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Sex Differences in Regional Muscle Hypertrophy and Elbow Flexion and Extension Strength

Andrija Mikša[1], Saša Vuk[1]

[1]University of Zagreb, Faculty of Kinesiology, Zagreb, Croatia

Abstract

Strength and hypertrophy are key factors in motor function. Although gender differences in muscle strength and size are well documented at the global level of muscle mass, less is known about how they manifest at the level of individual regions within the same muscle and whether differences in total muscle thickness are uniformly distributed along its entire length. Therefore, the goal of this research was to determine if there are differences in regional muscle thickness and elbow flexion and extension strength between male and female kinesiology students, and to examine the relationship between specific muscle regions and force production in these movements. The regional thickness of the biceps brachii and triceps brachii muscles was measured using B-mode ultrasound at three sites. The peak torque of elbow flexion and extension force was measured on an isokinetic dynamometer in a sample of 57 physically active university students, comprising 28 men and 29 women. It was shown that students have greater elbow flexion and extension strength and greater biceps and triceps brachii muscle thickness in all regions. Pearson's correlation showed a positive association between muscle thickness and the strength of elbow flexion and extension in both groups of subjects, but the patterns of association differed between male (r=0.33-0.65) and female (r=0.32-0.51) students. In men, elbow flexion strength was most closely associated with the distal part of the biceps brachii, whereas in women, stronger correlations were found in the proximal regions. Additionally, significant regional differences in hypertrophy were observed in the triceps brachii, which were more pronounced in women. In conclusion, distinct regions of a muscle may contribute differently to force production during elbow flexion and extension. Although minor sex-related differences in regional force contributions have been observed, the underlying physiological mechanisms remain unclear and require further investigation.

Keywords: *muscle size, muscle hypertrophy, isokinetic strength, gender differences*

Introduction

Strength and hypertrophy are known to be key factors in motor function, with gender differences in these characteristics resulting from a combination of biological, hormonal, and training-related factors (Abe, DeHoyos, & Pollock, 2000; Kanehisa, Ikegawa, & Fukunaga, 1994). On average, men possess greater muscle mass and absolute strength than women, but research shows that when relative changes and effect sizes are considered, both sexes progress at equal rates during resistance training (Gentil et al., 2016; Roberts, Nuckols, & Krieger, 2020). Women often make greater relative progress in upper body hypertrophy compared to the lower body, which may be attributed to their lower initial training level in this area (Nuzzo, 2022; Roberts et al., 2020). Although these differences are well documented at the global level of muscle mass, less is known about how they manifest at the level of individual regions within the same muscle. It is not clear whether the differences in total muscle thickness are uniformly distributed along its entire length or whether there are specific regions where gender differences are more pronounced.

Correspondence:

Andrija Mikša
University of Zagreb, Faculty of Kinesiology, Horvaćanski zavoj 15, 10110 Zagreb, Croatia
E-mail: andrija.miksa@kif.hr

Regional differences in hypertrophy are increasingly the subject of research, since there is evidence that muscle tissue does not grow uniformly in response to training, but that different exercises, loads and types of contractions can lead to selective growth of certain muscle parts (Nunes et al., 2023; Zabaleta-Korta, Fernandez-Pena, & Santos-Concejero, 2020; Zabaleta-Korta, Fernández-Peña, Torres-Unda, Garbisu-Hualde, & Santos-Concejero 2021). It has been found that certain exercises can target specific muscle heads within the same muscle group while changing the range of motion affects which muscle segments will be dominantly developed (Brandao et al., 2020; Matta et al., 2017; Wakahara, Fukutani, Kawakami, & Yanai 2013; Sato et al., 2021). Furthermore, even the type of muscle action – whether dominantly concentric or eccentric – can have a differential impact on regional hypertrophy, suggesting that local changes in muscle thickness may result from complex biomechanical and neurological processes (Benford, Hughes, Waldron, & Theis, 2021; Franchi et al., 2014). If such growth patterns are present in response to training, it is possible that there are innate gender differences in the distribution of muscle mass within individual muscles. Furthermore, if muscle thickness is not uniform throughout the muscle, hypertrophy assessment methods that rely on single-point measurements may be insufficiently precise.

