ORIGINAL ARTICLE

The relationship of foot anthropometry with countermovement jump and squat jump performance among male university-level athletes

Tim S. Babu. *Department of Sports Biomechanics. Central University of Rajasthan. Ajmer, India.*
Rohit Kumar Thapa . *Symbiosis School of Sports Sciences. Symbiosis International (Deemed University). Pune, India.*

ABSTRACT

This study assessed the relationship between foot anthropometry with countermovement jump (CMJ) and squat jump (SJ) performance among university-level male athletes. A total of 51 male athletes were selected from different sports. Various gross and acute anthropometric measurements were conducted. Each participant performed three CMJs and SJs each. Standing height has a moderate positive correlation with CMJ force (ρ = .368, p = .008) and power (ρ = .326, p = .019). Body mass demonstrated a high positive association with CMJ force (ρ = .568, p = .001) and a moderate positive correlation with power (ρ = .446, p = .001). The lower leg length was moderately positively correlated with CMJ flight time (ρ = .316, p = .024) (ρ = .311, p = .026), velocity (ρ = .304, p = .030), and power and showed a weak positive correlation with CMJ height (ρ = .290), p = .039). Foot length had a moderate positive correlation with CMJ force (ρ = .419, p = .002) and power (ρ = .377, p = .002). Conversely, a weak negative correlation was observed between foot arch height and both CMJ height (ρ = -.286, p = .042) and CMJ velocity (ρ = -.285, p = .043). These findings suggest the significant relationships between specific anthropometric characteristics with CMJ and SJ performance. However, the correlations showed moderate or lower strengths, underscoring the importance of further investigation.

Keywords: Performance analysis, Jump performance, Foot mechanics, Athletic performance, Muscular strength, Lower extremity.

Cite this article as:
Babu, T. S., & Thapa, R. K. (2025). The relationship of foot anthropometry with countermovement jump and squat jump performance among male university-level athletes. *Journal of Human Sport and Exercise, 20*(1), 157-168. https://doi.org/10.55860/2dzaj142

Corresponding author. *Symbiosis School of Sports Sciences, Symbiosis International (Deemed University), Pune, 412115, India.*
E-mail: rohit.thapa@ssss.edu.in
Submitted for publication July 17, 2024.
Accepted for publication September 02, 2024.
Published October 30, 2024.
Journal of Human Sport and Exercise. ISSN 1988-5202.

doi: https://doi.org/10.55860/2dzaj142

INTRODUCTION

Human feet are built uniquely to support the body's entire weight as permitted by foot anthropometry. The human foot is composed of around 100 muscles, ligaments, tendons, and 30 joints, in addition to 26 bones, which are the phalanges (n = 14), tarsal (n = 7), and metatarsal (n = 5). These anatomical components cooperate to stabilize the foot movement and balance in static and dynamic conditions, shock absorption, and transferring ground reaction forces (Hazari et al., 2021).

Vertical jump movements are crucial in many sporting events, such as basketball, football, badminton, and volleyball. Sometimes, jumping movements play a decisive role during a match. Whether it's a footballer jumping to score a header goal, a basketball player leaping to shoot a ball towards the basket, smashing the shuttlecock by a badminton player, or a volleyball player trying to spike the ball, this action can have an impact on the outcome of the match (Washif & Kok, 2022). Vertical jumps are widely used in athlete's training and testing (i.e., assessment). Vertical jump tests are commonly used to assess the lower limb power of athletes. Furthermore, jump training can also develop lower body strength and power and can contribute to enhanced neuromuscular control, landing mechanics, joint stability, and overall lower body strength (Markovic, 2007; Ramirez-Campillo et al., 2023; Thapa et al., 2024).

Two commonly used vertical jump assessments are the countermovement jump (CMJ) and squat jump (SJ) tests. CMJ is performed from the normal standing position with a quick downward movement and jumps vertically with the aim of achieving maximum height (Suchomel et al., 2016), where utilization of the stretch-shortening cycle (SSC) takes place. The SSC involves lengthening of the muscle (i.e., eccentric phase) followed by shortening of the muscle (i.e., concentric phase). In contrast, the squat jump starts from the squat position (i.e., ~3-5 seconds pause) and then jumps as high as possible. The pause during the squat position prevents the SSC from occurring and thus mainly focuses on the concentric phase of the muscle contraction (i.e., shortening of the muscles). Thus, such an assessment allows for measuring the concentric muscle power and force generation without elastic energy involvement (Petrigna et al., 2019).

The measurement of CMJ and SJ performance is plausible with a validated and reliable mobile-based video analysis software My Jump Lab (Şentürk et al., 2024). The application is an affordable alternative to expensive equipment (e.g., force platforms) (Bogataj et al., 2020). It uses the ability of the mobile to capture video in slow motion, which is then used for further analysis. For the evaluation of the flight time of CMJ and SJ the software uses the slow-motion video to estimate the participant's jump take-off and landing frames. An equation (Bosco et al., 1983) is then used to calculate the jump height using flight time from the recorded video. The equation used in the application is $h = t^2 \times 1.22625$, 'h' is the height in meters of the jump, and 't' denotes the flight time of the jump in seconds. It is a widely used method for calculating jump height from flight time (Balsalobre-Fernández et al., 2015). In addition, the application also uses a simple computational method using the body mass, push-off distance, and jump height to estimate force, velocity, and power during jumps, which has been validated and found reliable (Jiménez-Reyes et al., 2017).

