PAN
OPEN ACCESS
https://doi.org/10.20463/pan.2024.0025
Physical Activity and Nutrition | 2024;28(3):064-071

Received: 2024/03/14, Revised: 2024/06/26, Accepted: 2024/08/14, Published: 2024/09/30

*Corresponding author : Miguel A. Pérez

Strength, Performance & Body Composition Lab, Variante agua santa 7055, Viña del Mar, Zip code 2572007, Chile.

E-mail: m.angelper@gmail.com

Sex differences in upper and lower strength and their association with body composition among university students

Miguel A. Pérez[1†*] / **Gabriela P. Urrejola-Contreras**[2] / **Judith Hernández**[3] / **Pamela Silva**[1] / **Maximiliano Torres-Banduc**[4†]

1. Escuela de Ciencias de la Salud, Carrera de Kinesiología, Universidad Viña del Mar, Chile
2. Escuela de Ciencias de la Salud, Ciencias Aplicadas, Universidad Viña del Mar, Chile
3. Escuela de Ciencias de la Salud, Carrera de Nutrición, Universidad Viña del Mar, Chile
4. Facultad de Ciencias de la Salud, Universidad de Las Américas, Viña del Mar, Chile

† These authors contributed equally to this work

[Purpose] Sex strongly influences physical performance throughout adolescence, and excess fat mass is associated with several health and performance impairments. This study aimed to evaluate whether variations in strength between men and women dependent on lean mass and body fat content.

[Methods] This cross-sectional, quasi-experimental, non-probabilistic study involved 44 university students (22 men and 22 women, aged 19–29). Handgrip strength (HGS) was measured using an adjustable handgrip dynamometer, body composition was assessed using bioimpedance, and countermovement jumps (CMJ) were measured using a force platform. Data were analyzed using ANOVA to compare HGS and CMJ based on body mass, and the Pearson correlation coefficient was applied to examine the relationships between grip strength, body composition, and jump test performance.

[Results] Strength is significantly higher in men compared to women, as is countermovement jump. The strength of women corresponded to over 50% of that of men, whereas the quantity of lean mass in women corresponded to 55% of that of men. We found a significant relationship between strength and lean mass.

[Conclusion] This study supports the idea that both upper- and lower-body strengths are strongly influenced by lean mass, thereby contributing to sex differences. The primary factor in body composition that explains the disparities in HGS and CMJ between sexes is the proportion of fat mass to lean mass. Finally, the sex disparities observed between body composition and strength depend on lean mass content.

[Keywords] sex, lean mass, body composition, grip strength, countermovement jump, university students

INTRODUCTION

Muscle mass is considered a significant component of overall health[1]. Muscle strength is a clinical measure used to quantify muscle mass[2]. Higher lean mass is correlated with greater strength[3]. In young adults, higher muscle strength is associated with lower cardiometabolic risk[4], providing a protective effect against mortality from cancer, hypertension, and type 2 diabetes[5,6]. Handgrip strength (HGS) and vertical jump are the most commonly used tests to assess muscular strength in adolescents and young adults because of their high degree of reliability and validity[7,8]. HGS is used to assess hand function and serves as a possible indicator of present and future health[1,9,10]. Individuals with lower muscle strength early in life are more likely to have health issues related to weakness as they age[11]. The main factors influencing HGS are sex, age, physical activity, nutrition, and health conditions[12-14]. Anthropometric variables, including height, body weight, and body mass index (BMI) serve as important independent predictors of HGS[15].

Vertical jumps are employed to assess lower limb muscle strength and power performance[16-18]. The countermovement jump (CMJ) is a widely used tests that is considered reliable and valid for monitoring jump performance and lower limb strength[19]. Main factors influencing jumping performance are muscle strength, power capability[20,21], body composition[20,22], and technique[23]. There is mixed evidence on the contributions of age, weight, and body composition to vertical jump performance. Vertical jump performance decreases as body fat increases in young male adults[24], and there is a relationship between age and sex in vertical jump[25]. In contrast, a positive correlation was found between total body lean mass, fat mass and CMJ force and power[26], whereas the percentage of body fat (BF%) had an inverse correlation with vertical jump[27].

Sex strongly influences physical performance throughout adolescence[28,29]. Women generally do not match men's performance in tasks that demand high strength, muscular endurance, or physical work capacity[30,31]. Sex differences are evident in total body fat mass, particularly in the lower limbs of women, whereas men tend to have an increased lean body mass[32]. During puberty, hormonal differences drive a substantial increase in fat mass in females and a marked increase in muscle mass in males[33,34]. Consequently, higher fat infiltration and lower muscle mass in women may contribute to their poorer physical performance compared to men[29]. Fat accumulation within skeletal muscles is linked to muscle weakness and poor function[35]. Therefore, an increase in body mass index category is linked to a higher likelihood of low muscle strength in healthy adolescents. However, the extent of sex differences in strength varies by muscle group. In the lower limbs, women's strength typically reaches 60–80% of men's strength, while in the upper limbs, it is closer to 60%[36]. Chile ranks among the countries with the highest obesity rates globally for both children and adults[37]. Obesity is associated with several impairments, including an increased risk of high blood pressure, as well as deficits in memory, attention, and motor skills at all ages. Furthermore, we must consider that approximately 50–80% of children and adolescents who develop obesity early in life become obese later in life, increasing the risk of obesity in adulthood[38]. Thus far, no study has explored the effect of excess body fat while considering sex-specific differences in muscular strength performance, which serves as a possible indicator of health in adolescents and young adults. Therefore, the aim of this study was to evaluate whether the strength differences between men and women depend on lean mass and body fat mass content and to hypothesize that an excess of fat mass induces a decrease in strength, whereas a higher lean mass favors the development of strength.

