An Investigation into Peak Limb Compliance in College Sprinters

Lilian Sahibdeen
An Investigation into Peak Limb Compliance in College Sprinters

An honors thesis presented to the Department of Anthropology,
University at Albany, the State University of New York
In partial fulfillment of the requirements for graduation with Honors in Human Biology and graduation from The Honors College

Lillian Sahibdeen

Research Mentor and Advisor: John Polk, Ph.D.

May 2023
Abstract

During running, the limb acts as a mechanical spring where it compresses and recoils to release elastic potential energy with each ground contact. Maintaining maximal running speed is particularly important during sprinting. Individuals with stiffer limb springs are more efficient because of this. Limb stiffness can be calculated using Hooke’s law ($k = F / \Delta L$), where $k$ is the spring constant, $F$ is the peak ground reaction force, and $\Delta L$ is the change in hip height between the initiation of limb contact and the middle stance phase. Many factors contribute to limb stiffness and this study examines how stiffness varies with contact as well as how it's affected by body size. The extent to which knee and ankle flexion contribute to the changes in limb length will also be looked at. The study included nine elite college sprinters from the University of Illinois who hopped in place at different frequencies. Kinematic data and peak ground reaction forces were collected and analyzed. The results collected suggested that stiffness of ankle and knee angles varied with increasing frequency. The ankle exhibits greater compliance due to its adaptive nature and is the site of the highest elastic potential energy source and exhibited lower stiffness.
Acknowledgments

There have been many people that have helped me throughout the process of writing my thesis. My research partners, Madelyn Teale and Laurent Dorvilier Jr. have worked diligently with me in the last semester to bring this project to life. I never would have been able to complete this thesis without their help. My academic advisor, Jessica Somers, was immensely helpful in guiding me with opportunities for topics to complete my thesis on and was always a resource for any questions I had. Professor Polk was an amazing mentor throughout this entire process. From proposing the topic to me, explaining what needs to be done, teaching me how to analyze the data, and much more; he has contributed to seeing this project through to its completion.

I have been supported throughout my three years of college by my roommate, Claire. From the first day of college, she has inspired me to challenge myself and has helped me achieve goals that I never thought were possible.

Finally, I want to thank my parents, Robert, and Maureen, for encouraging me throughout this entire process. Their love and support always helped shine light into the darkness of any road bumps that came up. None of this would be possible without all that they have given me.
List of Figures

Figure 1: Spring-like mechanics of the lower limbs......................................................... 8
Figure 2: Position of sprinter on the force platform with kinematic markers......................9
Figure 3: Unacceptable hopping trial..............................................................................12
Figure 4: Acceptable hopping trial................................................................................12
Figure 5: Stiffness vs. Frequency....................................................................................13
Figure 6: Force vs. Frequency.........................................................................................14
Figure 7: Ankle angle vs. Frequency..............................................................................15
Figure 8: Knee angle vs. Frequency................................................................................15
Table of Contents

Abstract .................................................................................................................................................. ii

Acknowledgments.................................................................................................................................. iii

List of Figures ........................................................................................................................................ iv

Introduction

A. Lower limbs in relation to sprinting.................................................................................................. 1
B. The spring mass model...................................................................................................................... 2
C. The phases of sprinting in relation to hopping..................................................................................2
D. Lower limbs and their joints and tendons....................................................................................... 4

Literature Review.................................................................................................................................... 4

Methods

E. Subjects.............................................................................................................................................. 8
F. Measurement of stiffness................................................................................................................... 9
G. Data Collection..................................................................................................................................11

Results and Analysis

H. Hopping trials......................................................................................................................................13
I. Stiffness and force................................................................................................................................15
J. Ankle and knee angles ....................................................................................................................... 17

Conclusions and Implications

K. Discussion.......................................................................................................................................... 18
L. Future Implications............................................................................................................................. 19

References .............................................................................................................................................. 20
Introduction:

In 2005, Dr. John Polk and his student Nathan Vadeboncoeur worked with a team of sprinters from the University of Illinois to measure the effect of different training techniques on limb stiffness and sprint performance. This experiment used full-body kinematics with data from a force plate to analyze the force that was used while hopping and bouncing, along with their speed while sprinting. Using the data that they collected, my goal was to analyze the data that was recorded by Dr. Polk and Nathan to draw conclusions on which lower limbs were stiffest and how this affects peak limb compliance in college sprinters.