Understanding the connection between foot structure and vertical jump has important implications. There is a gap in research on the effect of toe length, heel length, arch height, and the maximum range of motion on vertical jump performance. The relationship between the different parameters of foot anthropometry and vertical jumps, such as CMJ and SJ performance, needs to be established in the literature. The study hypothesizes that there is a significant correlation between the anthropometric measurement of the foot and an individual's vertical jump performance. A shorter foot length and heel length can produce a greater vertical height, and a greater arch height, toe length, plantar flexion, and dorsiflexion will positively correlate with a higher vertical jump height.

MATERIAL AND METHODS

Participants

Fifty-one male athletes were recruited from Central University of Rajasthan. The age of the participants ranged between 18-26 years. The minimum requirement to be included in the study (i.e., inclusion criteria) was participation at the inter-university level competition in their respective games. Among the selected 51 participants, 14 participants played football, 9 participants played volleyball, 9 participants played cricket, 10 participants played basketball, 5 participants played badminton and 4 participants played. All the participants selected for the study had no history of musculoskeletal injury, history of lower limb surgery, or any other health condition during the data collection. All the participants provided their consent to participate in the study and signed informed forms after an explanation about the procedures and possible risks associated with the study.

Procedure

Familiarization session was conducted before the data collection to minimize the learning effect. During the familiarization session, the techniques of CMJ and SJ were explained and demonstrated. In addition, the explanation of the procedure for anthropometric measurements was also explained. Thereafter the experimental sessions included data collection for both the jumps and anthropometric measurement of the lower body and foot. All the assessments were conducted in an indoor hall of the university.

Anthropometric measurements

For the measurement of height, a stadiometer (Mediguard, JE Surgical Industries, India) was utilized. The standing height was measured with the participants standing erect without shoes in a stadiometer (Sørensen et al., 2020). In addition, a bioelectrical impedance machine (Charder Bioelectrical impedance, Taiwan) was used to measure the participant's body mass and BMI (Branco et al., 2023). A Gullick tape was used to measure the upper leg length, lower leg length, and calf muscle girth. Three measurements were taken for each, and the average was considered as the actual measurement for better accuracy (Rumbo-Rodríguez et al., 2021).

In the upper leg length measurement, the greater trochanter, the bony prominence on the lateral side of the upper thigh, nearer to the hip joint, was identified. The lateral knee joint line, which is the outermost point of the knee articulation where the tibia and femur bones meet, was located, and measurement was conducted (Schwab & Anighoro, 2022). Lower leg length was measured as the vertical distance from the head of the fibula to the most prominent part of the lateral malleolus. One end of the measuring tape was placed at the end of the lateral malleolus (Saeki et al., 2017). The Gulick tape was placed around the calf at the identified middle point in the largest circumference of the calf for the measurement (Kiss et al., 2024). The foot dorsiflexion and plantar flexion was measured using a goniometer (Patterson Medical Holdings Inc, Chaina). The participant's leg was marked at the midpoint between the lateral and medial malleoli. This mark was the reference point during the measurement. Participants were instructed to perform the dorsiflexion of the foot (i.e., bringing the top of the foot of the subject towards the shin). A ruler was set up on the surface which was parallel to the participant's heel. The distance between the reference mark on the ruler is the point where the foot dorsum is elevated during the dorsiflexion, was measured and recorded. For the measurement of plantar flexion, participants were asked to perform plantar flexion of the foot (i.e., pointing the foot downwards as much as possible without feeling any discomfort). The gap between the reference mark on the foot and ruler which is the point at where foot dorsum is at lower during the plantar flexion was measured and recorded (Pietrzak et al., 2022). All measurements were recorded in centimetres.

Foot anthropometric measurements

Three black marks were placed on the most visible part of the lateral malleolus, medial malleolus, and the first metatarsophalangeal joint. While sitting medial and lateral views of the right foot were digitally photographed using a high-resolution camera (Canon EOS 7D), where the foot was placed on a wooden block. On the side of the wooden block a millimetre-scale was placed for scaling. The tibia was aligned with respect to the reference box at a right angle. Each subject's right foot images were digitalized with a custom-designed MATLAB (The MathWorks, Inc., Natick, MA) code. The code measured the foot length, toe length, arch height, medial heel length, and lateral heel length by using the scaling provided by the millimetre scale in the images (Hawley, 2016).

Foot length is the horizontal distance between the most anterior part of the longest toe and the most posterior point of the calcaneus bone (Prasad & Rajasekhar, 2019). Toe length is the distance between the most distal portion of the big toe's proximal phalanx to the metatarsophalangeal joint big toe articulates with the corresponding metatarsal bone (Klein & Weil, 2020). Arch height is the vertical distance between the highest point of the longitudinal arch and the ground; navicular tuberosity is the midpoint of the arch. Lateral and medial heel length is the horizontal distance from the bottom of the heel and the most prominent part of the medial and lateral aspects of the malleolus, respectively. The average heel length was determined by summing the medial and lateral heel lengths, and the average heel length was used as the heel length (Hawley, 2016).