In addition to the fact that variability in muscle thickness may have significant implications for the methodology of muscle hypertrophy research, its functional importance also remains understudied. Numerous studies confirm the connection between muscle thickness and strength (Kanehisa et al., 1994), but it is still not clear which muscle region is the most important predictor of strength in certain movements. Different parts of the muscles can have different biomechanical functions, which means that the greater thickness of individual segments can have a more pronounced effect on force production in specific conditions (Brandao et al., 2020; Matta et al., 2017; Wakahara et al., 2013). Certain parts of the muscles may play a more dominant role in the development of elbow flexion and extension strength, whereby gender differences in regional hypertrophy patterns may affect the biomechanical function of the muscles in movements that require force generation.

Although it is known that there are gender differences in muscle strength and thickness, most studies to date have assessed muscle thickness at a single point (Abe et al., 2000; Coratella et al., 2018; Kojić et al., 2018) ignoring the possibility that hypertrophy may differ between different regions of the same muscle. Also, although numerous studies have confirmed the relationship between muscle thickness and strength (Akagi et al., 2018; Balshaw et al., 2018; Reggiani & Schiaffino, 2020), it is still not clear which muscle region has the strongest predictive value for force development in specific movements. Due to all the above, it is necessary to investigate regional differences in muscle thickness and their connection with strength in more detail, in order to more precisely determine possible sex-specific patterns and the biomechanical and functional significance of these differences.

Therefore, the goal of this research was to determine if there are differences in regional muscle thickness and elbow flexion and extension strength between male and female kinesiology students, and to examine the relationship between specific muscle regions and force production in these movements. It is expected that male students will have significantly greater muscle thickness and strength compared to female students, but also that patterns of regional hypertrophy will differ between genders. Furthermore, it is assumed that the correlation between muscle thickness and strength will be different depending on the observed muscle segment and that certain regions could have a greater influence on force development. The obtained results could contribute to a better understanding of gender differences in muscle morphology and function and provide useful guidelines for designing training aimed at optimizing muscle development and strength.

Methods

Participants

Fifty-seven respondents participated in the research, of which 28 men (age: 20.07±0.86 years; height: 183.88±5.49 cm; weight: 81.26±6.38 kg) and 29 women (age: 20.94±0.92 yrs; height: 166.43±4.64 cm; weight: 61.00±5.87 kg), students of the Faculty of Kinesiology, University of Zagreb, were selected as a convenient sample of the physically active population. Inclusion criteria included basic experience in weight training, good general health, absence of neurological and musculoskeletal disorders, and absence of a history of injury to the muscles trained in the study. Also, the subjects were not allowed to use anabolic steroids or other prohibited ergogenic substances for a period of at least six months before the start of the research. Before participating, all subjects were informed about the objectives and possible risks of the research and gave their written informed consent. The research was conducted in accordance with the Declaration of Helsinki, and the experimental protocol was approved by the Ethics Committee of the Faculty of Kinesiology, University of Zagreb (approval number: 22/2024).

Sample size analysis was performed using G*Power software (version 3.1.9.7; Universität Kiel, Germany) to ensure sufficient statistical power of the study. Based on previous research examining gender differences in strength and hypertrophy (Abe et al., 2000; Kanehisa et al., 1994), the expected effect (Cohen's d) was estimated at 0.8, corresponding to a large effect. The t-test for independent samples was used to compare two independent groups, with the selected significance level $\alpha=0.05$ and statistical power of 0.80. The results of the analysis showed that a minimum sample of 52 respondents (26 per group) is required for the detection of statistically significant differences, which means that the sample used in this research met the criteria of statistical reliability.

Measuring Instruments

Measurement of muscle thickness

Muscle thickness was assessed using a Siemens SONOLINE G40 ultrasound device with a supported linear probe VF10-5 (frequency range 10–5 MHz, dimensions 39×5 mm) (Siemens Medical Solutions USA, Inc., Mountain View, CA, USA, 2005). Device settings were optimized according to the manufacturer's user manual and remained unchanged during all measurements to ensure maximum data consistency. The probe was placed perpendicular to the surface of the skin and oriented transversely to the direction of the muscle fibers of the biceps brachii and triceps brachii muscles.

