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Sex segregation in strength sports: Do equal-sized muscles express the same levels of strength between sexes?

Ryo Kataoka[1] | Robert W. Spitz[1] | Vickie Wong[1] | Zachary W. Bell[2] | Yujiro Yamada[1] | Jun Seob Song[1] | William B. Hammert[1] | Scott J. Dankel[3] | Takashi Abe[4] | Jeremy P. Loenneke[1]

[1]Department of Health, Exercise Science, and Recreation Management, Kevser Ermin Applied Physiology Laboratory, The University of Mississippi, University, Mississippi, USA

[2]Department of Kinesiology and Physical Education, McGill University, Montreal, Quebec, Canada

[3]Department of Health and Exercise Science, Exercise Physiology Laboratory, Rowan University, Glassboro, New Jersey, USA

[4]Graduate School of Health and Sports Science, Juntendo University, Inzai, Japan

Correspondence
Jeremy P. Loenneke, Department of Health, Exercise Science, and Recreation Management, Kevser Ermin Applied Physiology Laboratory, The University of Mississippi, P.O. Box 1848, University, MS 38677, USA.
Email: jploenne@olemiss.edu

Abstract

Objectives: Concerns have been raised against the current two-sex binary category in sports competitions. The thesis states that if males and females were separated based on muscle size, it would negate the strength advantage between the sexes. We tested the possible sex differences in various strength outcomes when pair-matched for muscle thickness.

Methods: A total of 16 different data sets ($n = 963$) were assessed to pair-match females with males who had a muscle thickness value within 2%. We further compared the competition performances of the smallest male weight class within the International Powerlifting Federation (IPF) to different weight classes in females.

Results: Overall, 76%–88% of the strength assessments were greater in males than females with pair-matched muscle thickness, regardless of contraction types (i.e., isotonic, isometric, isokinetic). Additionally, males in the lightest weight division in the IPF largely outperformed females in heavier weight divisions.

Conclusions: Our results would suggest that segregation based on muscle mass or surrogates of muscle mass (e.g., lean body mass) might not be an appropriate classification to create fair competition within strength sports. This is not to refute the concept of the desegregation of the two-sex binary category but to present data that raises important concerns about the potential sex-based differences in strength performance.

1 | INTRODUCTION

Current classification systems for most sports employs segregation based on weight, age, and sex to ensure athletes compete in a fair environment. More recently, a policy that has been questioned is the two-sex binary category in sports competitions, separating athletes into two categories: male and female (Martínková, 2020; Travers, 2008; Tucker & Collins, 2010). Indeed, some researchers have asserted that desegregation would undo the binary assumption that males are superior to females in sports performance (Kerr & Obel, 2018). They further argue that once the components that produce superior/inferior performances are identified, it could be possible to reassemble classification categories to reflect these parts rather than classifying them only by sex (Kerr & Obel, 2018). The two-sex classification system also creates challenges for transgender athletes who do not meet the reassignment requirements (Schultz, 2011), along with ambiguity as to those specific requirements needing to be met in order to participate. The question of when it is fair to permit transgender athletes to compete in sports is a delicate issue, and how muscle size and strength are altered with gender-affirming treatment has been the focus of recent research (Hilton & Lundberg, 2021; Roberts et al., 2020; Wiik et al., 2020). In order to create a classification system that produces fair competition, it has been proposed that athletes could be classified based on their lean body mass (a surrogate for muscle mass) as a starting point. This could be potentially helpful in strength sports where the amount of muscle mass an individual has might impact their ability to produce force (Kerr & Obel, 2018). However, additional work is needed in order to determine what traits other than sex could influence the performance variables of relevance for each sport. For some sports, Kerr and Obel (2018) suggest that athletes might need to be separated based on fiber type composition and/or aerobic capacity.

Previous findings indicate that on average males have greater levels of absolute strength than females (Bishop et al., 1987; Heyward et al., 1986; Maughan et al., 1983; Miller et al., 1993; Pincivero et al., 2003). Since muscle and body size are generally correlated with the strength assessment outcomes (Ikai & Fukunaga, 1968; Markovic & Jaric, 2004), studies often report strength data normalized for muscle size or other anthropometrical measurements to compare sexes. For example, it was documented that differences between males and females were no longer significantly different from each other when statistically "controlling for" lean body mass, arm and thigh girth, and skinfold thickness (Heyward et al., 1986). Similarly, there was no significant sex difference in isotonic and isometric strength when expressed relative to the cross-sectional area of muscles (Miller et al., 1993). While dissimilarities in baseline fiber composition (Staron et al., 2000), lean body mass (Miller et al., 1993), muscle characteristics (Merrigan et al., 2018), neuromuscular function (Inglis & Gabriel, 2020; Trevino et al., 2019), and gene expression (Welle et al., 2008) may exist between males and females, "relative" strength might be similar between sexes (Bishop et al., 1987; Castro et al., 1995; Heyward et al., 1986; Schantz et al., 1983; Welle et al., 2008). Consequently, it has been suggested that the greater strength on average among males is primarily due to larger muscle fibers, and the force exerted by equal-sized muscles would be the same between males and females (Bishop et al., 1987). Although statistically or mathematically "controlling for" the muscle size to predict muscle strength between sexes may provide some insights, this approach may be limited by the fact that there is minimal overlap in muscle size between sexes. As such, whether males and females exhibit a different expression of strength when pair-matched on muscle size is still unknown. Pair matching allows the direct test of the thesis proposed, that is, does matching individuals on muscle size eliminate the male strength advantage. This also prevents potential issues associated with the commonly used ratio data (i.e., strength divided by muscle mass) (Allison et al., 1995; Curran-Everett, 2013). For example, standardization via division of one variable by another can misrepresent the relationship between the numerator and denominator if their relationship is not linear and the intercept of the regression slope of the numerator on the denominator is not zero (Atkinson et al., 2009). As the sex segregation policy in sports remains a heavily debated topic (Sharrow, 2021), examining the constructs that yield superior/inferior performance between sexes may help to reassemble the classifying system in sports. Therefore, the purpose of the present study is to investigate the possible sex differences in various strength outcomes with pair-matched muscle size (i.e., same muscle thickness size). In an attempt to test whether the desegregation of the two-sex binary category would create fair competition in strength sports (e.g., powerlifting), we further compare the performances of the smallest male weight class in the adult division of the International Powerlifting Federation (IPF) to different weight classes in females.

