The Relationship Between Foot Anthropometry and Jump Performance

by

Victoria Sloane Hawley

Honors Thesis

Appalachian State University

Submitted to the Department of Health and Exercise Science
and The Honors College
in partial fulfillment of the requirements for the degree of

Bachelor of Science in Exercise Science

May, 2016

Approved by:

____
Herman van Werkhoven, Ph.D., Thesis Director

____
Laura McArthur, Ph.D., Second Reader

____
Ted Zerucha, Ph.D., Director, The Honors College

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Abstract

Previous studies have examined how gross anthropometric measures such as weight, stature, and lower limb length affect jump performance (Fattahi et al., 2012; Aouadi et al., 2012). However, there is a gap in research investigating the relationship between acute anthropometric measures, such as heel length, toe length, and arch height, and jump performance. In addition, many previous studies do not include women (Baxter et al., 2011; Lee & Piazza, 2012; Scholz et al., 2008). This study examined acute anthropometric measure in relation to jump performance. It also included both men and women. We hypothesized that longer toes, shorter heels, and higher arches would predict a higher jump. Twenty-one females and twenty-one males participated in the study. Various gross and acute anthropometric measurements were recorded for each subject. Each subject performed three countermovement jumps (CMJs) and three squat jumps (SJs). Statistical analysis revealed that men jumped significantly higher than women, and were significantly larger for all anthropometric measures. For men only, no single anthropometric measure predicted jump height. For women only, shorter toes correlated with higher CMJs ($r= -0.604$, $p < 0.05$), shorter feet correlated with higher CMJs and SJs ($r= -0.533$, $r= -0.463$, $p < 0.05$), and lower weight correlated with higher SJs ($r= -0.464$, $p < 0.05$). These results suggest that the relationship between anthropometry and jump performance should not be assumed to be similar for men and women.

Introduction

Vertical jump height is affected by many anthropometric measures such as weight, stature, and lower limb length (Fattahi et al., 2012; Aouadi et al., 2012). Taller persons, or persons with a greater stature, tend to have a greater vertical jump height. In addition, there is a positive correlation between lower limb length and jump performance. Greater stature and longer lower length correlate with an increased ability to produce anaerobic power, therefore increasing vertical jump height (Aouadi et al., 2012). However, previous work does not always agree that longer or larger is better. Having shorter lower limbs allows the resistance for the movement of jumping to be performed closer to the axis of rotation, meaning that a person with shorter lower limbs must lift their body weight a smaller distance to produce the same vertical jump height as a person with longer lower limbs (Ackland, 2009). Furthermore, larger weight may produce negative effects on jump performance, decreasing the maximum height (Fattahi et al., 2012).

More recently researchers have investigated the effect of local measures of lower extremity anthropometry, specifically related to the human foot, to predict performance in running and sprinting (e.g. Scholz et al, 2008; Baxter et al, 2011). These more local measures have not been thoroughly investigated as to the effect they have on jumping performance. Vertical jump height correlates with and can predict running velocity (Lockie et al., 2015). Therefore, it could be argued that performance predictors for sprinting could also potentially predict vertical jumping performance. On average, sprinters have significantly shorter moment arms and significantly shorter toes than control subjects (Lee & Piazza, 2009). Muscle moment arm in this case refers to the perpendicular distance between the ankle joint and the line of action of the plantarflexor muscles posterior to the ankle joint. Internal measures of moment arm have been shown to correlate with external measures of heel length, and will be discussed in this context in this work. A shorter heel correlates with larger joint moment development, larger joint power output, and larger joint work output, resulting in larger muscle force development (Nagano et al., 2003). A shorter heel is therefore seen as beneficial in sprinting, and can be hypothesized to be beneficial in jumping and jumping-related tasks. Longer toes allow for more time of contact with the ground, therefore creating a greater acceleration due to ground reaction force. Thus, these variations allow sprinters to create more forward impulse (Lee & Piazza, 2009). These anthropometric adaptations, shorter heels and longer toes, could also be beneficial during a jumping task. Another measure associated with foot anthropometry that has received little attention is the height of the foot arch. It is currently unclear how jump height is affected by arch height.