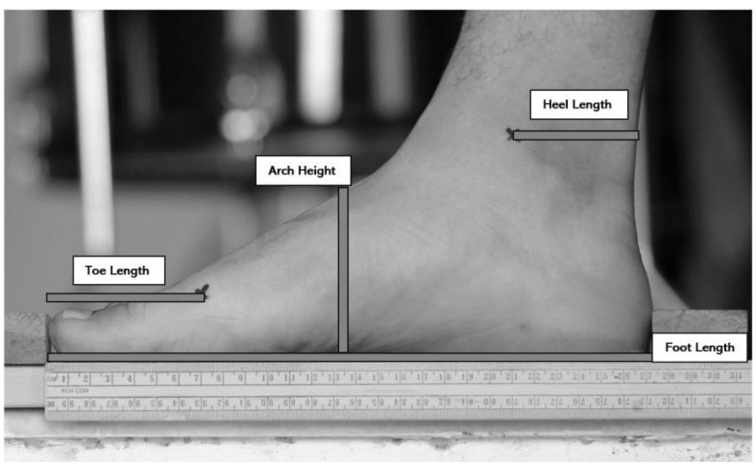

Figure 1. Medial foot anthropometric measures as determined by digital imaging.

Vertical jump measurements

The CMJ and SJ were recorded using an iPhone 12 mobile phone (Apple, India; HD 240 fps slow motion) and analysed with a validated and reliable mobile application (MyJump2). The video was recorded with the camera placed on a tripod at a height of ~40 cm from the ground surface and ~3 meters away from the participants. All videos were recorded from the sagittal plane and focused on capturing the take-off and landing phases of the jumps.

The participants performed a total of six jumps with no arm swing, 3 CMJs, and 3 SJs during the recording. The CMJs and SJs were performed in random order to reduce the risk of learning impact on performance.

Participants were instructed to jump as high as possible. Between the same type of jumps, subjects rested for 30 seconds. The subject rested for 3 minutes between differing jumps.

Statistical analysis
Data are presented as median and interquartile range (IQR). The normality of the data was assessed using the Shapiro-Wilk test. As data were non-normally distributed, Spearman's rank correlation coefficient test was used to verify the relationship between the anthropometric measurements and vertical jump performance. The magnitude of the correlation between test measures was interpreted as trivial (≤0.1), low (0.1–0.3), moderate (0.3–0.5), high (0.5–0.7), very high (0.7–0.9), and almost perfect (0.9–1.0) (Hopkins et al., 2009). All the statistical analyses were conducted using SPSS (version 26). For testing the hypothesis, the level of significance was set at $p \leq .05$.

RESULTS

Descriptive statistics, including the number of participants, median, and IQR of anthropometric variables, are presented in Table 1. Moreover, in Table 2, descriptive statistics, including the number of participants, median, and IQR of CMJ and SJ performance, are presented.

Table 1. Descriptive statistics of anthropometric variables.

n = 51	Median	IQR
Height (cm)	174.30	8.80
Body mass (kg)	64.70	14.80
Body mass index (kg/m²)	21.50	3.40
Upper Leg Length (cm)	54.10	5.80
Lower leg Length (cm)	51.80	4.50
Calf Girth (cm)	35.20	3.70
Dorsiflexion(cm)	88.00	9.00
Plantar flexion(cm)	156.00	14.00
Foot Length(cm)	26.33	2.08
Toe Length(cm)	6.96	0.47
Heel Length(cm)	6.17	0.42
Arch Height(cm)	7.18	0.51

Table 2. Descriptive statistics of jump performance.

Countermovement jump performance (n = 51)		
	Median	IQR
Jump Height (cm)	33.67	8.30
Velocity(m/s)	1.28	0.15
Force (N)	1387.45	415.36
Flight Time(s)	518.0	66.00
Power(W)	1816.68	507.29
Squat jump performance (n = 51)		
	Median	IQR
Jump Height (cm)	32.52	7.49
Velocity(m/s)	1.26	0.15
Force (N)	1433.56	396.63
Flight Time(s)	512.00	61.0
Power(W)	1779.38	534.79

The Spearman correlation coefficients (ρ) and their corresponding p-values (p) between foot anthropometry and other anthropometric variables with performance metrics of CMJ are presented in Table 3. Height showed a significantly moderate positive association with CMJ force (ρ = .368, *p* = .008) and power (ρ = .326, *p* = .019). Body mass had a high positive correlation with CMJ force (ρ = .568, *p* = .001) and a moderate positive correlation with power (ρ = .446, *p* = .001). Body mass index had a moderate positive correlation with both CMJ force (ρ = .423, *p* = .002) and power (ρ = .0288, *p* = .041). The upper leg length did not show any significant correlation with any of the CMJ performance metrics. Lower leg length had a moderate positive correlation with CMJ jump height (ρ = .290), *p* = .039), flight time (ρ = .311, *p* = .026), velocity (ρ = .304, *p* = .030), and power (ρ = .316, *p* = .024). Calf girth had a significant but weak correlation with CMJ force (ρ =.304, *p* = .030). No correlations were found with any of the parameters and either plantar flexion or dorsiflexion.

Table 3. Relationship between anthropometric measurements and countermovement jump performance.