2 | METHODS

2.1 | Pair-matched on muscle thickness data

This is a secondary analysis of previous data from our laboratory (all studies were approved by the Institutional Review Board and all participants provided written informed consent). The studies used for the current analysis had to include both males and females as well as measures of both muscle size and strength. All data were collected from individuals between the ages of 18–36 years. Muscle thickness was used as our measurement of muscle size. All images were taken by experienced technicians. Of note, a previous study showed that interrater reliability for measurements of muscle thickness between experienced and novice technicians was generally good-excellent (Carr et al., 2021). In addition, all measurements within each data set were made by the same technician. If more than one measurement site was included (e.g., 60% and 70% of the distance between the acromion process and lateral epicondyle for the upper arm), we averaged them together for a single estimate of muscle size. Measurements of muscle strength included isotonic, isokinetic, and isometric strength tests. Not all studies included all strength measurements. We also documented the individual's height, body mass, age, and training status.

We went through 16 different data sets with a total of 963 individuals (454 males and 509 females) (Abe et al., 2015; Abe, Wong, Spitz, et al., 2020; Bell et al., 2022; Buckner et al., 2017; Buckner et al., 2019; Buckner et al., 2020; Counts, Buckner, et al., 2016; Counts, Dankel, et al., 2016; Dankel et al., 2016; Dankel et al., 2017; Dankel et al., 2020; Jessee et al., 2019; Jessee, Buckner, et al., 2018; Jessee, Mattocks, et al., 2018; Song et al., 2021; Wong et al., 2020). Fifteen of the data sets have published papers associated with them, and one is from an investigation only recently completed and currently under review (primary outcome data not yet published but unrelated to the current study). If the data set was from a training study, we matched individuals on the pre-training values. Within each individual data set, we sorted the data to rank individuals from smallest to largest muscle thickness. Next to the muscle size variable was a dummy coded variable for sex (0 for male, 1 for female). We then went through and pair-matched females with males who had a muscle thickness value within 2% (a percentage difference that the authors considered small enough that the values would be practically equivalent). For example, if a female had a muscle thickness value of 3.0 cm, the pair-matched muscle thickness for males had to be from 2.94 to 3.06 cm. Each individual was used only once in the pair matching (i.e., one individual was not matched with more than one person in a study). We did this individually for each of the 16 data sets.

Details for measurements of muscle thickness differ based on whether the upper or lower limb was assessed. Specific details can be found within each individual paper. However, the method of assessment was equivalent across studies. Muscle thickness was captured with B-mode ultrasound. The ultrasound probe was coated with gel and held lightly against the individual's skin while maintaining a relaxed state. Muscle thickness was measured using manufacturer-provided on-screen digital calipers (or by ruler if printed) and was defined as the distance from the muscle-bone interface to the muscle-fat interface assessed to the nearest 0.01 cm. Images were saved on the ultrasound hard drive (or printed) and analyzed in a blinded fashion following the completion of the study. Details for the assessment of maximal strength also differed based on the test. For example, some of the tests included different speeds of isokinetic tests. Importantly, all the pair matching occurred within a single study which meant that each pair was assessed using the same method. Because isometric testing of the biceps or leg might differ from handgrip strength, we analyzed that data separately.

The thesis states that if individuals were separated based on muscle size, any strength advantage would be negated. To test this, we first ran a paired *t*-test on muscle thickness, isotonic strength, isometric strength, isokinetic strength, height, and body mass between sexes. Due to differences between studies, we reported standardized effect sizes (Cohen's d) and the 95% confidence intervals of that effect in order to provide an estimate of the magnitude of the difference. We also separated the results into the upper and lower body. Our main analysis, however, was a comparison of the rank scores. In other words, when males and females are pair-matched on muscle thickness, how often do males outperform females (or vice versa)? If pair-matching males and females based on muscle size does indeed negate strength differences, then there should be no favoring of males or females in who ranks higher. This was statistically analyzed using a binomial test against a value of .5. Statistical significance was set at $p \leq .05$. Statistical analysis was completed using IBM SPSS v. 27.

