DETERMINING THE CORRELATION BETWEEN
BIOMECHANICAL LOADINGS INDICATIVE OF
OVER-USE RUNNING INJURIES AND CORE
STRENGTH AND STABILITY

Undergraduate Honors Thesis

By

Steve Jamison

* * * * *

The Ohio State University
Department of Mechanical Engineering
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Dr. Ajit M.W. Chaudhari, Advisor
ABSTRACT

An estimated 74% of runners experience an over-use running injury over the course of a season. Over-use running injuries are injuries that occur due to repeated biomechanical loadings and include patellofemoral pain, iliobibial band syndrome, and stress fractures, to name a few. Hip adduction moment, knee adduction impulse, and vertical ground reaction force are examples of biomechanical loadings that have been shown to be indicators of specific over-use running injuries. Core strength and stability have both been shown to be indicative of over-use running injuries, but which injuries and how they relate is still unknown. The focus of this study was to try to determine the link between biomechanical loadings indicative of running over use injuries and core strength and stability. This was done by first measuring 14 subjects’ core strength and stability. Then, using motion capture equipment, specific biomechanical loadings were calculated. It was found that core strength correlates significantly with core stability, which was expected. It was also determined that both core strength and stability played a role in the biomechanical loads experienced during running. However, because of the relatively small sample size, the significance of these roles remains unknown.
ACKNOWLEDGEMENTS

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1.1 Motivation

Running is a very dynamic and demanding activity. It has been estimated that 74% of runners will incur a running over-use injury over the course of a season [1]. Despite this, running is growing in popularity as evidenced by the increasing number of running events, running clubs, and prevalence of running in the media. With a large population of runners and runners becoming injured, it is important to better understand the causes of these injuries and find possible preventative measures that runners can take to reduce their likelihood of injury.

Core training has also grown in popularity over the years. It is thought that a stronger or more stable core can improve performance in a wide variety of sports because the core is the link that connects the arms and torso to the lower limbs. If this link is stronger and more stable, the energy transfer throughout the body might be more efficient and improve over-all performance. It has also been hypothesized that a stronger and more stable core can aid in injury prevention. This last hypothesis provides the motivation for this research endeavor. If a link between core stability and biomechanical loadings that are indicative of injuries can be established, runners can include core stabilizing exercises into their work outs with good confidence that they will help reduce their injury risk.
1.2 Background

Biomechanical loadings are forces, moments, impulses, and angles that are applied to portions of the body. Some examples are vertical ground reaction force, (Figure 1), external hip adduction moment (Figure 2), knee adduction moment (Figure 3), external hip adduction impulse, external knee adduction impulse, and hip adduction angle (Figure 4). In these biomechanical loadings, external refers to the loadings that are applied by the outside world on the specified area. Some researchers report loadings as internal by assuming that the internal loadings are exactly equal and opposite the external loadings that are actually attained. This means that an internal knee abduction moment and an external knee adduction moment are assumed to be the same quantity. Unless otherwise stated, the loadings discussed throughout will be external loadings. Impulses are calculated by integrating the moment-time curve over one cycle, where one cycle would be one stance phase (Figure 5). This means that a knee adduction impulse is calculated by integrating the knee adduction moment over one cycle.
Figure 1: Physical representation of the resultant ground reaction force (arrow)
Figure 2: Representation of external hip adduction moment (circular arrows)
Figure 3: Representation of external knee adduction moment (circular arrows)
Figure 4: Representation of the hip adduction angle. The hip adduction angle $\theta$ is the angle formed between the femur and the vertical in the coronal (frontal) plane.
As stated previously, 74% of runners will incur a running over-use injury over the course of a season [1]. A running over-use injury is an injury that occurs due to repeated loadings over a period of time. This is different from an acute injury, such as an ankle sprain, that occurs at a specific instant in time. Some common running over-use injuries include patellofemoral pain (also known as runner’s knee and anterior knee pain), iliotibial band syndrome (ITBS), stress fractures, plantar fasciitis, and shin splints, though this is not an all-inclusive list [1]. This research focused on biomechanical loadings that are indicators of patellofemoral pain, ITBS, and stress fractures.
Patellofemoral pain is characterized by pain at the base of the femur, behind the patella (or knee cap). Stefanyshyn et al. [2] linked patellofemoral pain to internal knee abduction with both a retrospective and prospective study. In the retrospective study, patellofemoral pain patients experienced significantly higher internal knee abduction impulses than asymptomatic patients. In the prospective study, six out of 80 runners tested at the beginning of a running season developed patellofemoral pain in the first six months. This injured group had significantly higher internal knee abduction impulses than their matched controls [2].