To increase the reliability of the data, each measurement was repeated twice, and the average value was included in the analysis. In order to eliminate the potential mechanical pressure of the probe on the tissue, a contact gel was used, which ensured the standardization of the measurement procedure. In addition, the subjects were instructed to refrain from any intense physical activity on the day of the measurement and not to participate in resistance training 48 hours before the measurement.

Before the measurement, reference points were marked on the subjects' bodies with a waterproof marker, determined using a centimeter tape, in order to ensure the consistency of the measurement locations. After labeling, subjects spent 10 minutes in a supine position to allow stabilization of body fluids and avoid potential variation in results.

Measurements were taken in standardized positions, modified from Costa et al. (2021) and Matta et al. (2011), as these modifications demonstrated the highest reliability in pilot testing.

Biceps brachii: Subjects lay in a supinated position with the forearm relaxed in neutral rotation while the upper arm rested on a specially designed rest to minimize variability in arm position. Measurements were made at 60%, 70% and 80% of the total distance between the acromion and olecranon.

Triceps brachii: Subjects were in a pronated position with the upper arm placed at a 90° angle to the trunk, while the forearm was hanging freely from the table. Stabilization of the upper arm is made possible by means of a firm backrest. Measurements were made at 50%, 60% and 70% of the total distance between the acromion and olecranon.

This approach enabled a precise assessment of regional variations in muscle thickness, which made the obtained data reliable and comparable within the sample.

Measurement of muscle strength

Maximum concentric strength of the elbow flexors and extensors was assessed using a Biodex System 4 isokinetic dynamometer (Biodex Corporation, Shirley, New York, USA). Measurements were performed at an angular velocity of 60°/s, which is a standardized protocol (Damjan et al., 2024; Tourny-Chollet et al., 2000) for assessing muscle strength in isokinetic conditions.

Before starting the test, the subjects performed five submaximal warm-up repetitions, followed by a one-minute rest before the main test. In the test, three maximum repetitions of elbow flexion and extension were performed, with verbal motivation to ensure maximum engagement of the subjects.

The dynamometer was calibrated and set up according to the manufacturer's technical instructions. During testing, subjects sat in a custom dynamometer seat, with shoulders and pelvis stabilized by seat belts which eliminated unwanted trunk movements. The upper arm of the dominant arm was fixed on a specially designed support placed at an angle of 30° lateral to the sagittal plane of the trunk while the head of the dynamometer was adjusted to align with the transverse axis of rotation of the elbow joint.

During testing, subjects held the handle of the dynamometer with a hammer grip, performing flexion and extension movements in the range of motion from 10° to 130° (with 0° indicating a fully extended elbow).

This methodological standardization enabled accurate and reliable measurement of muscle strength, eliminating external variables that could affect the results.

Statistical analysis

All statistical procedures were performed using the IBM SPSS Statistics software package (version 24.0; IBM Corp., Armonk, NY, USA) and the Microsoft Excel program (Microsoft Corporation, 2018). Analysis of the ultrasound images was performed using ImageJ software (version 1.53c; National Institutes of Health, USA), which allowed accurate determination of muscle thickness based on the recorded ultrasound images.

To determine the differences between the sexes in muscle thickness and isokinetic strength, a t-test for independent samples was used, which identified statistically significant differences between male and female subjects. The relationship between muscle thickness and the maximum moment of elbow flexion and extension force was analyzed using the Pearson correlation coefficient, where the strength and direction of the relationship between the variables were interpreted.

In order to ensure that the data met the assumptions for parametric tests, the Shapiro-Wilk normality test was performed, while homogeneous variances between groups were checked by Levene's test of homogeneity of variances. All data met the requirements of parametric analyses.

Additionally, Cohen's d was used to assess the effect size of gender differences, with values of $d=0.2$ considered small, $d=0.5$ medium, and $d \geq 0.8$ a large effect. For correlation analyses, the strength of the association was interpreted according to the criteria: $r<0.3$ weak, $0.3 \leq r<0.5$ moderate, and $r \geq 0.5$ strong correlation.