2.2 | Comparison of the international powerlifting federation (IPF) competition results

The results of the past 5 years of the annual IPF World Open Classic Powerlifting Championship (2015–2019) were collected from the official website of the IPF (www.powerlifting.sport) and the IPF-approved powerlifting database website (www.openipf.org). The results of the 2021 Classic World Open Powerlifting Championship were excluded due to the change in weight categorization from previous years. The competition in the year 2020 was canceled as a result of the COVID-19 global pandemic. The top five highest lifted weight for each competition lift (squat, bench press, and deadlift) was collected from 2015 to 2019 for both males and females (Supplementary Tables 1–3). We selected the weight classes between males and females that were similar (but did not overlap). The weight class for males included the class of 59 (the lowest adult division), 66, 74, and 83 kg division. For females, the selected weight class was 57, 63, 72, and 84 kg (the weight class before the super heavyweight class of 84 kg+). We further compared the smallest weight class in the male adult division (59 kg) against the female divisions up to 84 kg (Table 2). If males in the lowest weight class outperformed females across weight categories, that might provide additional evidence against segregating events on the basis of muscle size in more of a real-world setting. Although we have no way of assessing muscle mass from body mass, it might be reasonable to speculate that females in the 84 kg have more fat free mass (a surrogate of muscle mass) than males in the 59 kg class. Consider an extreme example, if males in the 59 kg class had 10% body fat and females in the 84 kg class had 35% body fat, the females would still have approximately 1 kg more fat-free mass than males. It is unlikely that the females in the 84 kg class had 35% body fat. A previous study in large-sized female athletes (including powerlifters and track & field athletes) had body fat percentages from 17.4% to 26.5% (25% to 75% percentile) (Abe, Wong, Dankel, et al., 2020).

3 | RESULTS

3.1 | Comparison of pair-matched muscle thickness data

Because males were on average bigger than females, not all of the studies were able to form pairs according to our prespecified values of 2%. As such, pair matching was not possible in four of the 16 data sets (Buckner et al., 2017; Buckner et al., 2020; Dankel et al., 2016; Dankel et al., 2017). Four other studies provided one additional pairing each (4 pairs) (Buckner et al., 2019; Counts, Buckner, et al., 2016; Counts, Dankel, et al., 2016; Jessee, Mattocks, et al., 2018). Dankel et al. provided 15 pairs (Dankel et al., 2020), Wong et al. provided 10 pairs (Wong et al., 2020), Abe, Wong, Spitz, et al. (2020) provided 10 pairs (Abe, Wong, Spitz, et al., 2020), Bell et al. (under review) provided 11 pairs (Bell et al., 2022), Jessee, Buckner, et al. (2018) provided 8 pairs (Jessee, Buckner, et al., 2018), Jessee et al. (2019) provided 2 pairs (Jessee et al., 2019), Abe et al. (2015) provided 10 pairs (Abe et al., 2015), and Song et al. provided 4 pairs in the upper body and 18 pairs in the lower body (Song et al., 2021). Among five of the 12 data sets, we were able to obtain pairs from included individuals who were resistance trained (Abe, Wong, Spitz, et al., 2020; Buckner et al., 2019; Jessee et al., 2019; Jessee, Mattocks, et al., 2018; Wong et al., 2020). Three of those five (Buckner et al., 2019; Jessee et al., 2019; Jessee, Mattocks, et al., 2018) included only trained individuals with the other 2 studies including a mix of both trained and untrained (Abe, Wong, Spitz, et al., 2020; Wong et al., 2020). Five of the 12 data sets included individuals who were untrained (Bell et al., 2022; Counts, Buckner, et al., 2016; Counts, Dankel, et al., 2016; Dankel et al., 2020; Jessee, Buckner, et al., 2018). The other two studies did not collect information on training status (Abe et al., 2015; Song et al., 2021). Of the 92 pairs included, only 10 of the pairs included a trained and untrained individual. Given the small number of pairs and the research question (when matched for muscle thickness, does strength differ?), we did not explore training status further.

When pair-matched for muscle thickness, males were still stronger on average in every strength assessment (Table 1). Further, males also outranked females on every single strength assessment measured (Table 1). That is, within each pair, the muscle thickness was the same, but males had higher strength values than females (Figure 1). This was also true even when separated into the upper and lower body (Table 1).

3.2 | Comparison of the international powerlifting federation (IPF) competition results

The top five highest weights lifted for each competition lift (squat, bench press, and deadlift) of the IPF Classic World Open Powerlifting Championship (2015–2019) are shown in Supplementary Tables 1–3. The smallest weight class in the male adult division (59 kg) was compared with the female divisions up to 84 kg (57, 63, 72, and 84 kg weight classes included) (Table 2). Of those 5 years of competitions, the smallest weight class in males largely outperformed females in heavier weight classes in every competition lift (Table 2).

