Variability	0.14	0.31	0.08	0.20	30
Total Displacement (ML)	2.56	0.52	1.50	3.80	30
Total Displacement (AP)	4.28	1.10	2.10	6.34	30

Table 4

Descriptive Statistics for Variables Computed from X, Y Coordinates Reflecting Translation of Center of Pressure for Eyes Closed, Double-Legged Stance

Variables	Mean	*s*	Min	Max	*N*
Area	13.26	6.25	5.57	38.03	30
Distance	20.36	4.40	14.40	33.25	30
Variability	0.18	0.06	0.11	0.38	30
Total Displacement (ML)	3.33	0.75	1.85	4.56	30
Total Displacement (AP)	4.97	1.50	2.95	10.70	30

Table 5

Descriptive Statistics for Variables Computed from X, Y Coordinates Reflecting Translation of Center of Pressure for Eyes Closed, Right-Legged Stance

Variables	Mean	*s*	Min	Max	*N*
Area	13.33	6.80	2.75	36.74	30
Distance	21.46	5.48	13.25	38.68	30
Variability	0.19	0.06	0.11	0.39	30
Total Displacement (ML)	3.19	0.75	1.90	5.00	30
Total Displacement (AP)	5.20	1.60	2.40	10.09	30

Table 6

Descriptive Statistics for Variables Computed from X, Y Coordinates Reflecting Translation of Center of Pressure for Eyes Closed, Left-Legged Stance

Variables	Mean	*s*	Min	Max	*N*
Area	13.12	4.70	6.63	25.66	30
Distance	21.50	4.29	12.09	32.86	30
Variability	0.18	0.04	0.12	0.29	30
Total Displacement (ML)	3.21	0.73	2.09	4.97	30
Total Displacement (AP)	5.20	1.21	3.40	8.66	30

Table 7

Repeated Measures ANOVA Comparing the Mean Area for Eyes Open Double-Legged Stance Over Three Trials

Source	*ss*	*df*	*ms*	*F*	*p*
Between Subjects	936.91	29			
Within Subjects	2130.20	48			
Treatment	102.93	2	65.91	1.47[a]	.240
Error	2027.27	46	44.76		
Total	3066.11	77			

[a] Table *F* (.05) (2, 46) = 3.20

Mauchly's Sphericity = .719; *p* = .010

Greenhouse Geisser Epsilon = .781; df (treatment) = 1.57; df (error) = 45.56; Table *F* (1, 45) = 4.06

Table 8

Repeated Measures ANOVA Comparing the Mean Distance for Eyes Open Double-Legged Stance Over Three Trials

Source	*ss*	*df*	*ms*	*F*	*p*
Between Subjects	444.44	29			
Within Subjects	526.74	60			
Treatment	15.68	2	7.84	.89[a]	.416
Error	511.06	58	8.81		
Total	971.18	89			

[a] Table *F* (.05) (2, 58) = 3.16

Mauchly's Sphericity = .959; *p* = .559

Table 9

Repeated Measures ANOVA Comparing the Mean Variability for Eyes Open Double-Legged Stance Over Three Trials

Source	*ss*	*df*	*ms*	*F*	*p*
Between Subjects	.085	29			
Within Subjects	.122	60			
Treatment	.001	2	.000	.235[a]	.791
Error	.121	58	.002		
Total	.207	89			

[a] Table *F* (.05) (2, 58) = 3.16

Mauchly's Sphericity = .919; *p* = .305

Table 10

Repeated Measures ANOVA Comparing the Mean Total Displacement Mediolateral for Eyes Open Double-Legged Stance Over Three Trials

Source	*ss*	*df*	*ms*	*F*	*p*
Between Subjects	22.06	29			
Within Subjects	50.60	60			
Treatment	.938	2	.469	.55[a]	.581
Error	49.66	58	.856		
Total	72.66	89			

[a] Table *F* (.05) (2, 58) = 3.16

Mauchly's Sphericity = .985; *p* = .811

Table 11

Repeated Measures ANOVA Comparing the Mean Total Displacement Anteroposterior for Eyes Open Double-Legged Stance Over Three Trials

Source	*ss*	*df*	*ms*	*F*	*p*
Between Subjects	54.83	29			
Within Subjects	118.55	60			
Treatment	4.48	2	2.39	1.14[a]	.327
Error	114.07	58	1.97		
Total	173.38	89			

[a] Table *F* (.05) (2, 58) = 3.16

Mauchly's Sphericity = .917; *p* = .327

Table 12

Repeated Measures ANOVA Comparing the Mean Area for Eyes Open Left-Legged Stance Over Three Trials

Source	*ss*	*df*	*ms*	*F*	*p*
Between Subjects	300.42	29			
Within Subjects	729.36	60			
Treatment	37.93	2	18.97	1.59[a]	.212
Error	691.43	58	11.92		
Total	1029.78				

[a] Table *F* (.05) (2, 58) = 3.16

Mauchly's Sphericity = .932; *p* = .372

Table 13

Repeated Measures ANOVA Comparing the Mean Distance for Eyes Open Left-Legged Stance Over Three Trials

Source	*ss*	*df*	*ms*	*F*	*p*
Between Subjects	337.02	29			
Within Subjects	364.54	60			
Treatment	34.99	2	17.50	3.08[a]	.054
Error	329.55	58	5.68		
Total	701.56	89			

[a] Table *F* (.05) (2, 58) =

Mauchly's Sphericity = .985; p = .809

Table 14

Repeated Measures ANOVA Comparing the Mean Variability for Eyes Open Left-Legged Stance Over Three Trials

Source	*ss*	*df*	*ms*	*F*	*p*
Between Subjects	.028	29			
Within Subjects	.057	60			
Treatment	.002	2	.001	1.08[a]	.347
Error	.055	58	.001		
Total	.085	89			

[a] Table *F* (.05) (2, 58) = 3.16

Mauchly's Sphericity = .848; *p* = .100

Table 15

Repeated Measures ANOVA Comparing the Mean Total Displacement Mediolateral for Eyes Open Left-Legged Stance Over Three Trials

Source	*ss*	*df*	*ms*	*F*	*p*
Between Subjects	7.89	29			
Within Subjects	28.82	60			
Treatment	3.60	2	1.80	4.15[a]	.021
Error	25.22	58	.44		
Total	36.71	89			

[a] Table *F* (.05) (2, 58) = 3.16

Mauchly's Sphericity = .978; p = .735

Table 16

Repeated Measures ANOVA Comparing the Mean Total Displacement Anteroposterior for Eyes Open Left-Legged Stance Over Three Trials