Iliotibial (IT) band syndrome is characterized by inflammation of the IT band on the lateral side of the knee and has been linked to hip adduction angle [3], hip adduction impulse [4], peak hip adduction moment [4], and peak knee internal rotation [3]. Noehren et al. [3], in a prospective study, found that subjects who experienced ITBS in a two year period showed increased hip adduction angles and knee internal rotation than matched controls. MacMahon et al [4], in a prospective study, compared legs that eventually experienced ITBS to those that remained ITBS free. It was found that those legs that experienced ITBS exhibited significantly higher peak hip adduction moments and hip adduction impulses than those legs that were ITBS free [4].

Stress fractures are small cracks in the bone caused by repeated stresses on the bones and usually occur in the tibia or bones of the foot. Grimston et al. [5] investigated the link between stress fractures and ground reaction forces and found that peak ground reaction forces were indicative of stress fractures. They retrospectively analyzed the running of six female subjects that had experienced stress fractures in the past, but were injury free at the time of analysis and were back to their regular training distance, and
eight females with no prior history of stress fractures. Those subjects with a previous history of stress fractures exhibited significantly higher vertical ground reaction force (normalized by weight) than those subjects that had not experienced a stress fracture [5].

Other studies have focused on the relationship between core strength and stability and injury rates. The core muscles, or core, are a group of muscles located between the upper torso and the legs. The core is comprised of the abdominal, oblique, lower back, and hip muscles and it links the upper torso and arms to the lower limbs. Core strength can be determined with two types of tests. The first is by measuring the maximum force generated by the core muscles, or a subgroup of the core. The second is timing how long a specific contraction can be held above a given threshold. An example of this would be seeing how long a subject can hold their upper body greater than 30 degrees from the horizontal while in a sit-up type position. There are many conflicting definitions of core stability used in the literature which adds to the confusion when attempting to research this field. Core stability, for this study, is defined as the ability of the core to maintain a position in the presence of a perturbation.

Leetun et al. [6] prospectively followed 140 collegiate basketball and track athletes and determined that maximum force generated during a hip external rotation test was the most useful predictor of injury. Though the title of this particular study indicated that core stability measures were used to determine risk factors for injury, core strength measures were the only core dimensions quantified [6]. As was stated previously, core strength and core stability are not the same. Despite this they have been used interchangeably in the past, so one must be careful when reviewing literature in this area.
The relationship between core stability and injury rates has also recently been investigated. Zazulak et al. [7] prospectively followed 277 collegiate athletes after testing their core stability. The core stability test employed utilized a sudden force release system (Figure 6). Zazulak et al. [7] found that trunk displacement was a significant predictor of knee, ligament, and ACL injury risk in female athletes.

![Figure 6: A subject positioned in a multidirectional, sudden force release system utilized by Zazulak et al. [7]. Flexion (A), extension (B), and lateral bending (C) loads were applied via a system of pulleys.](image)

This previous research shows that the core plays a role in lower extremity injuries, though the mechanics of this relationship are unknown. It is not clear how the core influences the lower extremities and which injuries are related to core dynamics. In conclusion, the relationship between core stability and lower extremity mechanics needs to be examined.
1.3 Objectives

The objective of this research project was to determine if there is a correlation between biomechanical loads indicative of running over-use injuries and core strength and stability. This was done by using the Level Belt which quantifies a person’s core stability and also motion capture equipment. The motion capture equipment allowed us to determine the biomechanical loadings that have been shown to be indicators of injury. Both of these procedures will be described in more detail later.

