

Article

# Influence of Bilateral Upper Limb Morphological Asymmetry on Grip Strength Related to Gender in Non-Athlete University Students

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## Abstract

Bilateral morphological asymmetry of the upper limbs may influence grip strength even in semi-active young adults. Understanding this relationship is important for identifying early neuromuscular imbalances with implications for ergonomics and rehabilitation. This study aimed to examine associations between upper limb anthropometric characteristics and grip strength in non-athlete students, considering gender and manual dominance. The sample included 192 healthy university students (110 females, 82 males; mean age  $19.92 \pm 1.4$  years) without prior sports training. Thirteen bilateral anthropometric parameters of the upper limbs were assessed, including hand and palm dimensions, segmental lengths, and arm and forearm circumferences, along with grip strength measured by dynamometry in two positions: arm extended and arm flexed at  $90^\circ$ . Statistical analysis revealed significant differences in forearm length, arm and forearm circumferences, and grip strength ( $p < 0.001$ ). The dominant limb consistently demonstrated higher grip strength, with mean differences of approximately 2 kg. Male participants showed higher absolute values for all morphological and functional variables, whereas stronger correlations between distal upper-limb morphology and grip strength were observed in females. These findings indicate that, despite largely symmetric skeletal dimensions, moderate functional asymmetries exist and grip strength is influenced primarily by local muscular development rather than overall limb size.

**Keywords:** bilateral symmetry; upper limb morphology; grip strength; dynamometry; anthropometric analysis; functional asymmetry

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## 1. Introduction

Upper limb asymmetry is a phenomenon frequently observed even among apparently healthy young adults, such as students. These differences are influenced by factors such as manual dominance [1–3], daily habits of preferential hand use, and individual neuromuscular development. In students, who spend much time in sedentary or repetitive academic activities (writing, keyboard use), these asymmetries can become more pronounced, especially in the absence of functional balance generated through physical activity [4,5].

Over time, even minor differences can affect posture, movement ergonomics, or the distribution of muscular effort [6,7]. The evaluation of these discrepancies becomes essential not only for understanding general functional status, but also for preventing chronic imbalances, especially in the context of transition to active professional life. In this sense, analyzing morphological and functional symmetry offers a valuable perspective on body balance [8–10] and can support personalized interventions in physical education, rehabilitation, or even vocational selection.

This asymmetry can be morphological in nature: differences in length, width, circumference between the right and left limb; or functional: differences in grip strength [11,12], mobility, or motor coordination capacity.

Functional and morphological asymmetries [13–15] of the upper limbs [16,17] are frequently encountered among students, even in the absence of an active sports regimen. Differences in strength, length, or muscle mass differences between the right and left limbs can be explained both by manual dominance (right-handed vs. left-handed) and by disproportionate daily use of the dominant hand. These asymmetries can influence functional performance [18–20], posture, and risk of injury in daily life.

Studies have shown that even in the absence of sports practice, manual dominance [21] plays a significant role in the development of functional asymmetries [22], favoring the strength and muscle mass of the dominant limb [23]. Although the young adult population, especially students, is often perceived as functionally homogeneous, recent research suggests significant asymmetries in the upper limbs [24,25], even in the absence of sports training. These asymmetries can be explained by lateral dominance, but also by repetitive daily activities that involve preference for using a single hand.

A significant correlation was observed between grip strength and body segment size among young adults, with notable bilateral variations [26]. Additionally, Burdukiewicz et al. (2020) reported significant differences between athletes and sedentary students regarding the symmetry of grip strength and muscle mass [23]. This evidence suggests that asymmetry is a common characteristic among the university population and can serve as a useful indicator for functional assessments or corrective interventions. Moreover, differences in arm circumference, palm length, or grip strength [27] reflect not only natural anatomical variations, but also individual functional adaptations. Evaluating these asymmetries among non-athlete students [28–30] offers a valuable perspective on musculoskeletal balance status, with implications for prevention of imbalances, performance optimization, and early rehabilitation interventions. In this context, the present study aims to examine the relationship between bilateral morphological symmetry [31,32] and functional symmetry, offering a complete analysis of potential links between anthropometric parameters and force generation capacity at the upper limb level [33,34].

Based on an analysis of the specialized literature, we identified several gaps in research on morphological asymmetry and manual grip strength. Research on the influence of bilateral morphological asymmetry of the upper limbs on grip strength among non-athlete students has significant gaps that limit the validity and applicability of the results. From a methodological perspective, the current literature reflects a lack of standardization in measurement protocols, manifested through variability in criteria for defining significant morphological asymmetry and absence of consensus on relevant anthropometric parameters. Methods for evaluating grip strength vary in testing positions, number of attempts, and recovery intervals, compromising study comparability. Additionally, inadequate control of confounding variables such as lateral dominance, impact of sedentary behaviors, and occupational factors specific to the university population is observed. Aspects related to gender differences in the manifestation of asymmetry and the implications of different equipment and technology use on asymmetric development are insufficiently explored. From a conceptual perspective, uncertainties persist regarding

cause-and-effect relationships between morphological asymmetry and strength differences, and underlying neuromotor mechanisms remain unclear [35,36]. The lack of longitudinal studies prevents understanding of the dynamics of asymmetry development during the university period and the long-term implications for musculoskeletal health. The practical applicability of results is limited by the absence of reference values specific to the population and correlations with functional performance in daily activities [37,38]. These limitations highlight the necessity for standardized protocols, longitudinal studies, and a clear definition of the significance of morphological asymmetry in the context of the non-athletic university population. Research that integrates in a unified manner segmental measurements (lengths, circumferences, spans) with bilateral dynamometric evaluations among non-athlete students is relatively scarce and focuses especially on the assessment of motor components.