Overall, there is a gap in research on the effect of heel length, toe length, and arch height on jump performance. This study attempts to fill that gap. In addition, most studies concerning anthropometry and jumping exclusively include males. This study includes both males and females in an attempt to identify possible differences between sexes. The hypothesis is that a greater arch height, shorter heel length, and/or longer toes produce a greater vertical jump height. A person with a high arch is potentially able to store more elastic energy in the tendons and/or fascia during the squatting portion of a jump in order to use that energy to achieve a greater velocity at take off, thus resulting in a higher jump. A person with a shorter heel will have a decreased muscle shortening velocity for the same rotation, and will therefore have improved force production. A person with longer toes is able to stay in contact with the ground longer during take off, allowing a greater force production.

Methods

Subjects

Participants were recruited using posted flyers and the Appalachian State University student and faculty email list services. A total of 45 students participated in the study. As a result of inability to fully participate in the study and Vicon Nexus program errors, 3 participants were not included in data analysis. Subjects signed an informed consent form, completing a prescreening questionnaire, and were informed on the procedure. Approval was gained from the Institutional Review Board.

Forty-two students met the following criteria to participate in the study: (1) a healthy adult between the ages of 18 and 35; (2) no history of musculoskeletal injury, neuromuscular disease, or history of lower limb surgery; (3) able to participate without medical clearance according to the 2015 ACSM Exercise Preparticipation Health Screen Form.

Procedure

After each subject signed an informed consent form and completed the prescreening questionnaire, height, in inches, and weight, in pounds, was recorded. Height was converted to centimeters and weight converted to mass in kilograms after data collection. A stadiometer and scale were used to measure height and weight, respectively. The following measurements were recorded: (1) upper leg length (vertical distance from the anterior superior iliac spine to the top of the patella); (2) lower leg length (vertical distance from the head of the fibula to the most prominent part of the lateral malleolus); (3) lateral heel width (horizontal distance from the middle of the Achilles' tendon to the most prominent part of the lateral malleolus); (4) medial heel width (horizontal distance from the middle of the Achilles' tendon to the most prominent part of the medial malleolus). Measures 3) and 4) were used in final calculations of heel length as described below. An anthropometer was used to measure upper leg length, lower leg length, lateral heel width, and medial heel width.

After all measurement were taken, 3 black marks were placed on the most prominent part of the lateral malleolus, medial malleolus, and 1^{st} metatarsophalangeal joint. While sitting, medial and lateral views of the right foot were digitally photographed, with the foot placed on a wooden reference block. A millimeter-scale measuring tape was placed on the side of the wooden block for scaling. The tibia was aligned perpendicularly to the reference box. A custom designed MATLAB (Mathworks Inc, Natick, MA) code was written to digitalize images taken of each participant's medial and lateral right foot. Using the scaling provided by the measuring tape in the images, the code determined foot length, toe length, arch height, medial heel length, and lateral heel length (Figure 1). Medial and lateral heel