1.4 Organization

Chapter 2 will include a discussion on the methods and equipment used for this project. Chapter 3 will focus on the results attained from the research. Finally, chapter 4 will discuss the limitations of some of the equipment involved in the study and future work that can build off the findings from this project.
CHAPTER 2: Methods

2.1 Subject Recruitment

This study was approved by the Institutional Review Board at The Ohio State University. Fliers were posted throughout the Ohio State campus advertising the study to potential volunteers. To participate in this study, a subject must not have a prior history of serious lower extremity injury, lower extremity surgery, or open abdominal surgery. They must also be comfortable running and currently not suffering from any injuries. Subjects were not paid to participate in this study.

2.2 Core Strength Tests

A subject’s core strength was evaluated using two core strength tests: isometric hip external rotation and isometric hip abduction. For the isometric hip external rotation test, the subject sat on an evaluation table with their legs hanging off the edge, with the corner of the table against the back of the subject’s knee. A strap, secured to the table, was placed around the tibia of the subject, 310mm from the knee. JTech Medical’s Commander PowerTrack II handheld dynamometer was placed between the subject’s leg and the strap. The dynamometer recorded the peak force exerted while the subject rotated their ankle medially. The peak force generated was recorded for three trials of each leg. For a test to be valid the subject’s thigh had to remain on the table and arms
were to be crossed across the chest to ensure that only hip external rotation force was obtained. The test position can be seen in Figure 7.

![Figure 7: Subject in position for hip external test.](image)

The second core strength test used to evaluate each subject was the isometric hip abduction test. For this test, the subject was in a side-lying position. JTech Medical’s Commander PowerTrack II handheld dynamometer was placed between the subject’s thigh and a strap that was secured to the table 280mm from his/her greater trochantor. A
pillow was placed between the subject’s legs to maintain a neutral position. The subject raised his/her top leg upward, against the dynamometer which is being held by the strap (Figure 8). The peak force generated was recorded for three trials for each leg.

![Figure 8: Isometric hip abduction test set-up](image)

### 2.3 Core Stability Test

The “Level Belt” was used to quantify a subject’s core stability. First, a belt was secured around the subject’s body, taking care to cover the anterior superior iliac spine (ASIS). A tennis ball, encompassing accelerometers, was attached to the belt on the subject’s self reported dominant side (Figure 9). It was important to ensure that the axes of the “Level Belt” be aligned parallel with the coronal and sagittal planes of the subject. The “Level Belt” works by measuring the degree of rotation about a selected axis. A
tone sounds when a rotation exceeds a range which is set by the tester using a handheld PDA display.

![Image of Level Belt test set-up](image)

Figure 9: "Level Belt" test set-up. The sensor contains accelerometers that measure the subject’s pelvic rotation. The PDA the subject is holding provides the user-interface and was held by the tester, not the subject, in this study.

To prepare to be tested, the subject was asked to rotate their hips in such a way that will cause the “Level Belt” tone to sound, so that they can become familiar with the motion that is being measured. Once the subject was comfortable with the motion, they
were asked to find a position somewhere near the middle of the range where they felt comfortable (neutral position). The “Level Belt” was then zeroed so that rotation was measured relative to each subject’s neutral position. The subject was now ready to begin the test.

To begin the test, the acceptable range was set high (typically ten degrees) and the subjects were asked to transition from their neutral position to a single leg stance, elevating the non-stance foot to ankle height, just in front of them, as if they were about to take a step, and then transition back to their neutral position. If at any time during the test a tone sounded, indicating that the subject rotated beyond the selected range, the subject failed the test. If a tone did not sound, the subject passed, the range was tightened and the subject was asked to repeat the test. This continued until the subjects reached a range that they could not pass. Subjects were then tested one final time at their tightest range to confirm the score. This procedure was repeated for both legs on each axis. The subject’s recorded score was the tightest range that he/she passed. It is important to note that the lower the score for this test, the more stable the subject’s pelvis was during the test.