Source	*ss*	*df*	*ms*	*F*	*p*
Between Subjects	34.87	29			
Within Subjects	71.78	60			
Treatment	.13	2	.06	.05[a]	.95
Error	71.65	58	1.24		
Total	106.65	89			

[a] Table *F* (.05) (2, 58) = 3.16

Mauchly's Sphericity = .868; *p* = .137

Table 17

Repeated Measures ANOVA Comparing the Mean Area for Eyes Open Right-Legged Stance Over Three Trials

Source	*ss*	*df*	*ms*	*F*	*p*
Between Subjects	438.76	29			
Within Subjects	1059.47	60			
Treatment	13.42	2	6.71	.372[a]	.691
Error	1046.05	58	18.04		
Total	1498.23	89			

[a] Table *F* (.05) (2, 58) = 3.16

Mauchly's Sphericity = .882; p = .192

Table 18

Repeated Measures ANOVA Comparing the Mean Distance for Eyes Open Right-Legged Stance Over Three Trials

Source	*ss*	*df*	*ms*	*F*	*p*
Between Subjects	392.64	29			
Within Subjects	308.07	60			
Treatment	3.06	2	1.53	.29[a]	.749
Error	305.01	58	5.26		
Total	700.71	89			

[a] Table *F* (.05) (2, 58) = 3.16

Mauchly's Sphericity = .826; *p* = .069

Table 19

Repeated Measures ANOVA Comparing the Mean Variability for Eyes Open Right-Legged Stance Over Three Trials

Source	*ss*	*df*	*ms*	*F*	*p*
Between Subjects	.073	29			
Within Subjects	.135	41			
Treatment	.007	1	.005	1.50[a]	.234
Error	.128	40	.003		
Total	.208	70			

[a] Table *F* (.05) (1, 40) = 4.09

Mauchly's Sphericity = .565; *p* = .000

Greenhouse Geisser Epsilon = .697; df (treatment) = 1.39;
df (error) = 40.41; Table *F* (1, 40) = 4.09

Table 20

Repeated Measures ANOVA Comparing the Mean Total Displacement Mediolateral for Eyes Open Right-Legged Stance Over Three Trials

Source	*ss*	*df*	*ms*	*F*	*p*
Between Subjects	18.55	29			
Within Subjects	73.40	42			
Treatment	1.62	1	1.15	.66[a]	.474
Error	71.78	41	1.75		
Total	91.95	71			

[a] Table *F* (.05) (1, 41) = 4.08

Mauchly's Sphericity = .584; *p* = .001

Greenhouse Geisser Epsilon = .706; df (treatment) = 1.412; df (error) = 40.954; Table *F* (1, 40) = 4.09

Table 21

Repeated Measures ANOVA Comparing the Mean Total Displacement Anteroposterior for Eyes Open Right-Legged Stance Over Three Trials

Source	*ss*	*df*	*ms*	*F*	*p*
Between Subjects	26.19	29			
Within Subjects	64.67	60			
Treatment	2.22	2	1.11	1.03[a]	.364
Error	62.45	58	1.08		
Total	90.86	89			

[a] Table *F* (.05) (2, 58) = 3.16

Mauchly's Sphericity = .925; p = .334

Table 22

Repeated Measures ANOVA Comparing the Mean Area for Eyes Closed Double-Legged Stance Over Three Trials

Source	ss	df	ms	F	p
Between Subjects	1131.25	29			
Within Subjects	2433.21	60			
Treatment	126.31	2	63.16	1.59[a]	.213
Error	2306.89	58	39.77		
Total	3564.46	89			

[a] Table *F* (.05) (2, 58) = 3.16

Mauchly's Sphericity = .93; *p* = .362

Table 23

Repeated Measures ANOVA Comparing the Mean Distance for Eyes Closed Double-Legged Stance Over Three Trials

Source	*ss*	*df*	*ms*	*F*	*p*
Between Subjects	560.39	29			
Within Subjects	557.80	49			
Treatment	71.65	2	44.47	4.27[a]	.027
Error	486.15	47	10.40		
Total	1118.19	78			

[a] Table *F* (.05) (2, 47) = 3.2

Mauchly's Sphericity = .759; p = .021

Greenhouse Geisser Epsilon = .806; df (treatment) = 1.611; df (error) = 46.729; Table *F* (1, 46) = 4.05

Table 24

Repeated Measures ANOVA Comparing the Mean Variability for Eyes Closed Double-Legged Stance Over Three Trials

Source	*ss*	*df*	*ms*	*F*	*p*
Between Subjects	.094	29			
Within Subjects	.100	60			
Treatment	.002	2	.001	.662[a]	.519
Error	.098	58	.002		
Total	.194	89			

[a] Table *F* (.05) (2, 58) = 3.16

Mauchly's Sphericity = .924; $p = .332$

Table 25

Repeated Measures ANOVA Comparing the Mean Total Displacement Mediolateral for Eyes Open Left-Legged Stance Over Three Trials

Source	*ss*	*df*	*ms*	*F*	*p*
Between Subjects	19.24	29			
Within Subjects	50.60	60			
Treatment	2.18	2	1.09	1.31[a]	.279
Error	48.42	58	.84		
Total	69.84	89			

[a] Table *F* (.05) (2, 58) = 3.16

Mauchly's Sphericity = .889; p = .191

Table 26

Repeated Measures ANOVA Comparing the Mean Total Displacement Anteroposterior for Eyes Open Left-Legged Stance Over Three Trials

Source	*ss*	*df*	*ms*	*F*	*p*
Between Subjects	65.32	29			
Within Subjects	152.02	60			
Treatment	5.14	2	2.57	1.02[a]	.368
Error	146.88	58	2.53		
Total	217.34	89			

[a] Table *F* (.05) (2, 58) = 3.16

Mauchly's Sphericity = .980; *p* = .754

Table 27

Repeated Measures ANOVA Comparing the Mean Total Area for Eyes Closed Left-Legged Stance Over Three Trials

Source	*ss*	*df*	*ms*	*F*	*p*
Between Subjects	646.42	27			
Within Subjects	1425.28	41			
Treatment	57.53	1	39.21	1.14[a]	.32
Error	1367.75	40	34.53		
Total	2071.70	68			

[a] Table *F* (.05) (1, 40) = 4.09

Mauchly's Sphericity = .637; *p* = .003

Greenhouse Geisser Epsilon = .734; df (treatment) = 1.47; df (error) = 39.61; Table *F* (1, 39) = 4.09