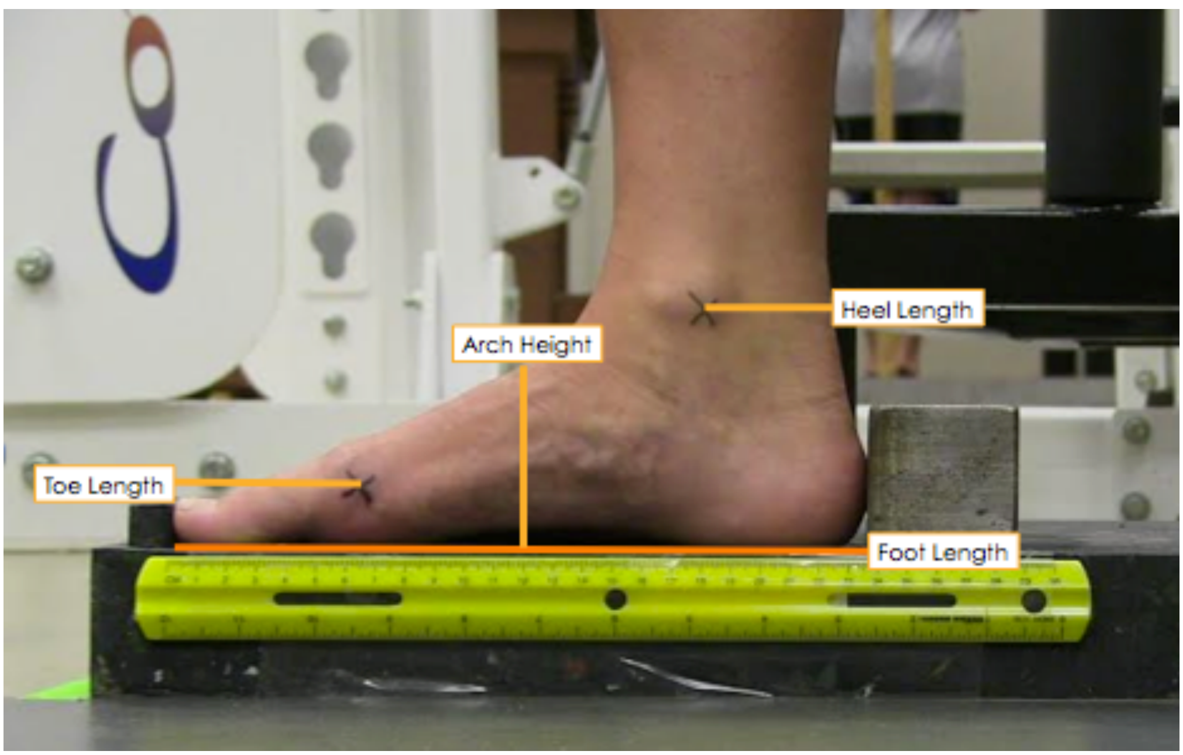

Figure 1: Anthropometric measures as determined by digital imaging.

length was defined as the horizontal distance from the back of the heel to the most prominent part of the medial and lateral malleolus respectively. Medial and lateral heel length was used to calculate the average heel length.

Before performing maximal jumps, subjects warmed up on a cycle ergometer for 5 minutes at a self-selected pace. Subjects performed jumps on a force plate (AMTI, Watertown, MA). The force plate was zeroed in between each jump to ensure a zero force reading before subjects stepped onto the force plate. Subjects performed 6 jumps: 3 countermovement jumps (CMJs) and 3 squat jumps (SJs). CMJs were performed starting in an erect position. Subjects then squatted and jumped in one continuous motion without pausing in the squat position. SJs were performed starting in the squat position. Subjects held the squat for three seconds before jumping. Subjects were instructed to keep their hands on their hips at all times during CMJs and SJs. CMJs and SJs were performed in random order to reduce the risk of learning impacting performance. Subjects rested for 30 seconds between jumps of the same kind. Subjects rested for 3 minutes between differing jumps. Using MATLAB (Mathworks Inc, Natick, MA), a code was developed to determine the vertical jump height of each jump using an impulse momentum equation from the collected force-time data:

$$\Sigma F \bullet \Delta t = m \Delta v,$$

- ΣF is the sum of forces acting on the body, $\Sigma F = GRF - W$, with GRF the ground reaction force and W is weight.,
- Δt is the change in time,
- m is mass, and
- Δv is change of velocity.

After calculating the peak velocity at take off by integrating a force versus time curve, the code used a projectile motion equation to calculate vertical jump height. Time of takeoff was assumed to occur when the force plate force reading moved below 10 N, as justified by a previous study (Rabita et al., 2015). The takeoff velocity method was used for the code to calculate maximal jump height (Moir, 2008).

Statistical Analysis

SPSS software was used to conduct statistical analyses. To determine the differences between men and women, two-tailed t-tests were used. Significance was set at $p < 0.05$. Correlational analysis was used to determine the relationship between anthropometric measures and jump height. R-values and p-values were both used to assess correlation analyses, with significance set at $p < 0.05$.

Results

Males performed significantly better than females for both CMJs and SJs (Table 1). For all anthropometric measures, males had significantly larger values than females (Table 1).

Next, the sexes were considered separately. For males, there were no significant correlations between any anthropometric variable and jumping performance for both CMJs and SJs (Table 2). When only considering female subjects, foot length and toe length showed significantly negative correlations with CMJ height, while foot length and weight showed significantly negative correlations with SJ height (Table 3). For both CMJs and SJs it appeared that weight, foot length, and toe length were either significant or trended toward significance in its correlation with jumping performance. All of these correlations had negative slopes.