2.4 Motion Capture Equipment

The motion capture lab used to record the subject’s running occupies a 3200 square foot room and utilizes eight Vicon MX-F40 cameras, two Bertec 4060-10 force plates embedded in the floor and Vicon’s Nexus software to interface with these components and record trials. The cameras were calibrated each day, prior to testing, to
minimize the error from the cameras. This calibration allowed the software to determine where each camera was in the lab in relation to the others and to the forces plates.

Retro-reflective markers were attached with two sided taupe tape to the subject’s legs utilizing a modified Point-Cluster Technique (PCT) (PCT as described in [8, 9] and shown in Figure 10 below). The modification was in the inclusion of upper body markers so that gross upper body motion could be recorded in addition to the lower limbs. The upper body marker placement was determined using Vicon’s Plug-In Gait model. (Vicon Motion Systems).
Figure 10: Full body PCT marker set shown from the front (A) and back (B) views. An oblique close-up of the legs is shown (C) to reveal more detail of the PCT marker set.

2.5 Experimental Procedure

Upon arriving at the lab, subjects were asked to read, understand, and sign both a personal health authorization form and an informed consent form. Demographic information and self reported injury history was then collected. The level belt and core
strength tests were administered and markers were placed on the subject in accordance with the previously mentioned techniques.

The first trial captured for each subject was a static calibration trial that included all of the markers. The second trial captured was also a static calibration trial, but for this trial the six medial markers and the two tibial plateau markers were removed (Figure 11). The medial markers were removed so that the subject can move more freely without the concern of knocking these markers off and the tibial plateau markers were removed because they were located too close to the femoral condyle markers. An explanation as to why these markers could be removed will be presented below in section 2.6.

![Figure 11: Medial and lateral tibial plateau markers removed after first static calibration trial](image)

The first dynamic trial captured was a range of motion trial of each leg that was used to find the subject’s hip joint centers. This trial was performed with the subject
standing on a small step with one foot and letting the other foot hang off to the side. The subject then raised and lowered their leg, while keeping it straight, in five positions around half a circle, before returning to the starting position with an arcing motion as seen in Figure 12.

Figure 12: Trajectories of the leg during the hip range of motion trial.

The second dynamic trial that was used for this study was a running trial. The subject was asked to run in a large looping circle around the gym at a comfortable running pace, being sure to run down a line where the force plates were located. The subjects were not informed about the force plates located in floor until after the motion capture was complete in an effort to ensure that the subjects did not change their stride to target a force plate. Three trials for each leg were captured for later processing. A successful trial was defined as having 1) one foot completely on a force plate, 2) the
subject’s speed remain constant as compared to other passes, and 3) no change in stride within a stride length of the force plates (no reaching or stutter stepping).

2.6 Data Analysis

A calibration trial was captured after all of the markers were placed on the subject. These markers were used to define both the tracking and anatomic coordinate systems. Each lower extremity segment (thigh, shank, and foot) had a set of markers that were used to track the motion of that segment. These markers defined the tracking coordinate system. Other markers on the subject were used to define the anatomical coordinate system. These markers were placed on anatomical landmarks like the medial and lateral femoral condyles, medial and lateral tibial plateaus, and medial and lateral malleoli, along with others. After capturing this calibration trial, the relationship between the anatomical and tracking coordinate systems can be established, so the markers that were used to determine the anatomical coordinate system could be removed. Only the six medial markers and the two lateral tibial plateau markers were removed, however.

A second calibration trial was captured after these six markers were removed. This trial was used by the Nexus software to auto-label markers in future dynamic trials. For many trials, the auto-label feature was only marginally successful, and operator intervention was required to ensure that each trial was labeled correctly.

Markers often could not be tracked through the entire trial. When this happened, Nexus was able to calculate an estimated trajectory based either on the marker motion before and after the gap or the motion of markers surrounding the marker in question.
Gaps longer than 10 frames were filled manually to ensure the most accurate trajectory was used. These gaps had to be filled before further processing could be completed.

