Journal of Coaching and Sports Science
Volume 4, Issue 2, 71-86.
e_ISSN: 2963-1483
https://www.journal.foundae.com/index.php/jcss/index
DOI: 10.58524/jcss.v4i2.742

Body Composition, Hand Grip Strength, and Leg Strength in Various Sports

Al Azim
Rajshahi University,
BANGLADESH

Houda Bougrine
Gafsa University,
TUNISIA

Jakir Hossain
Rajshahi University,
BANGLADESH

Ismail Laher
University of British Columbia,
CANADA

Karuppasamy Govindasamy
Symbiosis International (Deemed University),
INDIA.

Ayoub Saeidi
University of Kurdistan,
IRAN

Hassane Zouhal*
International Institute of Sport Sciences (2I2S), FRANCE.
Sport Performance Optimisation Research Laboratory (LR09SEP01), National Center for Medicine and Science (CNMSS), Tunisia.

Article Info

Article history:
Received: May 17, 2025
Revised: June 23, 2025
Accepted: August 17, 2025

Keywords:
Body composition;
Hand grip strength;
Leg strength ratio;
Lean body mass;
Body fat mass.

Abstract

Background: Body composition, leg strength ratio, and handgrip strength could significantly affect and predict aspects of health and athletic performance. We explored the association between body composition (BC), leg strength (LSR), and hand grip strength (HGS) among university athletes in different sports.
Aims: to investigate the multiple influences of these physical factors through other sports to provide a more integrated understanding of the total effect of these factors on athlete performance and selection.
Methods: Sixty-six university athletes (age: 22.76± 2.11y, BMI 21.57± 3.04 kg/m2) were enrolled for our study. The participants (39 males and 27 females) participated in cricket, volleyball, and athletics. Body composition (BC), including lean body mass (LBM), muscle mass (MM), skeletal muscle mass (SMM), body fat mass (BFM), basal metabolic rate (BMR), hand grip strength (HGS), and leg strength ratio (LSR), was assessed. A chi-square test and independent sample t-tests analyzed the differences between categorical and continuous variables. A one-way ANOVA was used to analyze the multiple comparisons (BMR, LSR, BFM, and HGS) across cricket, volleyball, and track and field athletes.
Results: The mean BFM in volleyball players was higher than in track and field athletes (14.20 ± 6.28 vs 8.44 ± 3.15, $p<0.05$). Analysis with a linear regression model adjusted for age, sex, BMI, and smoking habit indicated that LBM and BFM of participants were positively associated with HGS ($p<0.05$). However, an increase in HGS was associated with greater LSR in cricket ($p< 0.001$), volleyball ($p <0.0001$), and track and field athletes ($p< 0.01$).
Conclusions: Our findings suggest that body composition, hand grip strength, and leg strength may be useful in player selection and improving performance for specific sports. Our results indicate increased hand grip strength is associated with greater leg strength.

To cite this article: Al Azim., Bougrine, H., Hossain, J., Laher, I., Govindasamy, K., Saeidi, A., & Zouhal, H. (2025). Body composition, hand grip strength, and leg strength in various sports. *Journal of Coaching and Sports Science, 4*(2), 71-86. https://doi.org/10.58524/jcss.v4i2.742

INTRODUCTION

Body mass is determined by the sum of different body segments (Bazzocchi et al., 2016; Stagi et al., 2021; Motimath & A, 2025). Body composition (BC) has a four-compartment molecular and three-compartment tissue models. The three-compartment tissue model is widely used in

Corresponding author:
Zouhal, H., International Institute of Sports Science (2I2S), FRANCE, ✉hassane.zouhal@gmail.com

clinical and research settings to determine body composition (Moon et al., 2008), and describes the relationship between fat-free mass (FFM) and fat mass (FM) as well as the attainment of a low body fat percentage (%BF) and which are all considered desirable factors for athletes (Fields et al., 2018). Body composition is more than just body weight; it also looks at the proportions of different tissues and how they affect health (Prado & Heymsfield, 2014). Knowledge of BC improves performance according to sport-specific body size (Slater et al., 2018). Body composition is important for assessing performance and physical fitness before, during, and after sporting competitions and in practice sessions (Trexler et al., 2017). It influences an athlete's strength, speed, agility, endurance, flexibility, and overall performance (Silva, 2019). Measuring body composition and muscle features in teenage athletes can provide information about their susceptibility to injuries and peak performance (Tabassum & Azim, 2024).

Lean body mass (LBM), muscle mass (MM), skeletal muscle mass (SMM), and basal metabolic rate (BMR) each have specific functions in defining total body composition (Abidin, 2023). Furthermore, lean body mass is an important indicator of general and athletic health. It is commonly used in various sectors, including medicine, fitness, and nutrition, to assess a person's physical state (Prado & Heymsfield, 2014). Measuring and maintaining an appropriate LBM is important for athletes, gymnasts, and dancers regarding their strength, power, and overall physical performance (Fahs et al., 2020; Lobo et al., 2024). Muscle mass refers to the amount of muscle tissue in the human body. Muscle tissue comprises fibers that contract and generate force, allowing movement, stability, and posture (Blemker et al., 2024). A person's muscle mass determines how strong they are and how efficiently they can do various physical tasks. Maintaining adequate muscle mass is crucial for general health because it supports functional movements, bone health, and metabolic well-being (Argilés et al., 2016). Skeletal muscle mass is the total weight of skeletal muscle tissue, which allows for body movement (Tagliaferri et al., 2015).

Basal metabolic rate is the minimum energy (calories) required to sustain physiological activities at rest (Pavlidou et al., 2023). Age, gender, body composition, genetics, general health, smoking habit, and body cell mass impact BMR (Jeong et al., 2021 ;Ning et al., 2024). Leg muscle strength ratio (LSR) influences sprinting speed and performance regarding acceleration and force production (Pandy et al., 2021). The relationship between leg strength and variables, such as anaerobic performance, flexibility, and injury prevention, has been extensively observed in sports like wrestling, gymnastics, football, volleyball, basketball, and handball (Çimen Polat et al., 2018; Teixeira et al., 2015). BC and LSR have a strong relationship with muscle strength and body mass, especially LBM (Caspersen et al., 1985). Grip strength and leg press power correlate positively (Winger et al., 2021).

Another fitness parameter, handgrip strength (HGS), predicts various aspects of health, such as physical fitness, hand functionality, and nutritional status (Al-Asadi, 2018; Jarrett et al., 2020). Its predictive value is influenced by age, gender, BMI, and hand dimensions, among other factors (Jaafar et al., 2023). HGS is a basic measure of physical well-being and is important in activities that involve grabbing or gripping, as well as an individual's work capability (Hossain Parash et al., 2022). The measurement of HGS is important in evaluating the functional capacity of the upper extremities and the general physical health of athletes, such as those at the elite and sub-elite levels, who perform Olympic-style weightlifting (Erdağı, 2020). Hand grip strength (HGS) in cricketers has a positive correlation with height, weight, BMI, and hand and arm dimensions such as hand width, hand length, forearm length, arm length, and upper extremity length (Shanbhag & Kumar , 2021). In cricket and football, dominant HGS correlates positively with weight, height, mid-upper-arm circumference (MUAC), mid-upper arm diameter, mid-upper arm area, corrected mid-upper arm muscle area, and mid-upper arm fat area, BMI, percent body fat, and percent lean body weight but negatively with arm fat index and triceps skin thickness (Rukadikar, 2020, Rukadikar et al 2017).

Although the role of individual BC components, HGS, and LSR has been assessed in various sports settings, significant gaps remain in the literature. Most studies have focused on single factors or a single sport and disregarded a cross-comparison of athletes from multiple sports. Furthermore, little research has examined the combined effects of BC, HGS, and LSR on participant performance and selection in various sports. The present study attempts to overcome these limitations by comprehensively comparing the three most important physical attributes in cricket, volleyball, and track & field players. This study's novelty is that it combines body composition, handgrip strength, and leg strength into a holistic investigation to explore the relationship between the three and their impact on sport-specific performance. The study's focus on athlete selection background broadens its applied value, offering informative knowledge for coaches and sport scientists to optimize training and talent identification.

