# Quantitative Assessment of a Functional Movement Screen in Athletes using a Wireless Body Area Sensor Network

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Abstract: Technological solutions enabling the monitoring of human motion during sports and exercise by collecting quantifiable measurements are gaining increased attention as tools for evaluating progress in rehabilitation. Wireless technologies employing small sensors are particularly useful since they allow monitoring of kinematic data without affecting individuals in executing their motions. Advances in miniaturized and wireless technology will push capturing and clearly illustrate measurements in real time game situations. This will eventually eliminate capturing forces from simulated situations in the training room and tell us what actually happens on the playing field.

## 1 INTRODUCTION

Whenever any college athlete sustains an injury, one of the main concerns is how soon can he or she return to play. The answer to this question is not always straightforward because each athlete suffers from a unique injury. Returning to play too soon can increase the risk of re-injury or lead to a chronic problem, resulting in a longer recovery period. However, waiting too long can lead to unnecessary deconditioning and poor performance. Return-to-play decisions are fundamental to the practice of sports medicine. But the method used to make the decision varies greatly between different sports medicine programs. Although there are published articles that clearly identify individual components that go into these decisions, a quantitative assessment of functional movements is not currently used as an integral part of the medical decision-making process. There is a need to have an objective decision-based model developed for clinical use by sports medicine practitioners that take into account quantification of defined outcomes of players before allowing them to return to play.

Our project took one functional movement screen, the overhead squat, to look at how to access an athlete's ability to perform the squat quantitatively. To begin this process, we looked at the use of a Wireless Body Area Sensor Network (WBASN) that measures forces on the soles of the feet during an overhead squat exercise. The WBASN is a wireless network of wearable computing devices including medical body sensors that capture and transmit force data wirelessly to a monitoring base station like a laptop. This provides real time information about an athlete performing a functional movement in a non-invasive way The primary objective of this feasibility study was to build an inexpensive and highly reliable force measuring system using a WBASN designed and developed by memebers of the Center of Distributed and Mobile Computing Laboratory in the College of Engineering and Applied Sciences at the University of Cincinnati, Cincinnati, OH, United States.

The purpose of our study is to demonstrate the ability of collecting force data by using our WBASN in athletes performing an overhead squat exercise.

## 2 BACKGROUND

The NCAA and the National Athletic Trainers' Association have an injury surveillance system that collects injury reports submitted by trainers for roughly 380,000 male and female college athletes. It has been in operation since 1988 and through 2004

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there were 200,000 injury reports. An injury report is filed when an athlete misses a day or more of practice or competition and this equates to about 12,500 injuries per year, a number that has been rrelatively consistent over the years. Functional movement screens are evaluation tools used to assess the fundamental movement patterns of an individual. The screens can be used to determine whether an athlete has the essential movement and flexibility needed to participate in his/her sport.

The overhead squat is one of the key functional movement screens that can be used to determine an athlete's lower body flexibility, providing a visual indicator for the trainer in predicting the performance of an athlete during regular play or returning to play after an injury. Several joints and muscles are involved in performing an overhead squat. Currently our athletic trainers employ the squat test to note the degree of deficiency of postural balance in an athlete. Pressure data from the feet could help them to more accurately determine the extent of postural balance deterioration. To date, we have not found any report of a study measuring the forces on different parts of the soles of the feet during the overhead squat.

## 3 METHODS AND SYTEM DESIGN

Our invention is designed to wirelessly monitor athletes during an overhead squat test using wireless transducers and force sensors beneath the feet of an athlete. We conducted a pilot test of our system using both male and female athletes from the University of Cincinnati football and volleyball teams and all athletes were free of injuries at the time of the testing. Demographic data recorded for the subjects included age, weight and number of years of experience playing their primary sport.

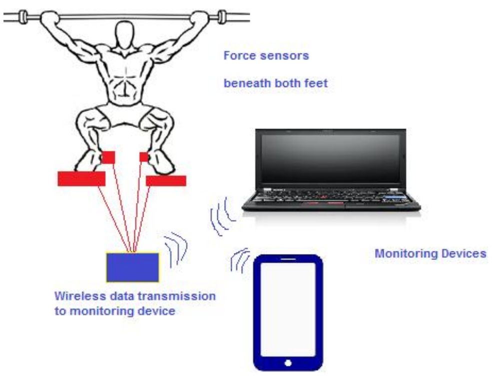


Figure 1: Current system design.