To calculate the biomechanical loadings that are indicative of over-use running injuries, each trial had to be analyzed using custom software. In this software, the femoral and tibial coordinate systems (definition and motion) were based on the PCT marker set [8]. The knee flexion axis was determined using the four markers placed on anatomic landmarks of the knee (medial/lateral femoral condyle, medial/lateral tibial plateau) [10]. A subject’s hip joint center was found using the hip joint center trial that was described above and methods from Camomilla et al. [11].

After each trial was analyzed, the biomechanical loadings of interest were extracted into a large table in excel for further evaluation. Then, the average of each loading for each subject was calculated, without regard to side. Forces were normalized by the subject’s body weight and moments were normalized by the subject’s body weight and height. The torques obtained from the core strength tests were also normalized by body weight and height.

The next step in data processing was to determine the correlation between the subject population’s average biomechanical loadings and their core strength and stability measures. A regression analysis was then used for the data sets that had relatively high correlations (R>0.4) to determine if the correlation was significant (P<0.05). Correlation coefficients and regression analyses were performed in Excel.
CHAPTER 3: Results

3.1 Population

14 subjects participated in this study, 10 male and 4 female (Table 1). Subjects ranged in age from 19 to 50 years old (average age being 26 years old). Subjects were between 54.8 and 92.2 kilograms, with an average of 70 kilograms. They also ranged in height from 1588mm to 1873mm, averaging 1756mm.

<table>
<thead>
<tr>
<th>Height [mm]</th>
<th>Weight [kg]</th>
<th>Age [yrs]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avg</td>
<td>1757</td>
<td>70</td>
</tr>
<tr>
<td>St. Dev.</td>
<td>88.4</td>
<td>11.1</td>
</tr>
<tr>
<td>Min</td>
<td>1588</td>
<td>55</td>
</tr>
<tr>
<td>Max</td>
<td>1873</td>
<td>92</td>
</tr>
</tbody>
</table>

3.2 Core Strength and Stability

Core strength, as measured by isometric hip external rotation, and core stability, as measured with the “Level Belt,” correlated well, though the only significant (P<0.05) relationship was with the anterior-posterior “Level Belt” score (Table 2). Isometric hip abduction did not correlate with either “Level Belt” score. Correlation coefficients being negative reflect a decrease in “Level Belt” score as core strength increases. This
intuitively makes sense, because a decrease in “Level Belt” score indicates a more stable core.

Table 2: Correlation coefficients (R) for core strength and stability measures.

<table>
<thead>
<tr>
<th></th>
<th>Core Strength Measures</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Hip External Rotation</td>
<td>Hip Abduction</td>
</tr>
<tr>
<td>&quot;Level Belt&quot;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anterior/Posterior</td>
<td>-0.544*</td>
<td>-0.057</td>
</tr>
<tr>
<td>Medial/Lateral</td>
<td>-0.447</td>
<td>-0.056</td>
</tr>
</tbody>
</table>

*correlation significant (P=0.044)

3.3 Core Measures and Biomechanical Loadings

Correlations between the biomechanical loadings that are indicative of running over-use injuries and core stability varied greatly. The most surprising correlation was between the Anterior/Posterior “Level Belt” score and peak vertical ground reaction force (R=−0.437). A negative correlation coefficient implies that as the “Level Belt” score increases, the normalized peak vertical ground reaction force decreases (Figure 13). This negative result appears to suggest that as core stability decreases, the likelihood of experiencing a stress fracture decreases. With a P value of 0.118, this relatively strong correlation was not significant.
The core stability measure and biomechanical load combination that had the highest correlation (R=0.5247) was the combination of the Medial/Lateral “Level Belt” score and peak internal tibial rotation with respect to the femur (Figure 14). This correlation suggests that as core stability increases (indicated by a decreasing “Level Belt” score), the probability of experiencing IT band syndrome decreases (indicated by a decrease in peak internal tibial rotation). This result showed a trend towards significance, with a P value of 0.054.
Other correlations between biomechanical loadings and core measures were shown to varying degrees (Table 3). The only other core stability measurement to correlate well with a biomechanical loading was the medial/lateral “Level Belt” score with knee adduction impulse. This correlation was positive, indicating that a more stable core implies a decrease in knee adduction impulse (linked to patellofemoral pain). Core strength also correlated well with biomechanical loadings. Isometric hip abduction strength correlated favorably with peak hip adduction moment (indicative of ITBS) and peak vertical ground reaction force (indicative of stress fractures). None of these strong correlations were significant, however.
Table 3: Correlation coefficients (R) for biomechanical loadings that have been linked to injury and core strength and stability measures. Correlations in bold were relatively high (R>0.4) but not significant (P>0.05)