	Performance	
	Males	**Females**
CMJ (cm)	36.6 ± 5.9	26.1 ± 3.6
SJ (cm)	35.7 ± 6.9	26.3 ± 4.6
	Anthropometry	
	Males	**Females**
Mass (kg)	85.6 ± 9.4	61.4 ± 11.4
Height (cm)	181.4 ± 6.3	166.1 ± 7.5
Upper Leg Length (cm)	46.9 ± 3.8	44.0 ± 3.8
Lower Leg Length (cm)	37.1 ± 2.3	33.9 ± 3.0
Foot Length (cm)	26.6 ± 1.1	23.9 ± 1.2
Toe Length (cm)	7.0 ± 0.6	6.2 ± 0.5
Moment Arm (cm)	5.0 ± 0.5	4.4 ± 0.3
Arch Height (cm)	7.3 ± 0.4	6.5 ± 0.3

Table 1. Mean and standard deviation of performance and anthropometric measures for males and females. All performance and anthropometric values were significantly different ($p < 0.05$).

Pooling the data of all subjects (combining sexes), all anthropometric measures were positively correlated with CMJ height ($p < 0.05$). For SJs, mass, height, foot length and arch height were positivity correlated with jump height ($p < 0.05$). However, upon further inspection of data, it is evident that males, who jump higher than females, also exhibit larger anthropometric values, which naturally leads to these positive correlations between jump height and anthropometric measures (Figure 2).

	CMJ		**SJ**	
	r	***p***	**r**	***p***
Height	0.229	0.317	0.196	0.394
Weight	-0.079	0.733	-0.063	0.788
Upper Leg Length	0.285	0.210	0.210	0.360
Lower Leg Length	0.052	0.822	0.053	0.819
Foot Length	-0.062	0.788	-0.120	0.605
Toe Length	0.105	0.652	-0.025	0.915
Moment Arm	-0.208	0.365	-0.217	0.345
Arch Height	0.056	0.810	-0.091	0.694

Table 2. Correlation coefficient and significance values between anthropometric values and performance measures for males. No correlations were significant with all $p > 0.05$.

	CMJ		**SJ**	
	r	***p***	**r**	***p***
Height	-0.351	0.118	-0.346	0.124
Weight	-0.377	0.092	-0.464	**.0340***
Upper Leg Length	-0.219	0.339	-0.159	0.490
Lower Leg Length	-0.123	0.595	-0.201	0.383
Foot Length	-0.533	**0.013***	-0.463	**0.035***
Toe Length	-0.604	**0.004***	-0.401	0.072
Moment Arm	-0.223	0.332	-0.311	0.170
Arch Height	-0.088	0.706	-0.101	0.662

Table 3. Correlation coefficient and significance values between anthropometric values and performance measures for females. * Significant correlation ($p < 0.05$)