For all analyses, a statistical significance level of $p<0.05$ was used while the statistical power of the study was set to 0.80, in order to reduce the probability of a second-type error. This approach ensured methodological rigor and reliability of the results.

Results

Descriptive statistics and gender differences

The basic descriptive indicators for the strength of elbow flexion and extension and the regional thickness of the biceps brachii and triceps brachii muscles are shown in Table 1. The results show that male students achieved significantly higher values in all tested variables compared to female students ($p<0.001$).

Table 1. Basic descriptive statistical indicators and differences between the sexes in the maximum moment of elbow flexion and extension force.

	Mean±SD (f)	Mean±SD (m)	Difference	%	t	p
Flexion	26.25±6.17	50.39±9.17	24.14	47.91	-11.63	0.00*
Extension	43.92±7.89	70.59±10.70	26.67	37.78	10.67	0.00*

Note: *p<0.05; f-female; m-male.

The average values of the maximum moment of force for elbow flexion in male students were 50.39±9.17 Nm, while in female students they were significantly lower (26.25±6.17 Nm). Similarly, the maximum elbow extension force moment was higher in male students (70.59±10.70 Nm) compared to female students (43.92±7.89 Nm), with the differences reaching significance (p<0.001).

Analysis of the regional thickness (Table 2) of the triceps brachii muscle showed that students had higher values at all measurement points. The biggest difference was recorded at 50% of the distance between the acromion and olecranon, where male students had an average thickness of 34.38±4.56 mm while in female students it was 24.01±2.62 mm (p<0.001). In biceps brachii, the greatest differences were observed at 80% of the distance between the acromion and olecranon, where the muscle thickness in male students was 40.66±3.73 mm while in female students it was 30.41±2.25 mm (p<0.001). Effect size analysis (Cohen's d) showed large effects for all variables (d=1.5–2.6), which indicates significant gender differences in muscle strength and thickness.

Table 2. Regional thickness of biceps brachii and triceps brachii muscles in male and female students.

	Mean±SD (f)	Mean±SD (m)	Difference	%	t	p
T70	23.45±3.82	32.27±3.02	8.82	27.33	9.42	0.00*
T60	26.36±2.52	35.37±3.67	9.01	25.47	10.77	0.00*
T50	24.01±2.62	34.38±4.56	10.37	30.16	10.54	0.00*
B80	30.41±2.25	40.66±3.73	10.25	25.21	2.54	0.00*
B70	27.02±2.41	36.09±4.05	9.07	25.13	10.28	0.00*
B60	22.84±2.32	31.07±3.36	8.23	26.49	10.73	0.00*

Note: *p<0.05; f-female; m-male; B80/70/60 – biceps brachii muscle thickness at 80, 70 and 60% of the distance between the acromion and olecranon; T70/60/50 – the thickness of the triceps brachii muscle at 70, 60 and 50% of the distance between the acromion and the olecranon.

The relationship between muscle thickness and strength

Pearson's correlation showed a significant positive association between muscle thickness and the strength of elbow flexion and extension in both groups of subjects, but the patterns of association differed between male and female students.

In triceps brachii (Table 3), the association with elbow extension strength was moderate in both sexes. The strongest correlation was recorded at 70% of muscle length, where it was r=0.45 (p<0.01) for male students, while it was slightly higher for female students (r=0.47, p<0.01).

Table 3. Pearson's correlation coefficients between the maximum moment of the elbow extension force and the regional thickness of the triceps brachii.

	T70	T60	T50
Male	0.45*	0.41*	0.33
Female	0.47*	0.33	0.32

*p<0.05; T70/60/50 – the thickness of the triceps brachii muscle at 70, 60 and 50% of the distance between the acromion and the olecranon.

In male students, biceps brachii thickness (Table 4) showed the strongest correlation with flexion strength at 80% (r=0.65, p<0.001), while in female students, the highest correlation values were observed at 60% of the muscle (r=0.51, p<0.001). These results suggest that different muscle regions may have different contributions to force generation between sexes.