<table>
<thead>
<tr>
<th></th>
<th>&quot;Level Belt&quot;</th>
<th>Core Strength</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A/P</td>
<td>M/L</td>
</tr>
<tr>
<td>Knee Adduction Impulse</td>
<td>0.327</td>
<td>0.420</td>
</tr>
<tr>
<td>Hip Adduction Impulse</td>
<td>0.255</td>
<td>0.262</td>
</tr>
<tr>
<td>Peak Hip Adduction Angle</td>
<td>-0.038</td>
<td>0.084</td>
</tr>
<tr>
<td>Peak Hip Adduction Moment</td>
<td>0.141</td>
<td>0.284</td>
</tr>
<tr>
<td>Peak Tibial Rotation</td>
<td>0.184</td>
<td><strong>0.525</strong></td>
</tr>
<tr>
<td>Peak Vertical GRF</td>
<td><strong>-0.437</strong></td>
<td>0.049</td>
</tr>
</tbody>
</table>

3.4 Discussion

The only major conclusion that can be drawn from this study so far is that core strength and stability correlate significantly with each other. This was shown with a significantly high correlation coefficient (P=0.044, R=-0.544) between isometric hip external rotation and the Anterior/Posterior “Level Belt” score. This result suggests that hip strength is a major contributor to the stability of the core during the “Level Belt” test.

Medial/Lateral “Level Belt” score correlated well with knee adduction impulse (R=.420), but was not significant (P=0.135). This suggests that as the stability of the core is compromised in the lateral direction, the trunk begins to move more side-to-side. This increased side to side motion increases the over all adduction moment experienced by the knee, and ultimately increases the knee adduction impulse. Since an increased knee adduction impulse has been shown to be an indicator of patellofemoral pain, a decrease in core stability could result in a greater risk in experiencing this running over-use injury.

Medial/Lateral “Level Belt” score has also been shown to correlate well with peak tibial rotation with respect to the femur (R=0.525), though this relationship is not
significant either (P=0.054). Once again, an unstable core could cause more side-to-side motion of the trunk. This excess motion could result in more external rotation of the femur because the motion of running, when combined with the lateral motion of the trunk, can cause twisting. Since the tibia is attached to the foot which does not rotate much during stance phase, since it’s on the floor and bearing a lot of weight, the tibia’s rotation is limited. An external rotation of the femur, with respect to the tibia, can also be seen as an interior rotation of the tibia, with respect to the femur. Peak knee internal rotation has been shown to indicate an increased risk of ITBS, so it follows that a decrease in core stability which causes an increased tibial rotation can also indicate an increase risk of ITBS.

Peak vertical ground reaction forces correlated strongly with the Anterior/Posterior “Level Belt” score (R=-0.437), though this correlation was not significant either (P=0.118). This relationship is opposite of those seen previously. A negative correlation suggests that as the core become more stable, peak vertical ground reaction force increases. This means that a more stable core might indicate an increased risk of stress fractures. If runners are keeping their core too tight and rigid while running, they may not be absorbing the ground reaction forces effectively in their midsection, forcing other parts of the body to absorb them. The most likely places for these forces to concentrate would be in the lower legs and feet, where stress fractures are often seen. This suggests that an increase in core stability can either increase or decrease injury risk.