The present study makes an original contribution by investigating the relationship between morphological and functional symmetry of the upper limbs in a population of young adult students who are semi-active or moderately active and do not engage in competitive sports. Unlike the existing literature, which predominantly focuses on elite athletes or clinical populations with musculoskeletal pathologies, this research adopts an integrated approach, combining detailed segmental anthropometric assessments with bilateral dynamometric measurements performed in two distinct positions. The main innovative aspects consist of: characterization of asymmetries in an intermediate population, representative of the majority of young people in academic settings, thus providing reference values for healthy individuals with moderate physical activity; simultaneous and correlated analysis of morphological parameters (segmental measurements of arm, forearm, and hand) and functional parameters (bilateral grip strength), enabling the identification of direct structure–function relationships; dynamometric evaluation in two different biomechanical contexts, which allows the detection of position-dependent asymmetries and provides a more comprehensive picture of bilateral functional capacity; and comparative analysis between sexes, both for morphological and functional asymmetries, as well as for the correlations between them, aspects insufficiently investigated in previous studies on non-athletic populations. This multidimensional approach allows not only the identification of the degree of morphological and functional asymmetry at the upper limb level, but also testing the hypothesis that structural asymmetries correlate with functional ones and that these relationships may differ according to gender and the biomechanical context of the assessment.

The study aims to identify bilateral differences and correlations between segmental anthropometric dimensions of the upper limbs and grip strength (evaluated by dynamometry) in young adults, students, and non-athletes, by gender and manual dominance.

The study hypothesis was that asymmetry at the upper-limb level influences manual grip strength (dynamometry) in non-athlete students and that these effects differ by gender and manual prevalence.

## 2. Materials and Methods

### 2.1. Participants

The study included 192 participants, of which 110 were female and 82 were male, with ages ranging between 18 and 26 years (mean age: 19.92 years). The mean body mass and height of the total sample were  $66.7 \pm 13.8$  kg and  $170.9 \pm 8.9$  cm, respectively. In the female group, mean body mass was  $60.1 \pm 10.0$  kg and mean height was  $165.7 \pm 6.6$  cm, while in the male group, mean body mass was  $75.5 \pm 13.4$  kg and mean height was  $177.9 \pm 6.2$  cm. All subjects were volunteers recruited from students at a higher education

institution, clinically healthy and fit for physical effort, without musculoskeletal conditions or other contraindications that could influence anthropometric or functional measurements. Clinically healthy students who did not have musculoskeletal conditions or other medical contraindications were included in the study and provided informed consent for participation. An additional inclusion criterion was the subjects' declaration that they do not regularly practice physical exercise or are not registered with any sports club, to ensure the sample was representative of the non-athlete young adult population.

## 2.2. Study Design

This study took place from 27 March to 15 May 2025, with the objective of measuring anthropometric parameters and dynamometry of the subjects' upper limbs. The anthropometric measurement sessions were conducted under similar conditions and with the same measurement instruments for all participants. The order of performing anthropometric measurements was identical for all subjects. Anthropometric measurements of the upper limbs were performed bilaterally (both on the right side and on the left side). All measurements were performed in the faculty's physical education halls. Participants wore specific sports clothing and were instructed not to engage in intense physical exercise for at least 12 h before testing. Each measurement was performed with the same apparatus and equipment by the same evaluator to reduce inter-rater variability. Each parameter was recorded once, except for dynamometry, where the highest value from two attempts was taken into consideration. Data were centralized in digital format (Microsoft Excel 2021), processed, and statistically validated before final analysis. For measurements, the following were used: a stadiometer for height, a digital scale, a digital caliper, a flexible measuring tape, and a digital dynamometer.

The study was approved by the Ethical Board of the Faculty of Physical Education and Mountain Sports of Transilvania University of Brasov under the document no. 101/26.03.2025.

## 2.3. Measurements

For this study, 15 measurements were performed: 13 anthropometric and two motor. All anthropometric measurements were conducted according to standardized anthropometric procedures based on internationally accepted guidelines. Anatomical landmarks, participant positioning, and measurement techniques were defined in advance and applied consistently across all participants, following principles commonly used in anthropometric research and comparable to those described in the International Society for the Advancement of Kinanthropometry (ISAK) framework and were performed with standardized equipment as follows: for anthropometric evaluations of widths and lengths at the hand and palm levels, we used a Mitutoyo 500-196-30 digital caliper with a measurement range of 0–100 mm, a reading precision of 0.01 mm, and a tolerance of  $\pm 0.01$  mm. Segmental lengths (such as forearm length, arm length, and upper limb length) were measured with a flexible tape measure (150 cm), and circumferences were measured with an ergonomic tape measure featuring a self-tightening mechanism to ensure uniform application without tissue compression (Seca 201, Seca GmbH, Hamburg, Germany). For evaluations of hand grip strength, a GRIPX digital dynamometer was used, with a capacity of 90 kg, electronic. Although no formal validation study specific to this model has been published, digital hand dynamometers have been shown to provide reliable and valid measurements of grip strength in young adult populations when standardized testing protocols are applied. Similar digital dynamometry devices [39] have been widely used in previous studies investigating grip strength and its relationship with anthropometric parameters in students and healthy adults, supporting the methodological adequacy of this approach.