Lower Limbs Function as a Spring During Running and Hopping

The mammalian gait can be described as acting in a spring-like manner when performing actions like running, sprinting, and hopping. To the entire body, the body is represented as a spring-mass model. The human body can bear its weight through the calcaneus in the foot (Yettram et al. 1993) therefore making the lower limbs being structure very important in supporting body mass. In this spring mass model, the stiffness of the leg sprint is defined as “the ratio of maximal ground reaction force to maximum leg compression at the middle of the stance phase” (Hobara et al. 2010). All these mechanisms lead to leg stiffness becoming higher with every increase in hopping frequency.

In relation to leg stiffness, the ankle plays a very important role. The ankle allows for the up-and-down motion of the foot and its stiffness is regulated by pre activity. In relation to this study, the steps that the sprinters take before performing the action of sprinting effects their overall performance. Actions such as stretches affect how the joint works and increases the effectiveness of the entire foot and directly increases the compliance of the lower limbs. The
hips are also important to gain and maintain speed which allows for the leg to be compressed like a spring with a fluid motion contributed by the flexion of the ankle and heel.

The Spring Mass Model

A spring mass model can be described as having a spring without mass that is attached to a point mass that is dependent of the mechanical components that are involved in how human run and hop in relation to their speed. During both running and hopping, human use flat angles in their landing which allows for maximum ground contact. This model predicts the mass energy that fluctuations the center of mass per distance which is like the hopping action that humans perform (Blickhan 1989). The main similarity between hopping and the spring mass model is the amount of energy that is stored. During hopping, it is more energetically expensive to hop at a frequency that is below one that is preferred which is what is to be expected from the spring mass model to work efficiently. In comparison to the spring mass model, the stiffness of the leg is determined by the ratio of maximal ground reaction to force the leg compression at the middle stance phase. Therefore, understanding the phases of sprinting are important. The action that sprinters perform in between each stride in relation to ground contact time in like hopping and training these muscles leads to the ability of being able to hop at a higher frequency.

To determine the preferred hopping frequency that someone has, three factors must be considered which is body mass, different hopping frequencies and contact time. Therefore, the goal of this study is to look at the anthropometric differences amount subject since those factors could influence the lower limb joints stiffness.

The Phases of Sprinting in Relation to Hopping
When performing actions like running, sprinting, or hopping there is a process that the lower limbs follow to ensure that it goes smoothly. The different phases of sprinting can be labeled as the start, acceleration, transition, maximal running, and deacceleration. A study done by Yu et al. (2016) showed that’s the acceleration phase is the most important since it is where the greatest net propulsive force is required to increase the sprinter’s velocity. The maximal running phase is also important as it can be compared to a plateau where sprinters are trying to maintain the maximum velocity that was built up in the acceleration phase. The differences in the ground reaction forces during this time also impacts the hopping ability of the sprinter. These investigators found that the direction in which the sprinter applies force to the ground yields better results that just hitting the ground with their foot with a great amount of force. Sprinters are trained to use their limbs in a way that yield the least amount of contact with the ground to maintain speed which is why springiness is so important in these phases. The tendons and muscles act as a spring and the extent to which it is stiff affects the person’s ability to achieve the necessary steps to perform an effective hopping motion. The compression of the spring like action of the lower limbs during these phases gives the sprinter the ability to push off the ground, launch into the air, and make minimal ground contact. A study done by Bobbert et al., (2011) found that during the first half of the ground contact phase, the leg length decreases and the ground reaction force increases. During the second half of the ground phase when preparing for liftoff, the opposite occurs where the leg length increases while the ground reaction force decreases. The hopping motion between touchdown and liftoff compresses the joints of the limbs to ensure that there is an adequate amount of energy being exerted that allows for minimal ground contact.
Lower limbs and their joints and tendons

Leg stiffness of the lower limbs is very dependent on their joints. Joint stiffness can be defined as the ratio of maximal joint sprint to maximum joint flexion at the middle of the stance phase (Hobara et al. 2010). The torsional stiffness of the joints determines how much the angle that the bone moves in response to the stress placed on the joint. As stated, before leg stiffness is largely affected by ankle stiffness and increases in leg stiffness that leads to an increase in hopping frequency is due to the changes that occur in ankle stiffness. A study done by Farley et al., 1998 showed that when ankle torsional stiffness increased, the knee was able to extend out longer at the touchdown phase.