Core strength measures also correlated well with some of the biomechanical loadings indicative of over-use running injuries. Peak external hip adduction moment was shown to correlate acceptably with isometric hip abduction (R=0.406), though it too
was not significant (P=0.150). This relationship intuitively makes sense. As hip abductor strength increases (internal strength), the ability to resist an external hip adduction moment increases. This can also be seen as a stronger hip abductor can exert a greater external hip adduction moment. This was seen in the biomechanical loads in the runner’s that we observed. As the runners’ hip abduction strength increased, so too did the external hip adduction moment that they experienced. Since an increase in peak hip adduction moment has been shown to indicate an increased risk of experiencing ITBS, an increase in isometric hip abduction strength could also be a risk factor for ITBS.

The final strong correlation was between isometric hip abduction strength and peak vertical ground reaction force (R=0.425), though, again, this connection was not significant (P=0.130). With a stronger hip abductor, a runner would probably be able to increase their push-off force. Since the push-off force often exhibits the peak vertical ground reaction force, this relationship was not surprising. Since peak vertical ground reaction force has been shown to be an indicator of stress fractures, isometric hip abduction strength could also be a risk factor for experiencing a stress fracture.

While the strong correlations between biomechanical loadings and core measures were not significant, they do suggest that the core plays a role in these loadings. The power analysis shows that these correlations could be significant with an appropriate sized population. To obtain a significant correlation (power of 80%, P<0.05, R>0.447), the total subject population would have to be at least 37 subjects, almost three times the population of this study [12].
CHAPTER 4: Limitations and Future Work

4.1 “Level Belt”

The “Level Belt” has several key limitations. The first, and perhaps the most concerning, is the fact that it is not necessarily measuring the stability of the core. Since the “Level Belt” test is done as the subject transitions from a double leg stance to a single leg stance and back, the belt is really measuring the ability of the core, along with the stance leg, to maintain a stable position. While the core is a very integral part of this stabilization, it is not the sole contributor.

Another limitation of the “Level Belt” is its lack of discrimination between subjects. The range used for this group of subjects was from four to ten degrees, in one degree increments. This forced each subject to be classified into only a few categories, making it harder to differentiate between subjects. It would be impractical to reduce increment size to half a degree because this increment is too small to be measured effectively during this type of test. The graph below has half degree measurements because the data is an average of two scores, one left and one right leg stance.
The final limitation of the “Level Belt” that needs to be mentioned as it pertains to this research is inter-tester reliability. The same investigator did not test every subject in this study so inter-tester reliability could be a concern. This limitation is believed to be minimal as the second tester was taught and learned the testing procedure from the first tester. The second tester also observed several tests before beginning testing on their own. Inter-tester reliability was never investigated though and should be considered a possible limitation until proven otherwise.
4.2 Motion Capture

It’s well known that the motion capture technique used in this study has its limitation as it pertains to skin artifact. Movement of the skin is a major source of error that has to be accepted for this type of analysis since it is impractical to attach markers to the bones themselves with this population. Capturing the movement of the skeleton underneath the skin is the objective when using motion capture equipment. Since the skin moves relative to this skeleton underneath, and markers can only be placed on the skin, motion capture techniques are forced to estimate the motion of the skeletal system by tracking the motion of the skin that surrounds it. In an attempt to minimize this error, the PCT marker set was used since the average motion of a group of markers would better represent the motion of the skeleton underneath as compared to a marker set with only a few markers per segment.

Another source of error comes from the knee flexion axis approximation. Since the knee flexion axis was based solely on the placement of markers, if there was an error during marker placement it would propagate directly to the knee flexion axis. A more functional knee flexion axis determination will be employed in the future, but this was the most accurate way of determining the axis that was available.

4.3 Future Work

A better core stability test needs to be developed. This new test should isolate the core to ensure that a true core stabilization measurement is obtained. The test should also be able to discriminate between subjects better than the “Level Belt.” The core stability
test employed by Zazulak et al. [7] did this effectively and the new test should be modeled off of theirs. After this new core stabilization test has been developed, more subjects should be recruited so that significant conclusions can be made based on this new data set.

If a significant correlation can be found between core stability and biomechanical loadings indicative of injury, a training program that focuses on improving core stability could be investigated. If a program could be developed that improved core stability, the effectiveness of this program in reducing biomechanical loadings indicative of running over-use injuries should be examined.