#### Anthropometric evaluations:

- Height—distance between the vertex (top of the head) and the sole level (support surface) in orthostatic position.
- Palm width—direct distance from the most lateral point of the second metacarpal head to the most medial point of the fifth metacarpal head.
- Palm width (thumb included)—direct distance from the most lateral point of the first metacarpal head to the most medial point of the fifth metacarpal head.
- Palm length—distance between the styloid line and the proximal phalanges between the middle and ring fingers.
- Hand length—distance between the styloid line and dactylion.
- Palm span—distance between the proximal phalanges of the little finger and the distal phalanges of the thumb, with fingers extended at maximum angles.
- Upper limb length—distance between the acromion and dactylion in orthostatic position, with the upper limb completely extended.
- Forearm length—distance between the lateral epicondyle of the humerus (olecranon) and the styloid process of the radius (styloid line where the prominence at the wrist is felt).
- Wrist circumference—on the styloid line, at the level of the styloid processes of the radius and ulna bones, i.e., at the two lateral bony prominences of the wrist. The measuring tape is placed exactly over these points, applied firmly but without compressing tissue, completely surrounding the joint.
- Relaxed forearm circumference—with the subject in orthostatic position and palm oriented anteriorly, half the distance between the lateral epicondyle and styloid process is determined, and the measuring tape is wrapped around the forearm.
- Flexed forearm circumference—with the subject in orthostatic position and palm oriented anteriorly, the subject is instructed to clench the fist and tense the forearm muscles in isometry, with the measuring tape wrapped around the forearm.
- Relaxed arm circumference—with the subject in orthostatic position and arm bent at the elbow at 90°, half the distance between the acromion and olecranon is determined and the measuring tape is wrapped at mid-distance, around the arm, without compressing tissues.
- Flexed arm circumference—with the subject in orthostatic position and arm bent at the elbow at 90°, in isometry, the subject is instructed to simultaneously clench the fist and flex the biceps, with the measuring tape wrapped around the arm.

Arm and forearm circumferences were analyzed as absolute anthropometric measures. Corrected circumferences adjusted for adipose tissue were not calculated, as skinfold thickness were not included in the study protocol. We aim to evaluate practical, field-based anthropometric indicators commonly used in educational and ergonomic settings, rather than estimates of isolated muscle cross-sectional area.

#### Motor evaluations:

- Dynamometry with extended arm—with the subject in orthostatic position with extended arm and palm oriented anteriorly, the subject is instructed to squeeze the dynamometer as hard as possible, without compensatory movements. Two attempts are performed with a 30 s pause between them. The highest value is recorded, expressed in kilograms (kg).
- Dynamometry with arm bent at 90°—with the subject in orthostatic position, with arm bent at the elbow joint at 90°, the subject is instructed to squeeze the dynamometer as hard as possible, without compensatory movements. Two attempts are performed with a 30 s pause between them. The highest value is recorded, expressed in kilograms (kg).

## 2.4. Statistical Analysis

Analyses were performed in IBM SPSS Statistics for Windows Version 26; IBM Corp., Armonk, NY, USA, with significance threshold  $\alpha = 0.05$  (bilateral). The statistical power of the sample was calculated with G\*Power 3.1.9.4. a priori/post hoc, indicating that for the main functional effects ( $d^2 \approx 0.46$ – $0.53$ ), a sample of ~28–37 participants would ensure power  $\geq 0.80$  ( $\alpha = 0.05$ ), while for smaller morphological effects, ~102 participants would be necessary. Our study included  $n = 192$  subjects; the achieved power for key results was  $\approx 1.00$  (functional) and  $\approx 0.97$  (e.g., forearm length), confirming sample adequacy for detecting effects of interest. For each bilateral variable, descriptive indicators (mean, standard deviation, minimum, maximum, skewness, kurtosis, CV%) and 95% confidence intervals (95% CI) were calculated. Left–right differences were evaluated using paired Student's *t*-tests; comparisons between genders were evaluated using independent Student's *t*-tests; and bivariate Pearson correlations were calculated between manual anthropometric measurements and dynamometric strength measurements. The coefficient of variation (CV) was calculated to highlight group homogeneity. We also calculated Cohen's *d* effect size. For paired tests, effect size was expressed through the statistical parameter Cohen's ( $d^2$ ). The Pearson correlation coefficient was used to identify correlations between anthropometric indicators and grip strength; analyses were performed separately by gender (M/F), laterality (left/right), and posture (extension/flexion at  $90^\circ$ ), with 12 anthropometric indicators per set. For identifying differences between the left and right upper segments. Before performing inferential analyses, the assumptions for parametric testing were examined. Data normality was assessed using the Shapiro–Wilk test, and homogeneity of variance was evaluated using Levene's test. These analyses supported the use of parametric statistical procedures.