Force sensors are transducers capable of determining the amount of difference in forces exerted on them. These sensors can be connected to an integrated circuit capable of wirelessly transmitting the sensed data to a monitoring station, which can either be a personal computer, laptop or a portable device such as tablet or smart phone. Figure 1 shows the prototype for monitoring performance using force sensors beneath the feet.

The athlete repeated the prescribed squat for a defined number of times and the system continuously analyzed the performance throughout. We can train the system to do intelligent analysis based on the history of an athlete performing squat. The received data will determine the relation of the force between heel and toes and will be displayed graphically in a format easily readable by the trainer. During the first stage of our investigation, we aimed to look at the relationships between the parameters discussed above with the force values that athlete's exert on their feet during an overhead squat. The output is a graphical display of the force in the toes versus the ones in the heels. This output was then evaluated from the perspective of weight, gender, age, and the number of years playing their sport.

### 3.1 Force and Pressure Sensors

Our system employs FlexiForce™ force sensors (Phidgets, Inc., Calgary, Alberta, Canada) beneath the soles of athletes for measuring the distribution of force in the feet. In an individual, not suffering from any injuries and having normal postural balance, the force exerted by the body on the feet is roughly equally distributed between the two legs.

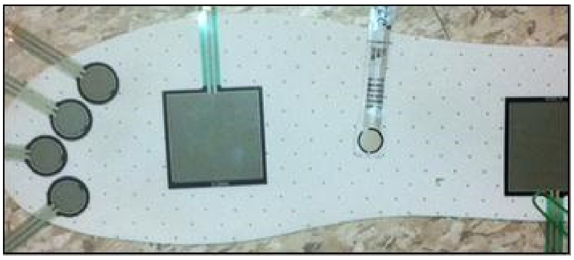

Figure 2: Flexiforce sensors arranged in shoe sole.

A diagram depicting the arrangement of such sensors is shown in Figure 2.

The flexiforce sensors used in our system are thin, flexible piezoresistive sensors that change resistance as the applied force changes. This resistance change is converted to voltage by the Phidgets™ adapter board that plugs into the Phidgets™ interface kit.

## 3.2 the Phidgets Interface Kit

The Phidgets interface kit provides a means to attach the force sensors and interface them to a computer for data acquisition and display. It consists of eight analog inputs that can be used to measure continuous quantities such as temperature, humidity, pressure, position etc. The force sensors can be attached to the analog inputs provided in the interface kit. Phidgets provides a mechanism to tune the sampling rates for the analog sense lines. The sampling rates can be set at 1ms, 2ms, 4ms, 8ms, up to 1000ms in steps of 8ms. The interface kit also provides a series of digital inputs in order to sense the states of certain devices such as push buttons, relays and logic gates. The kit incorporates a digital input hardware filter in order to eliminate false triggering from the ambient electric noise. The digital outputs provided from the kit can be used to drive LEDs and transistors. A diagram of the interface kit is shown in Figure 3.

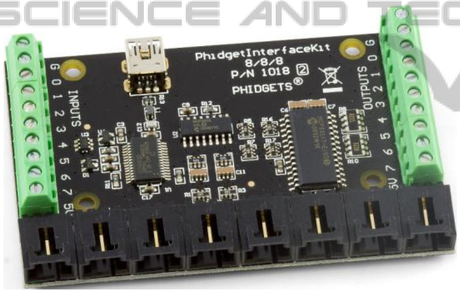


Figure 3: The Phidgets Interface Kit (Phidgets, Inc., Calgary, Alberta, Canada).

## 3.3 The Raspberry Pi

The Raspberry Pi is a system on a chip computer powered by a 700 MHz ARM chip. It has 512 megabytes of onboard RAM which is shared with a GPU. The whole device is just the size of a credit card and requires only 5 volts of power. This makes an appropriate choice for our system as its modest power requirements mean that the device can be battery powered. The system also has two USB ports. We use one port as the input from the Phidgets interface kit that sends the data from the force sensors in the shoe soles. The other USB port would be used to connect a Wi-Fi dongle that would ensure that the Pi is able to connect to a wireless network and transmit data to the server. This port can also be used to attach GSM/LTE dongles that would provide connectivity to cellular networks thereby ensuring a higher transmission rate and provides ability to be used in places without any Wi-Fi coverage. The Pi runs Raspbian which is a Linux distribution derived from Debian stable and is optimized for soft-floating point operations since the Pi does not support the hard floating point operands yet.