The main research question is: how do body composition, hand grip strength, and leg strength interact concerning performance and selection as an athlete in cricket, volleyball, and track and field? This question frames the investigation of the multiple influences of these physical factors through other sports to provide a more integrated understanding of the total effect of these factors on athlete performance and selection. This approach addresses the current gaps in the literature and provides a unique value added in this field by capturing multiple characteristics within a multi-sport perspective. We hypothesized that lean body mass and handgrip strength would positively correlate with leg strength, and that these relationships would vary by sport due to their differing biomechanical demands.

METHOD

Research Design

Data for this study were obtained from the Physical Education and Sports Science research group, University of Rajshahi. Participants were divided into three experimental groups: a) cricket group (n=28), b) volleyball group (n=24), and c) track and field group (n=14), including 100m sprinters (n=5), 200m sprinters (n=5), and long jumpers (n=4). The participants' training, nutrition, and psychological factors were closely monitored. Participants' body composition and physical fitness test results were assessed at the end of the 2022-2023 Bangladesh Inter-University Athletics Tournament. Every group underwent 90 days of regular activity in their specific sporting activities, with a minimum of two sessions and four hours of practice per week in each group. We measured LBM, MM, SMM, BMR, BFM, HGS, and LSR after 90 days of regular activity, using a body composition analyzer (InBCA, IN-F500, Shenzhen, China), hand grip dynamometer (Smedlay's Dynamo Meter, TTM, Tokyo, Japan), and leg strength measuring machine (zaRitz BM-220, TANITA Corp., Tokyo, Japan). HGS and LSR were assessed three times for measurement accuracy.

Participants

Following the recommended guidelines proposed by Beck (2013), we used G*Power software (version 3.1.9.6; Kiel University, Kiel, Germany) to pre-determine the required sample size for this study (Faul et al., 2007). The significance level (α) was established at 0.05, with a desired statistical power (β) of 0.95. We approximated an effect size of 0.5 to attain the requisite statistical power based on the findings of the study of Al-Asadi (2018). We determined that a sample size of at least 60 athletes would be sufficient, minimizing the probability of a type 2 statistical error.

Among the 82 reviewed surveys, 71 university athletes were considered suitable and volunteered to participate in the study. However, during the experimental phase, five participants withdrew due to sudden injuries sustained in their sports. Thus, the data in this study were gathered from the 66 participants (males=39; females=27) who completed all the experiment sessions. Participants were selected based on the following inclusion criteria: (1) actively participated in the inter-university competitions; (2) participated in at least 3 months of regular sports activity organized and oriented by a coach; and (3) had a minimum of 2 sessions and 4 hours of practice per week in each group. The exclusion criteria were as follows: (a) any diseases or illnesses that could affect performance in various tests and/or the use of any medications for any chronic medical condition; (b) the consumption of any substance (such as stimulants, narcotics, or psychotropic drugs), nutritional supplements and/or undergoing any restrictive diet control in the past three months that could impact hormone levels or athletic performance; (c) the use of any form of contraception, including pills, patches, injections, implants and intrauterine devices; and/or having any menstrual or endocrine abnormalities in the previous six months for female athletes; and (d) sleep issues and/or the consumption of alcohol.

The university athletes were informed about all the experiment details, including the schedule and the assessments they would need to complete before signing the consent. All protocols and methods received approval from the local research ethics committee of the Institute of Biological

Sciences, Rajshahi University, Bangladesh (No: 72(22)/320/IAMEBBC/IBSc, Serial Number: #00018), and adhered to the latest version of the Declaration of Helsinki.

Instruments

Body composition measurements

The individual being tested stood on the platform of the body composition analyzer (InBCA, IN-F500, Shenzhen). The analyzer used bioelectrical impedance analysis (BIA), as Ward (2019) has described. Electrodes on the platform and handgrip electrodes interacted with the individual's skin. A low-level electrical current was passed through the body, and the analyzer measured the impedance (resistance) to the flow of the electrical current. This provided detailed information on muscle and fat distribution. The analyzer typically provided a range of data, including, but not limited to: total body weight, LBM (muscle and other non-fat components), fat mass, body fat percentage, BMR, and segmental muscle and fat measurements.

Leg strength measurements

Leg strength ratio was measured using a bilateral isometric leg press measuring device (zaRitz BM-220, TANITA Corp., Tokyo, Japan). The participants performed three maximal voluntary contractions, and the average value was recorded (Hossain et al., 2024; Kera et al., 2022).

Hand strength measurements

The muscle strength of the anterior compartment of the forearm was measured using a handgrip dynamometer (Smedley's Dynamo Meter, TTM, Tokyo, Japan). Only the dominant hand was tested, which was determined by participant self-report (Von Hurst et al., 2013). The handgrip dynamometer was calibrated and adjusted to fit the hand size of the person before the assessment. The resting blood pressure of the study subjects was measured according to the standards of the American Heart Association (AHA) (Muntner et al., 2019). Each participant performed three trials for hand grip and leg strength assessments, with a 2-minute rest interval between trials. The highest value of the three was used for analysis. These measures ensured consistency and reduced fatigue bias.

Analysis plan

The SPSS software (IBM Corp. Released 2017. IBM SPSS Statistics for Windows, Version 25.0. Armonk, NY: IBM Corp.) was used to conduct all statistical analyses for this study. The differences in categorical variables (sex, BMI, smoking habit, type of students, and discipline area of players) and continuous variables (age, SBP, DBP, LBM, MM, BFM, SM, LSR, BMR, and HGS) were analyzed by chi-square tests and an independent sample t-test, respectively. A generalized linear regression model examined the relationships between BFM and LBM with HGS. The model was adjusted for age, sex, BMI, and smoking habits. To enhance the estimation accuracy in the regression model, the values of BFM and LBM with hand grip strength were log-transformed. Multiple comparisons (BMR, LSR, BFM, and HGS) across various sporting events (cricket, volleyball, and track and field athletes) were analyzed by one-way ANOVA followed by Bonferroni multiple comparison tests. A generalized linear regression analysis was used to assess the associations between BFM and LBM with the hand grip of the participants before and after adjusting for age, sex, BMI, and smoking habits. A Pearson correlation coefficient test evaluated the correlations of LSR with HGS. All results are shown using 95% confidence intervals; the minimum significance level was $p<0.05$.

RESULTS AND DISCUSSION

Results

The descriptive features of the study participants are summarized in Table 1. Our study included 66 participants, of whom 28 were cricketers, 24 were volleyball players, and 14 were involved in athletics. There were no significant differences in sex, BMI, smoking habits, and other socio-demographic variables among cricket, volleyball, and track and field athletics groups. There were 59.1% male and 40.9% female participants. There were variations in average BMI in the track and field athletes' group participants. None of the female participants were smokers, while 16.7% of male participants were smokers. Levels of systolic blood pressure (SBP) and diastolic blood pressure (DBP) were similar in the three study groups (Table 1).

Table 1. Descriptive Characteristics of Study Participants in Cricket, Volleyball, and Track and Field Groups

Parameters	All	Cricket	Volleyball	Athletics	*p*-value
Study participants [n, (%)]	66 (100)	28 (42.4)	24 (36.4)	14(21.2)	
Sex [n, (%)]					
Male	39 (59.1)	17(60.7)	12 (50)	10 (71.4)	0.684
Female	27 (40.9)	11(39.3)	12 (50)	4 (28.6)	
Age (years)[a]	22.76± 2.11	22.21± 1.99	23.46±2.11	22.64±2.13	0.101
BMI (kg/m²)[n, (%)]	21.57± 3.04	21.58 ± 3.46	22.31 ± 2.85	20.29 ± 2.04	0.141
Smoking [n, (%)]					
Yes	11 (16.66)	5 (17.86)	3 (12.5)	3 (21.43)	0.342
No	55 (83.34)	23 (82.14)	21 (87.5)	11 (78.57)	
SBP (mm Hg)[a]	109.51 ± 10.29	107.14 ± 11.70	111.81 ± 8.76	110.29 ± 9.31	0.254
DBP (mm Hg)[a]	69.14 ± 7.97	67.43 ± 7.75	71.58 ± 6.71	68.39 ± 9.76	0.160

The results are presented as mean ± SD. BMI was calculated as body weight (Kg) divided by body height squared (m²). P-values were obtained from the independent sample t-test and chi-square test, respectively. BMI was categorized into four groups: Underweight – below 18.5 kg/m², Normal – 18.5 to 24.9 kg/m², Overweight – 25.0 to 29.9 kg/m², and Obese – 30 kg/m² or higher (WHO, 1995). Abbreviations: BMI= Body Mass Index; SBP= Systolic Blood Pressure; DBP= Diastolic Blood Pressure.