## 3. Results

In Table 1, the analysis of the fourteen bilaterally measured anthropometric parameters reveals consistent differences between genders, especially in linear dimensions and circumferences, as well as good body symmetry between the left and right sides. Regarding palm width, the mean values were  $9.45 \pm 0.61$  cm in the female group and  $10.63 \pm 1.09$  cm in the male group, with the difference confirmed by 95% confidence intervals. Hand length showed a similar trend, with means of  $17.18 \pm 0.94$  cm in the female group and  $18.89 \pm 1.04$  cm in the male group. For circumferences, values were significantly higher in the male group. At the wrist level, the mean was 15.6 cm in the female group and 17.4 cm in the male group. The difference was accentuated at the flexed arm, where the female group had a mean circumference of  $27.9 \pm 3.95$  cm, while the male group had a mean circumference of  $32.9 \pm 4.24$  cm.

Comparison of the left and right sides did not reveal significant differences. Means were almost identical across genders, and confidence intervals overlapped. For example, forearm length was  $23.9 \pm 1.46$  cm (left) and  $24.3 \pm 1.54$  cm (right) in the female group, and  $26.3 \pm 1.69$  cm and  $26.6 \pm 1.75$  cm in the male group, respectively. These results suggest stable structural symmetry between the two sides of the body.

The most evident differences between genders were observed in strength tests (dynamometry). In the extended arm test, the female group had a mean of  $23.7 \pm 7.6$  kgf, while the male group had a mean of  $36.1 \pm 9.1$  kgf. In the bent arm test, results were similar:  $22.9 \pm 8.2$  kgf in the female group and  $36.2 \pm 8.5$  kgf in the male group. Maximum values reached 55 kgf in the female group and over 70 kgf in the male group, illustrating not only the difference between means, but also greater variability in the male group.

The study results confirm that the male group presents significantly larger dimensions and strength than the female group, while bilateral symmetry is well preserved. These observations are relevant to both the sports and ergonomic domains, as

well as to clinical applications, where assessment of body proportions and muscle strength can contribute to understanding functional performance and injury risk.

Descriptive characteristics of the sample showed clear differences between genders. Male participants presented higher mean body mass and height compared to female participants, while age distribution was comparable between groups.

**Table 1.** Descriptive statistics of the 14 parameters according to laterality and gender.

Parameters	Hand	Gender	Min.	Max.	X	SD	CI 95%		Kurtosis	CV%
							Lower	Upper		
Palm width with thumb (cm)	L	F	8.00	10.70	9.444	0.613	9.329	9.559	-0.509	6.496
		M	8.80	12.00	10.615	0.773	10.447	10.782	-0.564	7.283
	R	F	8.00	10.80	9.436	0.607	9.322	9.550	-0.276	6.438
		M	8.80	12.00	10.549	0.729	10.391	10.707	-0.219	6.912
Palm width (cm)	L	F	7.00	9.00	7.869	0.456	7.783	7.954	-0.294	5.800
		M	6.50	10.00	8.743	0.592	8.615	8.871	1.644	6.773
	R	F	6.70	9.50	7.790	0.493	7.697	7.882	0.709	6.325
		M	7.30	10.00	8.650	0.548	8.531	8.769	-0.354	6.338
Palm length (cm)	L	F	8.50	11.30	9.768	0.615	9.653	9.883	-0.300	6.292
		M	8.50	12.00	10.556	0.675	10.410	10.702	0.751	6.394
	R	F	8.40	11.30	9.720	0.602	9.607	9.833	0.025	6.195
		M	8.80	12.00	10.513	0.682	10.366	10.661	0.495	6.489
Hand length (cm)	L	F	15.50	19.80	17.406	0.881	17.240	17.571	-0.244	5.060
		M	17.00	21.00	18.744	0.908	18.547	18.940	-0.637	4.846
	R	F	13.20	20.50	17.380	1.052	17.182	17.577	1.720	6.051
		M	16.80	20.50	18.635	0.928	18.435	18.836	-0.664	4.979
Hand span (cm)	L	F	16.50	22.50	18.986	1.306	18.741	19.231	-0.386	6.881
		M	18.20	24.60	21.240	1.415	20.934	21.547	-0.437	6.662
	R	F	13.30	22.00	18.882	1.452	18.609	19.154	0.989	7.692
		M	18.80	25.30	21.223	1.463	20.906	21.540	-0.223	6.894
Forearm length (cm)	L	F	20.00	28.00	24.112	1.604	23.811	24.413	-0.251	6.651
		M	22.70	28.50	25.941	1.299	25.660	26.223	-0.389	5.007
	R	F	20.00	29.00	24.369	1.801	24.031	24.707	-0.027	7.392
		M	22.50	29.50	26.328	1.518	26.000	26.657	0.064	5.765
Arm length (cm)	L	F	27.00	36.00	31.490	1.946	31.125	31.855	-0.369	6.180
		M	27.00	43.50	33.155	3.161	32.471	33.839	1.185	9.534
	R	F	26.00	36.50	31.453	2.021	31.074	31.833	-0.220	6.427
		M	26.00	43.00	32.939	3.463	32.189	33.689	0.374	10.514
Wrist circumference (cm)	L	F	13.40	19.00	15.649	1.293	15.406	15.891	-0.428	8.263
		M	15.50	19.00	17.068	0.936	16.866	17.271	-0.806	5.487
	R	F	13.40	19.50	15.645	1.280	15.405	15.885	0.004	8.179
		M	15.50	19.00	17.082	0.889	16.889	17.274	-0.738	5.207
Relaxed forearm circumference (cm)	L	F	17.80	30.00	23.507	2.312	23.073	23.941	0.594	9.835
		M	22.00	32.50	26.937	2.299	26.439	27.434	-0.192	8.534
	R	F	18.40	30.30	23.876	2.266	23.451	24.302	0.454	9.491
		M	22.40	33.50	27.279	2.336	26.774	27.785	0.027	8.564
Tense forearm circumference (cm)	L	F	18.70	31.00	24.099	2.276	23.672	24.526	0.687	9.445
		M	23.00	33.50	27.677	2.407	27.156	28.198	-0.057	8.696
	R	F	19.10	31.00	24.476	2.269	24.050	24.902	0.451	9.270
		M	23.20	34.50	28.059	2.368	27.546	28.571	0.191	8.438
Relaxed arm circumference (cm)	L	F	18.40	38.30	26.106	3.644	25.422	26.790	1.093	13.957
		M	21.50	42.00	29.882	3.894	29.039	30.724	0.367	13.030

