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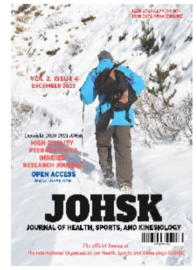

Sex Differences in the Association Between Muscular Strength and Adiposity in Healthy Adults

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ABSTRACT

Although sex differences in body composition are well established, differences in the relationship between adiposity and muscular strength remain elusive. Thus, the aim of this study was to determine sex differences in the relationship between muscular strength and adiposity in adults. Body mass index (BMI), waist circumference (WC), waist-to-height ratio (WtHR), skinfold, and bench press were assessed on 140 males and females aged 18-40 years. Normalized strength (NS) was determined by dividing bench press one-repetition maximum by body mass. Using linear regression, positive associations between NS and BMI were found in males [p=0.003, parameter estimate (PE)=0.051] and females (p=0.010, PE=0.021); inverse associations between NS and body fat percentage were found in males (p<0.001, PE=-0.035) and females (p=0.015, PE=-0.008); an inverse association between NS and WC was observed only amongst females (p=0.037, PE=-0.011); and no significant associations were found between NS and (WtHR) for either sex. Although the current study design does not permit determining causality, the findings suggest that resistance training may be more effective in reducing abdominal adiposity in females.

***Key words**: Bench Press, Body Composition, Muscle Strength, Resistance Training, Waist Circumference*

INTRODUCTION

Over the previous two decades, the prevalence of age-adjusted obesity has increased linearly among United States adults, with similar increases in males and females (Hales et al., 2020). Comorbidities commonly associated with obesity include type 2 diabetes (Daousi et al., 2006), musculoskeletal pain (Melissas et al., 2003), and impaired quality of life (Pimenta et al., 2015). Obesity has also been linked to limitations in skeletal muscle performance (Tomlinson et al., 2016). The damaging effects to skeletal muscle are partly a consequence of increased pro-inflammatory cytokines which are released from accumulated adipocytes (Pellegrinelli et al., 2015) and anabolic hormone reduction that is also linked to excessive adipose tissue (Galli et al., 2012). Furthermore, compared to subcutaneous adipose tissue, visceral adipose tissue (VAT) is exceptionally harmful to skeletal muscle development, indicating site-specific cross talk exists between adipocytes and skeletal muscle (Pellegrinelli et al., 2015).

Sex differences in body composition (Bredella, 2017), and the response of skeletal muscle to resistance training (Roberts et al., 2020), are well established. However, findings from studies are mixed in terms of the relationship of muscular strength with adiposity measures (Hardy et al., 2013; Keevil et al., 2015; Pasdar et al., 2019), especially when sex differences are considered. For example, a meta-analysis conducted on 16,444 adults aged 50-90+ years found that handgrip strength was positively associated with body mass index (BMI) among males only (Hardy et al., 2013). Conversely, in a cross-sectional study conducted on British adults aged 48-92 years by Keevil et al. (2015), handgrip strength was positively correlated with BMI, yet inversely related to waist circumference (WC) in both males and females (after adjustment for BMI). Additionally, most of the research conducted on the relationship between muscular strength and adiposity has focused on older or unhealthy populations, leaving the associations among healthy, young adults to be underreported.

Muscular strength (Grgic et al., 2020; Hamilton et al., 1992) and adiposity (Madden & Smith, 2016; Tran et al., 2018; Witt & Bush, 2005) can be assessed using a variety of instruments or tests. While BMI is a commonly used marker of obesity, it does not distinguish fat mass from fat-free mass and can be a poor predictor of body fat distribution and mass (Witt & Bush, 2005). Measurements such as WC and waist-to-height ratio (WHtR) are used to evaluate patterns of body mass distribution, specifically around the abdominal region, serving as proxy measures of VAT (Ashtary-Larky et al., 2018; Tran et al., 2018). Skinfold measurements similarly evaluate adiposity at different sites of the body (Madden & Smith, 2016). For muscular strength assessment, one-repetition maximum (1RM) testing is considered the gold standard (Grgic et al., 2020). However, this technique of measuring muscular strength is not as accessible as a handgrip dynamometer, which many researchers choose to measure muscular strength (Hardy et al., 2013; Keevil et al., 2015; Pasdar et al., 2019). The many techniques of assessing muscular strength and adiposity may contribute to the divergent findings from studies investigating associations between these two measurements. Using various total and abdominal adiposity measures to better understand mechanisms that influence sex differences in determinants of muscular strength will help inform intervention design for health and performance improvement. Thus, the purpose of this study was to determine sex differences in associations of muscular strength with adiposity measures in healthy, young adults.