Body composition parameters, leg strength, and handgrip strength

The power-to-weight ratio in track and field athletes depends on their LBM, whereas MM and SMM are indicators of muscular growth and affect strength and endurance (Cialdella-Kam & Manore, 2017). The analysis of body composition parameters and physical metrics (such as LBM, MM, SMM, BFM, BMR, LSR, and HGS) in the three study groups is shown in Table 2. The average values of MM (44.46±6.70 kg), SMM (25.32±3.63 kg), and basal metabolic rate (BMR) (1408±152.36 kg) were higher in the volleyball group compared to those participating in cricket and track and field athletics. However, BFM was increased in the volleyball group compared to the track and field athletics group (14.20 ± 6.28 vs. 8.44 ± 3.15 kg, p<0.05). Cricketers had a higher LBM (44.84±7.47) compared to the other groups; HGS was similar in all groups, although there was a non-significant increase in the field athletics group (p>0.05) (Table 2).

Table 2. Body Composition Parameters in Cricket, Volleyball, and Track and Field Athlete Groups.

Parameters	All	Cricket	Volleyball	Athletics	*p*-value
LBM (kg)	46.07± 6.91	44.84±7.47	47.64±6.54	45.83± 6.23	0.348
MM (kg)	43.25±7.12	42.43±7.49	44.46±6.70	42.84 ± 7.30	0.581
SMM (kg)	24.02±4.34	23.01±4.97	25.32±3.63	23.82 ± 3.74	0.157
BFM (kg)	12.11± 6.58	12.15± 7.42	14.20± 6.28	8.44 ± 3.15	0.031*
BMR (kcal)	1330± 243.46	1316.07 ±206.20	1408 ±152.36	1223 ±377.90	0.069
LSR (KG)	1.56 ±0.16	1.57±0.18	1.51 ±0.15	1.63 ±0.13	0.070
HGS (kg)	23.36 ±8.71	23.05 ±9.25	22.89 ±8.08	24.77 ±9.12	0.795

Results presented as means SD. Results and p-values were from one-way ANOVA. *: Volleyball is significantly different from athletics (p=0.031). LBM= Lean Body Mass, MM= Muscle Mass, SMM= Skeletal Muscle Mass, BFM= Body Fat Mass, BMR= Basal Metabolic Rate, LSR= Leg Strength and HGS= Hand Grip Strength.

Association between BFM, LBM, and hand grip strength in different sports.

A positive correlation exists between HGS and LBM in cricket and football players (Rukadikar et al., 2017). A linear regression analysis to investigate the relationship between BFM, LBM, and HGS indicated a positive association between LBM and HGS and an inverse association between BFM and

HGS in cricket and volleyball groups (Table 3). The adjusted β coefficient for LBM for cricket players was 0.986 (95% CI: 0.545, 1.427, p<0.001) and for BFM was -0.811 (95% CI: -1.508, -0.115, p=0.024). Similarly, in volleyball and athletics, the adjusted β coefficient for LBM was 1.118 (95% CI: 0.837, 1.399, p< 0.001) and 0.772 (95% CI: -0.217, 1.760, p=0.111) respectively, and for BFM was -2.100 (95% CI: -2.799, -1.401, p<0.001 and -1.687 (95% CI: -3.990, 0.617, p=0.132) respectively. These associations remained significant after adjusting for age, sex, BMI, and smoking habits.

Table 3. Association of BFM and LBM with HGS of study participants according to linear regression analysis

		Before adjustment		**After adjustment**	
	Variables	Hand grip strength β (95% CI)	*p*-value	Hand grip strength β (95% CI)	*p*-value
Cricket	Body fat mass (kg)	-0.461 (-0.928, 0.006)	0.053	-0.811 (-1.508, -0.115)	0.024
	LBM (kg)	0.765 (0.375, 1.156)	<0.001	0.986 (0.545, 1.427)	<0.001
Volleyball	Body fat mass (kg)	-0.772 (-1.227, -0.316)	<0.01	-2.100 (-2.799, -1.401)	<0.001
	LBM (kg)	1.087 (0.827, 1.346)	<0.001	1.118 (0.837, 1.399)	<0.001
Athletics	Body fat mass (kg)	-0.283 (-2.095, 1.529)	0.740	-1.687 (-3.990, 0.617)	0.132
	LBM (kg)	1.046 (0.402, 1.690)	0.004	0.772 (-0.217, 1.760)	0.111

Table 4. Intraclass Correlation Coefficients (ICCs) for Relative Reliability and Coefficients of Variation (CVs) for Absolute Reliability of the Applied Hand Grip Strength (HGS) and Leg Strength Ratio (LSR) Tests.

Measure	**ICC**	**95% Confidence Interval (CI)**	**CV%**
Hand Grip Strength (HGS)	.994	.990-.996	10.26
Leg Strength Ratio (LSR)	.912	.856-.946	37.28

β is adjusted for age, sex (males used as a referent group), BMI, and smoking habit (non-smokers used as a referent group), LBM= Lean Body Mass

ICC: Intraclass Correlation Coefficient, CI: Confidence Interval, and CV: Coefficient of Variation (%)

The next section describes the relative and absolute reliability of HGS and LSR measurements is described in the next section. The ICC findings showed excellent reliability for the HGS (0.994) and good reliability for the LSR (0.912). The CVs represent low variance in HGS (10.26%) compared to a higher LSR variation (37.28%), indicating that hand grip strength is evaluated more consistently.

Association between hand grip and leg strength in cricket, volleyball, and track and field athletes. We investigated whether increases in HGS are accompanied by increases in LSR using Pearson correlation coefficient tests (Figure 1). There was a significant correlation between HGS and LSR in the cricket (A, p< 0.001; r = 0.802), volleyball (B, p <0.0001; r = 0.706), and track and field athletics groups (C, p< 0.01; r = 0.678).