METHODS

Participants

A total of 44 university students (22 women and 22 men) aged between 19 and 29 years with similar levels of physical activity according to the IPAQ evaluation were recruited from the University Viña del Mar. This study employed a quasi-experimental, non-probabilistic design in a population of students from a kinesiology course. Thus, a participation rate of 90% was achieved. Subjects weight (men: 77.9 ± 2.6 kg; women: 63.9 ± 1.4 kg), height (men: 1.75 ± 0.01 m; women: 1.58 ± 0.01 m), and BMI (25.4 ± 0.8 in men and 25.3 ± 0.9 in women) are summarized in Table 1. Participants were fully informed about the study's purpose and procedures, and gave their written consent before taking part. The study adhered to the guidelines of the Declaration of Helsinki and received approval from the Scientific Ethics Committee of Viña del Mar University (CEC-UVM 03-23). Anonymity and confidentiality were strictly maintained for all collected data, and the study was conducted solely for scientific purposes. All participants completed and signed an informed consent form prior to the study. Additionally, they did not engage in physical activity on the day before the evaluation. On the day of the evaluation, they consumed a light breakfast without caffeine. The anthropometric and physical performance assessments were carried out in a single session. First, students who voluntarily wanted to participate attended the science school laboratory, where anthropometric parameters were measured, and later completed the IPAQ survey. Second, after explaining the procedure, grip strength was measured in both extremities. Third, a jump test was conducted, and impedance analysis measurements were performed.

Handgrip strength

To perform the HGS measurements, a hydraulic dynamometer with an adjustable grip (Baseline® model, USA) was used. Participants were instructed to stand upright with their arms at their sides and to squeeze with maximum force for 3 seconds in response to standardized verbal prompts from the researcher, and the number obtained before resetting the value to zero was recorded. The procedure was repeated three times for each hand, with a 1-minute rest between measurements, and the highest value recorded was

Table 1. Demographics, body composition, grip strength, and physical activity level.

Parameters	Females (n = 22)	Males (n = 22)
Age (years)	22 ± 0.9	23 ± 0.6
Weight (kg)	63.9 ± 1.4	77.9 ± 2.6*
Height (m)	1.58 ± 0.01	1.75 ± 0.01*
Waist circumference (cm)	68.22 ± 9.5	79.50 ± 10.2*
Body mass index (BMI)	25.3 ± 0.9	25.4 ± 0.8
Body fat mass (kg)	21.17 ± 6.2	18.73 ± 9.7
Fat free mass (FFM)(kg)	38.49 ± 4.7	59.97 ± 7.2*
Handgrip strength, (kg)		
Right hand (kg)	23.86 ± 4.2	43.98 ± 8.8*
Left hand (kg)	25.10 ± 8.7	42.93 ± 9.3*
Relative handgrip strength (kg/kg/m^2)	1.9 ± 0.4	3.6 ± 0.9*
Body mass index status. % (n)		
Normal (%)	47.6 (11)	50 (11)
Overweight (%)	38.1 (8)	40.9 (9)
Obese (%)	14.3 (3)	9.1 (2)

significant differences were assessed by an unpaired t-test and are indicated by *p < 0.05 and **p < 0.01, respectively.

used for analysis.

Anthropometric measures

Standardized techniques were used for body measurements[39], taking two measurements for each parameter and taking the mean of both. Weight was determined using a SECA scale (model 700, precision 50 g, Germany) by placing the subject in the center of the plate in light clothing. Height was measured using a stadiometer (SECA) with participants standing, shoes removed, shoulders relaxed, and facing away from the wall. BMI, expressed in kg/m², was calculated by dividing weight (kg) by height squared (m²). BMI was further categorized according to international adult standards as follows: underweight (BMI < 18.5), normal weight (BMI = 18.5–24.9), overweight (BMI = 25.0–29.9), and obese (BMI > 29.9)[25]. Waist circumference was measured with the abdomen exposed, arms relaxed and abducted at the end of normal expiration, ensuring that there was no pressure on the tape. A direct segmental multi-frequency bioelectrical impedance analysis device, InBody 270 (InBody Co. Ltd, South Korea) was used to assess body composition. The measurements were performed in temperature-controlled laboratories. Briefly, body composition was measured using a standardized protocol[40] with an eight-electrode multifrequency segment, which was regularly serviced and calibrated.

Jump performance

A force platform (Art Oficio PF-4000/50, Santiago, Chile) was used to conduct the countermovement jump (CMJ) test. Before testing, participants completed a 5-minute warm-up at a cadence of 60–70 rpm without resistance. During the test, participants positioned their feet parallel and shoulder-width apart, knees extended, and arms placed akimbo. After a rapid downward movement, the participants flexed their knees and hips, followed by a quick knee extension to achieve maximum vertical jump height. Each participant performed three CMJ repetitions, with a 1-minute break between attempts. The best performance was used for subsequent statistical analysis. To assess within-subject variation and the reliability of CMJ measurements, the coefficient of variation (CV) was calculated following the method described by Hopkins[41], with acceptable reliability defined as CV ≤ 10%[42].