METHODS

Participants

A cross-sectional study design was used to determine sex differences in the association between normalized strength (NS) using bench press 1RM and various measures of adiposity (WHtR, WC, BMI, and body fat percentage [BF%]). NS was calculated by dividing the subject's 1RM by their body mass (Hurd et al., 2011). The study used a convenience sample of adults recruited from a university and the surrounding area. Participants were recruited through word of mouth and class announcements. Each subject completed two data collection sessions separated by at least 48 hours. On the day of the 1RM testing, subjects were asked to refrain from caffeine ingestion prior to the test, refrain from vigorous exercise 24 hours prior to the test, and to eat a light meal 2 hours before the testing session.

One hundred forty subjects aged 18-40 years, including 66 males (mean ± *SD*: age: 21.59 ± 3.23 years; body mass: 80.57 ± 15.79 kg; height: 178.77 ± 6.45 cm) and 74 females (age: 20.95 ± 3.14 years; body mass: 67.79 ± 15.57 kg; height: 164.76 ± 6.59 cm) from a southeast Michigan university and the surrounding area, participated in this study. In this sample, 83.3% of males (49.92 ± 49.47 months, N=63) and 55.4% of females (32.50 ± 72.82 months, N=70) reported previous weight training experience. Recruiting materials included flyers displayed around the university campus, class announcements, and word of mouth. Subjects were excluded from the study if they were currently taking blood pressure medications, had high blood pressure, a muscular, bone, or joint injury, a contraindication to exercise, were pregnant, or had an uncontrolled medical condition or known balance impairment. This study was approved through the Oakland University Institutional Review Board (approval # 1328081-8), and informed consent was obtained from all subjects prior to study involvement.

Procedure

Subjects attended two separate data collection sessions. In the first session, subjects arrived at the university's strength lab where their age and sex were recorded. They also completed the Physical Activity Readiness Questionnaire Plus and a health history questionnaire to determine if it was safe for them to exercise (Bredin et al., 2013). Subjects reported their activity level by answering two questions in accordance with Kwon et al. (2018): "Do you lift weights?" and "How long have you been lifting weights?". Additionally, anthropometrics were assessed, and a bench press familiarization session took place. Personnel trained by the principal investigator taught the bench press movement to subjects, as described by Rippetoe and Kilgore (2007).

During the second data collection session, which occurred at least 48 hours after the first session, subjects arrived at the strength lab or university's recreation facility. Free weight testing equipment within both facilities was similar and allowed for reliable testing conditions. During this session, subjects completed a 1RM test for the bench press exercise following the National Strength and Conditioning Association (2015) testing protocol. NS was calculated by dividing the subject's 1RM by their body mass, developing a relative strength value (Hurd et al., 2011).

Subjects were instructed to perform the bench press through a full range of motion so that the bar touched the chest in the down phase, and elbows were fully extended in the up phase. They could self-select open or closed grip, and the grip width was determined by ensuring that the forearms were vertical in the down phase of the lift (Rippetoe and Kilgore, 2007). There was a minimum of one spotter present for this session to ensure that the weight was lifted in a safe manner. Subjects achieved a moderate intensity of five repetitions which was then used to predict 1RM.

The bench press 1RM test was administered by trained personnel with at least two spotters present to ensure that the exercises were conducted safely. Subjects were required to lift 10 repetitions at 50% of predicted 1RM, 5 repetitions at 70% of predicted 1RM, 3 repetitions at 80% of predicted 1RM, and 1 repetition at 90% of predicted 1RM, followed by up to five attempts to determine the subjects' actual 1RM (National Strength and Conditioning Association, 2015). Subjects were given three minutes of rest between 1RM attempts and after their last warm-up set.