4 | DISCUSSION

To the best of our knowledge, this is the first study to investigate the possible sex differences in various strength outcomes when pair-matched for muscle thickness. The results of our study found that 76%–88% of the strength assessments were greater in males than females with pair-matched muscle thickness, regardless of contraction types (i.e., isotonic, isometric, isokinetic) (Figure 1, Table 1). Additionally, it was found that male powerlifters who competed in the lightest weight division within the IPF outperformed females in heavier weight classes (Table 2). Collectively, these results may suggest that sex differences in strength might still exist even when muscle size is equal. This is an important point to note as segregation based on muscle mass or surrogates of muscle mass (e.g., lean body mass) might not be an appropriate classification to create fair competition within strength sports such as powerlifting.

The marked differences on average in absolute muscle strength between sexes are well documented (Bishop et al., 1987; Heyward et al., 1986; Maughan et al., 1983;

TABLE 1 A comparison of strength assessments with pair-matched muscle thickness between the sexes. Measurements of muscle strength included isotonic, isokinetic, and isometric strength tests. All data included were collected on individuals between the age of 18–36 years. An estimate of the magnitude of difference was reported with standardized effect sized (Cohen's d) and the 95% confidence intervals of the effect. A comparison of the rank scores is provided to illustrate how often males outperformed females (or vice versa) with equal-sized muscle thickness.

All	Male	Female	Cohen's d (95% CI)	Wins by males	Wins by females	Ties
Muscle thickness (cm)	3.72 (0.68)	3.72(0.68)	0.11 (−0.09, 0.31)			
Isotonic strength (kg)	24.6 (11.5)	18.0 (7.9)	1.04 (0.72, 1.3)	54*	5	3*
Isometric strength (AU)			0.5 (0.14, 0.86)	30*	4	0*
Isokinetic strength (Nm)	64.2 (64.9)	52.8 (52)	0.54 (0.23, 0.85)	35*	11	0*
Height (cm)	174.3 (17.9)	165 (6.7)	0.5 (0.28, 0.72)			
Body mass (kg)	72.0 (11.2)	75.7 (16.8)	−0.2 (−0.4, 0.004)			
Upper body only						
Muscle thickness (cm)	3.47 (0.42)	3.46 (0.42)	0.18 (−0.06, 0.43)			
Isotonic strength (kg)	15.4 (3.9)	11.8 (2.6)	1.0 (0.59, 1.4)	29*	3	2*
Isometric strength (Nm)	51.3 (7.4)	29.1 (4.5)	2.8 (0.4, 5.2)	4*	0	0*
Handgrip strength (Kg)	40.7 (7.4)	32.8 (5.3)	0.87 (0.35, 1.38)	18*	2	0*
Isokinetic strength (Nm)	35.6 (10.1)	29.5 (5.7)	0.73(0.38, 1.08)	29*	9	0*
Height (cm)	172.3 (20.5)	165.4 (6.6)	0.32 (0.07, 0.57)			
Body mass (kg)	69.1 (9.9)	79.1 (17.2)	−0.62 (−0.89, −0.35)			
Lower body only						
Muscle thickness (cm)	4.3 (0.79)	4.3 (0.79)	0.03 (−0.3, 0.4)			
Isotonic strength (kg)	35.7 (6.9)	25.5 (4.8)	1.4 (0.8, 1.9)	25*	2	1*
Isometric strength (Nm)	252.6 (83.9)	190.5 (23.6)	0.7 (0.01, 1.4)	8	2	0
Isokinetic strength (Nm)	200.1 (32.7)	163.4 (17.2)	0.92 (0.06, 1.6)	6	2	0
Height (cm)	179.1 (7.9)	164.1 (7.0)	1.6 (1.0, 2.2)			
Body mass (kg)	78.7 (11.4)	68 (13.2)	0.7 (0.28, 1.1)			

*Indicates a statistically significant difference ($p \leq .05$) from a proportion of 0.5 (binomial test).