Statistical analysis

The Shapiro–Wilk test was used to evaluate the normality of the data distribution, whereas homoscedasticity was analyzed using Spearman´s test. If a variable did not fit a normal distribution or the variances were heteroscedastic, a log-transformation of the data was performed. Subsequently, back-transformation was performed to inform the participants of the data. Descriptive data for categorical variables are presented as both relative and absolute frequencies, and were analyzed using an unpaired Student's t-test. Continuous data are expressed as means and standard deviations, stratified by sex and the dominant hand. Differences in HGS by BMI were assessed using a two-way ANOVA (sex [female, male] × BMI classification [normal, overweight, obese]), followed by Bonferroni post-hoc tests. Potential differences in CMJ parameters based on sex and body composition were similarly analyzed using a two-way ANOVA. Bivariate relationships between HGS, CMJ, and body composition were explored through correlation and regression analyses. The strength of correlations was classified as follows: very weak (0.0–0.2), weak (0.2–0.39), moderate (0.4–0.59), strong (0.6–0.79), and very strong (0.8–1.0). Multivariate regression was employed to examine the simultaneous effects of sex (male or female) on strength and body composition. An alpha level of $p < 0.05$ was considered statistically significant for all hypothesis tests, which were two-tailed. Statistical analyses were performed using GraphPad version 8.01 for Windows (GraphPad Software, Boston, MA, USA).

RESULTS

Table 1 presents the descriptive summary of the sample. As anticipated, men demonstrated greater handgrip strength in both absolute and relative terms (hand grip strength/BMI), as well as a larger average waist circumference. Most participants had BMI values classified as normal weight, with a homogeneous distribution across sexes (Women: 25.3 ± 0.9; Men: 25.4 ± 0.8). We also found that the mean of body fat mass is homogeneously distributed by sex and fat free mass (FFM) in men was higher than in women (Men: 59.97 ± 7.2; Women: 38.49 ± 4.7, $p < 0.05$). Additionally, the distribution of BMI categories (normal weight, overweight, and obese) was uniform across sexes, as shown in Table 1.

Handgrip strength and body composition

A two-way ANOVA showed that handgrip strength is significantly higher in men compared to women (men: 42.97 ± 1.1 kg; women: 24.18 ± 2.4 kg, $p < 0.0001$) (Figure 1A). In men, handgrip strength tended to decrease with increasing BMI (excess body fat mass), whereas in women no changes in handgrip strength were associated with changes in BMI. Grip strength did not correlate with body fat mass in women, whereas it showed a moderately negative correlation in men (r = -0.40). (Figure 1B). We found a very weak correlation between handgrip strength and FFM in women (r = -0.10), while a significant moderate positive relationship was observed in men (r = 0.44, $p < 0.05$) (Figure 1C). A two-way ANOVA showed that normal-weight women have significantly more fat mass in the right upper extremity than men (men: 0.55 ± 0.4 kg; women: 1.2 ± 0.3 kg, $p < 0.048$). However, no sex differences were observed in overweight or obesity status. Moreover, women have a lower amount of lean mass compared to men across all weight statuses (men: 3.4 ± 0.5 kg; women: 1.9 ± 0.3 kg) ($F(2,68) = 41.81$, $p < 0,0001$) (Figure 1D). Table 2 shows the percentages of strength and lean mass of women normalized to those of men (100%). In the upper limbs, women's grip strength is 52–62% of men's, while their lean mass in the right upper extremity is 54–62% of men's.

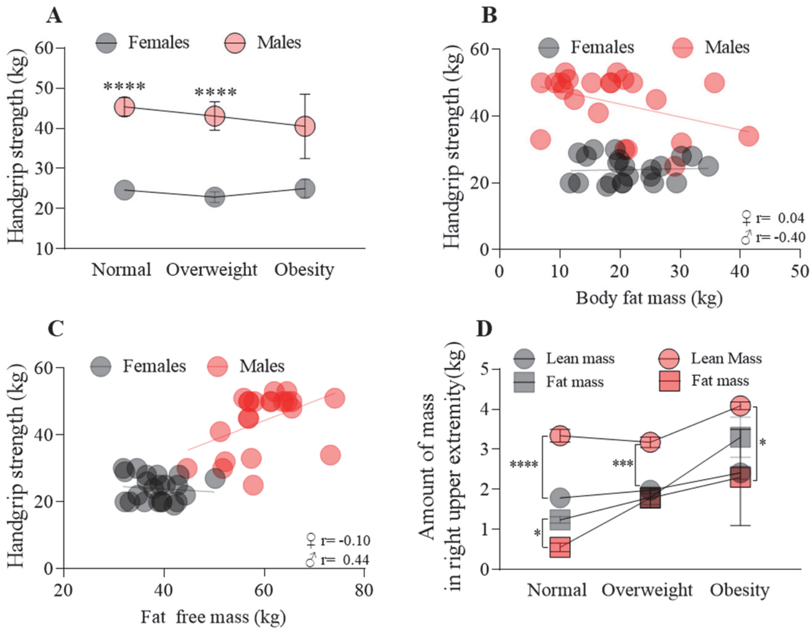

Figure 1. Association between handgrip strength and body composition. A. Grip strength is greater in males compared to females (Males: 43.0±1.4; Females: 24.20±0.7). In males, grip strength tends to decrease with increasing body mass index, while no changes in grip strength associated with body mass index are observed in females. B. Grip strength does not correlate with the amount of body fat mass in females (r = 0.04), while it has a negative correlation (r = -0.43) with body fat mass in males. C. Grip strength does not correlate with the amount of fat free mass in females (r= -0.12), while it has a moderately positive correlation (r=0.47) with fat free mass in males. D. Ratio of lean mass and fat mass in the right upper extremity in females (black) and males (red). The absolute fat mass is similar between both sexes (Males: red square; Females: black square), with exception in normal weight where females had a higher amount of fat mass compared to males. However, the amount of lean mass is higher in males (red circle) compared to females (black circle) across the body mass index status. *p < 0.5, **p < 0.01, ***p < 0.001, ****p < 0.0001, two-way ANOVA (a,d), regression analysis (b,c).