Height was measured to the nearest 0.1 cm using a stadiometer, and body mass to the nearest 0.1 lb using a beam balance scale, which was converted to kg. BMI was calculated as weight in kg divided by height in meters squared. WC was measured to the nearest 0.1 cm using a Gulick tape measure (Gulick II; Country Technology, Inc., Gays Mills, WI) and following National Institute of Health (2000) protocol. Skinfold measurements were taken using a Lange skinfold caliper to estimate density. For men, the sites included the chest, abdominal, and thigh, while the sites for females included the tricep, suprailiac, and thigh following American College of Sports Medicine protocols (2018). BF% was estimated from body density using the Jackson Pollock nomogram method (Jackson & Pollock, 1978).

Data Analysis

Males and females were analyzed separately. Descriptive statistics included the subjects' mean age, WC, height, weight, BMI, WHtR, BF%, bench press 1RM, NS, and weight training experience. Independent sample t-tests were computed to determine sex differences across measures using IBM SPSS Statistics for Windows, Version 26.0 (IBM Corp., Armonk, N.Y., USA). The relationship between NS and adiposity was explored using linear regression and examined how NS values were associated with BMI, WC, BF%, and WHtR values. BMI, WC, BF%, age, and weight training experience in months were controlled. Linear regression was performed using SAS, version 9.4. Statistical significance was determined at $p < 0.05$.

RESULTS

When examining subject characteristics, significant sex differences were evident for height, body mass, and weight lifting experience, such that males had higher values for height [95% confidence interval, CI = (11.83, 16.20); $p < 0.001$], body mass [95% CI = (7.54, 18.03); $p < 0.001$], and a higher percentage of individuals who had weight lifting experience [95% CI = (-0.43, -0.13), $p < 0.001$]. Subject characteristics for muscular strength and adiposity data are shown in Table 1, including significant sex differences in BF%, bench press 1RM, and NS.

Table 1. Adiposity and Strength Measurements of Subjects

Variables	Males (n=66)	Females (n=74)	*Sig* (2-Tailed)	95% CI of the Difference Lower	Upper
BMI (kg/m²)	25.15 ± 4.28	24.89 ± 5.21	0.751	-1.346	1.862
Body Fat (%)	13.91 ± 5.93	25.94 ± 6.17	0.001**	-14.053	-9.997
WC (cm)	86.86 ± 11.50	82.89 ± 12.44	0.053	-0.050	7.990
WHtR	0.49 ± 0.06	0.50 ± 0.07	0.131	-0.041	0.005
Bench Press 1RM (kg)	78.57 ± 23.85	32.25 ± 11.64	0.001**	40.148	52.486
Normalized Strength	0.98 ± 0.27	0.48 ± 0.16	0.001**	0.426	0.571

Note: Values are presented as mean ± standard deviation.
CI, confidence interval; WC, waist circumference; BMI, body mass index; WHtR, waist-to-height ratio; 1RM, one-repetition maximum
**Indicates significant difference between groups with p-value < 0.001

Table 2 presents parameter estimates (PE) of the regression between NS and adiposity measures. A significant positive association between NS and BMI was found in both males and females when controlling for BF%, WC, WHtR, age, and weight training experience. This relationship was stronger in males ($p = 0.003$, PE = 0.051) than in females ($p = 0.010$, PE = 0.021). Except for the potential outlier participant having a BMI close to 45 kg/m², the scatterplot in Figure 1A shows a perceptible increasing trend for each sex, in agreement with the above findings.

Table 2. Parameter Estimates of the Regression Between Normalized Strength and Adiposity Measures

	Males (n=66)			Females (n=74)		
Measure of Adiposity	Parameter Estimate	Standard Error	*p*-value	Parameter Estimate	Standard Error	p-value
BMI (kg/m²)	0.051	0.017	0.003*	0.021	0.008	0.010*
Body Fat (%)	-0.035	0.007	0.001**	-0.008	0.003	0.015*
WC (cm)	-0.005	0.009	0.591	-0.011	0.005	0.037*
WHtR	-0.289	1.805	0.873	0.531	0.763	0.488

Note: BMI, body mass index; WC, waist circumference; WHtR, waist-to-height-ratio
*Indicates significant difference between groups with p-value < 0.05
**Indicates significant difference between groups with p-value < 0.001

A significant inverse association was found between NS and BF% in both males ($p = <0.001$, PE = -0.035) and females ($p = 0.015$, PE = -0.008) when controlling for BMI, WC, WHtR, age, and weight training experience. Figure 1B shows a decreasing trend for each sex, in agreement with these negative associations.