Variables	Jump height		Flight time		Velocity		Force		Power	
	ρ	*p*-value	ρ	*p*-value	ρ	*p*-value	ρ	*p*-value	ρ	*p*-value
Height	.203	.153	.177	.214	.212	.136	**.368***	.008	**.326***	.019
Weight	-.076	.595	-.096	.502	-.060	.677	**.568***	.001	**.446***	.001
BMI	-.240	.089	-.259	.067	-.227	.110	**.423***	.002	**.288***	.041
ULL	-.086	.547	-.099	.489	-.050	.729	-.118	.408	-.197	.167
LLL	**.290***	.039	**.311***	.026	**.304***	.030	.244	.084	**.316***	.024
Calf Girth	-.135	.346	-.103	.471	-.116	.419	**.304***	.030	.209	.141
Dorsiflexion	-.160	.261	-.126	.380	-.165	.246	.152	.287	.073	.610
Plantar flexion	.163	.252	.154	.281	.134	.350	.020	.888	.025	.860
Foot Length	.232	.101	.174	.223	.165	.247	**.419***	.002	**.377***	.006
Toe Length	-.001	.992	-.010	.945	-.052	.717	-.011	.937	-.009	.950
Heel Length	.160	.262	.143	.317	.119	.407	.118	.409	.135	.346
Arch Height	**-286***	.042	-.243	.085	**-285***	.043	.145	.311	.001	.993

*Note. BMI- Body Mass Index, ULL- Upper Leg Length, LLL-Lower Leg Length. * Correlation is significant at the .05 level.*

Table 4. Relationship between anthropometric measures and squat jump performance.

Variables	Jump height		Flight time		Velocity		Force		Power	
	ρ	p-value	ρ	p-value	ρ	p-value	ρ	p-value	ρ	p-value
Height	.188	.187	.177	.213	.201	.158	.209	.140	.252	.074
Weight	-.100	.484	-.195	.171	-.198	.164	**.447***	.001	**.304***	.030
BMI	-.226	.111	.257	.069	**-.277***	.049	**.399***	.004	.230	.104
ULL	.001	.995	.072	.613	.120	.401	-.106	.458	-.049	.732
LLL	**.327***	.019	.249	.078	.263	.062	.011	.940	.132	.357
Calf Girth	-.127	.375	-.167	.242	-191	.178	.202	.255	.096	.504
Dorsiflexion	-.150	.294	-.106	.457	-.124	.388	.172	.226	.079	.581
Plantar flexion	.184	.197	.091	.527	.062	.665	-.021	.883	.014	.920
Foot Length	.145	.311	.104	.468	.104	.469	.228	.108	.234	.098
Toe Length	.102	.477	.147	.303	.138	.334	.003	.986	.054	.706
Heel Length	.206	.147	.210	.139	.186	.192	.074	.607	.138	.333
Arch Height	-.164	.251	-.133	.353	-.153	.283	.104	.469	.000	.999

*Note. BMI- Body Mass Index, ULL- Upper Leg Length, LLL- Lower Leg Length. * Correlation is significant at the .05 level.*

There was a significant moderate positive association between foot length and CMJ power (ρ = .377, *p* = .002) and force (ρ = .419, *p* = .002). There was a notable weak negative correlation between arch height and CMJ height (ρ = -.286, *p* = .042), which indicates that subjects with higher arch height have the tendency for lower heights. For arch height and velocity, a weak negative correlation was found (ρ = -.285, *p* = .043), which indicates that higher arch height has a tendency for lower jump velocity during CMJ.

The Spearman correlation coefficients (ρ) and their corresponding p-values (p) between foot anthropometry and other anthropometric variables with performance metrics of SJ are presented in Table 4.

Body mass showed a significant moderate positive correlation with both SJ force (ρ = .447, *p* = .001) and power (ρ = .304, *p* = .030). BMI showed a moderate positive correlation with SJ force (ρ = .399, *p* = .004); a weak negative correlation was also found between BMI and SJ velocity (ρ = -.277, *p* = .049). Upper leg length was not associated with any of the SJ parameters. Lower leg length positively correlated with SJ jump height (ρ = .327, *p* = .019). Calf girth, dorsiflexion, plantar flexion, foot length, toe length, heel length, and arch height did not significantly correlate with any SJ performance parameters.

DISCUSSION

The study aimed to examine the foot anthropometric and other anthropometric variables that are related to the foot with CMJ and SJ performance parameters such as jump height, jump flight time, jump velocity, jump force, and jump power measured through a video-based mobile application. The Spearman correlation analysis was used to identify the relationship between the anthropometric variables and vertical jump performance. Our findings showed height had a moderate positive correlation with CMJ jump force and power. In addition, body mass showed a high positive association with force and a moderate positive association with power during the CMJ. Moreover, body mass showed a positive moderate correlation with both force and power during SJ performance. Of note, the lower leg length had a moderate positive correlation with flight time, velocity, and power and a weak positive correlation with the jump height during the CMJ. In addition, a moderate positive correlation was observed between foot length and force and power during CMJ, and there was a weak positive correlation with lower leg length and SJ height. A weak negative correlation was also observed between foot arch height and jump height and velocity during CMJ.