Table 2. The percentage of strength and lean mass of females normalized to males (100%).

Parameters	HGS	FFM upper limbs	Jump force	Jump power	Jump height	FFM lower limbs
Normal weight	54.98%	53.60%	54.66%	45.70%	55.89%	62.66%
Overweight	51.18%	62.38%	73.14%	56.15%	67.47%	66.28%
Obesity	61.72%	59.11%	41.48%	57.45%	62.85%	66.06%
Mean	55.96%	58.4%	56.42%	53.1%	62.1%	65.0%

Data are means ± SEM. HGS: Handgrip strength; FFM: Fat Free Mass.

Table 3. Supplementary material. Pearson correlation (95% confidence interval) to handgrip strength across different sub-groups.

Parameters	n	Weight	Height	WC	Fat mass	% of fat mass	FFM	SMM
All subjects	44	0.42* (0.15-0.64)	0.79* (0.7-0.9)	0.38* (0.1-0.6)	-0.31* (-0.5-0.06)	-0.68* (-0,8- -0.5)	0.8* (0.7-0.9)	0.8* (0.7-0.9)
Females	22	0.29 (-0.1-0.6)	0.48* (0.1-0.8)	0.41 (-0.01-0.7)	0.04 (-0.4-0.4)	0.04 (-0.4-0.4)	-0.10 (-0.5-0.3)	-0.14 (-0.5-0.3)
Males	22	-0.12 (-0.5-0.3)	0.48* (-0.06-0.75)	-0.25 (-0.6 – 0.2)	-0.40* (-0.7-0.01)	-0.53* (-0.7- -0.1)	0.44* (0.03-0.8)	0.47* (0.04-0.8)
Normal weight	22	0.82* (0.6-0.9)	0.89* (0.8-1.0)	0.63** (0.3-0.8)	-0.67* (-0.8- -0.3)	-0.79*** (-0.9- -0.6)	0.84*** (0.6-0.9)	0.84*** (0.6-0.9)
Overweight	17	0.58* (0.1-0.8)	0.73*** (0.4-0.9)	0.54* (0.08-0.8)	0.09 (-0.5- 0.6)	-0.61* (-0.9- -0.1)	0.84*** (0.6-0.9)	0.84*** (0.6-0.9)
Obesity	5	0.15 (-0.9-1.0)	0.98 (0.4- 1.0)	0.95 (-0,1 – 1.0)	*0.48 (-0.9-0.9)	-0.95* (-0.9-0.06)	0.68 (-0.8- 1.0)	0.74 (-0.8- 1.0)

WC: waist circumference; FFM: Fat Free Mass; SMM: Skeletal Muscle Mass.* p < 0.05, **p < 0.01, ***p < 0.001.

Spearman's correlation coefficient showed a significantly moderate correlation between handgrip strength and height in both women (r = 0.48, $p < 0.05$) and men (r = 0.48, $p < 0.05$). A significantly strong correlation was observed between handgrip strength, FFM, and skeletal muscle mass (SMM) in men. However, we did not find any correlation among HGS, FFM, and SMM in women. When categorized by body mass index, a significantly strong and positive relationship was observed between grip strength and weight, height, waist circumference, fat mass, BF%, FFM, and SMM among individuals with a normal weight status (ranging from 0.63 to 0.89, $p < 0.05$) (Table 2). In overweight individuals, a significantly moderate-to-strong positive correlation was observed between handgrip strength and weight, height, waist circumference, BF%, FFM, and SMM (ranging from 0.54 to 0.84, $p < 0.05$). In the obesity group, we found a strong positive correlation between handgrip strength and height, waist circumference, BF%, FFM, and SMM (ranging from 0.68 to 0.98, $p < 0.05$) (Table 3, Supplemental material).

Jumping performance across gender, body composition, and its association with lean mass

For the CMJ force there was a statistically significant effect by sex (men: 901.8 ± 382.3N; women: 475.1 ± 89.27N, $p < 0.0001$), BMI category ($F(2,33) = 13.78$, $p < 0.0001$), and the interaction between sex and BMI ($F(2,33) = 3.38$, $p = 0.0459$) (Figure 2A). Furthermore, the CMJ force in the obese group was significantly higher than that in the other BMI categories ($p < 0.05$). Men generated twice the jump power of women ($p < 0.0001$), and no effect of BMI or the interaction between sex and BMI on power was found (Figure 2B). Furthermore, men had a significantly higher jump height in each body mass index status than women ($p < 0.0001$), and no effect of body mass index status on jump height was found (Figure 2C). Two-way ANOVA revealed that the amount of fat mass in the lower limbs was similar between women and men across all BMI categories. However, women have a lower amount of lean mass compared to men across all weight statuses (men: 9.6 ± 0.7 kg; women: 6.2 ± 0.5 kg) ($F(2,68) = 14.87$, $p < 0{,}0001$) (Figure 1D). Additionally, Table 2 shows the percentages of CMJ force, power, jump height, and lean mass of women normalized to those of men (100%). In the lower extremities, for women corresponded to a mean of 53% to 62% of those developed by men, while the amount of lean mass in women's lower extremities averaged 65% of that in men.