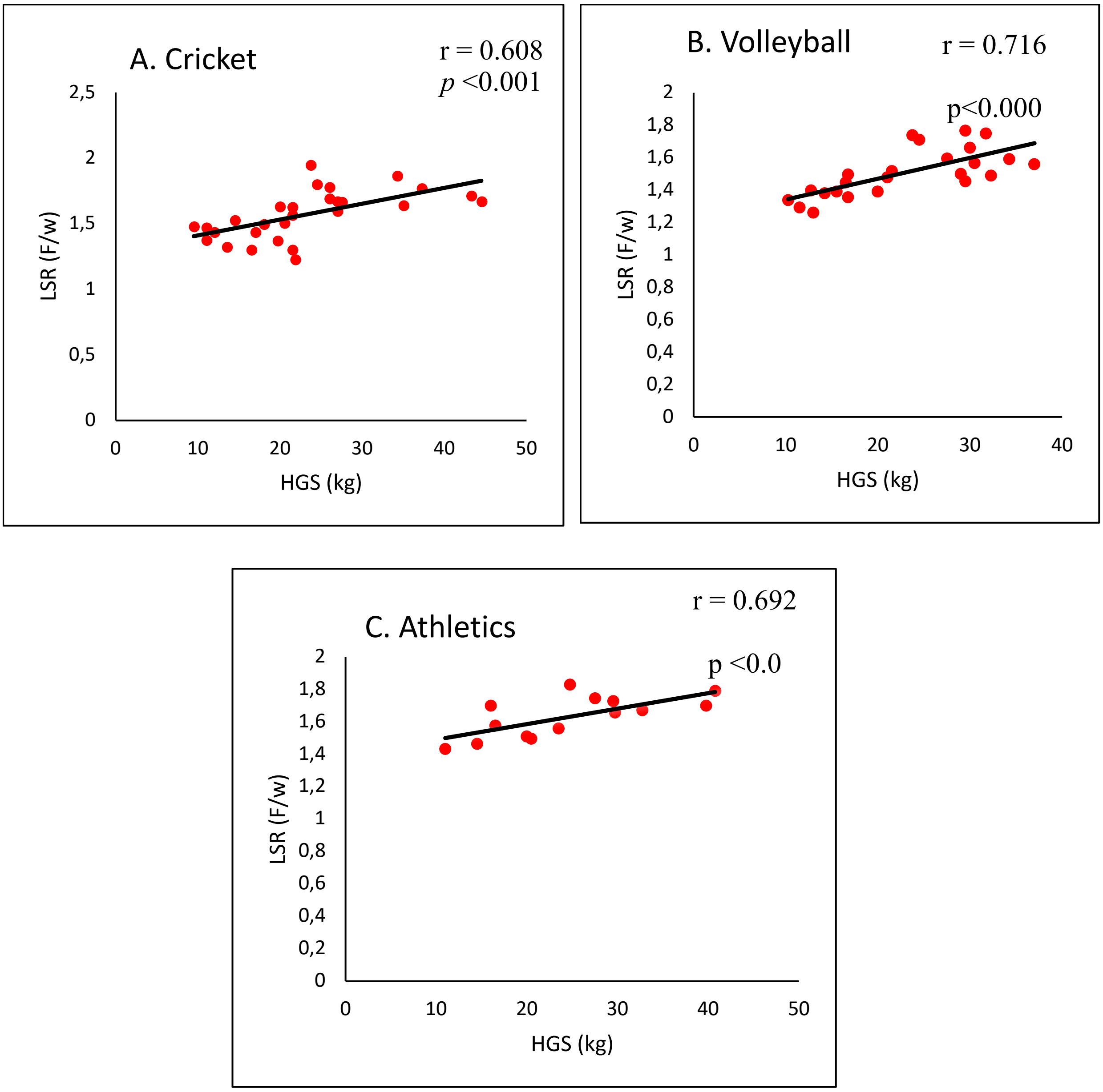


Figure 1. Association between hand grip strength and leg strength of the study subjects in cricket, volleyball, and track and field athletes. The r-values and p-values were calculated from Pearson correlation coefficient tests.

Comparisons between LBM, MM, and SMM of participants in cricket, volleyball, and track and field athletes. A one-way ANOVA test indicated that MM and SMM in the volleyball group were similar to those in the cricket and athletics groups. Thus, LBM remained unchanged in participants of the three study groups (Figure 2)

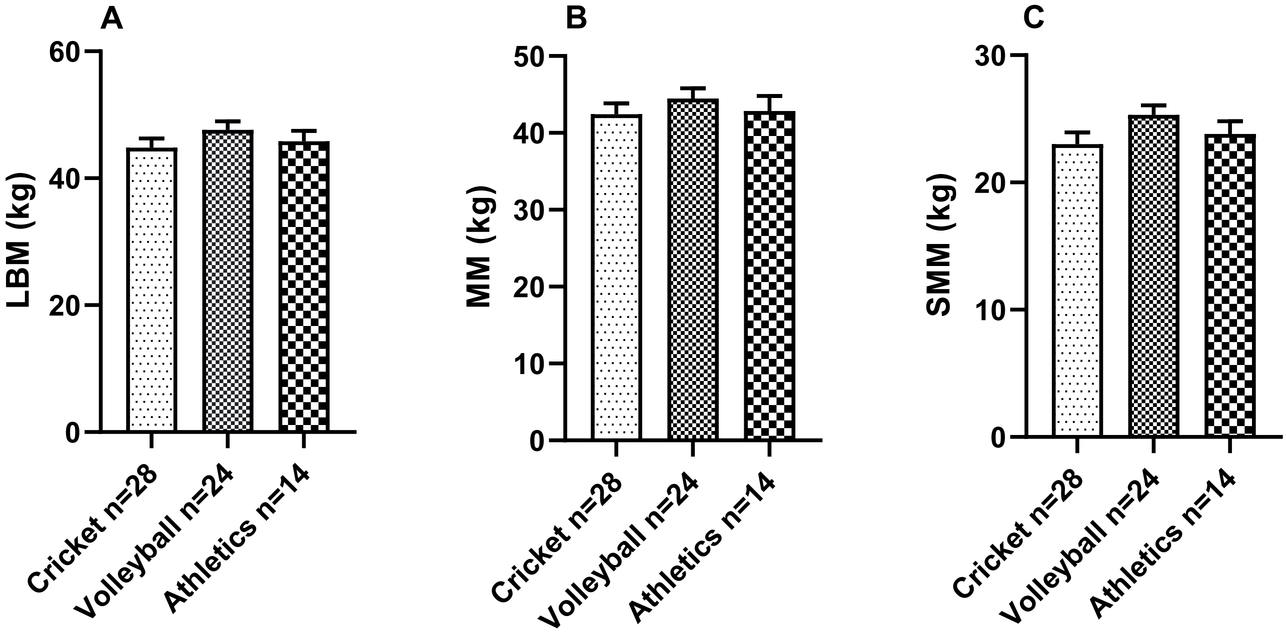
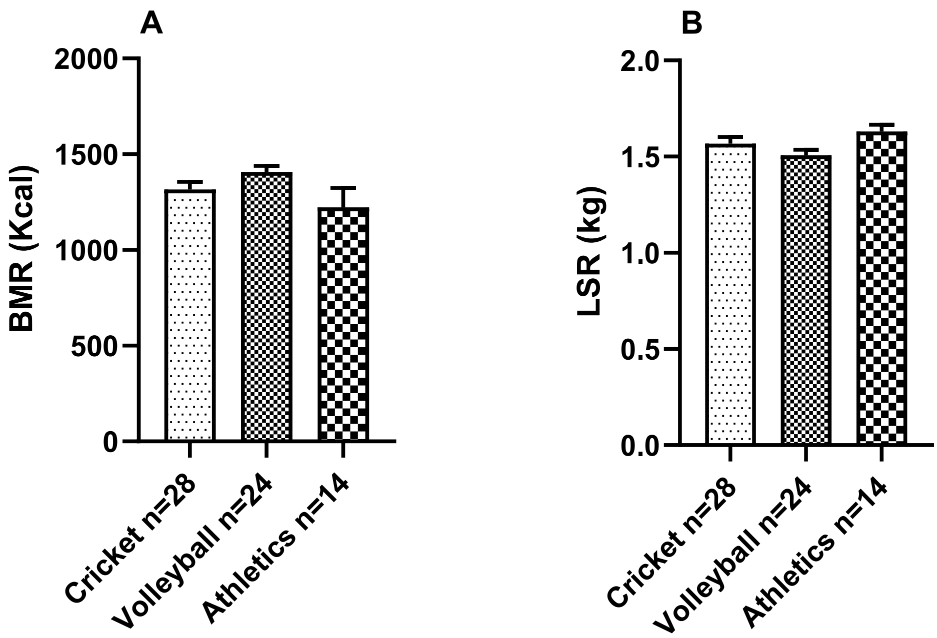


Figure 2. Analysis of LBM (A), MM (B), and SMM (C) of the participants in cricket, volleyball, and athletics. Data presented as Mean ± SEM. Results and p-values were from one-way ANOVA.

Comparisons of BMR, LSR, BFM, and HGS among cricket, volleyball, and track and field athletes' groups.

The mean BMR was not different in the volleyball group compared to the cricket and track and field athletes' groups (Figure 3). Participants in the track and field athletes' group had a greater average LSR than those in the cricket and volleyball groups. Furthermore, individuals involved in volleyball had a greater mean BFM ($p<0.05$) than those involved in track and field athletics. No differences in HGS were observed in the three study groups (Figure 3).