Table 2 also shows the results for the association between NS and WC in both males and females when controlling for BMI, BF%, WHtR, age, and weight training experience. No significant association between these variables was observed among males (p = 0.591, PE = -0.005); however, females exhibited a significant, but relatively weak inverse association between NS and WC (p = 0.037, PE = -0.011). The scatterplot in Figure 1C also indicates a weak linear relationship between NS and WC for each sex. No significant association was found between NS and WHtR for either sex.

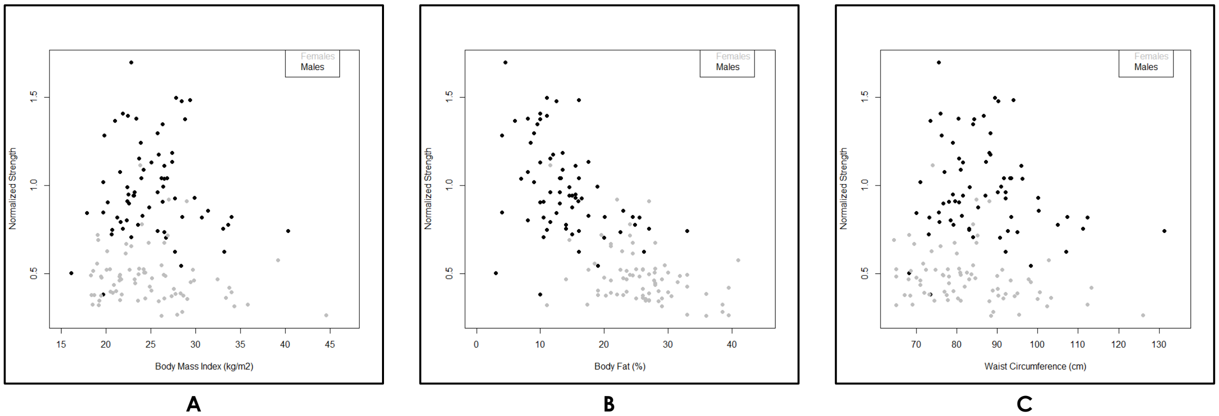

Figure 1. Associations between normalized strength and adiposity in males and females. In (A), Normalized Strength vs Body Mass Index (kg/m²) in females and males is depicted. In (B), Normalized Strength vs Body Fat (%) in females and males is depicted. In (C), Normalized Strength vs Waist Circumference (cm) in females and males is depicted.

DISCUSSION

The purpose of this study was to determine sex differences in the relationship between muscular strength and adiposity in healthy United States adults. To the knowledge of the authors, this was the first study to examine associations between muscular strength and adiposity in healthy young United States adults using gold standard strength testing and both regional and total body fat measurements. In both males and females, a high NS was associated with a high BMI and low BF%. Conversely, a high NS was associated with a low WC only in females.

The first key finding was the positive association between NS and BMI in both sexes, which was congruent with previous literature that investigated this relationship (Pasdar et al., 2019). Other authors (Keevil et al., 2015) have acknowledged that BMI may not be the most appropriate obesity marker when investigating relationships between adiposity and muscular strength, as it does not distinguish between fat-free mass (a predictor of muscle strength) and fat mass. While this association was significant in both sexes, it was stronger in males than in females. Pasdar et al. (2019) similarly found this association to be stronger among males than females. Sex differences in body composition may explain this. Lafortuna et al. (2005) determined that as males gain mass, they increase proportional amounts of fat-free mass and fat mass, while females tend to exhibit increases in fat mass nearly three times more than fat-free mass when body mass is increased. Thus, it may be that males on average have greater amounts of fat-free mass to produce more force than females at any given BMI.