The moderate correlation between standing height and force and power during CMJ may be attributed to the interconnection between these variables. For example, previous studies have stated that taller individuals may produce more power during jumps due to their longer limbs and quantity of muscle (Nishioka & Okada, 2022). However, although taller individuals may have the biomechanical advantages of longer limbs, this advantage will not always correspond to higher CMJ performance (Marshall & Moran, 2015; McErlain-Naylor et al., 2014). The key determinants of CMJ height are muscle strength, power, and technique instead of standing height alone (Thomas et al., 2022). This is also reflected in our current findings, as the standing height was not correlated with the jump height during the CMJ. Indeed, as previously stated the jump force and power were significantly correlated to the jump height in our current study. In addition, the maximum strength and rate of force development are two important factors that influence jump height (Van Hooren et al., 2022). Although, we did not include maximal strength measurements or the rate of force development, it is possible that these factors contributed to the jump height.

Another finding from our study was a high positive correlation between the body mass and CMJ force and a moderate positive correlation with SJ force and both SJ and CMJ power. This may be possible because the body mass affects the jump forces and power during CMJ and SJ performance. For example, individuals with heavier body mass should produce higher absolute force to overcome the gravitational pull to achieve a similar jump height when compared to an individual with a lighter body mass. The variations in power and force output can be reduced, and more accurate comparisons between individuals with different body mass can be made when these forces are normalized to the body mass (i.e., using the relative values) (Thomas et al., 2022). The current study findings related to the force and power during vertical jumps with body mass reinforce these conclusions. Similar to those mentioned above, the BMI includes both the body mass and standing height of an individual for its calculation, and thus, the results (i.e., moderate positive correlation between body mass index with CMJ, SJ force, and power) may be influenced by both variables.

Furthermore, there was a weak positive correlation between lower leg length and CMJ height and a moderate positive correlation between lower leg length and SJ height. Lower leg length has been shown to impact jump height for both CMJ and SJ directly. The complicated interaction between muscle power, the angle of joints, and the length of the limbs are all components of the biomechanics of jumping (O'Brien et al., 2009; Sharma, 2017). It may be possible that jump performance can be enhanced by longer lower legs that provide a greater advantage and more effective force transfer during the jump phases (Anicic et al., 2023). This advantage might have improved the jump performance and helped to reach a high vertical jump performance (Anicic et al., 2023). In addition, the CMJ consists of a preparatory downward movement (i.e., the eccentric phase), which uses the stretch-shortening cycle action to increase the muscle power output (Turner & Jeffreys, 2010). Previous studies have reported that individuals who have longer lower leg lengths can produce a greater amount of ground reaction forces (Pereira et al., 2006), enabling the individual to jump higher and longer legs contribute to enhanced jumping performance by increasing higher power output (Risnawati & Jusrianto, 2020). This is because more production of force and torque during the push off phase is possible with longer lever arms (i.e., longer lower leg length) (Tomita et al., 2020). Longer lower legs can increase the moment arm, which allows for increased toque production and the greater torque can result in higher take off velocities (Chen et al., 2022), However, for the SJ, the starting position is from the squatting position, where the SSC is not applicable and thus assesses only the concentric muscle power (Markovic et al., 2004). Similar to the CMJ, the individuals with longer lower leg length may have a mechanical advantage during the push off phase as compared to those who have short lower limbs (Hornsby et al., 2017; Panoutsakopoulos & Bassa, 2023). This might be one of the possible reasons why both jump clearly showed a direct correlation between lower leg length and jump height (Hornsby et al., 2017). It is also possible that the aforementioned reasons are responsible for the positive correlation between the lower leg length and CMJ flight time.

Lastly, a positive moderate correlation was reported between the calf girth and force during CMJ. An increased muscle mass at the calf may increase the force production capability thus improving the jump height (Cengizel et al., 2021). In addition, various factors can affect the vertical jump performance, including the size of the body and the mechanics of the limb. These factors indicate that foot length might play a key role in the overall movement of the body during the jump performance. The interaction between different aspects such as strength of the muscle, joint angle, and movement techniques are the determinants of CMJ power (Nuzzo et al., 2008; Sheppard et al., 2008). Our study also reported a moderate positive correlation between foot length and CMJ force and power. Foot length might have impact on how force is interchanged during CMJ take-off and landing phases, affecting how well the individual is performing the jumps (Ho et al., 2019). In addition, our study also reported a weak negative correlation between foot arch height and CMJ height and CMJ velocity (i.e., as arch height decreases there is a tendency to achieve more jump height). Previous studies have found that the use of foot orthoses affects lower limb mechanics and vertical jump performance in basketball players with different foot arch types. Specifically, individuals with flat feet, which are characterized by a shorter arch height, exhibited a significant difference in counter movement jump (CMJ) performance compared to those with normal arch height.(Ho et al., 2019). In contrast, other studies have reported that a lower arch height is usually linked with flat feet, which can cause a reduction in the jump height and velocity of CMJ due to less effective force generation. This is because the arch height acts like a spring during the vertical jump performance, providing more cushioning to the foot, reducing sudden impact, and helping to reach greater jump heights during CMJ(Carlock et al., 2004; Gathercole et al., 2015).