This project investigates which lower limbs joints are most the stiffest, least compliant, and why that is. Compliance can be defined as “the capacity of the tendon, which will be responsible for its storage by lengthening and subsequent release of energy by shortening,” (Alexander 1984). Understanding the mechanism of the lower limbs in relation to their joints and tendon was very important to make a justification for the correlation of stiffness to any anthropometric differences between different subjects.

Literature Review:

There has been research done in the past that focuses on hopping frequency in relation to stride frequency and in comparison, to the spring like motion of the lower limbs. What sets this study apart is the emphasis on investigating peak limb compliance in sprinters specifically. A study done by Farley et al., looked at how springs set stride frequency in bouncing gaits. The bouncing gait that humans undergo can influence the hopping frequency they are able to reach. Their main hypothesis was that animals select their optimal stride frequency where they can
behave most like a simple spring mass system. They did so by having humans hop forward on a treadmill over varying speeds and frequencies. Farley and her team found that the subjects preferred to hop at a frequency of 2.2 hops/s and this was for both hopping forward on the treadmill and in one singular spot. They also found that when hopping at higher frequencies that the preferred one, they still behaved like a spring mass system. They believed this was because they the force they were applying during ground contact was generating more muscular force. To minimize the cost of the muscular energy being used, their needs to be a high amount of spring like behavior with a longer time spent on the ground contact. My study looks at how the body, specifically the lower limbs have the most compliance allowing for optimal performance while hopping.

Step frequency, which is influenced by shorter limb lengths (Babic et al. 2007), can be manipulated to improve springing performance. The spring-mass model showed that step frequency changed with kinematic parameters and how this impacted their leg stiffness data. This model describes the storage and reuse of elastic energy when bouncing and running. The main parameter within this model that is looked at is the stiffness of the leg spring. This can be defined as the ratio between the maximal force and the maximal spring compression (Cavagna 1971). They found that when step frequency is manipulated, the increase in vertical stiffness can potentially lead to lower limb injury. This study relates to the overall question that is being asked because it connects step frequency which affects hop frequency and length to lower limb stiffness.

Although lower limb stiffness is required for athletes to optimally perform, too much stiffness can be detrimental. McMahon et al. (2012) conducted a literature review that focused on lower limb stiffness concerning its effect on performance and training. During a drop landing,
the body is like the spring mass body at both the near full extension and then as the range of left
flexion.

They found that increased leg stiffness led to shorter ground contact times when it came
to hopping and vertical jumping. To gain a faster running speed, there had to be the production
of greater ground reaction forces rather than increased step lengths. They saw that utilizing a
more flexible leg straight, the joints of the lower limbs were able to move through an extended
range. This resulted in an increase in muscle contraction velocities which then led to a greater
power output. The research that they looked at highlights that leg stiffness is connected to
successful performance in hopping. However, what they were unsure of was the magnitude of
leg stiffness required to optimize performance. This study also didn’t determine the specific
components of the lower limb like the ankle or knee to determine the role it plays in limb
stiffness These unknown variables are what my study focused when looking at the different
hopping frequencies and what it revealed about limb stiffness and compliance.

Determining specifically what lower limb joints are the least compliant can lead to
explaining how leg stiffness adapts to different types of training. Not only that but it relates to
the main question that is being asked; the correlation between any anthropometric differences
between subjects and which lower limbs specifically are the stiffest. Maloney and Fletcher
(2021) found that vertical stiffness had the strongest reliability when it came to performing tasks
such as hopping, jumping, changing directions, etc. However, there was a discrepancy in the
stiffness between the specific lower limbs. In their study, joint stiffness had the weakest
reliability while ankle stiffness was more reliable than the knee. They also found that there was a
greater stiffness with an increased intensity of running velocity. However, there was no
discussion of how the stiffness of different lower limbs correlates to anthropometric differences
in various subjects.
A study done by Chelly et al. (2000) suggested that the leg stiffness calculate from hopping using a frequency of 2 Hz on a force platform. The contact times of the hopping test, \( h_f = (g * t_f^2)/8 \) was correlated with the maximal velocity of a sprint but not the acceleration. The study focused on the relationship between limb stiffness in hopping and the relationship it has with sprinting. Their use of the spring mass model was used to identify the specific properties of the leg that contributed to the stiffness under the effect of the body mass while hopping. They concluded that the elastic properties of the spring like structure of the leg in relation to its stiffness increased with running velocity. This relationship between sprinting and velocity is not what my study looked at. By just focusing on the action of hopping within sprinters that are trained to undergo intense physical strains, a better understanding of limb compliance can be made in relation to the lower limbs spring like structure.