Table 4. Pearson's correlation coefficients between the maximum moment of elbow flexion force and the regional thickness of the biceps brachii.

	B80	B70	B60
Male	0.65*	0.56*	0.51*
Female	0.39*	0.46*	0.51*

*p<0.05; B80/70/60 – biceps brachii muscle thickness at 80, 70 and 60% of the distance between the acromion and olecranon.

Differences in patterns of regional hypertrophy

Analysis of relative differences (Table 2) between male and female students in regional muscle thickness showed that the distribution of hypertrophy was different between the sexes. In college students, the differences between biceps brachii regions were relatively uniform (25.13–26.49%), suggesting homogenous growth of the muscle along its length. In contrast, in triceps brachii, the differences between regions were greater (25.47–30.16%), which may indicate an uneven distribution of hypertrophy within the muscle or gender differences in the structure and activation of individual muscle heads.

Discussion

The main findings of this research indicate that male students have significantly greater muscle thickness and elbow flexion and extension strength than female students, with the differences being consistent in all observed regions of the biceps brachii and triceps brachii muscles. The association between muscle thickness and strength was statistically significant in both sexes, but regional association patterns differed between male and female students. While in male students the strength of elbow flexion was most strongly related to the distal part of the biceps brachii, in female students stronger correlations appeared in the proximal segments.

The obtained results are consistent with previous research that showed that men demonstrate higher values in muscle strength and muscle cross-section compared to women (Abe et al., 2000; Kanehisa et al., 1994). These differences can primarily be explained by differences in total muscle mass and hormonal profile, particularly higher testosterone levels in men, leading to greater hypertrophy capacity and absolute strength (Miller, MacDougall, Tarnopolsky, & Sale, 1993). However, it is important to note that relative changes in strength and hypertrophy after resistance training often do not show significant gender differences, as confirmed in previous studies (Gentil et al., 2016; Roberts et al., 2020).

Although the absolute values of muscle thickness were greater in men, interestingly, the differences in percentage values were almost identical for biceps brachii and triceps brachii (25-30%), suggesting that the gender difference in muscle mass is consistent among biceps and triceps brachii. These findings align with those of a recent MRI study, which reported that male recreational cyclists had greater gluteal muscle volume than their female counterparts; however, when muscle volume was normalized to body weight, no significant differences were found between sexes (Belzunce et al., 2023). Notably, the sex-related difference in muscle volume observed in that study, ranging from 20-30%, is similar to the findings of the present research.

In contrast, studies conducted on untrained individuals have demonstrated larger sex-related disparities in muscle mass (Abe et al., 2000; Kojić et al., 2018). It is plausible that regular training attenuates these differences. Supporting this, Janssen et al. (2000) reported that the disparity in muscle mass between males and females was greater in the upper body (approximately 40%) compared to the lower body (approximately 33%).

It is important to note that muscle volume and muscle thickness are not directly comparable, thus, precise comparisons across studies employing different measurement techniques are inherently limited. Nevertheless, in the study by Kojić et al. (2018), the difference in biceps brachii muscle thickness between males and females was approximately 40%, which aligns with the findings reported by Abe et al. (2000). Furthermore, the difference in triceps brachii muscle thickness between sexes was around 30%, a value consistent with the results of the current study.

The analysis of regional hypertrophy showed that there are slight differences in triceps brachii that are more pronounced in comparison with biceps brachii, especially in women. These findings raise the possibility that anatomical and functional characteristics of the triceps brachii lead to different growth patterns between the sexes.

One of the key findings of this research is that greater muscle thickness does not necessarily mean proportionally greater strength, but the relationship between these variables depends on the muscle region and the sex of the subject. In male students, the distal biceps brachii segment had a stronger relationship with elbow flexion strength compared to the proximal parts, while in female students, this relationship was more pronounced in the middle and proximal segments. This finding suggests that the mechanisms of force production may be different between the sexes and that the distribution of muscle mass within the muscle may play a significant role in the development of strength. Studies addressing this topic remain limited, and numerous questions still require answers. Research investigating the effects of different exercises on biceps brachii muscle thickness may partially aid in the interpretation of the present findings. Specifically, it appears that various exercises can induce region-specific hypertrophy along different portions of the muscle. For instance, several studies have examined the effects of different elbow flexion exercise variations on regional hypertrophy of the biceps brachii.