There was a very weak positive relationship between jump force and body fat mass in women (r = 0.10), while men exhibited a weak correlation (r = 0.2) (Figure 3A).

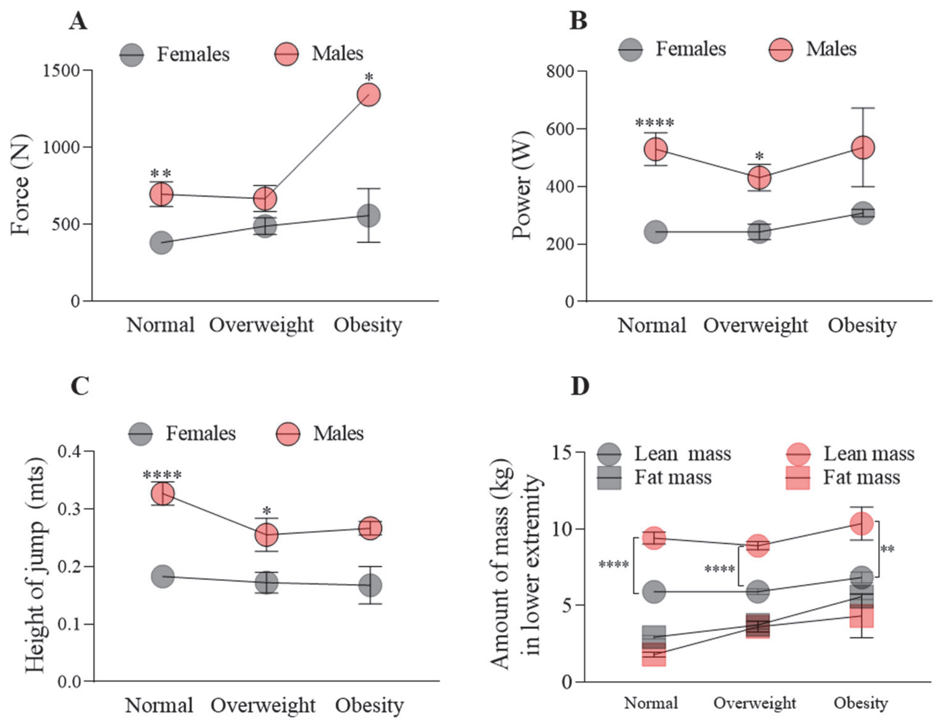

Figure 2. Relationship between jumping parameters, and body composition. A. Males have a significantly higher jumping force in each body mass index status compared to females. Furthermore, force is influenced by both sex ($p < 0.001$) and body mass index ($p < 0.05$). B. Males generate twice the jump power of females, and no effect of body mass index on power was found. C. Males have a significantly height of jump in each body mass index compared to females, and no effect of body mass index on height of jump was found. D. Ratio of lean mass and fat mass in the lower extremity in females (black) and males (red). The absolute fat mass is similar between both sexes (Males: red square; Females: black square). However, the amount of lean mass is higher in males (red circle) compared to females (black circle) across the body mass index status. *$p < 0.5$, **$p < 0.01$, ***$p < 0.001$, ****$p < 0.0001$, two-way ANOVA.