Tense arm circumference	R	F	19.20	38.00	26.330	3.664	25.642	27.018	1.226	13.916
		M	21.50	43.00	29.987	3.767	29.171	30.802	1.368	12.563
	L	F	21.00	41.00	27.760	3.702	27.065	28.455	1.492	13.335
		M	23.70	47.00	32.868	4.239	31.951	33.786	1.158	12.898
Extended arm dynamometry (kg)	R	F	21.60	41.00	28.008	3.626	27.328	28.689	1.284	12.946
		M	24.70	47.00	33.118	4.306	32.186	34.050	1.029	13.002
	L	F	13.50	36.80	23.865	5.019	22.923	24.807	-0.346	21.031
		M	20.00	64.50	36.450	10.606	34.154	38.746	-0.211	29.097
Bend arm dynamometry (kg)	R	F	12.50	44.50	25.862	6.232	24.692	27.032	-0.237	24.096
		M	19.90	69.30	38.728	11.707	36.194	41.262	-0.315	30.230
	L	F	9.90	39.90	23.098	5.515	22.063	24.134	0.201	23.877
		M	18.50	71.00	35.235	11.295	32.791	37.680	1.150	32.055
	R	F	10.70	36.80	25.004	6.059	23.866	26.141	-0.536	24.233
		M	19.50	62.90	37.505	11.122	35.097	39.912	-0.615	29.656

Min—minimum; Max—maximum; X—mean; SD—standard deviation; CI 95%—confidence interval 95%; CV—coefficient of variation; L—left; R—right; F—female; M—male.

The comparative analysis in Table 2 of upper limb anthropometric parameters revealed clear differences between genders, with consistently higher values in the male group across all linear dimensions and circumferences, as well as in muscle strength tests. At the same time, no notable differences were observed between the left and right sides, suggesting stable bilateral body symmetry. Regarding palm and hand dimensions, the male group showed superior values compared to the female group across width, length, and span. For example, hand length was approximately 2 cm greater in the male group, and palm span exceeded female group values by about 2.5 cm, with differences statistically confirmed ( $p < 0.001$ ). At the level of proximal segments (forearm and arm), differences became even more evident. Mean forearm length was greater in the male group by approximately 2 cm, and arm length by 4–5 cm. These results confirm that gender differences are expressed more markedly at the level of large bone and muscle structures. The most evident contrasts were observed in circumferences. Under conditions of muscle contraction, arm circumference in the male group exceeded that of the female group by nearly 5 cm, reflecting differences in muscle mass.

In muscle strength tests, the contrast was clearly superior in favor of the male group. Dynamometry values showed differences of approximately 12–13 kg between genders in both the extended-arm and bent-arm tests ( $p < 0.001$ ). Thus, the data support the idea of a pronounced gender difference at the upper-limb level, as evidenced by higher values in the male group across all anthropometric parameters and muscle strength. However, bilateral symmetry between the left and right sides suggests that these differences are uniformly distributed and do not depend on laterality.