There are a few limitations in our study that should be acknowledged. Firstly, the study included only male university-level athletes. Hence, the findings generated from this study should not be extrapolated to female or higher-level athletes. Secondly, the CMJ and SJ assessments were conducted using video-based software. Although video-based software is valid and reliable, using a gold-standard force platform would be suggested for future research studies. Thirdly, the study lacked information about the subjects' training history and proficiency in functional movement techniques, which are crucial for optimal performance in the CMJ and SJ. Lastly, the samples included participants from various sports backgrounds, which may have affected the findings. The current research may be used as a proof-of-concept study for future research focusing on athletes from a particular sport.

CONCLUSION

In conclusion, our study revealed that significant correlation between the anthropometry of the foot and lower limb with the performance of CMJ and SJ. However, the magnitude of the correlation ranged from low to moderate. While the study offers guidance for coaches working with athletes, further research is needed to explore the correlations found.

AUTHOR CONTRIBUTIONS

Conceptualization, T.S.B. and R.K.T.; methodology, T.S.B. and R.K.T; software, T.S.B.; formal analysis, T.S.B.; investigation, T.S.B.; resources, T.S.B.; data curation, T.S.B.; writing—original draft preparation, T.S.B.; writing—review and editing, R.K.T.; project administration, T.S.B. Both authors have read and agreed to the published version of the manuscript.

SUPPORTING AGENCIES

No funding agencies were reported by the authors.

DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

REFERENCES

Anicic, Z., Janicijevic, D., Knezevic, O. M., Garcia-Ramos, A., Petrovic, M. R., Cabarkapa, D., & Mirkov, D. M. (2023). Assessment of Countermovement Jump: What Should We Report? Life (Basel, Switzerland), 13(1), 190. https://doi.org/10.3390/life13010190

Balsalobre-Fernández, C., Glaister, M., & Lockey, R. A. (2015). The validity and reliability of an iPhone app for measuring vertical jump performance. Journal of Sports Sciences, 33(15), 1574-1579. https://doi.org/10.1080/02640414.2014.996184

Bogataj, Š., Pajek, M., Andrašić, S., & Trajković, N. (2020). Concurrent Validity and Reliability of My Jump 2 App for Measuring Vertical Jump Height in Recreationally Active Adults. Applied Sciences, 10(11), 3805. https://doi.org/10.3390/app10113805

Bosco, C., Luhtanen, P., & Komi, P. V. (1983). A simple method for measurement of mechanical power in jumping. European Journal of Applied Physiology and Occupational Physiology, 50(2), 273-282. https://doi.org/10.1007/BF00422166

Branco, M. G., Mateus, C., Capelas, M. L., Pimenta, N., Santos, T., Mäkitie, A., Ganhão-Arranhado, S., Trabulo, C., & Ravasco, P. (2023). Bioelectrical Impedance Analysis (BIA) for the Assessment of Body Composition in Oncology: A Scoping Review. Nutrients, 15(22), 4792. https://doi.org/10.3390/nu15224792

Carlock, J. M., Smith, S. L., Hartman, M. J., Morris, R. T., Ciroslan, D. A., Pierce, K. C., Newton, R. U., Harman, E. A., Sands, W. A., & Stone, M. H. (2004). The Relationship Between Vertical Jump Power Estimates and Weightlifting Ability: A Field-Test Approach. The Journal of Strength and Conditioning Research, 18(3), 534. https://doi.org/10.1519/R-13213.1

Cengizel, Elif & Cengizel, Çağdaş. (2021). Investigation of the relationship between calf circumference and jumping, speed, agility in young male basketball players. Journal of Sport and Health Research. 13. 33-42.

Chen, S., Wang, D., Zhang, Q., Shi, Y., Ding, H., & Li, F. (2022). Relationship Between Isokinetic Lower-Limb Joint Strength, Isometric Time Force Characteristics, and Leg-Spring Stiffness in Recreational Runners. Frontiers in Physiology, 12, 797682. https://doi.org/10.3389/fphys.2021.797682

Gathercole, R., Sporer, B., Stellingwerff, T., & Sleivert, G. (2015). Alternative Countermovement-Jump Analysis to Quantify Acute Neuromuscular Fatigue. International Journal of Sports Physiology and Performance, 10(1), 84-92. https://doi.org/10.1123/ijspp.2013-0413

Hawley, V. S. (2016). The relationship between foot anthropometry and jump performance (Doctoral dissertation, Appalachian State University).

Hazari, A., Maiya, A. G., & Nagda, T. V. (2021). Kinematics and Kinetics of Ankle and Foot Complex. In A. Hazari, A. G. Maiya, & T. V. Nagda, Conceptual Biomechanics and Kinesiology (pp. 165-180). Springer Singapore. https://doi.org/10.1007/978-981-16-4991-2_13

Ho, M., Kong, P. W., Chong, L. J., & Lam, W. (2019). Foot orthoses alter lower limb biomechanics but not jump performance in basketball players with and without flat feet. Journal of Foot and Ankle Research, 12(1), 24. https://doi.org/10.1186/s13047-019-0334-1

Hopkins, W. G., Marshall, S. W., Batterham, A. M., & Hanin, J. (2009). Progressive Statistics for Studies in Sports Medicine and Exercise Science. Medicine & Science in Sports & Exercise, 41(1), 3-12. https://doi.org/10.1249/MSS.0b013e31818cb278