Table 28

Repeated Measures ANOVA Comparing the Mean Distance for Eyes Closed Left-Legged Stance Over Three Trials

Source	*ss*	*df*	*ms*	*F*	*p*
Between Subjects	534.11	27			
Within Subjects	613.13	56			
Treatment	16.50	2	8.25	.75[a]	.48
Error	596.63	54	11.05		
Total	1147.24	83			

[a] Table *F* (.05) (2, 54) = 3.17

Mauchly's Sphericity = .890; *p* = .219

Table 29

Repeated Measures ANOVA Comparing the Mean Variability for Eyes Closed Left-Legged Stance Over Three Trials

Source	*ss*	*df*	*ms*	*F*	*p*
Between Subjects	.05	27			
Within Subjects	.12	56			
Treatment	.01	2	.002	1.10[a]	.34
Error	.11	54	.002		
Total	.17	83			

[a] Table *F* (.05) (2, 54) = 3.17

Mauchly's Sphericity = .870; *p* = .163

Table 30

Repeated Measures ANOVA Comparing the Mean Total Displacement Mediolateral for Eyes Closed Left-Legged Stance Over Three Trials

Source	*ss*	*df*	*ms*	*F*	*p*
Between Subjects	15.16	26			
Within Subjects	65.87	33			
Treatment	2.02	1	1.63	.82[a]	.395
Error	63.85	32	1.99		
Total	81.03	59			

[a] Table *F* (.05) (1, 32) = 4.15

Mauchly's Sphericity = .380; *p* = .000

Greenhouse Geisser Epsilon = .617; df (treatment) = 1.24; df (error) = 32.10; Table *F* (1, 32) = 4.15

Table 31

Repeated Measures ANOVA Comparing the Mean Total Displacement Anteroposterior for Eyes Closed Left-Legged Stance Over Three Trials

Source	*ss*	*df*	*ms*	*F*	*p*
Between Subjects	44.13	27			
Within Subjects	125.48	56			
Treatment	5.12	2	2.56	1.15[a]	.325
Error	120.36	54	2.23		
Total	169.61	83			

[a] Table *F* (.05) (2, 54) = 3.17

Mauchly's Sphericity = .942; *p* = .462

Table 32

Repeated Measures ANOVA Comparing the Mean Area for Eyes Closed Right-Legged Stance Over Three Trials

Source	*ss*	*df*	*ms*	*F*	*p*
Between Subjects	1342.06	27			
Within Subjects	2091.31	37			
Treatment	60.08	1	45.65	.80[a]	.410
Error	2031.23	36	57.15		
Total	3433.37	64			

[a] Table *F* (.05) (1, 36) = 4.11

Mauchly's Sphericity = .481; *p* = .000

Greenhouse Geisser Epsilon = .658; df (treatment) = 1.32; df (error) = 35.54; Table *F* (1, 35) = 4.12

Table 33

Repeated Measures ANOVA Comparing the Mean Distance for Eyes Closed Right-Legged Stance Over Three Trials

Source	*ss*	*df*	*ms*	*F*	*p*
Between Subjects	839.73	27			
Within Subjects	1092.53	56			
Treatment	3.18	2	1.59	.08[a]	.924
Error	1089.35	54			
Total	1933.26	83			

[a] Table *F* (.05) (2, 54) = 3.17

Mauchly's Sphericity = .885; *p* = .203

Table 34

Repeated Measures ANOVA Comparing the Mean Variability for Eyes Closed Right-Legged Stance Over Three Trials

Source	*ss*	*df*	*ms*	*F*	*p*
Between Subjects	.110	27			
Within Subjects	.153	56			
Treatment	.002	2	.001	.330[a]	.721
Error	.151	54	.003		
Total	.263	83			

[a] Table *F* (.05) (2, 54) = 3.17

Mauchly's Sphericity = .820; *p* = .076

Table 35

Repeated Measures ANOVA Comparing the Mean Total Displacement Mediolateral for Eyes Closed Right-Legged Stance Over Three Trials

Source	*ss*	*df*	*ms*	*F*	*p*
Between Subjects	16.52	27			
Within Subjects	42.36	56			
Treatment	2.51	2	1.26	1.70[a]	.192
Error	39.85	54	.74		
Total	58.88	83			

[a] Table *F* (.05) (2, 54) = 3.17

Mauchly's Sphericity = .917; *p* = .323

Table 36

Repeated Measures ANOVA Comparing the Mean Total Displacement Anteroposterior for Eyes Closed Right-Legged Stance Over Three Trials

Source	*ss*	*df*	*ms*	*F*	*p*
Between Subjects	71.66	27			
Within Subjects	204.25	56			
Treatment	20.31	2	10.16	2.98[a]	.059
Error	183.94	54	3.41		
Total	275.91	83			

[a] Table *F* (.05) (2, 54) = 3.17

Mauchly's Sphericity = .837; *p* = .099

Appendix F

Description of Variables

The x and y coordinates for center of pressure of the right foot, left foot, and whole body will be used to calculate the five dependent variables: area (A), distance (D), variability (V), total displacement (TD), and asymmetry scores (AS). Area (A) will be defined as the ground that was covered by the center of force (COF) translation and will be calculated using the formula for the area of an ellipse: $A = \pi ab$. The mean area of the three trials will be used in data analysis.

Distance (D) will be defined as the total linear distance from one point of COF to the next. This will be calculated using the Pythagorean theorem for determining the length of a hypotenuse:

$$a^2 + b^2 = c^2$$

In this equation, a is equal to the distance traveled on the y-axis, b is equal to the distance traveled on the x-axis, and c is equal to the distance from one x,y data point to the next. The subsequent values will be added to reveal the distance the COF traveled from the start of data collection to the end. The mean distance of three trials will be used in data analysis.

Variability (V) is the variation of the distances that the COF travels from on X,Y coordinate to the next. Variability will be calculated using a standard deviation formula:

$$SD = (\sqrt{(\sum x_2 - x_1)^2 / (n-1)})$$

In this equation, x_2 is equal to one distance, while x_1 is equal to the distance that the first will be compared to. The value *n* will be equal to the sample size. The mean variability score of three trials will be used in data analysis.

Total displacement (TD) of COF will be determined by taking the antero-posterior (AP) maximum and minimum point difference, as well as that of the medio-lateral (ML) maximum and minimum. The equations for these values will be as follows:

$$TD_{ML} = MAX_{ML} - MIN_{ML}$$

$$TD_{AP} = MAX_{AP} - MIN_{AP}$$

The mean total displacement will be used in the data analysis.