Next, consistent with other studies (Jackson et al., 2010), NS and BF% were found to be inversely associated among males and females. While Jackson et al. (2010) suggested muscular strength acts as a protective mechanism against excessive body fat accumulation, it is also apparent that increased body fat is deleterious to skeletal muscle. Obese adipocytes induce atrophy by diminishing the expression of contractile proteins in myotubes and increasing secretion of cytokines and chemokines, most notably interleukin (IL)-6 and IL-1β (Pellegrinelli et al., 2015). Therefore, adipose tissue may cause muscle wasting, and the results from the present study concurred by demonstrating increases in BF% were associated with decreases in NS.

In addition to investigating relationships between whole-body measurements of adiposity (BMI and BF%) with NS, this relationship was evaluated using regional measurements of adiposity, including WC and WHtR. Only the females had a significant inverse association between NS and WC. Previous reports on this association have been inconsistent. In a study by Pasdar et al. (2019), handgrip strength was positively associated with WC among Iranian males and females. Conversely, Keevil et al. (2015) determined that handgrip strength was inversely associated with WC among both sexes. Possible explanations for this disparity include differences in subject characteristics, such as age, nationality, and health-status. VAT, which can be estimated using WC measurements, has shown to be more toxic to skeletal muscle than subcutaneous adipose tissue (Pellegrinelli et al., 2015), explaining why NS values decreased as WC increased. Studies have shown while males tend to have larger amounts of VAT than females, VAT has a stronger association with cardiometabolic risk factors in females than males (Schorr et al., 2018). It is possible that the damaging effects of VAT on muscle cells are also heightened in females, thus explaining the inverse association found between NS and WC.

Finally, no significant association was found between NS and WHtR for either sex. This relationship is not one that has been thoroughly studied. WHtR is often used as an effective measurement for predicting diseases, such as hypertension (Rezende et al., 2018), but does not appear to be significantly linked to NS.

Some limitations to this study should be considered. A small sample size limited the analyses the authors initially performed on the data collected. In accordance with Keevil et al. (2015) and Pasdar et al. (2019), a larger sample size would have permitted the subjects to be grouped into sex-specific BMI quartiles, where their strength and WC could be further analyzed. Next, BMI does not distinguish between fat mass and fat-free mass, and, therefore, limits the distinction between the association of fat mass and muscular strength. Additionally, the age range of the study was 18-40 years, but the mean age of the male subjects was 21.59 ± 3.23 years, and the mean age of the female subjects was 20.95 ± 3.14 years. Thus, these findings may be more generalizable to younger adults closer to college age. Finally, only one measure on muscular strength was evaluated in this study. Incorporating measures of upper and lower body muscular strength would allow for a better indication of the relationship between adiposity and overall strength.

The strengths of this study include multiple measurements of total and abdominal adiposity. Total body fat evaluations were included, such as BMI and BF%, as well as regional body fat evaluations, WC and WHtR. This study was unique, as few studies have assessed NS and adiposity associations using a variety of adiposity measurements. Additionally, the gold standard of strength testing, 1RM testing (Grgic et al., 2020), was used in this study to determine NS, whereas other studies have relied on handgrip strength, a surrogate measure of total strength (Hardy et al., 2013; Keevil et al., 2015; Pasdar et al., 2019). In the future, similar studies evaluating muscular strength and adiposity associations may benefit from using multiple strength tests, including upper and lower body tests.

CONCLUSION

Sex differences in the relationship between muscular strength and adiposity are apparent. Clinicians and trainers alike may use the findings of this study to inform program design for health enhancement and sport performance. Understanding sex differences in muscular strength and adiposity associations may aid clinicians in writing exercise prescriptions for decreased health risk in patients following tenants of precision medicine, while trainers may use these findings to increase performance of athletes. While larger BMI values are associated with increased NS, increases in BF% are associated with lower NS values. Thus, these findings suggest that athletes who hope to increase their muscular strength may need to monitor their dietary intake closely as improvements in fat-free mass likely promote strength gains but increases in fat-mass may be deleterious to muscular strength. Given that abdominal adiposity was inversely associated with NS only in females, resistance training may have a more profound effect on VAT in females compared to males. However, longitudinal studies are necessary to determine sex differences in changes to VAT following regular resistance training.

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