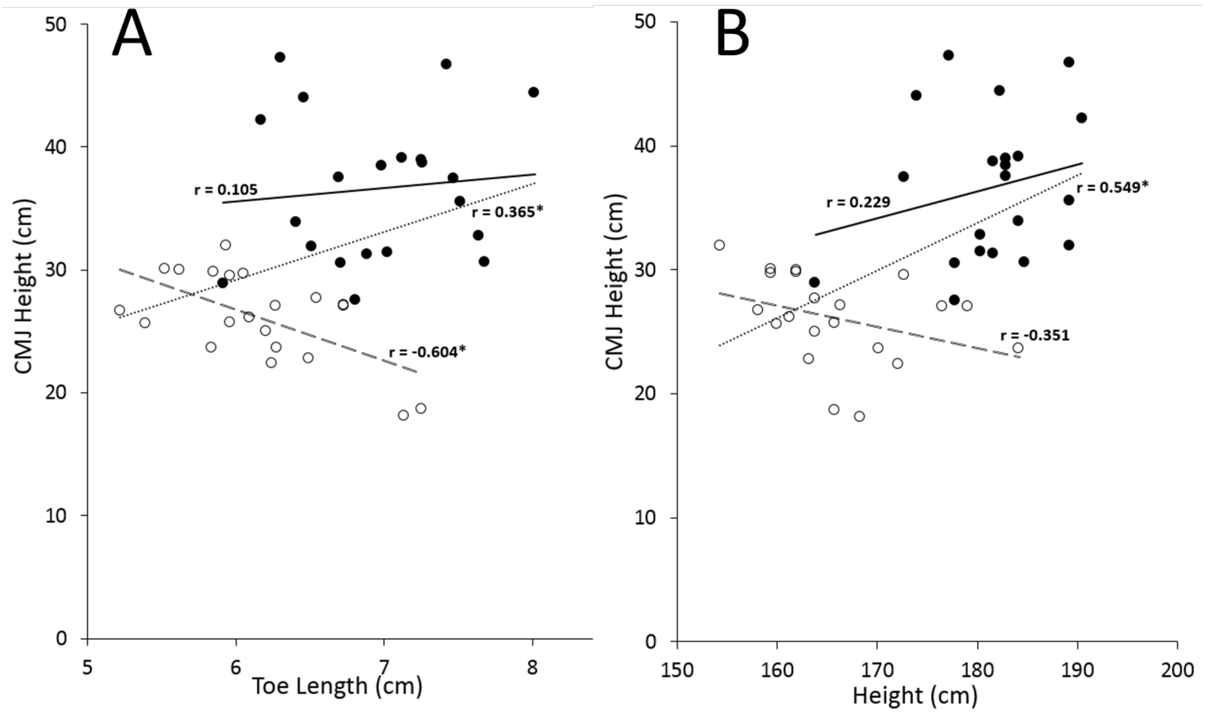

Figure 2. Example of relationship between CMJ height and toe length (**A**) and CMJ height and height or stature (**B**). **A.** For females (*open circles, dashed line*), a significant negative correlation exists between CMJ height and toe length. For males (*closed circles, solid line*), the correlation is not significant. For the combined group a significant positive correlation exists between CMJ height and toe length (*dotted line*). **B.** There is no significant correlation for females (*open circles, dashed line*) or males (*closed circles, solid line*) between CMJ height and body height. However the combined groups shows a significant positive correlation (*dotted line*). * Significant correlations ($p<0.05$)

Discussion

In general, males are have significantly larger anthropometric values and jump higher than females. There were significant differences between males and females in performance and anthropometric measures. For males, no anthropometric measures predicted jump performance. For females, foot length and toe length predicted CMJ performance, while foot length and weight predicted SJ performance. Toe length, foot length, and weight produced negative correlations with jump performance for females.

Males performed significantly higher CMJs and SJs than females. This could be due to a multitude of factors including increased height, increased upper leg length and lower leg length (Aouadi et al., 2012), and increased muscle mass. With more muscle mass, males can produce a higher rate of force development and peak force during take off, increasing the height of their jumps. The positive correlation between toe length, heel length, and jump performance for males and females, as a whole, is due to males generally have larger anthropometric values. This would mean that they have longer toes and longer heels, as well as jump higher. Therefore, the correlation between these anthropometric measures and jump performance may not be functionally significant because it is purely due to a difference in general size between the two sexes.

We hypothesized that shorter heels would predict a higher jump. This hypothesis was not supported, and it is unclear why we did not find this to be true. Although males and females had significantly different heel length values, with males having significantly longer heels, heel length did not correlate with jump height for either sex. Our hypothesis was based on the idea that sprinters typically have shorter heels (Lee & Piazza, 2009), and that since sprinting has been compared to jumping in previous studies (Aouadi et al., 2012; Lockie et al., 2015), jumpers would also have a shorter heel length. However, studies that compare jumping to sprinting are not correlational. They simply compare measures from a sprinting group to measures from a jumping group (Aouadi et al., 2012). Since the two movements are, in fact, different, a longer moment arm may be beneficial to jumpers. More studies need to be done on the subject to reach a conclusion.