Asymmetry scores are meant to determine the degree to which the COF is directly between the right and left feet. The equation is as follows:

If the asymmetry score is 0%, there is perfect symmetry of center of pressure between the right and left foot. If it is positive, the symmetry is to the left; if negative, symmetry is to the right. Asymmetry scores will only be calculated for the two-footed static stance. This value will show whether there is a difference in the way injured and uninjured subjects distribute weight.

Appendix G
Raw Data Table

		Age	Height	Weight	Injured(I)	Days/wk of	DSEO2L: AREA			DSEO2L: DISTANCE		
Subject #	Gender	(yr)	(in)	(lbs)	Uninj'd(U)	physical activity	Tr. 1	Tr. 2	Tr. 3	Tr. 1	Tr. 2	Tr. 3
1	F	20	65.35	119	U	3--5	11.35	9.82	7.74	19.32	19.29	11.77
2	M	18	75	180	I	3--5	13.99	8.74	8.98	23.47	21.34	17.81
3	M	21	72	232	I	3--5	14.49	7.93	23.43	24.01	17.18	21.99
4	F	24	68	160	I	5--7	13.1	10.72	5.9	18.17	18.07	13.03
5	M	21	66.54	177.78	I	1--3	5.69	10.25	9.94	14.55	15.79	17.17
6	F	25	67	130	U	5--7	17.53	8.05	15.09	20.75	15.53	22.14
7	F	21	61.02	109	U	1--3	4.71	2.51	7.26	14.88	13.91	17.94
8	F	23	67	141	I	5--7	4.93	6.97	7.69	14.94	16.95	18.6
9	M	19	64	165	U	5--7	5.01	8.94	5.96	12.6	18.47	16.67
10	F	18	59.88	130	U	5--7	4.82	3.84	4.33	14.36	13.4	11.69
11	F	19	70	170	U	5--7	6.28	3.93	4.51	14.49	11.59	14.28
12	M	20	66.73	176	I	5--7	25.79	18.91	19.29	29.95	27.18	23.76
13	F	21	68.5	168.89	U	3--5	11.15	7.78	8.72	17.15	12.3	12.57
14	M	21	68.11	185	U	1--3	7.8	7.89	6.29	23.33	19.11	19.7
15	M	22	64.96	175.56	I	1--3	3.97	4.98	4.7	12.96	12.76	17
16	F	28	63.19	142	U	5--7	3.53	11.94	11.28	14.27	19.45	15.52
17	M	23	67.32	164.44	U	1--3	18.01	15.8	20.07	31.26	20.71	29.86
18	F	24	62.99	123.33	U	1--3	10.01	7.93	24.2	21.98	21.46	23.46
19	M	24	71	175	I	3--5	6.9	4.88	7.88	16.04	16.18	15.31
20	F	22	62.99	122.22	U	1--3	6.7	10.85	13.01	15.98	16.59	14.7
21	F	20	65.35	170	U	5--7	8.23	10.13	8.48	19.91	20.47	14.26
22	F	19	63.19	146.67	U	3--5	7.19	6.31	7.6	13.68	13.49	16.1
23	F	23	65	178	I	3--5	18.56	14.28	9.88	25.73	18.26	15.86
24	F	19	63.77	138.5	I	5--7	11.4	13.01	16.33	19.13	17.82	20.48
25	F	20	67	175	I	3--5	7.81	5.64	4.86	14.67	17.5	16.44
26	F	21	64	130	U	3--5	10.4	14.17	12.81	17.81	20.92	18.44
28	M	19	71	195	I	5--7	20.23	22.19	45.03	22.54	27.18	33.67
30	F	19	63	130	I	5--7	9.09	9.7	5.81	19.36	19.24	11.44
31	F	21	65	157	I	3--5	13.1	7.92	8.59	15.78	18.38	13.58
32	F	23	68.11	135	I	5--7	13.29	12.75	19.84	20.24	16.69	20.76

Appendix G
Raw Data Table

	DSEO2L: VARIABILITY			DSEO2L: TDML			DSEO2L: TDAP			DSEORL: AREA		
Subject #	Tr. 1	Tr. 2	Tr. 3	Tr. 1	Tr.2	Tr. 3	Tr.1	Tr. 2	Tr. 3	Tr. 1	Tr. 2	Tr. 3
1	0.13	0.16	0.15	3.96	2.12	2.37	3.65	5.9	4.16	8.47	5.76	3.49
2	0.21	0.15	0.12	3.4	2.12	2.64	5.24	5.25	4.33	13.23	6.63	9.52
3	0.19	0.13	0.18	3.36	2.7	8.04	5.49	3.74	3.71	9.56	6.75	11.34
4	0.18	0.18	0.12	3.17	4.11	2.04	5.26	3.32	3.68	3.99	3.99	10.56
5	0.15	0.14	0.17	2.5	3.2	3.41	2.9	4.08	3.71	3.62	8.34	2.84
6	0.15	0.16	0.17	3.04	2.01	3.4	7.34	5.1	5.65	6.24	6.4	7.1
7	0.12	0.12	0.16	2.15	1.56	2.16	2.79	2.05	4.28	9.03	7.75	3.47
8	0.12	0.13	0.17	2.02	2.31	2.72	3.11	3.84	3.6	6.39	9.93	14.95
9	0.14	0.15	0.14	2.26	3.17	2.04	2.82	3.59	3.72	18.36	5.96	19.45
10	0.1	0.09	0.1	2.23	2.09	1.57	2.75	2.34	3.51	8.49	7.24	5.05
11	0.13	0.09	0.1	1.98	2.84	2.01	4.04	1.76	2.86	4.89	5.39	5.24
12	0.31	0.43	0.21	3.99	5.46	3.91	8.23	4.41	6.28	38.8	12.97	11.4
13	0.13	0.1	0.09	4.15	2.47	2.81	3.42	4.01	3.95	7.31	12.06	9.33
14	0.18	0.18	0.17	2.7	2.57	1.7	3.68	3.91	4.71	12.62	14.85	12.68
15	0.09	0.09	0.14	1.56	2.28	1.65	3.24	2.78	3.63	3.57	10.29	8.51
16	0.13	0.16	0.13	1.51	3.07	3.13	2.98	4.95	4.59	7.43	11.5	6.47
17	0.24	0.16	0.24	4.03	4.55	5.03	5.69	4.42	5.08	12.05	4.9	11.49
18	0.18	0.19	0.28	3.1	3.52	5.35	4.11	2.87	5.76	3.8	6.28	5.11
19	0.16	0.11	0.13	1.88	1.53	2.4	4.67	4.06	4.18	5.84	17.45	6.64
20	0.14	0.13	0.11	2.33	2.24	2.72	3.66	6.17	6.09	4.09	6.2	2.78
21	0.14	0.19	0.14	2.68	2.86	3.12	3.91	4.51	3.46	5.22	6.84	4.13
22	0.1	0.1	0.14	2.57	1.95	2.06	3.56	4.12	4.7	3.76	4.77	4.6
23	0.33	0.13	0.18	7.16	2.27	3.87	3.3	8.01	3.25	7.83	5.79	1.82
24	0.18	0.23	0.17	4.16	2.99	3.76	3.49	5.54	5.53	7.96	8.94	7.39
25	0.14	0.16	0.13	1.95	1.59	1.37	5.1	4.52	4.52	4.39	5.61	5.48
26	0.16	0.19	0.2	3.74	3.72	3.57	3.54	4.85	4.57	10.61	9.94	8.91
28	0.25	0.26	0.47	3.38	4.1	3.55	7.62	6.89	16.15	14.16	24.14	12.58
30	0.22	0.21	0.14	2.56	1.93	2.09	4.52	6.4	3.54	4.33	4.46	7.07
31	0.14	0.17	0.11	3.86	3.02	2.26	4.32	3.34	4.84	3.8	8.03	9.88
32	0.24	0.15	0.23	3.07	3.64	3.77	5.51	4.46	6.7	7.9	9.85	4.55