Hornsby, W., Gentles, J., MacDonald, C., Mizuguchi, S., Ramsey, M., & Stone, M. (2017). Maximum Strength, Rate of Force Development, Jump Height, and Peak Power Alterations in Weightlifters across Five Months of Training. Sports, 5(4), 78. https://doi.org/10.3390/sports5040078

Jiménez-Reyes, P., Samozino, P., Pareja-Blanco, F., Conceição, F., Cuadrado-Peñafiel, V., González-Badillo, J. J., & Morin, J.-B. (2017). Validity of a Simple Method for Measuring Force-Velocity-Power Profile in Countermovement Jump. International Journal of Sports Physiology and Performance, 12(1), 36-43. https://doi.org/10.1123/IJSPP.2015-0484

Kiss, C. M., Bertschi, D., Beerli, N., Berres, M., Kressig, R. W., & Fischer, A. M. (2024). Calf circumference as a surrogate indicator for detecting low muscle mass in hospitalized geriatric patients. Aging Clinical and Experimental Research, 36(1), 25. https://doi.org/10.1007/s40520-024-02694-x

Klein, E. E., & Weil, L. (2020). 2nd Metatarsophalangeal Joint Pathology: Pre-dislocation Syndrome. In D. E. Tower (Ed.), Evidence-Based Podiatry (pp. 47-71). Springer International Publishing. https://doi.org/10.1007/978-3-030-50853-1_4

Markovic, G. (2007). Does plyometric training improve vertical jump height? A meta-analytical review. British Journal of Sports Medicine, 41(6), 349-355. https://doi.org/10.1136/bjsm.2007.035113

Markovic, G., Dizdar, D., Jukic, I., & Cardinale, M. (2004). Reliability and factorial validity of squat and countermovement jump tests. Journal of Strength and Conditioning Research, 18(3), 551-555. https://doi.org/10.1519/1533-4287(2004)18<551:RAFVOS>2.0.CO;2

Marshall, B. M., & Moran, K. A. (2015). Biomechanical Factors Associated With Jump Height: A Comparison of Cross-Sectional and Pre-to-Posttraining Change Findings. Journal of Strength and Conditioning Research, 29(12), 3292-3299. https://doi.org/10.1519/JSC.0000000000001008

McErlain-Naylor, S., King, M., & Pain, M. T. G. (2014). Determinants of countermovement jump performance: A kinetic and kinematic analysis. Journal of Sports Sciences, 32(19), 1805-1812. https://doi.org/10.1080/02640414.2014.924055

Nishioka, T., & Okada, J. (2022). Associations of maximum and reactive strength indicators with force-velocity profiles obtained from squat jump and countermovement jump. PLOS ONE, 17(10), e0276681. https://doi.org/10.1371/journal.pone.0276681

Nuzzo, J. L., McBride, J. M., Cormie, P., & McCaulley, G. O. (2008). Relationship Between Countermovement Jump Performance and Multijoint Isometric and Dynamic Tests of Strength. Journal of Strength and Conditioning Research, 22(3), 699-707. https://doi.org/10.1519/JSC.0b013e31816d5eda

O'Brien, T. D., Reeves, N. D., Baltzopoulos, V., Jones, D. A., & Maganaris, C. N. (2009). The effects of agonist and antagonist muscle activation on the knee extension moment-angle relationship in adults and children. European Journal of Applied Physiology, 106(6), 849-856. https://doi.org/10.1007/s00421-009-1088-4

Panoutsakopoulos, V., & Bassa, E. (2023). Countermovement Jump Performance Is Related to Ankle Flexibility and Knee Extensors Torque in Female Adolescent Volleyball Athletes. Journal of Functional Morphology and Kinesiology, 8(2), 76. https://doi.org/10.3390/jfmk8020076

Pereira, C. S., Silva, J. G. M., & Sacco, I. C. N. (2006). Effects of mild leg length discrepancy on vertical ground reaction forces in running. Journal of Biomechanics, 39, S544. https://doi.org/10.1016/S0021-9290(06)85237-1

Petrigna, L., Karsten, B., Marcolin, G., Paoli, A., D'Antona, G., Palma, A., & Bianco, A. (2019). A Review of Countermovement and Squat Jump Testing Methods in the Context of Public Health Examination in Adolescence: Reliability and Feasibility of Current Testing Procedures. Frontiers in Physiology, 10, 1384. https://doi.org/10.3389/fphys.2019.01384

Pietrzak, K., Miechowicz, I., Nowocień, K., Kraszewski, B., & Rzymski, P. (2022). The agreement and repeatability of measurements of ankle joint dorsiflexion and poplietal angle in healthy adolescents. Journal of Foot and Ankle Research, 15(1), 67. https://doi.org/10.1186/s13047-022-00572-1

Prasad, S. A., & Rajasekhar, S. S. S. N. (2019). Morphometric analysis of talus and calcaneus. Surgical and Radiologic Anatomy, 41(1), 9-24. https://doi.org/10.1007/s00276-018-2101-6

Ramirez-Campillo, R., Thapa, R. K., Afonso, J., Perez-Castilla, A., Bishop, C., Byrne, P. J., & Granacher, U. (2023). Effects of Plyometric Jump Training on the Reactive Strength Index in Healthy Individuals Across the Lifespan: A Systematic Review with Meta-analysis. Sports Medicine, 53(5), 1029-1053. https://doi.org/10.1007/s40279-023-01825-0