There was no relationship between toe length and jump height for males, yet there was a significant relationship between toe length and CMJs for females. In addition, foot length was significantly related to CMJs and SJs, as well as weight for SJs in females. These relationships indicate that females with smaller toes and feet, as well as women who weigh less, jump higher. This may indicate a size principle, where smaller females produce higher jumps. The reason why smaller females produced higher jumps is unclear. However, females who participate in particular sports requiring a lot of jumping and training, such as dance, are generally smaller. Female dancers typically have less body mass compared to a normative female (Clarkson et al., 1989). Therefore it is possible that having smaller anthropometric features is more beneficial for females. More research needs to be done on the subject to determine if this size principal exists.

Although males and females had significantly different arch height values, with males having significantly higher arches, arch height did not correlate with jump height for either sex. We hypothesized that a higher arch would predict a higher jump based on the idea that storage of energy in the arch has been shown to be useful in sprinting (Chang et al., 2010), but jumping is a different movement than running. Studies need to be conducted specifically determining the relationship between arch height and jump performance.

For males, no anthropometric measures predicted jump height. In contrast, toe length, foot length, and weight predicted jump height for females. More studies need to be conducted to understand why these differences may occur. From the data obtained in this study, it could be hypothesized that females with smaller anthropometric measures (shorter toes, shorter feet, less weight, etc.) jump higher. These females could potentially be training more, such as the case with dancers, which would make them better at jumping and performance tasks. Training may also improve male jump performance, but smaller anthropometric measures will not. Research looking at jump performance and anthropometric measures in activity-specific populations needs to be conducted.

Another reason our hypothesis was disproved may be that our subject pool was different than previous studies done on the subject. Many previous studies only included males as well as a lesser number of subjects than our study (Fattahi et al., 2012; Aouadi et al., 2012; Baxter et al, 2011). Individual anthropometric differences may affect jump performance. In addition, individual experiences with jumping may affect jump performance. Subjects who have participated in sports involving jumping their entire lives, such as dancing or basketball, may be predisposed to jump higher. Other subjects who were not involved in activities requiring a lot of jumping may not be comfortable with the task or as good at it.

More studies need to be conducted to determine the effects of various anthropometric measures such as arch height, toe length, and heel length on jumping. Anthropometric measures beneficial to sprinters may not be beneficial to jumpers. Since males are generally larger than females in all anthropometric measures, they jump higher. The only significant results were that women with shorter toes and heels, and lower weight, jumped higher than their female counterparts. Shorter toes and heels do not fit our hypothesis, and therefore need more studies conducted on the subject.

Literature Review

Introduction

Previous studies have been conducted to determine the effect of gross anthropometric measures such as height, leg length, body mass, etc. on jumping tasks. More recent studies attempted to determine the relationship between local measures specifically related to the foot and sprinting and/or running (e.g. Scholz et al, 2008; Baxter et al, 2011) and mobility in elderly populations (Lee & Piazza, 2012). However, two anthropometric measures, foot arch height and ankle muscle moment arm, have not been studied as pertaining to jumping tasks. In addition, previous studies focus on male populations specifically. Therefore, the purpose of this literature review is to review previous work done on the relationship between anthropometric measures and jump performance, as well as lower extremity anthropometry in other tasks.

Anthropometry and Jumping

Various anthropometric measures such as stature, weight, lower limb length, etc. have been studied in relation to jumping. Fattahi et al. (2012) looked at seventeen different measurements in relation to jump height. In the case of elite male volleyball spikers and setters, they found a significant relationship between shank length, foot length, weight, and maximum calf circumference and vertical jump height. For liberos, there was a significant relationship between weight and vertical jump height. A larger weight produced a negative effect on vertical jump height, decreasing the height of the jump, while a larger shank length, foot length, and/or maximum calf circumference had positive effects, or increased the height of the jump. Also studying elite male volleyball players, Aouadi et al. (2012) found that stature is a significant predictor of vertical jump height. The taller a player was, the higher the jump was. Similarly, players with longer lower limbs produced higher vertical jumps. This is because taller players, or players with longer lower limbs, were able to produce more anaerobic power.