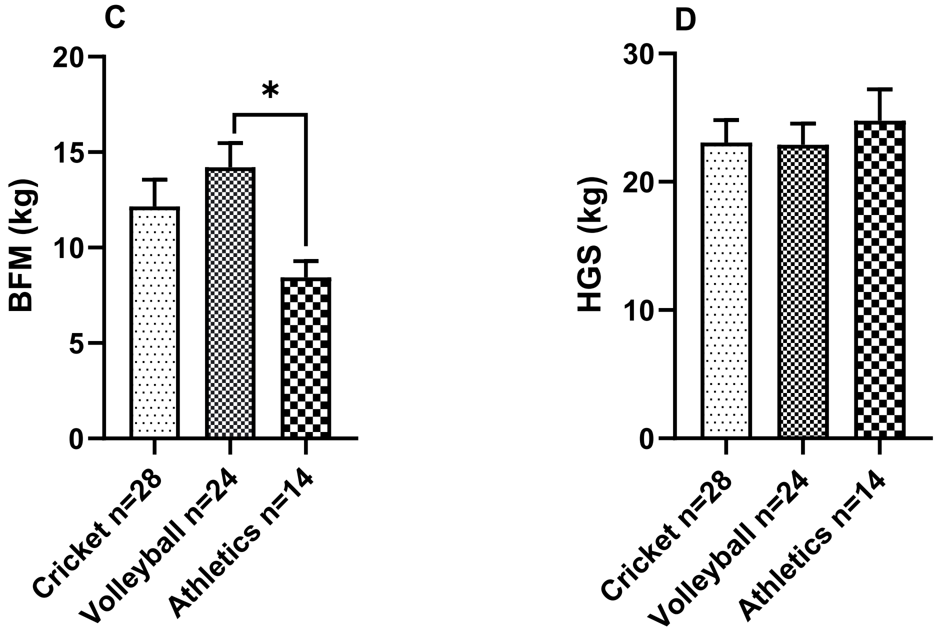


Figure 3. Comparative analysis of BMR, LSR, BFM, and HGS of subjects in the cricket, volleyball, and track and field athletes' groups. Results presented as Mean ± SEM. Results and p-values (*p<0.05) were from one-way ANOVA.

Discussion

Our study explored the association between body composition, leg strength, and hand grip strength in university athletes participating in different sports. We assessed LBM, MM, SMM, BMR, BFM, LSR, and HGS in participants in cricket, volleyball, and track and field athletes. Our findings indicated differences only in BFM between volleyball and track and field participants. Our study also indicated a positive correlation between LBM and an inverse correlation between BFM and HGS in the participants involved in cricket and volleyball.

Hand grip strength is essential for success in various sports disciplines, including basketball, football, badminton, cricket, and volleyball (Cronin et al., 2017; Singla & Hussain, 2018). The LBM in the cricket group was positively correlated with HGS (p<0.001). Both LBM and BFM were correlated in volleyball players (p<0.001), but BFM showed an inverse correlation with hand grip strength (Table 3). BC determines an athlete's success and performance (Silvestre et al., 2006). BC is closely related to strength, power, and explosive performance in sports such as cricket, volleyball, football, and athletics. It is possible that HGS training could improve the execution of various gross motor movement patterns in hand-based athletes and other athletes, too. An athlete can enhance maximal isometric HGS by implementing resistance-training interventions that target the development of muscle mass and overall strength in the lower and upper body. However, technical ability, physical capacity, body composition, and anthropometry can enhance an athlete's power to apply force to an object or use force during a specific sport-specific movement (Farley et al., 2020; Zaggelidis, 2016).

HGS and LSR are important measures of physical fitness because they reflect both upper and lower body power and are especially important in sports that require explosive power, such as cricket, running, volleyball, and athletics, where performance is dependent on quick and forceful movements (Nefesoğlu & Bas, 2021). Hand grip strength (HGS) in cricketers has a positive correlation with height, weight, BMI, and hand and arm dimensions such as hand width, hand length, forearm length, arm length, and upper extremity length (Shanbhag & Kumar , 2021). HGS and LSR are influenced by shared neuromuscular characteristics, including motor unit recruitment, muscle cross-sectional area, and neuromuscular coordination (Elgueta-Cancino et al., 2022). There is a positive relationship between HGS and LSR in swimmers. Our study indicates varying correlations between LSR and HGS in different sports groups, where HGS was correlated with LSR in individuals who played cricket (p<0.001, r = 0.608) (Figure 1A). In addition, our results also indicate that LSR and HGS are also positively associated ($p<0.0001$, $r=0.716$, $p<0.01$, $r=0.692$, respectively) in volleyball and athletics (Figures 1B and C).

Volleyball players have a reduced fat mass and increased FFM compared to non-athletic individuals. Our findings that the LBM was higher in participants in cricket compared to volleyball and track and field athletes are consistent with the results of (Vincenzo et al., 2020). Additionally, when comparing study subjects in cricket and track and field athletes to those in the volleyball group, MM was higher in the volleyball group. In addition, SMM was greater in volleyball players than in participants in the cricket and athletics groups (Figure 2C). Volleyball emphasizes explosive jumping and rapid movements, such as spiking and blocking (Brazo-Sayavera et al., 2017). These actions require greater lower-body strength and power, resulting in the development of larger leg muscles, including quadriceps, hamstrings, and calf muscles (Majstorović et al., 2020).
Additionally, overhead serving and attacking in volleyball require strong shoulder and upper body muscles (Parmar et al., 2020). Serving and attacking in volleyball strain the shoulder and upper body muscles due to the repetitive and vigorous movements required. Consequently, we hypothesize that the combination of lower and upper-body muscle engagement in volleyball may increase muscle mass, as our results support.

Most adolescent athletes have an increase in BMR, indicating adaptation to strenuous physical activity, and the BMR of male volleyball athletes is greater than that of the general population (Desbrow et al., 2014; Qaddomi, 2003). Our study demonstrates that BMR was similar in cricket and track and field athletes (100m sprints, 200m sprints, and long jumps) but higher in volleyball players. Several factors could explain the higher BMR we measured in volleyball compared to cricket players and other track and field athletes. Volleyball involves brief bursts of intense activity, such as during jumping and rapid lateral movements, which contribute to the development and maintenance of muscle mass (Tiaprapong & Tiaprapong 2022). The frequent leaps and explosive movements by volleyball players promote growth of lean muscle tissue, likely requiring more energy at rest, making it important to monitor both the training plans and food habits to attain an appropriate body composition on a volleyball team (Caparello et al., 2023). Cricket, on the other hand, primarily involves intermittent bouts of running and standing, resulting in a lower impact on muscle mass and BMR (Stahlschmidt, 2022). Those involved in track and field athletics have varying BMR levels depending on the event. Still, long-distance runners may have a lower BMR due to their emphasis on endurance training, which emphasizes efficient energy use (Stenqvist, 2016).

Leg squat training increases leg muscle strength in badminton players more effectively than in 100-meter running sprinters (Nugroho et al., 2025). However, comparison of leg strength in track event athletes, cricketers, and volleyball players did not produce conclusive results. The findings of our study indicate that leg strength was greater in track event athletes compared to cricket and volleyball players, which may be due to the specific training and biomechanical demands of their respective sports. Athletes rely on their leg muscles for explosive power, speed, and endurance in track and field events (Bazyler et al., 2017). Sprinters, for example, require greater leg strength to generate maximum force during brief, high-intensity bursts of activity (Kavaliauskas, 2022) while jumping and hurdles require robust leg musculature for takeoffs and landings (Jayathunga & Chandana, 2022). Cricket and volleyball require different skill sets: cricket players require leg strength and flexibility for batting, bowling, and fielding, while volleyball players use their legs mostly for leaping and lateral movements.

Our study indicates that volleyball players have a significantly greater BFM level than track and field athletes ($p<0.05$). Volleyball players may have higher body fat percentages because body fat aids buoyancy and the ability to remain afloat during jumping and diving (Acar & Eler, 2019). In addition, the physical demands of volleyball differ, with taller players requiring more body fat for insulation and energy storage because they are less likely to overheat during extended periods of play (Mielgo-Ayuso, 2015).