Figure 4: The Raspberry Pi (Raspberry Pi Foundation, UK).

## 3.4 System Architecture

The ultimate goal of our project is to build a comprehensive, portable system for acquiring data from individuals, transmit them securely to a server and develop tools and interfaces for subsequent analysis and visualization. The data acquisition module of our system is totally battery powered and Wi-Fi enabled, thereby making it portable to be deployed anywhere. The analysis module of the system would run on a dedicated server enabling faster computation of the acquired data and support of a rich GUI that would make use of the system easier for users. Data pertaining to a particular individual would be time stamped and stored in the database. The system would enable various statistical computations to be performed on the gathered data. The system would also employ Fuzzy Logic and distributed consensus protocols to analyse patterns of injuries and recovery rates of various individuals and aid doctors and medical personnel in making appropriate decisions for patients recuperating from the injuries. A schematic diagram of our proposed system is shown in Figure 5.

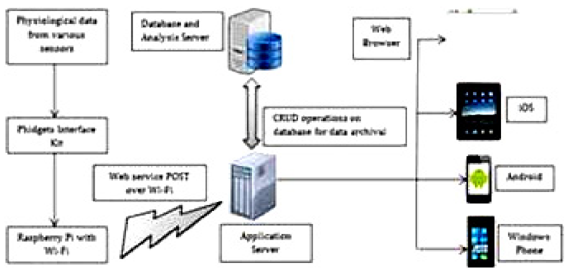


Figure 5: The proposed system architecture.

Our system will employ multiple force sensors on the shoe soles to be used by the athletes. This data can be gathered by the interface kit on its analog input lines.

However, the interface kit does not have any processing power. Therefore, we are employing a Raspberry Pi to provide the required processing power to the system. The interface kit and the Pi would be battery powered in order to make it portable. The Raspberry Pi would be equipped with a USB Wi-Fi dongle that would provide it with wireless capabilities and allow it to be connected to the campus network. Our system would also allow the Pi to be equipped with GSM/LTE dongles that would give it a larger range and increased data rates. Here, we also propose that the Raspberry Pi would run an HTTP server that would post the gather data over a web service to a database server. The goal is to enable the wireless transmission of the pressure data to a central repository for storage.

### 3.5 Experimental Set up

Each athlete has to undergo an assessment of their body posture during an overhead squat. Below are the standardized instructions they followed for performing the overhead squat (Butler et al., 2010).

1. Stand tall with feet approximately shoulder width apart in a comfortable position and toes pointing forward.
2. Grasp the rod in both hands.
3. Press the rod so that it is directly above the head.
4. While maintaining an upright torso, and keeping heels in contact with the ground and the rod in position, descend as deep as possible.
5. Hold the descended position for a count of two, then return to the starting position.


Figure 6: Experimental WBASN set-up for the overhead squat.

We drew an “X” on the floor to mark the center of mass for each subject. Athletes were instructed to put their feet in a comfortable position around the “X”. We put our video cameras in the following set-up: the front camera at 300cm from “X”, the side camera – 350cm from “X”, camera height in front – 153cm, and the camera height on side – 103.5cm.

We instructed the athletes to perform 3 repetitions of overhead squats. The only specific instruction was how to place the feet on the sensors. Verbal instruction included “3 repetitions of overhead squats slowly with a two second pause at the bottom”.

The 3 male players are identified below as subject1, subject2 and subject3 and the 3 female volleyball players by subject4, subject5 and subject6.

Table 1: Demographics.

| SUBJECT | AGE | EXPERIENCE | WEIGHT | SPORTS |
|---|---|---|---|---|
| **1 (Male)** | **21** | **14 yrs** | **177 lbs** | **Football** |
| **2 (Male)** | **21** | **14 yrs** | **209 lbs** | **Football** |
| **3 (Male)** | **21** | **8 yrs** | **250 lbs** | **Football** |
| **4 (Female)** | **19** | **7 yrs** | **177 lbs** | **Volleyball** |
| **5 (Female)** | **20** | **7 yrs** | **160 lbs** | **Volleyball** |
| **6 (Female)** | **19** | **9 yrs** | **162 lbs** | **Volleyball** |

We conducted experiments by placing force sensors beneath the athlete’s feet in two distinct areas of foot - the heel and toes. Then, we asked each player to perform three iterations of squats and we recorded the force values every second. We captured the force data of both the toe and heel during the front-overhead and back-overhead squats. We also video recorded the overhead squat testing session so that the subject’s performance could be analyzed by the athlete’s trainers and their analysis could be correlated with the force data that the WBASN system captured wirelessly.