**Table 2.** Paired sample test analysis of the anthropometrics and dynamometric parameters according to handedness.

Parameters	Hand	$\Delta X$	SD	95% CI		t	p	d
				LL	UL			
Palm width with thumb (cm)	L	9.945	0.895	9.818	10.073	1.392	0.166	0.100
	R	9.911	0.859	9.789	10.034			
Palm width (cm)	L	8.240	0.675	8.144	8.336	3.537	0.001	0.255
	R	8.156	0.669	8.060	8.251			
Palm length (cm)	L	10.098	0.756	9.990	10.206	1.857	0.065	0.134
	R	10.055	0.749	9.948	10.162			
Hand length (cm)	L	17.971	1.114	17.813	18.130	1.412	0.160	0.102

	R	17.913	1.176	17.745	18.080			
Hand span (cm)	L	19.942	1.757	19.692	20.192	1.049	0.296	0.076
	R	19.882	1.856	19.618	20.147			
Forearm length (cm)	L	24.880	1.746	24.631	25.128	-3.697	0.000	-0.267
	R	25.198	1.943	24.922	25.475			
Arm length (cm)	L	32.204	2.656	31.825	32.582	1.116	0.266	0.081
	R	32.091	2.817	31.690	32.492			
Wrist circumference (cm)	L	16.261	1.346	16.069	16.453	-0.357	0.721	-0.026
	R	16.270	1.334	16.080	16.460			
Relaxed forearm circumference (cm)	L	24.995	2.862	24.588	25.403	-9.482	0.000	-0.684
	R	25.355	2.848	24.949	25.760			
Tense forearm circumference (cm)	L	25.650	2.926	25.233	26.067	-10.007	0.000	-0.722
	R	26.030	2.911	25.615	26.444			
Relaxed arm circumference (cm)	L	27.749	4.186	27.154	28.345	-1.996	0.047	-0.144
	R	27.922	4.120	27.335	28.508			
Tense arm circumference (cm)	L	30.005	4.721	29.333	30.677	-2.506	0.013	-0.181
	R	30.258	4.722	29.586	30.931			
Straight arm dynamometry (kg)	L	29.232	10.050	27.801	30.662	-6.345	0.000	-0.458
	R	31.360	10.989	29.796	32.925			
Bended arm dynamometry (kg)	L	28.274	10.373	26.798	29.751	-7.315	0.000	-0.527
	R	30.346	10.565	28.842	31.850			

CI—interval of confidence; LL—lower limit; UL—upper limit; SD—standard deviation; d—effect size; L—left; R—right; t—Student's t; *p*—significance level; d = Cohen's effect size, statistical significance was set at  $p < 0.01$ .

The results of the paired test in Table 3, analyzed separately for the female group and male group, show that bilateral asymmetry in anthropometric parameters is reduced for most measurements. For the forearm, both in the female and male groups, consistent differences were evident between the left and right sides. In the female group, right forearm circumference was approximately 0.33 cm greater at rest and 0.35 cm in contraction, both differences being highly significant ( $p < 0.001$ ). The effect was of moderate magnitude ( $d \approx -0.66$  and  $-0.72$ ), suggesting clear muscular development of the dominant side. In the male group, values were similar: +0.40 cm at rest and +0.42 cm in contraction on the right side ( $p < 0.001$ ,  $d \approx -0.63$  and  $-0.74$ ). The largest differences appeared in grip strength. The female group had on average 2.1 kg more strength in the right hand, both with extended arm and bent arm. Both results were extremely statistically significant ( $p < 0.001$ ) and with moderate effects ( $d \approx -0.5$ ). In the male group, differences were almost identical: -2.14 kg for extended arm and -2.09 kg for bent arm, confirming the same tendency of superior strength on the right side ( $p < 0.001$ ).

Analysis of effect size (Cohen's *d*) revealed important differences between structural and functional parameters of the upper limbs. For most linear measurements (palm length and width, hand or arm length, wrist circumference), *d* values were very small (below 0.2), indicating small effects and little practical relevance. This result suggests bilateral structural symmetry, with minimal differences between the left and right sides. In contrast, for muscular and functional parameters, effects of moderate to large magnitude were identified. Forearm circumference showed effects ranging from  $d = -0.63$  to  $d = -0.74$ , in both the female and male groups, in the relaxed state and during contraction. These values indicate consistent differences in favor of the right side, reflecting more pronounced muscular development in the dominant forearm. Additionally, grip strength presented moderate effects (Cohen's  $d \approx -0.5$  to  $-0.6$ ), confirming a clear functional difference between the literalities. The approximately 2 kg difference in favor of the right

hand, observed in both the female and male groups, demonstrates the practical relevance of these effects. Thus, Cohen's *d* values suggest that while bone and articular dimensions remain largely symmetric, bilateral asymmetry with practical effect manifests especially at the muscular and functional level, being closely linked to manual dominance.

**Table 3.** Paired Sample test analysis between left and right hands of the anthropometrics and dynamometric parameters according to gender.