A study done by Alcatraz et al., (2008) suggested that during the maximum velocity phase, the sprinter should increase the running speed when their foot finally contacts the ground. This counteracts the decrease in the running speed because of the air resistance from the swing phase. The swing phase is when the leg leaves the ground and is in the air but has not contacted the ground again. The investigators compared the kinematics of sprinting at maximum velocity to the kinematics of sprinting using three specific sprint training devices. A study that was like the one at hand is that of Korff et al. (2009) where they looked at the development of lower limb stiffness in adolescents and the affect it has on their maximal vertical jumping power. They found that lower limb stiffness is influenced by passive elastic structures of the musculoskeletal system as the body develops in adolescence.

Although these studies investigated what limb stiffness was, how it can impact a sprinter’s performance and variables that impact limb stiffness; there has not been research done
on the differences in stiffness in specific lower limbs and the correlation to other anthropometric qualities. There also haven’t been many studies that make this connection to that of the sprinter hopping at various frequencies.

Methods:

Subjects

Before the study began, all participants were briefed on the purpose of the study, the purpose of their participation in the study, risks, the benefits of doing the study, and the guarantee of their anonymity. Seven male subjects from an NCAA Division 1 University of Illinois track team completed documentation that asked questions about their general health, any previous injuries, overall medical history, and readiness to participate in physical activity. The setting of the study was an indoor running track. Subjects were split into two training groups where they performed various circuit training or polymetric exercises twice a week for about 20 minutes. This training was performed through the duration of the Big 10 championships that they were already scheduled to participate in that took place at the end of February. Two measurement sessions took place where their limb stiffness and propulsive properties were taken. The first measurement session was conducted in January 2005 and the second occurred right after their Big 10 championship in early March of 2005.
Figure 1. Diagram depicting the spring-like mechanics of lower limbs in a hopping motion where \( \Delta L \), \( bw \), \( bpdy \) weight, and \( s \) = seconds

**Measurement of Stiffness**

During both measuring sessions, the subjects were asked to wear snug fitting shorts and a t-shirt. Before the actual data was collection, 27 lightweight markers were placed onto the subject’s bone landmarks. These landmarks consisted of the shoulders, arms, knees, hip, ankles, and feet. For my study kinematic measurements were obtained using a 12-camera Motion Analysis (motionanalysis.com) at 240 Hz system. The landmarks that were analyzed were the subject’s greater trochanter, knee ankle, and fifth metatarsal head (figure 2). These high precision pearl reflective markers improve the spherical accuracy of the identification of the movements of different lower limbs at greater distances with lower exposure thresholds. This application
connected with the 12-camera Motional Analysis system to collect measurements of each sprinter. Before the measurements occurred, subjects were asked to perform a variety of warmup exercises to ensure that their muscles were properly stretched for maximal performance.

![Figure 2](image)

**Figure 2.** Picture that shows the correct placement of the reflective kinematic markers. Each marker is placed on the bony prominent of the greater trochanter, knee, ankle, and fifth metatarsal head. The figure also shows them position that the sprinters stood on top of the force plate.

During each of the two sessions, subjects were asked to perform six frequencies of repeated hopping exercises. The purpose behind the repeated hopping exercises was to assess how limb spring properties varies with increasing speed frequencies. Subjects were asked to hop in place on a AMTI 400600 force platform (AMTI.biat) at different frequencies for a duration of 10 seconds per frequency. The subjects were instructed to match their hopping frequency to a metronome with the frequencies of 0.5 Hz, 1 Hz, 2 Hz, 3 Hz, 4 Hz, and 5 Hz. During the hopping experiment, subjects were instructed to place their hands on their hips to minimize any
upper body movements that could affect the lower limb movements that were being measured. To ensure that the height of each jump was the same, subjects were asked to jump on the force plate until their shoulders touched a string which was at least 10cm. To measure both force and duration of contact, subjects jumped on the force platform with one or both feet. Knee and ankle angles were also obtained from the kinematic data now of contact at two points: touchdown (TD) and midstance (MS). The study evaluated how stiffness changed with increased hopping frequency by measuring the height of the jumps and the amount of joint flexion at the knee, hip, and ankle. Subjects were given breaks between 10 second hopping bouts and were informed that they had the option to decline hopping to at any or all the frequencies.