Track event athletes, particularly sprinters, also tend to have lower body fat percentages, as excess body fat can hinder their ability to move quickly and efficiently. These athletes concentrate on muscle growth, which can help treat or delay type 2 diabetes, resulting in lower body fat levels.63 However, our findings indicate that hand grip strength was higher in track and field athletes than in cricket and volleyball. Athletes in throwing events such as the shot put and discus require robust grip strength to control the implements and ensure proper technique and force production.

Implications

The study's results can assist coaches and sports scientists in customizing training plans according to players' strength and body composition. Early talent identification may benefit from hand grip strength, which serves as a substitute for total physical health and playing technique, such as in cricket (batting grip and throwing accuracy), volleyball (ball control during blocks and spikes), and in athletics (throws, which are integral to the shot put and discus grip strength). Performance and lean body mass are positively correlated, emphasizing the necessity of personalized training techniques. Nutritional planning can be guided by knowledge of body composition patterns unique to a certain sport. Track athletes with stronger legs may benefit from concentrated lower-body training. All things considered, this study backs the inclusion of physiological evaluations in athlete development initiatives.

Research contribution

This study looks at important performance factors that affect leg strength in sports like volleyball, cricket, and athletics, including lean body mass and hand grip strength. The findings show that college athletes have different muscle and fat distributions based on their sport. There's also a noteworthy link between hand grip strength and body fat, with higher fat possibly leading to lower grip strength. This research offers a handy guide for spotting student-athletes' skills and boosting performance. It helps coaches make informed decisions about selecting players using solid, unbiased measures. Looking ahead, it opens doors for research on a wider range of sports.

Limitations

Our study has limitations, including: (1) While G Power was used to determine the sample size required for our study due to its exploratory nature, future research with a larger sample size is needed to confirm our findings; (2). The small sample size of the Bangladesh Inter-University Athletics Championships limits the generalizability of the results; (3). Gender differences were not examined in this study, leaving an opportunity for future research to more carefully investigate sports-specific body composition indices between sexes; (4) Our investigation did not examine Menstrual cycle phases and training loads. Training volume and intensity were not standardized across sports, which may have affected strength and body composition outcomes. This is an important consideration for future longitudinal studies. Despite these limitations, our study lays the groundwork for future large-scale studies to better understand the link between body composition, physical fitness, and sports performance to optimize outcomes in various sporting disciplines.

Suggestions

While our findings provide preliminary evidence for physiological markers in sports performance, they are specific to a Bangladeshi university athlete population. They may not generalize across age groups, competitive levels, sports, or countries. Later studies should use a wider and more varied sample to improve the generalizability of the results. A sex-based analysis is suggested to investigate gender variations in strength and body composition. We also acknowledge the limitation of not including training hours due to inconsistent self-reported data and recommend their inclusion in future studies. Incorporating dietary and hormonal evaluations might yield a more profound understanding. Researchers should also investigate the impact of biomechanical and psychological elements on sports performance.

Funding

No funding was received for this research.

CONCLUSION

Body composition is important for health and fitness, while hand grip strength has a greater role in some sporting events. Our findings can help to tailor guidelines for selection procedures in various sporting activities, and may be of interest to researchers, sports authorities, and players alike. The results of this pilot study indicate that body composition, hand grip strength, and leg strength may be important in player selection and improving performance in specific sports. Our findings suggest increased hand grip strength is associated with increased leg strength. In addition, we determined a positive relationship between fat mass, lean body mass, and hand grip strength in cricket and volleyball players. Coaches and sports scientists should be able to use these results to develop specific training modalities focused on improving handgrip strength and body composition according to the individual demands of their players. The well-conditioned musculature of both the upper and lower body, which is developed through resistance training, can only enhance performance in numerous sporting activities. In addition, we could research the impact of nutritional and psychological factors on muscular strength and body composition in future studies. These factors can essentially influence an athlete's overall physical health and performance, thus providing a deeper insight into the elements of sports achievements. The findings of this study might be useful in selecting players in specific sports and help improve the body composition of players to improve their performance.

ACKNOWLEDGMENT

All university athletes who participated in this study have been grateful to the authors. We especially thank the University of Rajshahi's Department of Physical Education and Sports Science for their assistance and collaboration.

AUTHOR CONTRIBUTION STATEMENT

In our manuscript, AA, HB, JH, IL, KG, AS, and HZ contributed: AA conceptualized the study, designed the methodology, analyzed the results, and coordinated data collection. HB and IL contributed to the study design. KG and AS contributed to designing the methodology and data collection. HZ and JH performed data analysis, interpreted the results, drafted the manuscript, and critically revised it for intellectual content.

AI DISCLOSURE STATEMENT

The author used Quillbot to enhance the clarity, structure, and flow of the manuscript during preparation. After using Quillbot, the author thoroughly reviewed and edited the content as needed and took full responsibility for the publication's content.The authors declare that this research was prepared, researched, written, and edited without the aid of artificial intelligence (AI) techniques.

CONFLICT OF INTEREST

The authors of this article declare that there are no conflicts of interest related to this publication. No financial relationships or personal affiliations influenced the results or interpretations of this study.

REFERENCES

Abidin, N. Z. (2023, July 1). The "fat or fit paradox" in postmenopausal women: A cross-sectional study on the association between skeletal muscle mass, adiposity, and muscle strength. *Muscles Ligaments and Tendons Journal, 13*(03), 494-103. https://doi.org/10.32098/mltj.03.2023.20

Acar, H., & Eler, N. (2019). the relationship between body composition and jumping performance of volleyball players. *Journal of Education and Training Studies, 7*(3), 192. https://doi.org/10.11114/jets.v7i3.4047

Al-Asadi, J. N. (2018). Handgrip strength in medical students: Correlation with body mass index and hand dimensions. *Asian Journal of Medical Sciences, 9*(1), 1-6. https://doi.org/10.3126/ajms.v9i1.18577

Argilés, J. M., Campos, N., Lopez-Pedrosa, J. M., Rueda, R., & Rodriguez-Mañas, L. (2016). Skeletal muscle regulates metabolism via interorgan crosstalk: Roles in health and disease. *Journal of the American Medical Directors Association, 17*(9), 789–796. https://doi.org/10.1016/j.jamda.2016.04.019

Bazyler, C. D., Mizuguchi, S., Harrison, A. P., Sato, K., Kavanaugh, A. A., DeWeese, B. H., & Stone, M. H. (2017). Changes in muscle architecture, explosive ability, and track and field throwing performance throughout a competitive season and after a taper. *Journal of Strength and Conditioning Research, 31*(10), 2785–2793. https://doi.org/10.1519/JSC.0000000000001619

Bazzocchi, A., Ponti, F., Albisinni, U., Battista, G., & Guglielmi, G. (2016). DXA: Technical aspects and application. *European Journal of Radiology, 85*(8), 1481–1492. https://doi.org/10.1016/j.ejrad.2016.04.004

Beck, T. W. (2013). The importance of a priori sample size estimation in strength and conditioning research. *Journal of Strength and Conditioning Research, 27*(8), 2323–2337. https://doi.org/10.1519/JSC.0b013e318278eea0

Blemker, S. S., Brooks, S. V., Esser, K. A., & Saul, K. R. (2024). Fiber-type traps: Revisiting common misconceptions about skeletal muscle fiber types with application to motor control, biomechanics, physiology, and biology. *Journal of Applied Physiology, 136*(1), 109–121. https://doi.org/10.1152/japplphysiol.00337.2023

Brazo-Sayavera, J., Nikolaidis, P. T., Camacho-Cardenosa, A., Camacho-Cardenosa, M., Timón, R., & Olivares, P. R. (2017). Acute effects of block jumps in female volleyball players: The role of performance level. *Sports, 5*(2), 1-10. https://doi.org/10.3390/sports5020030

Caparello, G., Galluccio, A., Ceraudo, F., Pecorella, C., Buzzanca, F., Cuccomarino, F., Bonofiglio, D., & Avolio, E. (2023). Evaluation of body composition changes by bioelectrical impedance vector analysis in volleyball athletes following mediterranean diet recommendations during Italian Championship: A pilot study. *Applied Sciences, 13*(5), 1-13. https://doi.org/10.3390/app13052794

Caspersen, C. J., Powell, K. E., & Christenson, G. M. (1985). Physical activity, exercise, and physical fitness: Definitions and distinctions for health-related research. *Public Health Reports*, *100*(2), 126–131.