## 4 RESULTS AND DISCUSSION

We captured the force data in our experimental set-up and retrieved it to generate the graphical display for the athletic trainers. Based on the variations in the force values, we identified three main different postures which lead to significant changes in the corresponding force values on their feet as shown below.

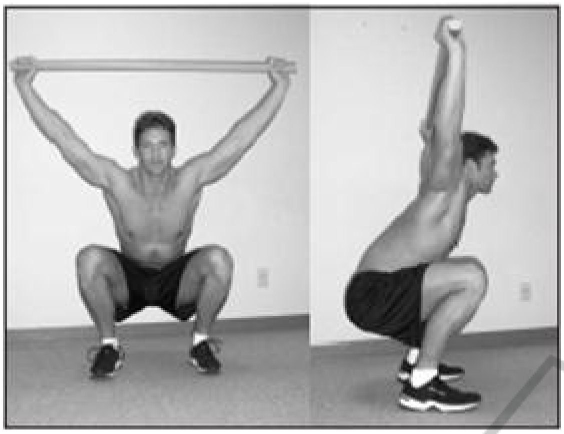

Figure 7a: Overhead squat position 1 (Kiesel et al., 2007).

Figure 7b: Overhead squat position 2 (Kiesel et al., 2007).

Figure 7c: Overhead squat position 3 (Kiesel et al., 2007)

We noticed that the force values collected using our experimental set-up in a wireless environment changes a lot during the three different postures of the squat test. The graphical interface we developed helped in comparing the performance among different players and the two genders. We plotted the time (seconds) on the X-axis and the force value (pounds) on the Y-axis. A few of the performances of the athletes are shown in Figure 8.

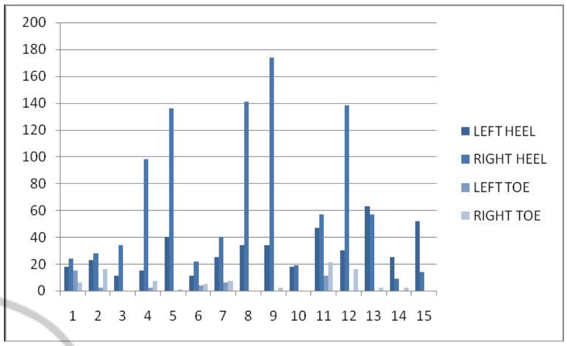


Figure 8: Squat force value of toe and heel of female subject 4.

We collected data from the player's heel and toe as he/she performed the squat. This data is plotted in Figure 8 for female subject4 and Figure 9 for the male subject3. A good squat should have high values of force for the heel since the heel takes the bulk of his weight while the force values at the toe should be less since as they do not need to support the weight.

From the graph we can see that the force values show three large spikes that correspond to the athlete performing the three squats. For male subject3, his heel force data shows the three spikes. However, his toe has also registered some large values which show that he did not perform the squat properly. Female subject4's force values in the heel show three well defined spikes while her toe values have zero values corresponding to the actual squats. This can be considered as an ideal squat force value. We also discuss some of the other performance characteristics which lead to some important observations by the trainers as they correlated the graphical values with on-field performances of the athletes affected by prior injuries.

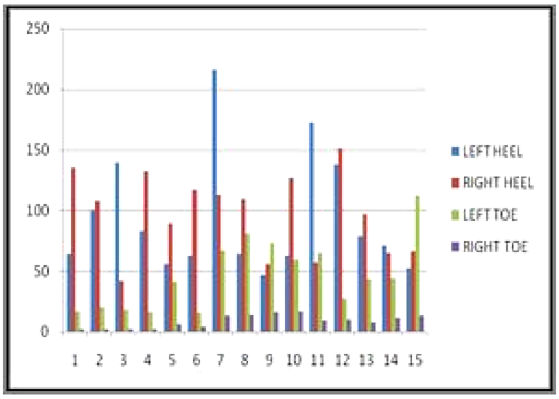


Figure 9: Force value of toe and heel of male subject 3.