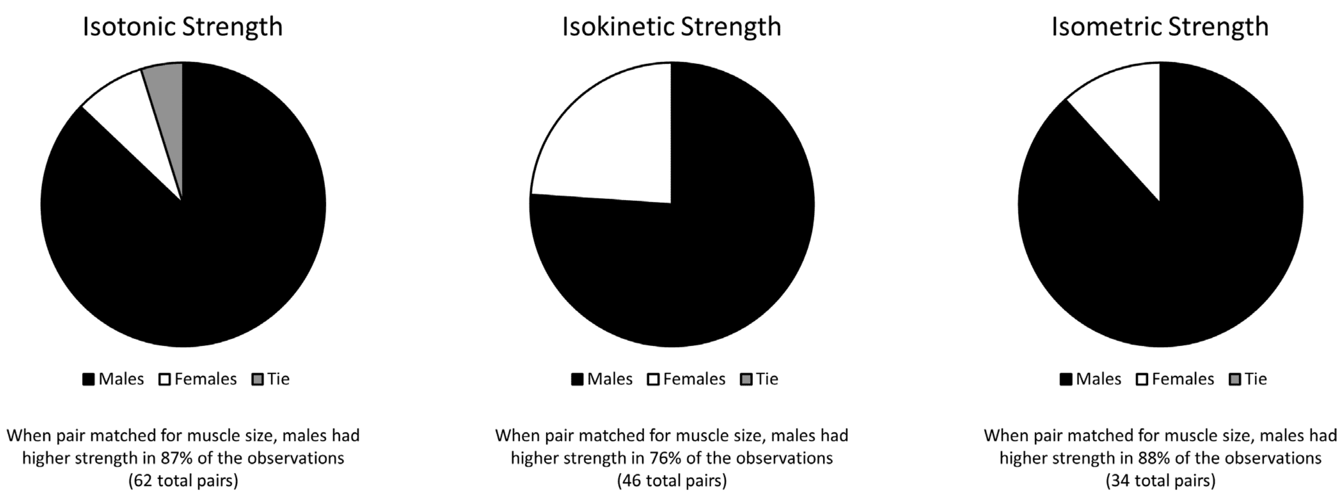

FIGURE 1 A comparison of the rank scores in strength assessments. Measurements of muscle strength included isotonic, isokinetic, and isometric strength tests.

Miller et al., 1993; Pincivero et al., 2003). The main premise of this paper was to address whether this male strength advantage would be eliminated with pair-matched muscle thickness. The interaction between the anatomical and neuromuscular factors influencing muscle force-generating capacity has been discussed

TABLE 2 The comparison of competition lifts between the smallest weight class in the male (M) adult division (59 kg) and different female (F) adult divisions (57, 63, 72, and 84 kg). The results of the competition lifts are presented as raw values (kg).

	2015	2016	2017	2018	2019
Squat (kg)					
Male 59 kg versus Female					
1st	226 (M)	227.5 (M)	227.5 (M)	227.5 (M)	243 (F at 84 kg)
2nd	215 (M)	222.5 (M)	222.5 (M)	225 (M)	230 (F at 84 kg)
3rd	210 (M)	220 (M)	220 (M)	225 (M)	222.5 (M)
4th	197.5 (F at 84 kg)	215 (M)	217.5 (M)	213 (F at 84 kg)	220 (M)
5th	195 (M)	200 (F at 84 kg)	212.5 (M)	212.5 (M)	220 (M)
Bench press (kg)					
Male 59 kg versus Female					
1st	170 (M)	171 (M)	167.5 (M)	165 (M)	167.5 (M)
2nd	147.5 (M)	150 (M)	150 (M)	152.5 (M)	150 (M)
3rd	142.5 (M)	142.5 (M)	145 (M)	142.5 (M)	145 (M)
4th	140.5 (F at 63 kg)	141.5 (F at 63 kg)	144 (F at 72 kg)	142.5 (F at 63 kg)	142.5 (M)
5th	140 (M)	140 (M)	140 (M)	140 (M)	137.5 (M)
Deadlift (kg)					
Male 59 kg versus Female					
1st	260 (M)	271 (M)	265 (M)	274 (M)	275 (M)
2nd	250 (M)	240 (M)	245 (M)	260 (M)	252.5 (F at 84 kg)
3rd	240.5 (M)	235.5 (M)	240 (M)	241.5 (M)	250 (M)
4th	240.5 (F at 72 kg)	230 (F at 72 kg)	237.5 (F at 72 kg)	235 (M)	246 (F at 84 kg)
5th	235 (M)	230 (M)	230 (M)	230.5 (F at 84 kg)	245 (M)

(Aagaard et al., 2001; Trezise et al., 2016), albeit the extent to which each factor influences maximal strength has yet to be fully elucidated. Although not exhaustive, muscle size (Fukunaga et al., 2001), intrinsic motor neuron properties (Aagaard, 2003), and architectural arrangement of its fibers (Lieber & Fridén, 2000) have received attention in this regard. Notably, males tend to have larger type I and type II myofibers compared with females, yet the number of fibers per motor unit and the number of motor units may not differ between sexes (Miller et al., 1993). While dissimilarities in motor unit behavior may exist between sexes (Inglis & Gabriel, 2020, 2021), it is often hypothesized that the sex differences in muscle size would account for the major proportion of the sex differences in strength (Bishop et al., 1987; Inglis & Gabriel, 2020). This implies that if males and females were separated based on muscle size, that would negate the strength advantage (Bishop et al., 1987). Previous studies have demonstrated that sex differences in strength were no longer apparent when statistically or mathematically "controlling for" the muscle size (Heyward et al., 1986; Miller et al., 1993). While this may provide some insight, this approach may be limited by the fact that there is minimal overlap in muscle size between sexes. That is, the correlation between sex (the IV) and muscle size (the covariate) is so strong that there is little unique variance in sex (the IV) left to be shared with strength (the DV) (Miller & Chapman, 2001). In contrast to these previous findings, when we directly tested the proposed thesis (does matching individuals on muscle size eliminate the male strength advantage?), our analyses demonstrated that the majority of males were still stronger in every strength assessment after accounting for differences in muscle thickness.