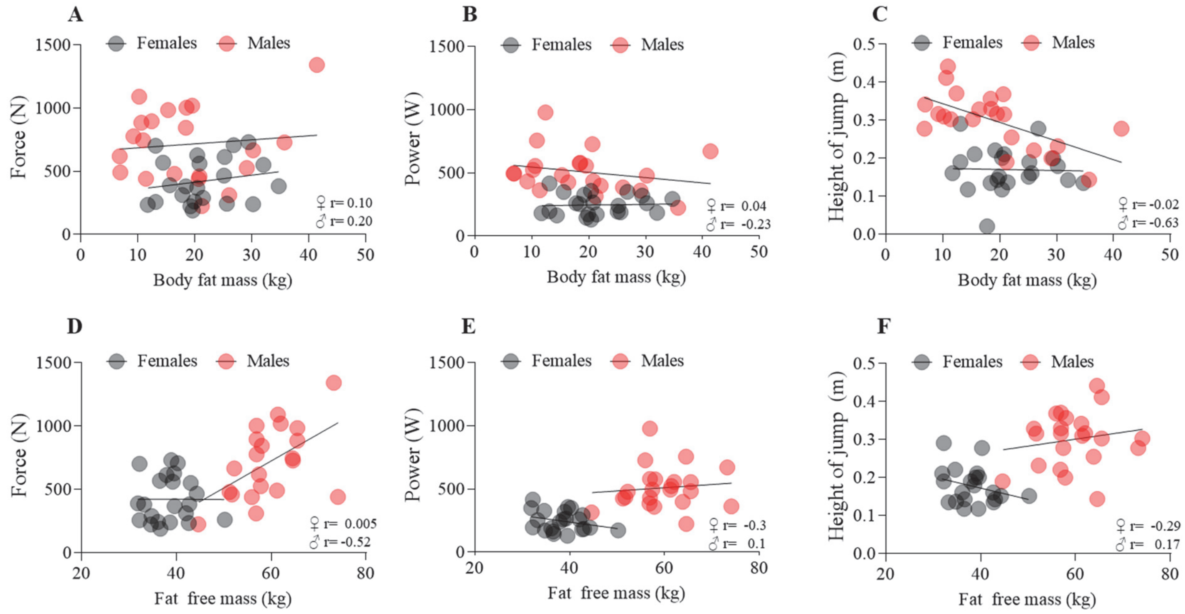

Figure 3. Correlation between jumping parameters, and body composition. A. There is a weak positive correlation between jump force and the amount of body fat mass in males (r= 0.10) and female (r = 0.20). B. There is a weak negative correlation between force and body fat mass in males (r = -0.23), while it has not correlation with body fat mass in females (r = 0.04). C. Height of jump power has a significantly moderate negative correlation (r = 0.6) with body fat mass in males, while it has not correlation (r = -0.02) with body fat mass in females. D. There is a significantly moderate positive correlation between jump force and the amount of fat free mass in males (r = 0.52), while it has not correlation (r = -0.005) with fat free mass in females. E. There is a weak positive correlation between power and fat free mass in males (r = 0.1), whereas there is a weak negative correlation between power and fat free mass in females (r= -0.3). F. There is a weak positive correlation between height jump and fat-free mass in males (r = 0.17), whereas there is a weak negative correlation between height jump and fat-free mass in females (r = -0.3). *p < 0.5, **p < 0.01, ***p < 0.001, ****p < 0.0001.

There was a weak inverse relationship between power and body fat mass in men (r = -0.23), whereas there was no correlation with body fat mass in women (r = 0.04) (Figure 3B). There is no correlation between jump height and body fat mass in women (r = -0.02), whereas men exhibited a significantly strong inverse correlation between jump height and body fat mass (r = -0.63) (Figure 3C). There was no relationship between jump force and FFM in women (r = 0.005), whereas there was a significantly moderate inverse relationship between jump force and FFM in men (r = -0.52) (Figure 4D). There was a weak inverse relationship between jump power and FFM in women (r = -0.30), while men exhibited a very weak correlation (r = 0.10) (Figure 3E). Additionally, there was a weak positive correlation between jump height and FFM in men (r = 0.17) and a weak inverse relationship with FFM in women (r = -0.29) (Figure 3F).

DISCUSSION

This study aimed to evaluate whether differences in strength between men and women depend on lean mass and body fat content. First, regarding the upper limbs, women's grip strength ranged from 52% to 62% of men's grip strength, and the quantity of lean mass in the right upper extremity of women corresponds to 54–62% of that in men. Second, a significant relationship was observed between grip strength and both BF% and fat-free mass across all participants. This finding correlates with that of Zaccagni et al. (2020) who found that HGS varies significantly between sexes and is directly influenced by body composition. However, HGS did not correlate with body fat mass in women, whereas a moderate negative correlation was found in men. These sex-related differences in HGS may be attributed to variations in the amounts of fat mass and lean mass in the upper limbs[31]. Muscle volume is considerably lower in women due to reduced testosterone production, while the fat mass percentage is higher under the influence of estrogen[33]. In this study, men demonstrated more than 50% greater HGS than women, which aligns with the findings of Mansour et al.[31], who reported significantly higher HGS in men across all age groups. Men also possess nearly twice the lean mass and half the fat mass in the right upper extremity compared to women, primarily due to distinct morphological and physiological variations[43,44]. Sartorio et al.[45] identified sex and sex hormones as the primary factors influencing HGS. Furthermore, women's strength in the upper limbs is equivalent to 40% of that of men[46]. In this study, we found that the strength level of women was 55% of that of men.

Our findings indicated that male CMJ performance parameters were more than 40% better than those of women (p < 0.0001), which agrees with the findings of McMahon et al.[47] in which men produced greater strength and power. However, these differences diminished after adjusting for body mass and were entirely eliminated when the parameters were adjusted for lean mass[31]. We found that men had significantly more lean mass in the lower body than women ($p < 0.0001$), which aligns with the findings of Janssen et al.[43], who reported higher lean mass in men across all age groups. There were no sex differences in body fat mass of the lower limbs. Prior research has indicated that changes in body composition and endocrine factors may account for variations in physical performance[48]. Excess fat among female students has been found to have a disadvantageous effect on vertical jump performance[31].

Our evidence supports the idea that strength disparities between men and women are linked to differences in lean mass. First, our study revealed a significant inverse correlation between handgrip strength (HGS) and body fat mass in men. Additionally, we found that an increase in lean mass significantly correlated with an improvement in handgrip strength in men. Second, sex disparities in grip strength and CMJ parameters were in concordance with the quantity of lean mass. For example, women's grip strength is 52–62% of men's, while their lean mass in the upper limbs is 54–62% of that of men. Additionally, at the lower limb level, the CMJ force, power, and height of women corresponded to 56–58% of those of men, whereas the quantity of lean mass in the lower limbs of women corresponded to 65% of that of men. Third, in men the CMJ force exhibited a significant positive correlation with lean mass.

This study presents several strengths and weaknesses. Although our sample of healthy students may not fully reflect the broader population, it is sufficient for drawing meaningful conclusions. Additionally, the homogeneity of the sample regarding age limited our ability to assess changes in strength across different age groups. Further investigations should be conducted using other experimental groups to corroborate our results and obtain new data.

The results of this study suggest that lean mass significantly influences both upper and lower body strength, contributing to differences between the sexes. The primary factor in body composition that explains the disparities in HGS and CMJ between women and men is the ratio of fat mass to lean mass. Finally, the differences in the relationship between body composition and strength among university students varied according to the amount of lean mass present.