We observed the following:

a) In order to distinguish a good squat from a bad one, the player should exert more pressure in the heel than the toes.

b) Figure 10 indicates that pressure exerted on left heel is comparatively more that of right heel, thus the balance is biased towards the left side.

c) Figure 10 also illustrates the comparison of force between heel and toe of each leg of male subject1. We observe that the force exerted on left heel is more than left toe, which indicates a good squat initially. The peak indicates a descent during the squat where more pressure is exerted on the heel during all the three iterations. Comparing our results in Figure 9, we find somewhat similar results, as well some dissimilarity where the pressure exerted on the heel at any instant is more than that of the toe, which is an indication of a good squat, as also confirmed by the trainers.

Another important aspect is to compare the performance of two different athletes playing the same game. According to the trainers, this comparison really helps to understand the capability of the players in playing continuously during the sport season. Our WBASN experimental set-up gave the trainers an opportunity to distinguish between player squat performances, providing a robust means of evaluating the athlete's performance.

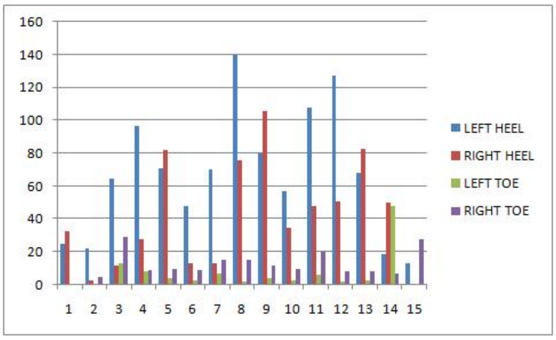


Figure 10: Squat force value of toe and heel of male subject 1.

We compared the force squat values between male subject1 and male subject3, both from the football team and found the following observations as shown in Figure11:

a) During the three repetitions of the overhead squat performance, male subject3 seems to do good squat with an appropriate postures as compared to his team member male subject1. The heel force values remain consistent over the time progression for male subject3. For an ideal squat, the heel takes the bulk of the body weight during and the force values should remain at a higher peak in a consistent fashion. For male subject1, both the left and right heel values are not consistent and change frequently indicating poor form during the test. This correlates with the athlete's relatively poorer performance on the field. The control on body weight during the squat testing has always been an important criterion to determine good, average and poor athletes. Therefore our WBASN experimental set-up is relevant and can help a trainer to categorize the players based on quantifiable performance metrics.

b) Unlike the right heel, the force value exerted by the male subject3 on the right heel is continuous which is more discrete. This leads to an inference that the male subject1 could not maintain the balance of his body while maintaining an upright torso, and keeping his heels and the rod in position, while descending as deep as possible, as shown in Figure7a. We compared the force values in the toe for both the athletes to distinguish their athletic conditions based on their performance.

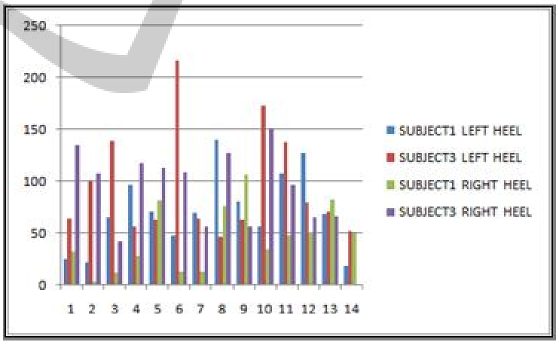


Figure 11: Difference in squat force value of heel part between male subject 1 and male subject 3.

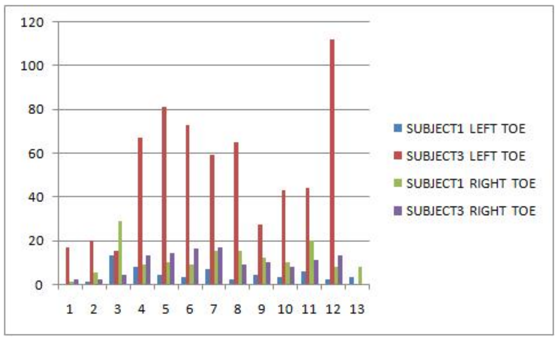


Figure 12: Difference in squat force value of toe part between male subject 1 and male subject 3.