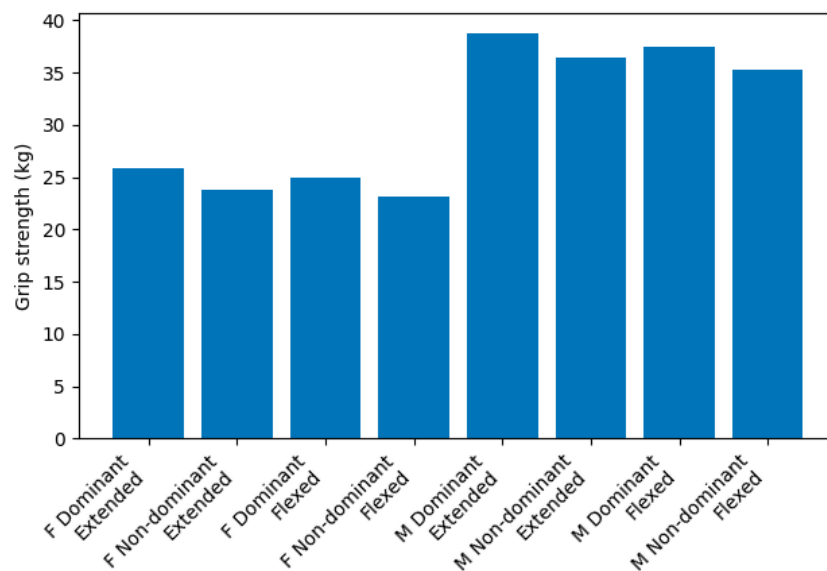
Parameters	Gender	$\Delta X$	SD	95% CI		t	p	d
				LL	UL			
Palm width with thumb (cm)	F	-0.010	0.286	-0.044	0.064	-0.367	0.714	0.035
	M	-0.066	0.395	-0.021	0.152	-1.509	0.135	-0.167
Palm width (cm)	F	-0.079	0.335	0.015	0.141	-2.452	0.016	-0.236
	M	0.927	0.327	0.020	0.164	-2.564	0.012	2.835
Palm length (cm)	F	-0.043	0.273	-0.009	0.094	1.641	0.104	-0.158
	M	0.042	0.372	-0.039	0.124	1.037	0.303	0.113
Hand length (cm)	F	0.022	0.700	-0.110	0.154	0.327	0.744	0.031
	M	0.109	0.350	0.031	0.185	2.808	0.006	0.311
Hand span (cm)	F	0.091	0.824	-0.065	0.246	1.156	0.250	0.110
	M	0.017	0.730	-0.143	0.177	0.212	0.833	0.023
Forearm length (cm)	F	-0.268	1.072	-0.471	0.065	-2.624	0.010	-0.250
	M	-0.387	1.345	-0.682	-0.090	-2.601	0.011	-0.288
Arm length (cm)	F	0.037	1.081	-0.168	0.240	0.353	0.725	0.034
	M	0.216	1.746	-0.167	0.599	1.119	0.266	0.124
Wrist circumference (cm)	F	-0.005	0.337	-0.069	0.058	-0.169	0.866	-0.015
	M	-0.014	0.352	-0.090	0.064	-0.344	0.731	-0.040
Relaxed forearm circumference (cm)	F	-0.371	0.477	-0.462	-0.281	-8.165	0.000	-0.778
	M	-0.342	0.585	-0.471	-0.214	-5.299	0.000	-0.585
Tense forearm circumference (cm)	F	-0.378	0.480	-0.469	-0.287	-8.254	0.000	-0.788
	M	-0.382	0.584	-0.510	-0.253	-5.919	0.000	-0.654
Relaxed arm circumference (cm)	F	-0.222	0.855	-0.384	-0.061	-2.732	0.007	-0.260
	M	-0.105	1.544	-0.444	0.234	-0.615	0.540	-0.068
Tense arm circumference (cm)	F	-0.255	0.745	-0.396	-0.114	-3.592	0.000	-0.342
	M	-0.250	1.967	-0.682	0.182	-1.151	0.253	-0.127
Straight arm dynamometry (kg)	F	-2.017	3.769	-2.729	-1.305	-5.613	0.000	-0.535
	M	-2.278	5.638	-3.517	-1.039	-3.660	0.000	-0.404
Bended arm dynamometry (kg)	F	-1.923	3.147	-2.518	-1.328	-6.409	0.000	-0.611
	M	-2.270	4.784	-3.320	-1.218	-4.295	0.000	-0.475

CI—interval of confidence; LL—lower limit; UL—upper limit; SD—standard deviation; M—male; F—female; *d*—effect size; *t*—Student's *t*; *p*—significance level; statistical significance was set at  $p < 0.01$ .

Mean grip strength values for dominant and non-dominant upper limbs in female and male participants, measured with the arm extended and with the arm flexed at 90°. Dominant limbs correspond to the right side for the majority of participants.

Table 4, Figure 1, reveals distinct association patterns, with relative structural symmetry and asymmetric, gender-dependent functionality. Among female participants, Pearson correlation analysis reveals significant associations between forearm and wrist circumference variables and grip strength. For example, flexed forearm circumference (right) correlates strongly with grip strength in extended position ( $r = 0.262$ ,  $p = 0.006$ ) and bent position ( $r = 0.305$ ,  $p = 0.001$ ). In contrast, wrist and relaxed forearm circumference show significant bilateral correlations, with *r* values ranging between 0.256 and 0.350 ( $p <$

0.01). These results suggest that distal segmental muscular development is an efficient predictor of functional strength in the female population. Notably, palm width also correlates significantly with right-sided grip strength ( $r = 0.436$ ,  $p < 0.001$ ), suggesting a possible structural influence of the support base on force transmission.