To further test whether the desegregation of the two-sex binary category would create fair competition in strength sports, the strength performances (i.e., squat, bench press, deadlift) of the smallest adult male division (59 kg) in the IPF were compared with different weight classes in females (57, 63, 72, and 84 kg). Although muscle mass cannot be assessed from body mass, we speculated that females in heavier weight divisions would possess greater amounts of muscle mass than males in the lightest weight division (an example is illustrated in the Methods section). Our results indicated that male powerlifters who competed in the lightest weight division still outperformed females across different weight categories. Thus, our findings might provide evidence against pair-matching on muscle mass to classify athletes in strength sports (e.g., powerlifting). Some hypothesized mechanisms other than (or in addition to) muscle mass that might contribute to sex differences in muscle strength include the androgen-evoked (i.e., testosterone) regulations in corticospinal motor neuron threshold (Bonifazi et al., 2004), intracellular calcium release (Estrada et al., 2003), and sex-based differences in fiber type compositions (i.e., greater type II fibers in males) (Staron et al., 2000). Importantly, future studies are warranted on whether these components contribute to the sex difference in muscle strength. In addition, considering that muscle force is largely influenced by the number of the motor units recruited and firing rate (Enoka & Duchateau, 2017), it may be worth investigating the sex difference in neuromuscular recruitment strategies with equal-sized muscles. While dissimilarities in motor unit behavior have been noted between sexes previously (Inglis & Gabriel, 2020, 2021), it is still unknown whether the sex difference in strength is due to the difference in neuromuscular recruitment strategies when muscle size is equal.

Our study is not without limitations. First, pair-matching on muscle size was only performed with muscle thickness data. Thus, our results may not necessarily generalize to other muscle size measurements. However, muscle thickness has been shown to correlate with MRI-measured cross-sectional area in the lower body ($r = 0.82$; Franchi et al. (2018)), MRI-measured cross-sectional area in the upper body ($r = 0.61$; using data from Loenneke et al. (2019)), and lean body mass from DXA (both regional ($r = 0.77$) and total ($r = 0.73$); using data from Abe et al. (2016)). Future studies may test possible sex differences in strength with pair matching on different surrogates for muscle mass (i.e., lean body mass). Second, the comparison of sex differences in strength outcomes was limited to elbow flexion and handgrip strength for the upper body and knee extension strength for the lower body. In addition, while we included a number of strength assessments (i.e., isotonic, isometric, isokinetic strength) in the analyses, no sports-specific performances were assessed with pair-matched muscle size in the current study. Nonetheless, our analysis model closely resembles the proposed thesis of matching with muscle mass (Kerr & Obel, 2018), and we demonstrated that sex differences in muscle strength existed with pair-matched muscle thicknesses, with males being stronger than females. Furthermore, we illustrated that even the lightest adult weight class in males largely outperformed females in heavier weight classes in the IPF Classic World Open Powerlifting Championship. While this was not a true representation of a classification system that has been suggested to create (i.e., classified based on athletes' lean body mass), we believe that the current results of pair-matched muscle thickness data and powerlifting data provide evidence of sex differences in strength performance.

5 | CONCLUSION

Concerns have been raised against the current two-sex binary category in sports competitions. It has been proposed that athletes could be classified based on their lean body mass (a surrogate for muscle mass) as a starting point of a classification system to produce fair competition. Our results indicate that when muscle thickness was pair-matched between sexes, 76%–88% of the strength assessments were greater in males than females, regardless of contraction type (i.e., isotonic, isometric, and isokinetic). Additionally, we found that males who competed in the lightest weight division in the IPF outperformed females who competed in heavier weight divisions to a large extent. As such, if athletes are classified based on their lean body mass, desegregation of the two-sex binary category may not create fair competition in strength sports. This is not to refute the concept of the desegregation of the two-sex binary category but to present data that raises important concerns about the potential sex-based differences in strength performance.

AUTHOR CONTRIBUTIONS

Ryo Kataoka, Robert W. Spitz, Vickie Wong, Yujiro Yamada, Zachary W. Bell, Jun Seob Song, William B. Hammert, Scott J. Dankel, Takashi Abe, and Jeremy P. Loenneke contributed to the conception and plan for the manuscript. Ryo Kataoka and Jeremy P. Loenneke compiled the data and independently confirmed the data. Ryo Kataoka, Scott J. Dankel, and Jeremy P. Loenneke analyzed the data. Ryo Kataoka, Robert W. Spitz, Vickie Wong, Zachary W. Bell, Yujiro Yamada, Jun Seob Song, Scott J. Dankel, Takashi Abe, and Jeremy P. Loenneke collected the original muscle thickness and strength data. Ryo Kataoka wrote the initial draft of the manuscript. Ryo Kataoka, Robert W. Spitz, Vickie Wong, Yujiro Yamada, Zachary W. Bell, Jun Seob Song, William B. Hammert, Scott J. Dankel, Takashi Abe, and Jeremy P. Loenneke carefully reviewed the manuscript and provided comment. All authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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None.

CONFLICT OF INTEREST

Authors are aware of no competing interests.

DATA AVAILABILITY STATEMENT

Data is available upon reasonable request of the corresponding author. The powerlifting data is publicly available from the official website of the IPF (www.powerlifting.sport) and the IPF-approved powerlifting database website (www.openipf.org).