In an ideal squat, the athlete should distribute the weight through with equal pressure on their entire foot from the heels through the toes and maintain this foot position throughout the overhead squat as they complete the exercise with their shoulders back and their back straight (Tolliver). The weight should be kept distributed on their upper thighs and the heels or balls of your feet, neither on the toes nor their knees. It's more to get the athlete to get off his/her toes than to literally squat only on the heels. This observation is clearly visible from Figure 12 where male subject3 put a majority of the force on the right toe as compared to the same in the left toe, indicating the trainer that the subject cannot balance his body weight due to inflexibility. Force values on both the heel and toes are very important when determining the potential performance of the athletes as they can be indicative of postural balance, body flexibility and other cognitive factors which affect the performance of athletes.

## 4.1 Decisions by the Athletic Trainers

Based on previous subjective analysis of the trainers, and the past history of injuries, the additional force value information can significantly help trainers and healthcare professionals to prescribe exercises for an increased flexibility.

Sports medicine personnel will be able to determine progression of rehabilitation based on the graphical force values and it will help them to determine return-to-play estimates.

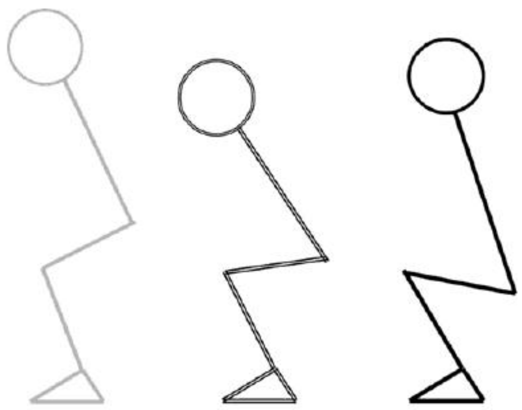


Figure 13: Classification of three different groups in squat.

A healthcare professional will be able to advise the athletes to discontinue any exercise depending on their medical history and the graphical output analysis of the WBASN that we have developed. The initial results in the form of graphical display have been helpful in classifying 6 athletes in three groups of overhead squat performance as being shown in Figure 13.

The result of our study suggests that squat performances judged mainly on the force values on both the heels and the toes in the athletes totally differs among athletes in group1, group2 and group3. The overhead squat performance in the group3 is thought to be better than the others, as subjectively classified by the sports medicine professionals.

## 4.2 Future Work

Another feature that will be incorporated into the system is the measurement of sway in an athlete while he/she is performing the overhead squat. An athlete without injuries will perform the squat following a certain gesticulation. However, athletes with injuries will deviate from expected motions. Our system will incorporate gyroscopes and three axis accelerometers on the chest and two shoulders to determine the degree of deviation from the expected motion. As before, data can be stored and analyzed to provide the coach with a complete picture of an athlete's fitness.

Additional work will be carried out to develop a system to enhance the security of the communications channel from the data acquisition device to the application server. Public Key Cryptography using Elliptic Curve Cryptography maybe a viable option since it gives a reasonable amount of security without a lot of computational overhead. A caching server may also be incorporated in the system so as to reduce the load on the database/analysis server for data that is most frequently requested and/or that needs not be computed in real time. The applications running in the devices may also be enhanced to enable the running of various what-if scenarios that can give an estimate of the time required for an individual to recover completely.

Most of these systems in WBASN employ wireless devices to provide an unobtrusive experience for the users. Therefore, most of these systems are also inherently susceptible to the delays and failures that are common in wireless systems. For a system to be effective in healthcare, it must be robust and provide mechanisms to ensure the reliable delivery of medical data in case of an emergency. Therefore, we need to explore the problem and importance of reliability in a WBASN and develop a framework for ensuring the guaranteed delivery of data packets.

Questions that will have to be investigated in the future include:

a) Can the sensors be placed in the shoes and/or attached to the athletes for both training and in-game situations?
b) Will measured forces on soles indicate weakness in the ankles?
c) If we determine deviation in the movement of an athlete when standing up from the overhead squat can the degree of deviation give us an idea of the degree of injury?

## 5 CONCLUSIONS

We were successful in quantifying some of the movement of an athlete performing an overhead squat. Our long term goal is to develop a means of quantifying the movement in even more detail so numerical scores can be measured to quantitatively access the degree of flexibility of an athlete based on their performance of an overhead squat.

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