Risnawati, R., & Jusrianto, J. (2020). Relationship of Leg Muscle Explosion Power and Leg Length to High Jump Ability in Students of Physical Education Study Program Universitas Pendidikan Muhammadiyah Sorong. Proceedings of the Proceedings of the First International Conference on Science, Technology and Multicultural Education, ICOCIT-MUDA, July 25th-26th, 2019, Sorong, Indonesia. Proceedings of the First International Conference on Science, Technology and Multicultural Education, ICOCIT-MUDA, July 25th-26th, 2019, Sorong, Indonesia, Sorong, Indonesia. https://doi.org/10.4108/eai.25-6-2019.2294307

Rumbo-Rodríguez, L., Sánchez-SanSegundo, M., Ferrer-Cascales, R., García-D'Urso, N., Hurtado-Sánchez, J. A., & Zaragoza-Martí, A. (2021). Comparison of Body Scanner and Manual Anthropometric Measurements of Body Shape: A Systematic Review. International Journal of Environmental Research and Public Health, 18(12), 6213. https://doi.org/10.3390/ijerph18126213

Saeki, J., Ikezoe, T., Nakamura, M., Nishishita, S., & Ichihashi, N. (2017). The reliability of shear elastic modulus measurement of the ankle plantar flexion muscles is higher at dorsiflexed position of the ankle. Journal of Foot and Ankle Research, 10(1), 18. https://doi.org/10.1186/s13047-017-0199-0

Schwab, J. M., & Anighoro, K. (2022). Understanding Leg Length and Offset. In J. M. Matta & A. P. Sah (Eds.), Anterior Hip Replacement (pp. 271-281). Springer International Publishing. https://doi.org/10.1007/978-3-030-91896-5_21

Şentürk, D., Yüksel, O., & Akyildiz, Z. (2024). The concurrent validity and reliability of the My Jump Lab smartphone app for the real-time measurement of vertical jump performance. Proceedings of the

Institution of Mechanical Engineers, Part P: Journal of Sports Engineering and Technology, 17543371241246439. https://doi.org/10.1177/17543371241246439
Sharma, H. B. (2017). Anthropometric Basis of Vertical Jump Performance: A Study in Young Indian National Players. Journal of Clinical and Diagnostic Research. https://doi.org/10.7860/JCDR/2017/23497.9290
Sheppard, J. M., Cronin, J. B., Gabbett, T. J., McGuigan, M. R., Etxebarria, N., & Newton, R. U. (2008). Relative Importance of Strength, Power, and Anthropometric Measures to Jump Performance of Elite Volleyball Players. Journal of Strength and Conditioning Research, 22(3), 758-765. https://doi.org/10.1519/JSC.0b013e31816a8440
Sørensen, G. V. B., Riis, J., Danielsen, M. B., Ryg, J., Masud, T., Andersen, S., & Jorgensen, M. G. (2020). Reliability and agreement of a novel portable laser height metre. PLOS ONE, 15(4), e0231449. https://doi.org/10.1371/journal.pone.0231449
Suchomel, T. J., Lamont, H. S., & Moir, G. L. (2016). Understanding Vertical Jump Potentiation: A Deterministic Model. Sports Medicine, 46(6), 809-828. https://doi.org/10.1007/s40279-015-0466-9
Thapa, R. K., Sarmah, B., Chaware, U., Afonso, J., Moran, J., Chaabene, H., & Ramirez-Campillo, R. (2024). Fast and Slow Jump Training Methods Induced Similar Improvements in Measures of Physical Fitness in Young Females. Women in Sport and Physical Activity Journal, 32(1), wspaj.2023-0071. https://doi.org/10.1123/wspaj.2023-0071
Thomas, C., Jones, P. A., & Dos'Santos, T. (2022). Countermovement Jump Force-Time Curve Analysis between Strength-Matched Male and Female Soccer Players. International Journal of Environmental Research and Public Health, 19(6), 3352. https://doi.org/10.3390/ijerph19063352
Tomita, D., Suga, T., Terada, M., Tanaka, T., Miyake, Y., Ueno, H., Otsuka, M., Nagano, A., & Isaka, T. (2020). A pilot study on a potential relationship between leg bone length and sprint performance in sprinters; are there any event-related differences in 100-m and 400-m sprints? BMC Research Notes, 13(1), 297. https://doi.org/10.1186/s13104-020-05140-z
Turner, A. N., & Jeffreys, I. (2010). The Stretch-Shortening Cycle: Proposed Mechanisms and Methods for Enhancement. Strength & Conditioning Journal, 32(4), 87-99. https://doi.org/10.1519/SSC.0b013e3181e928f9
Van Hooren, B., Žiga Kozinc, Smajla, D., & Šarabon, N. (2022). Isometric single-joint rate of force development shows trivial to small associations with jumping rate of force development, jump height, and propulsive duration. JSAMS Plus, 1, 100006. https://doi.org/10.1016/j.jsampl.2022.100006
Washif, J. A., & Kok, L.-Y. (2022). Relationships Between Vertical Jump Metrics and Sprint Performance, and Qualities that Distinguish Between Faster and Slower Sprinters. Journal of Science in Sport and Exercise, 4(2), 135-144. https://doi.org/10.1007/s42978-021-00122-4