ORCID

Takashi Abe https://orcid.org/0000-0003-0568-1004
Jeremy P. Loenneke https://orcid.org/0000-0001-5409-9075

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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Supplementary Table 1. The results of the past five years of the annual IPF Classic World Open Powerlifting Championship (2015-2019). The results of the squat are presented as raw values (kg).

Squat (kg)

Male	2015	2016	2017	2018	2019
59 kg	1. 226 2. 215 3. 210 4. 195 5. 192.5	1. 227.5 2. 222.5 3. 220 4. 215 5. 192.5	1. 227.5 2. 222.5 3. 220 4. 217.5 5. 212.5	1. 227.5 2. 225 3. 225 4. 212.5 5. 212.5	1. 222.5 2. 220 3. 220 4. 215 5. 210
66 kg	1. 240.5 2. 225.5 3. 225 4. 222.5 5. 215	1. 245.5 2. 245 3. 235 4. 230 5. 222.5	1. 250 2. 249 3. 242.5 4. 232.5 5. 222.5	1. 253 2. 247.5 3. 245 4. 235 5. 232.5	1. 263 2. 250 3. 247.5 4. 240 5. 237.5
74 kg	1. 252.5 2. 250 3. 250 4. 247.5 5. 242.5	1. 257.5 2. 257.5 3. 255 4. 255 5. 245	1. 270 2. 265.5 3. 257.5 4. 252.5 5. 247.5	1. 276 2. 275.5 3. 263.5 4. 257.5 5. 255	1. 283 2. 275 3. 268 4. 267.5 5. 257.5
83 kg	1. 270 2. 270 3. 260 4. 260 5. 252.5	1. 298 2. 277.5 3. 270 4. 270 5. 265	1. 290 2. 277.5 3. 277.5 4. 277.5 5. 272.5	1. 299 2. 298.5 3. 287.5 4. 285 5. 277.5	1. 313 2. 295 3. 295 4. 295 5. 287.5
Female					
57 kg	1. 172.5 2. 162.5 3. 145 4. 137.5	1. 174 2. 155 3. 152.5 4. 150	1. 174.5 2. 172.5 3. 160 4. 153.5	1. 170 2. 170 3. 157.5 4. 157.5	1. 178 2. 172.5 3. 172.5 4. 172.5

	5. 137.5	5. 147.5	5. 150	5. 155	5. 162.5
63 kg	1. 167.5 2. 162.5 3. 160 4. 157.5 5. 152.5	1. 178 2. 160 3. 160 4. 160 5. 157.5	1. 165 2. 162.5 3. 160 4. 160 5. 157.5	1. 183.5 2. 175 3. 170 4. 165 5. 162.5	1. 188 2. 185.5 3. 172.5 4. 170 5. 170
72 kg	1. 182.5 2. 180 3. 175 4. 170 5. 167.5	1. 188 2. 180 3. 177.5 4. 175 5. 168	1. 196 2. 193 3. 185 4. 180 5. 180	1. 195 2. 190 3. 185 4. 182.5 5. 181.5	1. 203 2. 197.5 3. 197.5 4. 192.5 5. 192.5
84 kg	1. 197.5 2. 192.5 3. 187.5 4. 185 5. 177.5	1. 200 2. 197.5 3. 190 4. 190 5. 182.5	1. 206.5 2. 202.5 3. 200 4. 195 5. 195	1. 213 2. 205 3. 200 4. 195 5. 192.5	1. 243 2. 230 3. 200 4. 200 5. 195

Supplementary Table 2. The results of the past five years of the annual IPF Classic World Open Powerlifting Championship (2015-2019). The results of the bench press are presented as raw values (kg).

Bench Press (kg)

Male	**2015**	**2016**	**2017**	**2018**	**2019**
59 kg	1. 170 2. 147.5 3. 142.5 4. 140 5. 135	1. 171 2. 150 3. 142.5 4. 140 5. 140	1. 167.5 2. 150 3. 145 4. 140 5. 140	1. 165 2. 152.5 3. 142.5 4. 140 5. 135	1. 167.5 2. 150 3. 145 4. 142.5 5. 137.5
66 kg	1. 182.5 2. 172.5 3. 162.5	1. 188.5 2. 160 3. 157.5	1. 182.5 2. 160 3. 155	1. 205.5 2. 167.5 3. 167.5	1. 175 2. 170 3. 162.5