Appendix G
Raw Data Table

	DSEORL: DISTANCE			DSEORL: VARIABILITY			DSEORL: TDML			DSEORL: TDAP		
Subject #	Tr. 1	Tr. 2	Tr. 3	Tr. 1	Tr.2	Tr. 3	Tr.1	Tr. 2	Tr. 3	Tr. 1	Tr. 2	Tr. 3
1	19.31	18.65	14.44	0.18	0.15	0.13	2.71	2.62	1.99	3.98	2.8	2.23
2	18.61	19.84	21.07	0.17	0.18	0.16	2.91	1.9	2.9	5.79	4.44	4.18
3	20.32	21.74	21.81	0.18	0.15	0.22	2.94	2.38	2.73	4.14	3.61	5.29
4	14.44	14.35	14.13	0.13	0.13	0.13	1.99	2.05	2.76	2.55	2.48	4.87
5	13.75	16.17	16.15	0.11	0.15	0.12	2.34	2.43	1.49	1.97	4.37	2.43
6	15.52	11.4	14.52	0.12	0.09	0.12	1.78	2.54	1.92	4.46	3.21	4.71
7	18.52	19.1	13.94	0.17	0.15	0.11	3.22	3.38	1.56	3.57	2.92	2.83
8	13.53	12.97	19.64	0.12	0.1	0.13	2.12	2.09	2.82	3.84	6.05	6.75
9	18.36	15.47	16.79	0.16	0.14	0.25	4.76	1.91	4.3	4.91	3.97	5.76
10	14.49	18.79	10.4	0.13	0.13	0.11	3.08	2.1	2.69	3.51	4.39	2.39
11	15.74	16.16	11.74	0.12	0.1	0.09	2.72	1.87	1.99	2.29	3.67	3.35
12	28.02	26.9	28.26	0.61	0.23	0.23	11.68	2.65	3.19	4.23	6.23	4.55
13	17.61	11.44	16.14	0.14	0.09	0.13	2.63	3.64	2.89	3.54	4.22	4.11
14	26.75	24.51	20.55	0.21	0.17	0.23	2.98	2.59	3.21	5.39	7.3	5.03
15	11.5	12.64	16.46	0.09	0.12	0.14	1.51	3.21	2.65	3.01	4.08	4.09
16	18.74	15.85	16.16	0.15	0.14	0.12	2.14	2.62	1.89	4.42	5.59	4.36
17	19.72	16.78	24.62	0.16	0.14	0.2	2.22	2.22	2.33	6.91	2.81	6.28
18	14.17	11.59	12.34	0.13	0.09	0.09	1.35	1.95	1.62	3.58	4.1	4.02
19	13.33	15.35	16.92	0.12	0.14	0.15	1.63	2.78	1.98	4.56	7.99	4.27
20	9.77	12.77	9.26	0.11	0.11	0.07	1.54	1.68	1.42	3.38	4.7	2.49
21	13.9	15.88	13.69	0.11	0.14	0.1	1.73	2.74	1.58	3.84	3.18	3.33
22	11.71	16.14	11.64	0.11	0.12	0.11	1.47	1.97	1.98	3.26	3.08	2.96
23	13.28	12.94	7.92	0.16	0.14	0.08	2.88	1.93	1.77	3.46	3.82	1.31
24	14.09	18.16	17.16	0.1	0.14	0.18	1.98	2.29	2.45	5.12	4.97	3.84
25	13.61	10.21	14.65	0.11	0.09	0.1	1.57	1.8	3.09	3.56	3.97	2.26
26	19.1	21.19	18.09	0.18	0.16	0.15	3.15	3.14	2.88	4.29	4.03	3.94
28	18.29	18.59	17.04	0.22	0.21	0.17	2.99	5.21	2.53	6.03	5.9	6.33
30	12.93	11.72	14.49	0.09	0.1	0.11	1.92	1.98	1.79	2.87	2.87	5.03
31	15.7	17.71	15.37	0.11	0.16	0.13	1.76	2.05	2.4	2.75	4.99	5.24
32	17.15	16.31	14.08	0.18	0.15	0.11	2.74	3.03	1.82	3.67	4.14	3.18