ACKNOWLEDGMENT

We extend our gratitude to the team for their cooperation in designing the study and discussing the results. We would like to thank Editage (www.editage.co.kr) for their assistance with English editing. The publication fees were funded by the Escuela de Ciencias de la Salud, Universidad Viña del Mar, Chile. The authors state that they have no conflicts of interest.

REFERENCES

1. Bohannon RW. Muscle strength: clinical and prognostic value of hand-grip dynamometry. *Curr Opin Clin Nutr Metab Care.* 2015;18: 465-70.
2. Koo BK. Assessment of muscle quantity, quality and function. *J Obes Metab Syndr.* 2022;31:9-16.
3. Thomas MH, Burns SP. Increasing lean mass and strength: a comparison of high frequency strength training to lower frequency strength training. *Int J Exerc Sci.* 2016;9:159-67.
4. Ramírez-Vélez R, Correa-Bautista JE, Lobelo F, Izquierdo M, Alonso-Martínez A, Rodríguez-Rodríguez F, Cristi-Montero C. High muscular fitness has a powerful protective cardiometabolic effect in adults: influence of weight status. *BMC Public Health.* 2016;16: 1012.
5. Lee MR, Jung SM, Bang H, Kim HS, Kim YB. Association between muscle strength and type 2 diabetes mellitus in adults in Korea: data from the Korea national health and nutrition examination survey (KNHANES) VI. *Medicine (Baltimore).* 2018;97:e10984.
6. Wang Y, Lee D chul, Brellenthin AG, Sui X, Church TS, Lavie CJ, Blair SN. Association of muscular strength and incidence of type 2 diabetes. *Mayo Clin Proc.* 2019;94:643-51.
7. Aoyama M, Suzuki Y, Onishi J, Kuzuya M. Physical and functional factors in activities of daily living that predict falls in community-dwelling older women: functional factors related to falls. *Geriatr Gerontol Int.* 2011;11:348-57.
8. Zaccagni L, Toselli S, Bramanti B, Gualdi-Russo E, Mongillo J, Rinaldo N. Handgrip strength in young adults: association with anthropometric variables and laterality. *Int J Environ Res Public Health.* 2020;17:4273.
9. Bohannon RW. Hand-grip dynamometry predicts future outcomes in aging adults. *J Geriatr Phys Ther.* 2008;31:3-10.
10. Li S, Zhang R, Pan G, Zheng L, Li C. Handgrip strength is associated with insulin resistance and glucose metabolism in adolescents: evidence from national health and nutrition examination survey 2011 to 2014. *Pediatr Diabetes.* 2018;19:375-80.
11. McGrath RP, Kraemer WJ, Snih SA, Peterson MD. Handgrip strength and health in aging adults. *Sports Med.* 2018;48:1993-2000.
12. Davarzani S, Babaei N, Ebaditabar M, Djafarian K, Shab-Bidar S. Associations of physical activity with cardiorespiratory fitness, muscle strength, and body composition. *Pediatr Endocrinol Diabetes Metab.* 2020;26:183-91.
13. Manoharan VS, Sundaram SG, Jason JI. Factors affecting hand grip strength and its evaluation: a systemic review. *Int J Physiother Res.* 2015;3:1288-93.
14. Peolsoon A, Hedlung R, Oberg B. Intra- and inter-tester reliability and reference values for hand strength. *J Rehabil Med.* 2001;33: 36-41.
15. Dhananjaya JR, Veena HC, Mamatha BS, Sudarshan CR. Comparative study of body mass index, hand grip strength, and handgrip endurance in healthy individuals. *Natl J Physiol Pharm Pharmacol.* 2017;7:594-8.
16. Kitamura K, Pereira LA, Kobal R, Abad CCC, Finotti R, Nakamura FY, Loturco I. Loaded and unloaded jump performance of top-level volleyball players from different age categories. *Biol Sport.* 2017;34:273-8.
17. Petrigna L, Karsten B, Marcolin G, Paoli A, D'Antona G, Palma A,