A very important determinant in many jumping and sprinting related activities is the moment arm, similar to heel length. Many studies agree that a shorter moment arm is more beneficial. This is because a shorter moment arm correlates with larger joint moment development, larger joint power output and larger joint work output. A smaller moment arm results in a lesser muscle shortening velocity for the same amount of rotation than a larger moment arm. This then results in larger muscle force development (Nagano et al., 2003). We can then take this evidence and predict that a smaller moment arm will result in a higher vertical jump. In addition, athletes with shorter limbs, or levers, allows the resistance to the movement being performed closer to the axis of rotation. However, only focusing on the length of limbs to determine jumping performance will not yield accurate results. In actuality, athletes who participate in jumping sports are typically tall with long lower limbs relative to trunk length (Ackland, 2009).

Very little research has been done on the relationship between arch height and vertical jump height. However, higher arches decrease mediolateral control of a single-limb stance, therefore reducing single-leg balance (Cobb et al., 2014). Presumably, this would also negatively affect balance during a double-leg stance since both feet have less surface area in contact with the ground. This would eventually lead to a smaller vertical jump height.

Lower Extremity Anthropometry in Other Tasks

Though most research shows that longer lower extremities are preferable for a larger vertical jump height, the opposite is true for optimal sprinting capacity. Elite sprinters generally have shorter lower extremities, shorter moment arms, and longer toes. On average, sprinters have 25% shorter Achilles' tendon moment arms than non-sprinters. Longer toes allow for more time of contact with the ground, therefore creating a greater acceleration due to ground reaction force. Thus, these variations allow sprinters to create more forward impulse (Lee & Piazza, 2009). The idea that a shorter moment arm is preferable for a sprinter is in agreement with most studies conducted on the subject. Another study by Baxter et al. (2011) found that sprinters have shorter plantarflexor moment arms. In addition, sprinters have longer forefoot bones, which would be in agreement with sprinters having longer toes. According to Baxter et al. (2011), differences in the center of rotation of a foot while sprinting may be due to the length of the moment arm. Also suggested is the idea that a shorter rearfoot, or larger ratio of forefoot to rearfoot length, would be beneficial for sprinters.

Shorter moment arms are beneficial in tasks other than sprinting. Studies on both older male adults (Lee & Piazza, 2012) and long distance runners (Scholz et al, 2008) show a relationship between increased performance and shorter moment arms. In long distance runners, a longer Achilles' tendon moment arm correlates with higher oxygen uptake during a maximal oxygen consumption testing protocol (Mooses et al., 2015). This means that long distance runners with longer Achilles' tendon moment arms are requiring more oxygen and have worse running economies. The length of the moment arm directly correlates to running economy. In a study by Scholz et al. (2008), there was a significant relationship between shorter Achilles' tendon moment arms and reduced metabolic energy consumption. It was suggested that runners with a shorter Achilles' tendon moment arm would have higher values of elastic energy recoil during running. In other words, these runners can convert a higher percent of kinetic energy into elastic energy. Yet other studies disagree. Kunimasa et al. (2014) found that in long distance runners, a longer Achilles' tendon moment arm and lower foot lever ratio improve running performance. This is because by having a longer Achilles' tendon moment arm, the required muscle activity and Achilles' tendon force during running is reduced. More studies need to be done to determine if a shorter or longer Achilles' tendon moment arm is beneficial.

In the case of older adults, a shorter moment arm might be more related to the 6-Minute Walk Test, used to determine functionality in older adults with reduced mobility, than ankle strength or power and walking velocity (Lee & Piazza, 2012).

Another anthropometric measure considered in running performance is the calcaneal tuber, similar to moment arm. A shorter calcaneal tuber may reduce energy costs during running. This evolutionary change was brought on by a change in the climate that Homo sapiens inhabited. However, a shorter calcaneal tuber may have no effect on energy costs during walking (Raichlen et al., 2011). Though many different anthropometric measures correlate with greater abilities, no single measure can completely explain differences in running economies and/or sprinting abilities (Barnes et al., 2014).

There is conflicting research concerning toe length and running ability. Lee & Piazza (2009) found that sprinters have longer toes and that this is actually helps them achieve greater acceleration. However, a study by Rolian et al. (2009) argues that having shorter toes decreases the cost of flexing toes during bipedal locomotion, and therefore is more beneficial than longer toes for long distance runners. Increasing toe length by as much as 20% can double the amount of required mechanical work and metabolic cost. In a study focusing on running economy and running performance in distance runners, longer upper leg length, total leg length, and total leg length to body height ratio correlated with better running performance. However, running performance was not associated with running economy (Mooses et al., 2015). This suggests that many factors contribute to running performance and running economy. Likewise, many factors beyond lower body anthropometry will contribute to vertical jump height.