Appendix G
Raw Data Table

	DSEOLL: AREA			DSEOLL: DISTANCE			DSEOLL: VARIABILITY			DSEOLL: TDML		
Subject #	Tr. 1	Tr. 2	Tr. 3	Tr. 1	Tr.2	Tr. 3	Tr.1	Tr. 2	Tr. 3	Tr. 1	Tr. 2	Tr. 3
1	8.17	12.21	7.77	16.97	15.26	15.55	0.16	0.14	0.14	2.15	3.59	2.4
2	8.9	7.25	5.52	17.61	21.71	15.94	0.19	0.18	0.14	2.95	1.82	2.02
3	10.51	11.28	5.31	21.56	19.21	17.62	0.23	0.22	0.14	5.6	3.53	2.26
4	15.14	15.62	5.09	16.64	15.62	14.99	0.13	0.13	0.11	2.83	3.1	1.97
5	11.4	8.86	6.22	19.84	16.94	18.04	0.13	0.13	0.15	3.33	3.09	2.82
6	11.67	7.73	5.95	16.77	13.91	15.14	0.13	0.1	0.13	2.63	2.31	1.36
7	4.34	4.77	6.65	15.35	15.21	15.21	0.11	0.1	0.12	1.99	2.21	2.21
8	7.66	5.58	4.11	20.55	16.81	12.78	0.19	0.13	0.09	2.86	2.06	1.96
9	6.81	3.81	4.08	14.42	15.18	12.35	0.11	0.09	0.1	2.71	1.77	1.63
10	11.05	12.25	10.98	17.97	17.58	12.16	0.15	0.16	0.08	2.45	2.63	2.93
11	11.34	3.48	7.39	17.42	10.5	12.77	0.15	0.09	0.11	2.87	1.29	2.29
12	10.78	19.64	15.51	21.54	23.82	20.72	0.22	0.22	0.17	3.34	3.29	3.65
13	9.75	13.75	5.14	13.01	17.76	13.61	0.12	0.15	0.11	2.62	3.11	1.32
14	18.48	14.84	8.14	31.52	30.66	22.74	0.24	0.18	0.19	4.56	4.08	2.61
15	2.94	2.01	2.33	11.84	11.4	8.13	0.1	0.09	0.06	1.36	1.68	1.46
16	8.55	8.13	17.52	13.01	14.17	18.81	0.09	0.13	0.22	3.32	2.73	2.73
17	18.72	12.93	6.57	23.21	24.53	22.05	0.17	0.24	0.17	3.26	3.94	2.18
18	6.68	6.46	8.83	18.83	15.23	15.94	0.2	0.16	0.15	1.91	1.78	2.92
21	6.28	14.15	14.97	15.98	19.67	25.52	0.13	0.17	0.21	2.02	3.56	2.4
20	3.04	4.76	9.25	12.65	14.53	13.44	0.12	0.15	0.12	1.64	1.81	3.27
21	5.96	3.79	4.91	20.64	12.67	14.47	0.15	0.1	0.12	2.79	2	2.35
22	8.75	8.24	8.79	13.88	15.65	22.29	0.1	0.15	0.19	3.2	2.06	2.93
23	7.48	13.49	3.62	12.63	14.26	13.6	0.11	0.14	0.12	2.33	3.45	1.59
24	10.77	7.85	6.73	16.87	16.3	15.8	0.14	0.12	0.13	2.34	2.42	2.4
25	8.68	8.59	4.3	12.47	15.03	11.59	0.09	0.15	0.1	2.27	2.43	1.57
26	4.62	8.52	8.99	15.6	19.42	18.11	0.12	0.18	0.17	1.98	2.81	2.84
27	9.61	10.78	14.3	15.02	15.52	16.15	0.14	0.19	0.19	2.17	2.75	2.17
30	3.05	6.33	3.33	10.39	17.57	12.78	0.09	0.14	0.1	1.92	2.55	1.93
31	18.02	11.39	9.66	19.14	19.95	15.89	0.16	0.19	0.14	4.42	3.02	2.29
32	16.01	6.98	17.9	18.65	15.49	17.9	0.12	0.16	0.16	3.22	1.82	2.24

Appendix G
Raw Data Table

	DSEOLL: TDAP			DSEC2L: AREA			DSEC2L: DISTANCE			DSEC2L: VARIABILITY		
Subject #	Tr. 1	Tr.2	Tr. 3	Tr.1	Tr. 2	Tr. 3	Tr. 1	Tr.2	Tr. 3	Tr.1	Tr. 2	Tr. 3
1	4.84	4.33	4.12	8.27	7.88	6.2	20.27	18.16	19.51	0.19	0.17	0.17
2	3.84	5.07	3.48	27.01	4.02	17.24	29.39	17.7	25.05	0.22	0.14	0.24
3	2.39	4.07	2.99	10.79	1.018	28.6	22.49	19.91	25.2	0.21	0.19	0.22
4	6.81	5.85	3.29	27.84	18.97	11.39	22.72	16.65	19.12	0.15	0.15	0.14
5	4.36	3.65	2.81	16.91	12.54	12.42	19.42	20.05	19.97	0.13	0.15	0.17
6	5.65	4.26	5.57	18.77	11.05	14.8	22.2	20.41	20.99	0.15	0.16	0.13
7	2.78	2.75	3.83	4.97	7.03	11.46	16.25	18.87	18.38	0.13	0.14	0.12
8	3.41	3.45	2.67	14.08	10.03	11.54	23.87	20.74	19.39	0.17	0.18	0.19
9	3.2	2.74	3.19	5.32	12.68	8.72	13.86	17.5	14.95	0.11	0.15	0.12
10	5.74	5.93	4.77	9.24	4.47	5.07	18.52	12.5	15.15	0.13	0.13	0.11
11	5.03	3.43	4.11	32.13	6.25	9.89	21.6	13.9	16.95	0.16	0.09	0.13
12	4.11	7.6	5.41	24.61	16.09	19.76	38.07	28.64	27.02	0.37	0.32	0.27
13	4.74	5.63	4.96	12.92	6.29	12.21	17.66	13.54	20.27	0.11	0.13	0.14
14	5.16	4.63	3.97	10.05	7.62	9.17	31.21	23.63	26.21	0.28	0.18	0.23
15	2.75	1.52	2.03	13.6	9.81	19.2	15.56	20.02	17.65	0.11	0.16	0.15
16	3.28	3.79	8.17	26.44	13.06	6.5	24.62	16.02	18.75	0.18	0.13	0.2
17	7.31	4.18	3.82	31.35	12.42	19.78	26.53	25.82	27.13	0.21	0.24	0.21
18	4.45	4.62	3.85	9.09	12.79	20.14	20.95	20.84	22.3	0.15	0.17	0.22
19	3.96	5.06	7.94	7.39	5.33	3.99	20.03	15.83	17.54	0.18	0.13	0.12
20	2.36	3.35	3.6	3.67	8.59	5.54	11.98	17.72	17.34	0.14	0.19	0.16
21	2.72	2.41	2.66	10.51	18.77	5.74	16.69	18.46	17.47	0.17	0.19	0.14
22	3.48	5.09	3.82	5.39	8.31	9.3	13.87	12.47	16.87	0.13	0.08	0.11
23	4.09	4.98	2.9	7.62	5.35	19.31	18.56	17.9	20.39	0.14	0.17	0.18
24	5.86	4.13	3.57	12.33	8.19	13.91	19.87	15.71	21.01	0.15	0.13	0.23
25	4.87	4.5	3.49	7.19	18.89	15.56	14.72	20.6	16.57	0.13	0.17	0.13
26	2.97	3.86	4.03	13.76	10.31	6.77	20.4	19.83	17.28	0.22	0.15	0.13
28	5.64	4.99	8.39	28.97	52.05	33.07	29.76	35.65	34.33	0.28	0.32	0.53
30	2.02	3.16	2.2	18.74	7.44	15.45	24.4	12.62	23.39	0.27	0.13	0.23
31	5.19	4.8	5.37	10.67	11.36	9.71	24.25	21.61	18.39	0.19	0.17	0.13
32	6.33	4.88	5.71	13.65	18.74	11.36	20.71	22.31	22	0.21	0.27	0.17