Cialdella-Kam, L., & Manore, M. M. (2017). Diet and exercise approaches for reversal of exercise-associated menstrual dysfunction. in body composition. CRC Press.

Çimen, P. S., Bulgay, C., Yarım, İ., Cicioğlu, H. İ., & Çetin, E. (2018). Analysis of the relationship between elite wrestlers' leg strength and balance performance, and injury history. *Sports, 6*(2), 35. https://doi.org/10.3390/sports6020035

Cronin, J., Lawton, T., Harris, N., Kilding, A., & McMaster, D. T. (2017). A brief review of handgrip strength and sport performance*. Journal of Strength and Conditioning Research, 31*(11), 3187–3217. https://doi.org/10.1519/JSC.0000000000002149

Desbrow, B., McCormack, J., Burke, L. M., Cox, G. R., Fallon, K., Hislop, M., Logan, R., Marino, N., Sawyer, S. M., Shaw, G., Star, A., Vidgen, H., & Leveritt, M. (2014). Sports dietitians Australia position statement: Sports nutrition for the adolescent athlete. *International Journal of Sport Nutrition and Exercise Metabolism, 24*(5), 570–584. https://doi.org/10.1123/ijsnem.2014-0031

Elgueta-Cancino, E., Evans, E., Martinez-Valdes, E., & Falla, D. (2022). The effect of resistance training on motor unit firing properties: A systematic review and meta-analysis. *Frontiers in physiology, 13*(1), 1-11. https://doi.org/ 10.3389/fphys.2022.817631

Erdağı, K. (2020). The study of the correlations between handgrip strength and some anthropometric characteristics of upper extremity of elite and sub-elite olympic style weightlifting athletes. *Physical Education of Students, 24(*1), 19-30. https://doi.org/10.15561/20755279.2020.0103

Fahs, C., Humphries, K., & Campbell, M. (2020). Regional body composition and its relationship to performancein powerlifters with physical disabilities: A pilot study. *Journal of Trainology, 9*(2), 60–63. https://doi.org/10.17338/trainology.9.2_6

Farley, J. B., Stein, J., Keogh, J. W. L., Woods, C. T., & Milne, N. (2020). The relationship between physical fitness qualities and sport-specific technical skills in female, team-based ball players: A systematic review. *Sports Medicine - Open, 6*(1), 1-20. https://doi.org/10.1186/s40798-020-00245-y

Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods, 39*(2), 175–191. https://doi.org/10.3758/BF03193146

Fields, J. B., Metoyer, C. J., Casey, J. C., Esco, M. R., Jagim, A. R., & Jones, M. T. (2018). Comparison of body composition variables across a large sample of national collegiate athletic association women athletes from 6 competitive sports*. Journal of Strength and Conditioning Research, 32*(9), 2452–2457. https://doi.org/10.1519/JSC.0000000000002234

Hossain, J., Azim, A., & Author, M. H. (2024). Kinetics and kinematic analysis of different phases in 100m sprints. *International Journal of Physical Education, Sports and Health, 11*(3), 183–190. https://doi.org/10.22271/kheljournal.2024.v11.i3c.3341

Hossain, P., M. T., Khazri, H. B., Mustapha, Z. A., & Shimmi, S. C. (2022). Predicting handgrip power of young adult population among major ethnic groups of Sabah: A multivariate analysis. *Journal of Physiological Anthropology, 41*(1), 1-16. https://doi.org/10.1186/s40101-022-00297-x

Jaafar, M. H., Ismail, R., Ismail, N. H., Md Isa, Z., Mohd Tamil, A., Mat Nasir, N., Ng, K. K., Ab Razak, N. H., Zainol Abidin, N., & Yusof, K. H. (2023). Normative reference values and predicting factors of handgrip strength for dominant and non-dominant hands among healthy Malay adults in Malaysia. *BMC Musculoskeletal Disorders, 24*(1), 74. https://doi.org/10.1186/s12891-023-06181-8

Jarrett, H., Basyal, B., Nelson, P., Gupta, N., & Taylor, A. (2020). A prospective study of handgrip strength and outcomes in a cardiovascular intensive care unit. *Journal of the American College of Cardiology, 75*(11), 2000. https://doi.org/10.1016/S0735-1097(20)32627-9

Jayathunga, J. A. L. N., & Chandana, A. W. S. (2022). Biomechanical model and kinematic analysis of hurdle clearance flight phase: A review. *International Journal of Research in Engineering and Innovation, 6*(1), 38–47. https://doi.org/10.36037/IJREI.2022.6104

Jeong, S. H., Jang, B. N., Kim, S. H., Jang, S. I., & Park, E. C. (2021). Investigation of the association between smoking behavior and metabolic syndrome using lipid accumulation product index among South Korean adults. *International journal of environmental research and public health, 18(*8), 4151. https://doi.org/ 10.3390/ijerph18084151

Kavaliauskas, M. (2022). *All-out sprinting: Reliability and sensitivity of testing, and the effects of work-to-rest ratio and exercise modality* [Thesis Magister, Edinburgh Napier University] https://doi.org/10.17869/ENU.2022.2948392

Kera, T., Kawai, H., Takahashi, J., Hirano, H., Watanabe, Y., Fujiwara, Y., Ihara, K., Kim, H., & Obuchi, S. (2022). Development of a screening formula for sarcopenia using ground reaction force during sit-to-stand motion. *Gait & Posture, 93*(1), 177–182. https://doi.org/10.1016/j.gaitpost.2022.02.001

Lobo, J., Tanucan, J. C., Camarador, R., Azim, A., Setiawan, E., Arao, H. F., & Fernando, L. (2024). Revolutionizing dance education through the assessment of online videoconferencing to increase participation in dance: Learning Philippine Traditional Dances. *Empirical Studies of the Arts*, *43*(2), 1070-1096. https://doi.org/10.1177/02762374241288701

Majstorović, N., Dopsaj, M., Grbić, V., Savić, Z., Vićentijević, A., Aničić, Z., Zadražnik, M., Toskić, L., & Nešić, G. (2020). Isometric strength in volleyball players of different age: A multidimensional model. *Applied Sciences, 10*(12), 1-12. https://doi.org/10.3390/app10124107

Mielgo-Ayuso, J. (2015). Influencia de la composición corporal en el rendimiento físico de. *Nutricion hospitalaria*, *2*(1), 849–857. https://doi.org/10.3305/nh.2015.31.2.7658

Moon, J. R., Tobkin, S. E., Smith, A. E., Roberts, M. D., Ryan, E. D., Dalbo, V. J., Lockwood, C. M., Walter, A. A., Cramer, J. T., Beck, T. W., & Stout, J. R. (2008). Percent body fat estimations in college men using field and laboratory methods: A three-compartment model approach. *Dynamic Medicine, 7*(1), 1-9. https://doi.org/10.1186/1476-5918-7-7

Motimath, B., & A Pasha, M. (2025). Enhancing youth cricket performance: Insights from field-based assessments of strength, endurance, and agility. *Journal of Coaching and Sports Science*, *4*(1), 12–22. https://doi.org/10.58524/jcss.v4i1.390

Muntner, P., Shimbo, D., Carey, R. M., Charleston, J. B., Gaillard, T., Misra, S., Myers, M. G., Ogedegbe, G., Schwartz, J. E., Townsend, R. R., Urbina, E. M., Viera, A. J., White, W. B., Wright, J. T., & on behalf of the American Heart Association Council on Hypertension; Council on Cardiovascular Disease in the Young; Council on Cardiovascular and Stroke Nursing; Council on Cardiovascular Radiology and Intervention; Council on Clinical Cardiology; and Council on Quality of Care and Outcomes Research. (2019). Measurement of Blood Pressure in Humans: A Scientific Statement From the American Heart Association. *Hypertension, 73*(5), 1-32. https://doi.org/10.1161/HYP.0000000000000087