PAN Physical Activity and Nutrition

Bianco A. 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. *Front Physiol.* 2019;10:1384.
18. Suchomel TJ, Nimphius S, Stone MH. The importance of muscular strength in athletic performance. *Sports Med.* 2016;46:1419-49.
19. Markovic G, Dizdar D, Jukic I, Cardinale M. Reliability and factorial validity of squat and countermovement jump tests. *J Strength Cond Res.* 2004;18:551-5.
20. Ćopić N, Dopsaj M, IvanoviĆ J, NešiĆ G, JariĆ S. Body composition and muscle strength predictors of jumping performance: differences between elite female volleyball competitors and nontrained individuals. *J Strength Cond Res.* 2014;28:2709-16.
21. Sattler T, Sekulic D, Spasic M, Osmankac N, Vicente João P, Dervisevic E, Hadzic V. Isokinetic knee strength qualities as predictors of jumping performance in high-level volleyball athletes: multiple regression approach. *J Sports Med Phys Fitness.* 2016;56:60-9.
22. Nikolaidis PT, Gkoudas K, Afonso J, Clemente Suarez VJ, Knechtle B, Kasabalis S, Kasabalis A, Douda H, Tokmakidis S, Torres-Luque G. Who jumps the highest? Anthropometric and physiological correlations of vertical jump in youth elite female volleyball players. *J Sports Med Phys Fitness.* 2017;57:802-10.
23. Krzyszkowski J, Chowning LD, Harry JR. Phase-specific predictors of countermovement jump performance that distinguish good from poor jumpers. *J Strength Cond Res.* 2022;36:1257-63.
24. Davis DS, Briscoe DA, Markowski CT, Saville SE, Taylor CJ. Physical characteristics that predict vertical jump performance in recreational male athletes. *Phys Ther Sport.* 2003;4:167-74.
25. Siglinsky E, Krueger D, Ward RE, Caserotti P, Strotmeyer ES, Harris TB, Binkley N, Buehring B. Effect of age and sex on jumping mechanography and other measures of muscle mass and function. *J Musculoskelet Neuronal Interact.* 2015;15:301-8.
26. Legg L, Rush M, Rush J, McCoy S, Garner JC, Donahue PT. Association between body composition and vertical jump performance in female collegiate volleyball athletes. *Int J Kinesiol Sports Sci.* 2021;9:43.
27. Abidin N, Adam M. Prediction of vertical jump height from anthropometric factors in male and female martial arts athletes. *Malays J Med Sci.* 2013;20:39-45.
28. Sekulic D, Spasic M, Mirkov D, Cavar M, Sattler T. Gender-specific influences of balance, speed, and power on agility performance. *J Strength Cond Res.* 2013;27:802-11.
29. Shephard RJ. Exercise and training in women, part I: influence of gender on exercise and training responses. *Can J Appl Physiol.* 2000;25:19-34.
30. Boisseau N. Influence du sexe sur le métabolisme à l'exercice et en récupération. implications nutritionnelles. *Sci Sports.* 2004;19:220-7.
31. Mansour G, Kacem A, Ishak M, Grélot L, Ftaiti F. The effect of body composition on strength and power in male and female students. *BMC Sports Sci Med Rehabil.* 2021;13:150.
32. Doré E, Martin R, Ratel S, Duché P, Bedu M, Van Praagh E. Gender differences in peak muscle performance during growth. *Int J Sports Med.* 2005;26:274-80.
33. Sinha-Hikim I, Artaza J, Woodhouse L, Gonzalez-Cadavid N, Singh AB, Lee MI, Storer TW, Casaburi R, Shen R, Bhasin S. Testosterone-induced increase in muscle size in healthy young men is associated with muscle fiber hypertrophy. *Am J Physiol Endocrinol Metab.* 2002;283:E154-64.
34. Wells JCK. Sexual dimorphism of body composition. *Best Pract Res Clin Endocrinol Metab.* 2007;21:415-30.
35. Goodpaster BH, Park SW, Harris TB, Kritchevsky SB, Nevitt M, Schwartz AV, Simonsick EM, Tylavsky FA, Visser M, Newman AB. The loss of skeletal muscle strength, mass, and quality in older adults: the health, aging and body composition study. *J Gerontol A Biol Sci Med Sci.* 2006;61:1059-64.
36. Miller AEJ, MacDougall JD, Tarnopolsky MA, Sale DG. Gender differences in strength and muscle fiber characteristics. *Eur J Appl Physiol.* 1993;66:254-62.
37. World Health Organization. Obesity. *WHO.* 2023. Available on: https://www.who.int/health-topics/obesity#tab=tab_1.
38. Dietz WH, Gortmaker SL. Preventing obesity in children and adolescents. *Annu Rev Public Health.* 2001;22:337-53.
39. National center for health statistics. National health and nutrition examination survey (NHANES) anthropometry procedures manual. *CDC.* 2013.
40. Mattoo TK, Lu H, Ayers E, Thomas R. Total body water by BIA in children and young adults with normal and excessive weight. *PLoS One.* 2020;15:e0239212.
41. Hopkins WG. Measures of reliability in sports medicine and science. *Sports Med.* 2000;30:1-15.
42. Pérez-Castilla A, McMahon JJ, Comfort P, García-Ramos A. Assessment of loaded squat jump height with a free-weight barbell and smith machine: comparison of the takeoff velocity and flight time procedures. *J Strength Cond Res.* 2020;34:671-7.
43. Janssen I, Heymsfield SB, Baumgartner RN, Ross R. Estimation of skeletal muscle mass by bioelectrical impedance analysis. *J Appl Physiol.* 2000;89:465-71.
44. Ramos-Sepúlveda JA, Ramírez-Vélez R, Correa-Bautista JE, Izquierdo M, García-Hermoso A. Physical fitness and anthropometric normative values among Colombian-Indian schoolchildren. *BMC Public Health.* 2016;16:962.
45. Sartorio A, Lafortuna CL, Pogliaghi S, Trecate L. The impact of gender, body dimension and body composition on hand-grip strength in healthy children. *J Endocrinol Invest.* 2002;25:431-5.
46. Bartolomei S, Grillone G, Di Michele R, Cortesi M. A comparison between male and female athletes in relative strength and power performances. *J Funct Morphol Kinesiol.* 2021;6:17.
47. McMahon J, Jones P, Dos'Santos T, Comfort P. Influence of dynamic strength index on countermovement jump force-, power-, velocity-, and displacement-time curves. *Sports.* 2017;5:72.
48. Kapsis DP, Tsoukos A, Psarraki MP, Douda HT, Smilios I, Bogdanis GC. Changes in body composition and strength after 12 weeks of high-intensity functional training with two different loads in physically active men and women: a randomized controlled study. *Sports.* 2022;10:7.