Appendix G
Raw Data Table

	DSEC2L: TDML			DSEC2L: TDAP			DSECRL: AREA			DSECRL: DISTANCE		
Subject #	Tr. 1	Tr.2	Tr. 3	Tr.1	Tr. 2	Tr. 3	Tr. 1	Tr.2	Tr. 3	Tr.1	Tr. 2	Tr. 3
1	2.26	1.64	2.09	4.66	6.12	3.78	9.35	11.34	13.58	20.92	17.82	25.15
2	5.93	1.89	4.11	5.8	3.29	5.34	7.76	8.22	8.82	18.69	21.74	17.57
3	4.69	3.43	5.15	2.93	3.78	7.07	15.52	9.03	7.72	19.56	20.88	21.35
4	4.16	4.95	3.58	8.52	4.88	4.05	8.43	16.37	14.37	19.35	27.33	23.27
5	3.5	2.58	4.65	6.15	6.19	3.4	8.03	14	15.78	20.75	26.09	24.35
6	3.88	2.05	3	6.16	6.86	6.28	16.03	14.92	25.67	28.15	17.69	23.27
7	2.02	2.35	3.49	3.13	3.81	4.18	5.98	12.58	10.94	14.4	27.09	22.33
8	3.39	4.48	4.44	5.29	2.85	3.31	15.33	17.96	9.46	23.41	16.85	21.59
9	2.41	4.4	3.88	2.81	3.67	2.86	11.07	9.72	13.15	16.24	20.75	22.03
10	2.43	2.07	1.49	4.84	2.75	4.33	18.14	8.8	7.61	14.09	16.32	12.7
11	6.63	2.09	4.96	6.17	3.81	2.54	3.83	3.89	1.53	15.1	14.98	9.68
12	4.42	3.88	4.2	7.09	5.28	5.99	28.57	40.43	41.21	43.46	34.39	38.19
13	3.53	3.61	3.86	4.66	2.22	4.09	16.39	21.24	15.33	16.22	22.4	22.12
14	3.23	2.07	2.8	3.96	4.69	4.17	13.23	28.35	55.96	29.22	37.02	39.56
15	4.44	3.58	3.33	3.9	3.49	7.34	8.98	7.2	6.36	19.47	14.8	18.49
16	3.87	4.41	1.93	8.7	3.77	4.29	11.55	17.41	24.46	15.85	25.87	31.65
17	5.35	3.22	4.89	7.46	4.91	5.15	13.09	13.22	8.5	28.17	32.35	17.56
18	3.28	3.71	4.19	3.53	4.39	6.12	6.62	10.2	10.15	16.26	19.69	16.27
19	2.85	2.62	1.71	3.3	2.59	2.97	4.58	14.12	23.69	13.95	14.09	28.32
20	2.06	2	1.5	2.27	5.47	4.7	5.51	13.41	4.75	12.95	15.31	17.56
21	3.28	3.51	3.26	4.08	6.81	2.24	11.34	10.78	8.34	21.87	19.74	17.28
22	1.9	1.89	2.71	3.61	5.6	4.37	9.67	13.33	11.3	19.26	22.42	22.86
23	2.35	2.39	4.72	4.13	2.85	5.21	10.73	13.74	5.05	21.56	16.69	10.06
24	2.89	2.82	2.33	5.43	3.7	7.6	30.04	17.81	8.02	30.42	27.62	14.28
25	2.13	3.19	2.57	4.3	7.54	7.71	11.46	8.63	9.38	17.97	15.15	18.08
26	3.86	3.72	2.78	4.54	3.72	2.78	21.47	36.61	115.25	26.47	32.48	40.54
28	3.56	5.37	4.48	10.36	12.34	9.4	17.94	7.01	12.28	27.68	18.18	20.8
30	2.52	1.93	3.63	9.47	4.91	5.42	14.33	8.67	13.56	14.33	16.91	23.57
31	2.26	4.59	4.56	6.01	3.15	2.71	6.93	8.34	9.68	17.77	16.97	15.36
32	2.85	2.73	3.07	6.1	8.74	4.71	11.21	12.77	12.32	20.99	28.52	23.47