Nefesoğlu, İ., & Bas, O. (2021). The effect of the kinanthropometric profile on leg strength and hand grip strength in young female swimmers. *Türkiye Spor Bilimleri Dergisi, 5*(1), 1-15. https://doi.org/10.32706/tusbid.899573

Ning, L., He, C., Lu, C., Huang, W., Zeng, T., & Su, Q. (2024). Association between basal metabolic rate and cardio-metabolic risk factors: Evidence from a Mendelian Randomization study. *Heliyon, 10*(7), 1-14. https://doi.org/10.1016/j.heliyon.2024.e28154

Nugroho, S., Hidayat, R. A., Komari, A., Pratama, K. W., Karakauki, M., & Ali, S. K. S. (2022). Effect of plyometric exercise and leg muscle endurance on the agility and VO_2max of badminton athletes. *Physical Education Theory and Methodology, 22*(3s), S71-S78. https://doi.org/10.17309/tmfv.2022.3s.10

Pandy, M. G., Lai, A. K. M., Schache, A. G., & Lin, Y. (2021). How muscles maximize performance in accelerated sprinting. *Scandinavian Journal of Medicine & Science in Sports, 31*(10), 1882–1896. https://doi.org/10.1111/sms.14021

Parmar, A., Scott, M., Brand, C., & Jones, T. W. (2020). An assessment of the contractile properties of the shoulder musculature in elite volleyball players using tensiomyography. *International Journal of Sports Physical Therapy, 15*(6), 1099–1109. https://doi.org/10.26603/ijspt20201099

Pavlidou, E., Papadopoulou, S. K., Seroglou, K., & Giaginis, C. (2023). Revised harris–benedict equation: New human resting metabolic rate equation. *Metabolites, 13*(2), 1-12. https://doi.org/10.3390/metabo13020189

Prado, C. M. M., & Heymsfield, S. B. (2014). Lean tissue imaging: A new era for nutritional assessment and intervention. *Journal of Parenteral and Enteral Nutrition, 38*(8), 940–953. https://doi.org/10.1177/0148607114550189

Qaddomi, A. N. (2003). Body mass index and resting metabolic rate of the men volleyball players. *An-Najah University Journal for Research - B (Humanities), 17*(1), 31–54. https://doi.org/10.35552/0247-017-001-002

Rukadikar, C., Mali, S., Rukadikar, A., & Mundewadi, S. (2017). Correlation of lean body mass, hand grip strength in football and cricket players: A cross-sectional study. *National Journal of Physiology, Pharmacy and Pharmacology, 7*(10), 1-6. https://doi.org/10.5455/njppp.2017.7.06201719062017

Rukadikar, D. C. A., Mundewi, & S.A., Mali, S., (2020). Correlation of various anthropometric parameters and nondominant hand grip strength in cricket and football players. European *Journal of Molecular & Clinical Medicine (EJMCM), 7*(11), 5971-5977.

Shanbhag, A. R., & Kumar, N. (2021). Correlations of anthropometric measurement and handgrip strength between collegiate cricket fast and spin bowlers. *Indian Journal of Physiotherapy and Occupational Therapy, 15*(4), 1-10. https://doi.org/10.37506/ijpot.v15i4.16487

Silva, A. M. (2019). Structural and functional body components in athletic health and performance phenotypes. *European Journal of Clinical Nutrition, 73*(2), 215–224. https://doi.org/10.1038/s41430-018-0321-9

Silvestre, R., West, C., Maresh, C. M., & Kraemer, W. J. (2006). Body composition and physical performance in men's soccer: A study of a national collegiate athletic association division i team. *The Journal of Strength and Conditioning Research, 20*(1), 177–183. https://doi.org/10.1519/R-17715.1

Singla, D., & Hussain, M. E. (2018). Association between handgrip strength and back strength in adolescent and adult cricket players. *International Journal of Adolescent Medicine and Health, 32*(4), 20170177. https://doi.org/10.1515/ijamh-2017-0177

Slater, G., O'Connor, H., & Kerr, A. (2018). Optimising physique for sports performance. In P. A. Hume, D. A. Kerr, & T. R. Ackland (Eds.), Best Practice Protocols for Physique Assessment in Sport (27–36). Springer, Singapore. https://doi.org/10.1007/978-981-10-5418-1_3

Stagi, S., Irurtia, A., Rosales Rafel, J., Cabras, S., Buffa, R., Carrasco-Marginet, M., Castizo-Olier, J., & Marini, E. (2021). Segmental body composition estimated by specific BIVA and dual-energy X-ray absorptiometry. *Clinical Nutrition, 40*(4), 1621–1627. https://doi.org/10.1016/j.clnu.2021.02.043

Stahlschmidt, Z. R. (2022). Flight capacity drives circadian patterns of metabolic rate and alters resource dynamics. *Journal of Experimental Zoology Part A: Ecological and Integrative Physiology, 337*(6), 666–674. https://doi.org/10.1002/jez.2598

Stenqvist, T. B. (2016). *Prevalence of Relative Energy Deficiency in Sport among well-trained male Norwegian cyclists and long-distance runners* [Master's thesis, Universitetet i Agder; University of Agder].

Tabassum, & AZİM, A. (2024). Common sports injuries, training load and treatment strategies for optimal recovery in female university athletes. *Intenational Journal of Active & Health Aging, 2*(2), 53-59. https://doi.org/10.5281/ZENODO.14551109

Tagliaferri, C., Wittrant, Y., Davicco, M.-J., Walrand, S., & Coxam, V. (2015). Muscle and bone, two interconnected tissues. *Ageing Research Reviews, 21*(1), 55–70. https://doi.org/10.1016/j.arr.2015.03.002

Teixeira, J., Carvalho, P., Moreira, C., Carneiro, A., & Santos, R. (2015). Muscle strength assessment of knee flexors and extensors. Comparative study between basketball, football, handball and volleyball athletes. *International Journal of Sports Science, 5*(5), 192-200. https://doi.org/10.5923/j.sports.20150505.04

Tiaprapong, K., & Tiaprapong, K. (2022). The relationship between respiratory muscle strength and physical performance in college volleyball players. *Sport Mont, 20*(2), 41–45. https://doi.org/10.26773/smj.220607

Trexler, E. T., Smith-Ryan, A. E., Mann, J. B., Ivey, P. A., Hirsch, K. R., & Mock, M. G. (2017). Longitudinal body composition changes in NCAA division i college football players. *Journal of Strength and Conditioning Research, 31*(1), 1–8. https://doi.org/10.1519/JSC.0000000000001486

Vincenzo, O, D., Marra, M., Sammarco, R., Speranza, E., Cioffi, I., & Scalfi, L. (2020). Body composition, segmental bioimpedance phase angle and muscular strength in professional volleyball players compared to a control group. *The Journal of Sports Medicine and Physical Fitness, 60*(6), 870–874. https://doi.org/10.23736/s0022-4707.20.10548-6

Von Hurst, P. R., Conlon, C., & Foskett, A. (2013). Vitamin D status predicts handgrip strength in young adult women living in Auckland, New Zealand. *The Journal of Steroid Biochemistry and Molecular Biology, 136*(1), 330–332. https://doi.org/10.1016/j.jsbmb.2012.11.015

Ward, L. C. (2019). Bioelectrical impedance analysis for body composition assessment: Reflections on accuracy, clinical utility, and standardisation. *European Journal of Clinical Nutrition, 73*(2), 194–199. https://doi.org/10.1038/s41430-018-0335-3

Winger, M. E., Caserotti, P., Ward, R. E., Boudreau, R. M., Hvid, L. G., Cauley, J. A., Piva, S. R., Harris, T. B., Glynn, N. W., & Strotmeyer, E. S. (2021). Jump power, leg press power, leg strength and grip strength differentially associated with physical performance: The Developmental Epidemiologic Cohort Study (DECOS). *Experimental Gerontology, 145*(1), 111172. https://doi.org/10.1016/j.exger.2020.111172

Zaggelidis, G. (2016). Maximal isometric handgrip strength (HGS) in greek elite male judo and karate athletes. *Sport Science Review, 25*(1), 320-333. https://doi.org/10.1515/ssr-2016-0017