**Data Collection**

After the trials were completed, many of the measurements were recorded and organized by subject, trial, and the activity that was being performed whether it was sprinting or hopping. This was done in 2005 with very little of it being recorded on a computer. When this study started in October 2022, this data was uploaded to a Google folder organized by activity and subject. The subjects were divided between myself and my research papers. I worked with subjects four subjects and was given their kinematic, kinetic, and finished hop stick data. Within each of these categories the hopping data contained the results that was used to answer the question of this. The focus was on the left lower limbs due to the simple reasoning that the sensors placed on the right side of the lower limbs either fell off or didn’t pick up motion when the sprinters landed on the force plate.

Due to discrepancies during the data collection and computational errors, the data was not appropriate to analyze. Over the next four months, the kinematic data was “cleaned” where we removed errors and inconsistencies from the data to improve its quality (Rahm et al. 2000). For
the files that could not be cleaned due to large portions of the data being missing yielding graphs that did not match the numbers we were hoping to yield were excluded in the analysis of results.

After all the acceptable data files were created, it was clear that only the hopping data could be used. The data was clean when there was a clear trendline that represented the hopping motion of the left foot (figure 4). Of this clean data there were specific points of the lower limbs that were focused on. These points were the frame, time, left greater trochanter (x, y, z), left knee (x, y, z), left ankle (x, y, z), left foot (x, y, z), knee angle, ankle angle, hipx=toex, and hip height. Hip height was calculated using the distance formula where between the left greater trochanter (x, y, z) and left foot (x, y, z). The hopping kinematic data was transferred to MATLAB where Dr. John Polk created a code within MATLAB to better analyze the data to derive numbers that represented the liftoff, midstance, and touchdown of each subject. Once in MATLAB a graph representing the pattern of these hops were created and 24 points were selected to represent eight cycles of liftoff, midstance, and touchdown.

After these points were selected, a new file was created that allowed for the analysis of each of the 24 points. These points were split into the knee, ankle, toey, hip height, and the time it took for each of these actions that the sprinter did when hopping on the force plate. These numbers were then used to find the average stance duration, hop interval, knee(ms-td), ankle (ms-d), hip height (ms-td), knee ms, knee td, ankle ms, hip height td, and hip height ms were calculated. Analysis of these averages were guided by looking for specific ranges for each variable to ensure that the data was good to use and fully clean. These ranges were as followed: knee td in the 150s, knee ms in the 150s, ankle ms in the 90s, hip height td in the 950s, and hip height ms in the 900s. If variables still didn’t fall within the correct ranges, then that subject was not used in the analysis. The variables that did fall within those ranges were used for the calculation of hop frequencies. The data collected was also used to calculate limb stiffness using
Hooke’s law (k=F/DL) which assumes that the limb acts as a spring (Blickhan 1989) where k is the spring constant, and F is the peak ground reaction.

**Results and Analysis**

**Hopping trials**

![Nathan Trial 12 Hopping Graph](3)

Figure 3. Graph depicting a hopping trial before it was cleaned for data analysis. Lftx, lfty, and lftz represents the left foot going in the x, y, and z direction. X is the horizontal direction, y is the vertical direction, and z is perpendicular.
Figure 4. Graph depicting data after it was clean and could be used for analysis. Lftz, lfty, and lftx represent the left foot going in the x, y, and z direction. X is the horizontal direction, y is the vertical direction, and z is perpendicular.

These graphs display data from both subjects during one of the hopping and sprinting trials. Figure 3 is a graph that displays the data in its raw form before it was cleaned for accuracy. The graphs show the data points as they were recorded by the participant. However, it cannot be used in this form as it is not consistent with the actual movements due to there being markers that had fallen off or didn’t pick up on the movement. Figure 4 is what the data looks like after it was cleaned and shows what the hopping movement from the participant looked like. The pattern of the repeated hopping movement is what allowed for the analysis of data to calculate the frequency the subject was hopping at.
Figure 5. Graph of stiffness versus frequency where there is a positive correlation shown. The diamond represents the interindividual mean and the error bars represents the +1 and -1 standard deviation. As the frequency increases, the stiffness also increases. The trend line is a good fit for the data.

As seen in Figure 5, stiffness increases as frequency increases. The trendline has a slope of 0.0471 which shows that there is a direct, positive relationship between both stiffness (BW/mm) and frequency (Hz). In this graph, the frequency at 2Hz shows a variation between the average and standard deviation to be insignificant suggesting that limb stiffness is affected by
hopping frequency. As the frequency increased, the stiffness of the limb did as well. The data was collected at the midstance of the hop which can be translate to that of a run since they both can be reflected in the spring mass model. The graph indicates that when the lower limb compresses it allows for the storage of a large amount of potential anergy that is released once the spring (the limb) elongates.