Appendix G
Raw Data Table

	DSECRL: VARIABILITY			DSECRL: TDML			DSECRL: TDAP			DSECLL: AREA		
Subject #	Tr.1	Tr. 2	Tr. 3	Tr. 1	Tr.2	Tr. 3	Tr.1	Tr. 2	Tr. 3	Tr.1	Tr. 2	Tr. 3
1	0.19	0.14	0.22	2.41	2.27	2.97	4.94	6.36	5.82	6.64	12.07	11.67
2	0.17	0.18	0.2	2.56	1.67	2.53	3.86	6.27	4.44	6.93	6.7	17.1
3	0.16	0.21	0.17	4.05	2.09	2.89	4.88	5.5	3.4	13.37	11.06	5.45
4	0.18	0.26	0.24	4.08	3.94	3.15	2.63	5.29	5.81	9.85	18.61	10.48
5	0.13	0.22	0.18	3.55	3.6	4.64	2.88	4.95	4.33	15.71	8.81	7.89
6	0.22	0.15	0.18	2.75	3.38	3.17	7.42	5.62	10.31	10.22	14.14	11.81
7	0.13	0.19	0.22	2.53	3.04	3.9	3.01	5.27	3.57	13.39	8.78	9.87
8	0.18	0.14	0.16	4.04	2.92	2.86	4.83	7.83	4.21	35.34	17.46	24.18
9	0.17	0.15	0.16	4.17	2.25	3.39	3.38	5.5	4.94	22.83	10.65	11.22
10	0.14	0.13	0.11	7.5	1.97	2.92	3.08	5.69	3.32	5.75	7.62	6.92
11	0.12	0.12	0.08	1.84	2.65	1.21	2.65	1.87	1.61	1.74	10.68	8.11
12	0.47	0.24	0.35	3.89	3.73	7.38	9.35	13.8	7.11	14.39	8.04	10.19
13	0.3	0.2	0.17	4.44	3.83	3.76	4.7	7.06	5.19	18.74	12.5	8.57
14	0.27	0.36	0.55	4.33	5.27	5.05	3.89	6.85	14.11	15.85	14.81	18.81
15	0.15	0.16	0.15	2.46	2.42	1.91	4.65	3.79	4.24	7.23	6.29	6.38
16	0.12	0.19	0.39	2.11	3.48	3.12	6.97	6.37	9.98	140.32	6.21	16.05
17	0.23	0.23	0.16	3.43	2.49	2.54	4.86	6.76	4.26	13.09	14.36	8.48
18	0.17	0.15	0.1	2.13	2.29	2.55	3.96	5.69	5.07	7.99	5.65	11.05
19	0.17	0.11	0.18	3.12	2.42	3.09	1.87	7.43	9.76	33.46	14.71	12.91
20	0.13	0.14	0.16	2.7	3.29	2.28	2.6	5.19	2.65	6.02	6.88	9.62
21	0.16	0.15	0.15	3.72	3.26	3.36	3.88	4.21	3.16	16.23	22.95	19.57
22	0.17	0.18	0.18	3.04	2.23	2.9	4.05	7.61	4.96	10.4	8.1	7.71
23	0.15	0.15	0.1	2.9	2.8	1.89	4.71	6.25	3.4	8.82	9.92	7
24	0.23	0.23	0.2	4.51	4.42	3.44	8.48	5.13	2.97	16.77	16.61	17.73
25	0.14	0.14	0.16	3.06	2.89	2.38	4.77	3.8	5.02	19.91	9.08	11.7
26	0.23	0.49	0.92	4.13	5.61	25.3	6.62	8.31	5.8	12	17.86	11.16
28	0.24	0.2	0.18	3.72	1.95	2.87	6.14	4.58	5.45	14.86	30.81	19.28
30	0.16	0.16	0.15	3.02	2.2	4.09	6.04	5.02	4.22	20.33	18.36	15.72
31	0.11	0.09	0.15	2.36	2.48	2.14	3.74	4.28	5.76	24.67	8.57	10.09
32	0.16	0.25	0.2	2.96	2.59	3.07	4.82	6.28	5.11	6.81	28.89	17.28

Appendix G
Raw Data Table

	DSECLL: DISTANCE			DSECLL: VARIABILITY			DSECLL: TDML			DSECLL: TDAP		
Subject #	Tr.1	Tr. 2	Tr. 3	Tr. 1	Tr.2	Tr. 3	Tr.1	Tr. 2	Tr. 3	Tr.1	Tr. 2	Tr. 3
1	18.06	20.04	19.48	0.12	0.17	0.15	2.29	3.54	2.88	3.69	4.34	5.16
2	23.58	17.78	20.19	0.18	0.17	0.19	1.57	2.6	2.1	5.62	3.28	10.37
3	19.26	23.98	19.7	0.28	0.26	0.19	3.39	3.11	2.57	5.02	4.53	2.7
4	18.81	14.65	20.63	0.14	0.22	0.22	2.59	3.16	3.79	4.84	7.5	3.52
5	24.9	21.85	22.04	0.22	0.2	0.17	3.65	2.67	2.03	5.48	4.2	4.95
6	20.67	22.32	22.69	0.15	0.2	0.19	2.05	2.14	2.74	6.35	8.41	5.49
7	23.08	20.79	17.03	0.2	0.18	0.13	2.69	2.86	2.93	6.34	3.91	4.29
8	27	28.48	27.83	0.24	0.23	0.2	4.62	2.91	3.58	9.74	7.64	8.6
9	26.54	18	20.85	0.24	0.17	0.16	3.17	3.81	3.08	9.17	3.56	4.64
10	10.81	11.29	14.16	0.08	0.16	0.12	2.04	2.87	1.89	3.59	3.38	4.66
11	13.83	20.31	18.32	0.13	0.15	0.15	2.58	2.2	1.94	5.3	6.18	5.32
12	25.93	29.75	25.71	0.18	0.27	0.22	3.38	4.45	4.17	5.42	2.3	3.11
13	14.01	20.04	19.45	0.12	0.18	0.14	3.16	2.22	2.56	7.55	7.17	4.26
14	33.42	29.87	35.3	0.23	0.24	0.23	3.59	3.75	4.13	5.62	5.03	5.8
15	16.06	14.78	16.49	0.12	0.13	0.14	2.53	2.55	2.37	3.64	3.14	3.43
16	39.6	16.08	21.07	1.24	0.13	0.19	31.29	2.95	3.26	5.71	2.68	6.27
17	28.05	29.65	19.73	0.25	0.22	0.24	3.48	3.18	3.83	4.79	5.75	2.82
18	18.07	19.99	19.78	0.16	0.15	0.22	3.15	2.25	2.83	3.23	3.2	4.97
19	31.87	21.42	19.79	0.32	0.2	0.17	4.82	3.07	2.95	8.84	6.1	5.57
20	19.88	15.17	21.93	0.18	0.09	0.15	2.67	2.24	2.46	2.87	3.91	4.98
21	25.93	27.62	24.67	0.22	0.2	0.17	4.15	4.15	4.49	4.98	7.04	5.35
22	21.47	23.18	17.16	0.16	0.16	0.12	3.27	3.05	2.49	4.05	3.38	3.94
23	12.8	16.84	12.97	0.14	0.12	0.13	2.74	1.71	3	4.1	7.39	2.97
24	16.66	19.63	23.51	0.13	0.13	0.19	3.57	3.56	4.41	5.98	5.94	5.12
25	24.89	21.19	18.64	0.16	0.15	0.11	3.87	3.1	2.8	6.55	3.73	5.32
26	28.87	27.59	18.79	0.26	0.19	0.19	3.98	4.15	3.36	3.84	5.48	4.23
28	20.21	25.13	24.68	0.26	0.38	0.23	2.14	9.43	3.33	8.84	4.16	7.37
30	22.88	28.73	25.55	0.24	0.18	0.24	3.01	3.82	3.94	8.6	6.12	5.08
31	31.07	22.48	16.28	0.25	0.12	0.12	4.52	2.61	2.98	6.95	4.18	4.31
32	20.39	20.44	24.02	0.13	0.37	0.15	2.39	8.36	3.24	3.63	4.4	6.79

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