Jumping as Related to Running and Walking

Vertical jump height correlates with and can predict running velocity (Lockie et al., 2015). Therefore, we can assume that running velocity, or sprinting, will predict vertical jump height. Since we know that more elite sprinters have shorter moment arms and other various anthropometric measures to explain their abilities, we may infer that these qualities will be present in subjects with higher vertical jumps. Such measures may include smaller moment arms, longer toes, longer forefoot bones, etc.

In terms of running economy, the correlation with jumping or hopping is weak (Hébert-Losier et al., 2014). Therefore, jumping may only predict sprinting, or vice versa. This is probably because both a vertical jump and sprinting are anaerobic activities that require power and short bursts of energy. Running economy refers more to long distance running, an aerobic activity that requires exerting energy over a long period of time. Another study including amputee soccer players found that there is a significant relationship between squat jumps and sprinting as well as countermovement jumps and sprinting (Özkan et al., 2012). In contrast, a study by Vescovi et al. (2008) found that the relationship between a countermovement jump was stronger with longer distances rather than a typical sprint distance. However, they also concluded that a variety of tests are needed to determine the true relationship between sprinting, vertical jump height, and agility.

Differences Between Males and Females

Most research done on the relationship between anthropometric measures and jumping and/or sprinting involves only males. It is difficult to get a full picture of such measures with one sex excluded. Interestingly, Vescovi et al. (2008) found that jumping has a stronger relationship to long distance running rather than sprinting, opposite of most research. Yet this article only included females, whereas others include only males (Hébert-Losier et al., 2014; Lockie et al., 2015) or both males and females. Based on this evidence, we may be able to conclude that sprinting performance predicts vertical jump height in males whereas long distance running performance predicts vertical jump height in females. More research needs to be done on the subject, and more studies need to include females in order to gain an accurate compilation of evidence.

Methods of Measure

There are several methods to measure vertical jump height. The most common measurement device, and arguably most accurate, is the laboratory force plate. A laboratory force plate could record force data at frequencies up to 2000 Hz, much better than a portable force plate at 500 Hz. The laboratory force plate can be used to calculate acceleration by recording ground reaction force. Using this data, velocity can be calculated and then displacement of center of mass. Displacement of center of mass us used to determine the vertical jump height.

Less accurate, a belt mat feeds a tape measure through the center of a rubber mat. The tape measure is then connected to the subject's waist by a belt. The tape measure is fed through the mat until the subject reaches maximum height. The vertical jump height can then be read from the tape measure.

A contact mat records time of flight after the first depression of the mat when the subject takes flight until the second depression of the mat when the subject lands. An equation using time of flight and the gravitational constant determines vertical jump height.

A Vertec consists of a pole with plastic slabs stacked on top of each other in half-inch increments. The slabs can swivel around the pole so that the subject is able to displace them during a jump. The subject uses a swinging motion of the dominant arm during the vertical jump to reach the highest possible slab. The difference between standing reach height and jumping reach height is the vertical jump height.

The laboratory force plate is the most accurate method to measure vertical jump height, followed by the portable force plate and belt mat, and then the Vertec and contact mat (Buckthorpe et al., 2012).

Conclusion and Recommendations

Anthropometric measures such a moment arm length, toe length, lower extremity length, etc. are important in determining jumping, sprinting, and running abilities. It seems that a shorter moment arm length is beneficial for all three abilities. However, it is uncertain if longer or shorter toes are more beneficial to running and/or sprinting. Many other measures need additional research to determine their effectiveness. It is likely that a combination of all measures truly determines a person's ability to jump, and that each individual may be different. In addition to testing different measures, females need to be included in studies. This will give a more accurate depiction of what measures are beneficial to everyone, not just males. There seems to be a relationship between running, sprinting, and vertical jump height, so we can conclude that many measures affecting running and sprinting will also affect vertical jump height.

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