![Graph of force versus frequency](image)

(6)

Figure 6. Graph of force versus frequency. There is a constant relationship between the force measured in body weight and frequency.

In this graph of force vs. frequency the data collected from the 1 Hz missing since it did not act in a spring like way. This did not go with what was hypothesized so these trials were excluded the final analysis of data and the graphs that were made. The trendline is constant since
there was no change in body weight between the increasing frequencies which allows for a calculation on stiffness to be made.

**Ankle and knee frequencies**

![Graph](image)

*Figure 7. Graph that shows the ankle angle versus frequency where an indirect relationship is depicted. As the frequency increases, the degree of the ankle angle decreases.*
Figure 8. Graph of knee angle versus frequency. There is an indirect relationship between knee angle and frequency whereas the frequency increases, the degree of the knee angle decreases.

As the frequency increased Hz, the knee angle td-ms (degrees) decreased, Figure 7 displays a trendline with a slope of -9.2957 which illustrates the indirect relationship shared between the knee angle and frequency. The frequency of 2 Hz, knee angle contributes to the low stiffness while 3 Hz displayed a very low compliance rate at the knee. At 4 Hz, there as little change in knee angle from 3 Hz.

**Conclusions and Implications**

**Discussion**

After analyzing the data in the stock plots, it was concluded that hopping at the 1Hz frequency was inconclusive and excluded from analysis. Enhanced leg stiffness facilitates efficient energy transfer during ground contact, enabling more energy generated by the muscles to be stored as elastic potential energy during stance and released as kinetic energy. This elastic
energy transfer reduces heat loss and enhances efficiency, suggesting a positive correlation between stiffer limbs and higher speeds, thus improving overall performance. The contributions of knee and ankle angles to stiffness varied with increasing speed, with the ankle exhibiting greater flexibility due to its mobile and adaptable nature. The ankle, being the site of the highest elastic energy storage potential, exhibited lower stiffness.

In conclusion, the data from the sprinter’s hops on the force plate reveals that faster individuals have stiffer limbs. Increasing speed leads to the contribution of knee and ankle angles to vary.

**Future Implications**

In the future, there are many variables that can be tested to compare to the results of this study. The first would be to increase the sample size. This study started out with more subjects but only seven were able to yield appropriate measurements that we could analyze. Increasing the sample size while improving the techniques used to gather the measurements will allow for a better representation of the population. By repeating the experiment with a larger sample size, there will be more data to work with and could possibly yield results for 1Hz and could show a change in the results seen for the subsequent frequencies.

Another study that could be done based off this one would be to compare the results to other types of runners and nonrunners. Long distance runners train differently than that of a sprinter as sprinters are expected to run at varying speeds for a short amount of time. Sprinters mainly build up their intensity of their running speed to achieve optimum performance and they are expected to run as fast as they can in a short amount of time. The buildup to the optimum speed was shown in this study where the stiffness in the ankle allows for the knee to be able to lift higher off the ground. It also enables the sprinter to land on the ball of their foot rather than their toes leading to have more energy to push off the ground which each hopping motion. Long
distance runners run at a slower pace to store their energy since their muscles are being used for a longer period. Due to these differences, it is likely that the results of long-distance runners hopping frequency can yield to a different limb having peak compliance. The same can be said for nonrunners. This population has little to no training and their muscles and joints are not used to be used in a way that allows for proper liftoff to achieve the hopping frequencies that sprinters have. Knowing the results of these two populations can help come to an overall conclusion about what limbs have peak limb compliance.

One last variable that could be tested are different genders. This study consisted of an all-male population. If the study was repeated with female sprinters, it may lead to different results. There are many anthropometric differences between males and females including males having a higher body mass, higher body surface area, and longer limb length. Since these factors all contribute to the subject’s ability to perform the exercises in the study; it is likely that women will yield different results. The results from this study could reveal if there is a difference in peak limb compliance with females or if they are similar.

References


Babić, Vesna & Harasin, Dražen & Dražan, Dizdar. (2014). Relation of the variables of power and morphological characteristic to the kinematic indicators of maximal speed running. Kinesiology (kinesiology.office@kif.hr); Vol.39 No.1.