Kassiano et al. (2025), in a study involving untrained women who performed incline biceps curls twice weekly (3 sets per session), reported increases in muscle thickness of 11.2%, 8.6%, and 6.4% in the proximal (50%), middle (60%), and distal (70%) regions of the muscle, respectively. Similar findings were reported by Costa et al. (2019), who studied young men with minimal training experience and a four-month detraining period prior to the intervention. Using a combination of three exercises – incline curls, traditional curls, and preacher curls – they recorded a greater increase in the proximal region (17.7%) compared to the middle (11.2%) and distal (11.3%) regions. In contrast, the group performing only traditional curls exhibited more modest increases (7.5%, 7.0%, and 9.3%, respectively).

The authors attributed the preferential hypertrophy of the proximal region to the incline curl exercise, whereas preacher curls have more recently been associated with pronounced distal hypertrophy (Kassiano et al., 2025; Pedrosa et al., 2023). The incline curl produces the greatest external moment of force during the latter half of the movement (approximately 70–120° of elbow flexion), which may explain the predominant activation of the middle portion of the muscle. These findings suggest that different exercises and loading conditions can elicit region-specific increases in muscle thickness. However, sex-related differences in regional hypertrophy patterns and their underlying mechanisms remain largely unexplored.

In the triceps brachii, the association between muscle thickness and extension strength was moderate in both sexes, with the strongest correlation observed at 70% muscle length. This finding may indicate that the segments of the triceps brachii near the tendon transition zone play a key role in force generation, which is in line with biomechanical research that shows that different parts of the muscle can have a specialized function depending on the angle of the joint and the type of contraction (Brandao et al., 2020; Wakahara et al., 2013). Whang et al. (2025) reported a stronger association (r=0.70) between triceps brachii muscle thickness and isometric strength than observed in the present study. To the best of the authors' knowledge, the relationship between regional variations in muscle thickness and muscle strength has not yet been systematically explored.

These findings emphasize the importance of measuring hypertrophy at multiple muscle points, rather than relying on single measurements. For coaches and sports scientists, the application of ultrasound analysis can be a useful tool for monitoring progress and optimizing training interventions. Future research should further examine how different training methods affect regional hypertrophy and strength and how individual variations in muscle mass distribution can affect athletic performance and injury prevention.

Although the results of this study provide important insights into gender differences in muscle hypertrophy and strength, certain limitations should be considered. First, a convenient sample of kinesiology students, who are more physically active than the general population, was used, which may limit the generalizability of the findings. Further research should include a wider range of subjects, including untrained individuals and athletes of different levels of training.

Second, although ultrasound analysis allowed precise estimation of muscle thickness, other aspects of muscle architecture, such as muscle fiber length and pennation angles, which may also have a significant impact on force production, were not assessed.

Conclusion

This research confirmed the existence of significant gender differences in the regional thickness and strength of the biceps brachii and triceps brachii muscles in physically active male and female kinesiology students. College students showed higher absolute values of muscle thickness and strength, but patterns of association between muscle thickness and force generation differed between sexes. In men, elbow flexion strength was most strongly related to the distal part of the biceps brachii, while in women, higher correlations were recorded in the proximal regions. Similarly, regional variations in hypertrophy were identified in the triceps brachii, which were more pronounced in women.

In conclusion, distinct regions of a muscle may contribute differently to force production during elbow flexion and extension. Although minor sex-related differences in regional force contributions have been observed, the underlying physiological mechanisms remain unclear and require further investigation. The findings of the present study contribute to a better understanding of sex-related differences in muscle hypertrophy and strength, and may inform the development of more effective and individualized training interventions. Future research should investigate how specific training methods influence regional muscle hypertrophy and functional outcomes, with the aim of optimizing athletic performance and reducing the risk of injury.

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Conflict of Interest
The authors declare that there is no conflict of interest.

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