	4. 157.5 5. 152.5	4. 155 5. 155	4. 150.5 5. 150	4. 162.5 5. 160	4. 162.5 5. 160
74 kg	1. 210.5 2. 175.5 3. 167.5 4. 167.5 5. 160	1. 195 2. 190 3. 187.5 4. 185 5. 182.5	1. 192.5 2. 190 3. 190 4. 187.5 5. 185	1. 190 2. 177.5 3. 175 4. 170 5. 165	1. 195 2. 190 3. 187.5 4. 182.5 5. 175
83 kg	1. 205 2. 202.5 3. 187.5 4. 180 5. 175	1. 208 2. 202.5 3. 200 4. 187.5 5. 180	1. 208.5 2. 192.5 3. 190 4. 190 5. 187.5	1. 214.5 2. 214 3. 190 4. 185 5. 182.5	1. 215.5 2. 210 3. 195 4. 190 5. 187.5
Female					
57 kg	1. 102.5 2. 100 3. 90 4. 88 5. 87.5	1. 105 2. 102.5 3. 87.5 4. 85 5. 85	1. 107.5 2. 102.5 3. 100 4. 100 5. 100	1. 97.5 2. 95 3. 95 4. 95 5. 90	1. 115.5 2. 105 3. 102.5 4. 102.5 5. 100
63 kg	1. 140.5 2. 110 3. 95 4. 90 5. 85	1. 141.5 2. 115 3. 110 4. 105 5. 97.5	1. 112.5 2. 107.5 3. 107.5 4. 96 5. 95	1. 142.5 2. 130 3. 107.5 4. 105 5. 97.5	1. 130 2. 107.5 3. 105 4. 102.5 5. 102.5
72 kg	1. 115.5 2. 115 3. 115 4. 112.5 5. 107.5	1. 117.5 2. 115 3. 112 4. 110 5. 107.5	1. 144 2. 130 3. 122.5 4. 117.5 5. 110	1. 130 2. 125 3. 120 4. 117.5 5. 115	1. 122.5 2. 120 3. 118.5 4. 118 5. 112.5
84 kg	1. 136	1. 135	1. 135	1. 135	1. 137

	2. 112.5 3. 110 4. 106 5. 105	2. 115 3. 112.5 4. 110 5. 110	2. 125 3. 117.5 4. 112.5 5. 110	2. 127.5 3. 125 4. 112.5 5. 110	2. 128.5 3. 127.5 4. 127.5 5. 117.5

Supplementary Table 3. The results of the past five years of the annual IPF Classic World Open Powerlifting Championship (2015-2019). The results of the deadlift are presented as raw values (kg).

Deadlift (kg)

Male	**2015**	**2016**	**2017**	**2018**	**2019**
59 kg	1. 260 2. 250 3. 240.5 4. 235 5. 223	1. 271 2. 240 3. 235.5 4. 230 5. 225	1. 265 2. 245 3. 240 4. 230 5. 227.5	1. 274 2. 260 3. 241.5 4. 235 5. 227.5	1. 275 2. 250 3. 245 4. 245 5. 240.5
66 kg	1. 278 2. 275 3. 265 4. 250 5. 245	1. 282.5 2. 272.5 3. 270 4. 267.5 5. 265	1. 285 2. 270 3. 265 4. 260 5. 260	1. 297.5 2. 285.5 3. 280 4. 270.5 5. 270	1. 272.5 2. 270 3. 265 4. 265 5. 262.5
74 kg	1. 305 2. 300 3. 297.5 4. 295 5. 292.5	1. 302.5 2. 300 3. 300 4. 292.5 5. 278.5	1. 322 2. 292.5 3. 290 4. 285 5. 285	1. 305 2. 292.5 3. 292.5 4. 290.5 5. 287.5	1. 312.5 2. 312.5 3. 307.5 4. 297.5 5. 290
83 kg	1. 302.5 2. 300 3. 297.5 4. 292.5 5. 290	1. 317.5 2. 315 3. 311 4. 306.5 5. 305	1. 325 2. 325 3. 322.5 4. 315 5. 312.5	1. 317.5 2. 317.5 3. 315.5 4. 305 5. 302.5	1. 326.5 2. 326 3. 325 4. 325 5. 320

Female					
57 kg	1. 190 2. 170 3. 165 4. 165 5. 162.5	1. 187.5 2. 185 3. 180 4. 177.5 5. 177.5	1. 190.5 2. 187.5 3. 180 4. 177.5 5. 177.5	1. 187.5 2. 187.5 3. 185 4. 177.5 5. 177	1. 203 2. 197.5 3. 185 4. 182.5 5. 182.5
63 kg	1. 197.5 2. 187.5 3. 185 4. 180 5. 180	1. 205 2. 190 3. 190 4. 187.5 5. 182.5	1. 200 2. 192.5 3. 190 4. 182.5 5. 180	1. 221.5 2. 202.5 3. 202.5 4. 195 5. 192.5	1. 217.5 2. 205 3. 202.5 4. 200 5. 195
72 kg	1. 240.5 2. 202.5 3. 201.5 4. 192.5 5. 187.5	1. 235 2. 205 3. 202 4. 200 5. 185	1. 237.5 2. 212.5 3. 210 4. 205 5. 202.5	1. 227.5 2. 202.5 3. 200 4. 200 5. 200	1. 242.5 2. 237.5 3. 225 4. 222.5 5. 222.5
84 kg	1. 217.5 2. 207.5 3. 200 4. 197.5 5. 195	1. 212.5 2. 205 3. 200 4. 200 5. 192.5	1. 215 2. 215 3. 207.5 4. 207.5 5. 205	1. 230.5 2. 222.5 3. 222.5 4. 215 5. 210	1. 252.5 2. 246 3. 225 4. 217.5 5. 215