**Figure 1.** Grip strength differences between dominant and non-dominant upper limbs by sex and testing position.

In male subjects, relationships are less pronounced. Still, significant correlations are observed between relaxed forearm circumference (left) and grip strength in both positions ( $r \approx 0.29$ ,  $p < 0.01$ ), as well as between flexed arm circumference and grip strength ( $r = 0.264$ ,  $p = 0.016$ ). This functional asymmetry in the expression of correlations suggests a different biomechanical model between genders. In the female group, grip strength appears more dependent on distal parameters (forearm, wrist). In contrast, in the male group, strength is distributed more diffusely and influenced by additional neuromuscular factors not directly reflected in segmental morphology. Additionally, the consistency of significant relationships on the right side in both the male group and female group confirms functional lateral dominance, with associated morphological adaptations.

**Table 4.** Pearson correlations between dynamometric measurements and anthropometric parameters in relation to gender and handedness.

Parameters	Gender	Side	Straight Arm Dynamometry		Bended Arm Dynamometry	
			<i>r</i>	<i>p</i>	<i>r</i>	<i>p</i>
Palm width with thumb (cm)	M	L	-0.125	0.262	-0.014	0.902
		R	0.025	0.821	0.092	0.409
	F	L	0.144	0.134	0.157	0.104
		R	0.281 **	0.003	0.256 **	0.007
Palm width (without thumb) (cm)	M	L	0.121	0.279	0.133	0.235
		R	0.130	0.245	0.143	0.200
	F	L	0.274 **	0.004	0.327 **	0.001
		R	0.437 **	0.000	0.422 **	0.000
Palm length (cm)	M	L	0.198	0.076	0.192	0.085
		R	0.210	0.064	0.205	0.071
	F	L	0.175	0.069	0.153	0.113
		R	0.205 *	0.033	0.152	0.115

Hand length (cm)	M	L	0.112	0.317	0.104	0.350
		R	0.033	0.766	0.027	0.810
	F	L	0.223 *	0.020	0.193 *	0.044
		R	0.275 **	0.004	0.270 **	0.005
Hand span (cm)	M	L	0.181	0.104	0.150	0.180
		R	0.191	0.087	0.161	0.147
	F	L	0.093	0.337	0.162	0.092
		R	0.068	0.482	0.104	0.281
Forearm length (cm)	M	L	0.236 *	0.032	0.211	0.063
		R	0.253 *	0.021	0.225 *	0.049
	F	L	0.212 *	0.027	0.218 *	0.023
		R	0.085	0.378	0.100	0.303
Arm length (cm)	M	L	0.298 **	0.006	0.266 *	0.015
		R	0.303 **	0.005	0.270 *	0.014
	F	L	0.008	0.930	0.007	0.944
		R	0.106	0.272	0.065	0.501
Wrist circumference (cm)	M	L	0.195	0.080	0.176	0.113
		R	0.210	0.064	0.201	0.070
	F	L	0.326 **	0.001	0.354 **	0.000
		R	0.265 **	0.005	0.326 **	0.001
Relaxed forearm circumference (cm)	M	L	0.317 **	0.004	0.309 **	0.005
		R	0.328 **	0.003	0.315 **	0.004
	F	L	0.319 **	0.001	0.285 **	0.003
		R	0.259 **	0.007	0.307 **	0.001
Tense forearm circumference (cm)	M	L	0.333 **	0.002	0.322 **	0.003
		R	0.342 **	0.002	0.328 **	0.003
	F	L	0.342 **	0.000	0.275 **	0.004
		R	0.265 **	0.005	0.308 **	0.001
Relaxed arm circumference (cm)	M	L	0.355 **	0.001	0.349 **	0.001
		R	0.365 **	0.001	0.358 **	0.001
	F	L	0.265 **	0.005	0.238 *	0.013
		R	0.157	0.103	0.260 **	0.006
Tense arm circumference (cm)	M	L	0.384 **	0.000	0.378 **	0.000
		R	0.395 **	0.000	0.389 **	0.000
	F	L	0.254 *	0.008	0.228 *	0.017
		R	0.174	0.070	0.251 *	0.008

\* M—group of male; F—group of female; L—left; R—right; r = Pearson correlation coefficient. \*\* Statistical significance was set at  $p < 0.01$ . \*\* Correlation magnitude was interpreted as follows: trivial ( $r < 0.10$ ), small ( $r = 0.10$ – $0.29$ ), moderate ( $r = 0.30$ – $0.49$ ), and large ( $r \geq 0.50$ ).

#### 4. Discussion

The main purpose of this study was to investigate the relationship between segmental morphological dimensions of the upper limbs and grip strength in the context of bilateral asymmetry in young non-athletes. By analyzing differences in the upper limbs and between genders, the study aimed to highlight possible functional or structural imbalances. The obtained results contribute to understanding how the preferential use of one upper limb and anthropometric characteristics influence functional performance, even in the absence of organized sports training.

Statistical analysis revealed significant differences between the dominant and non-dominant limbs in functional parameters, especially grip strength, which showed clear superiority of the dominant limb across testing positions. This functional asymmetry

appears as a systematic and recurrent phenomenon, reflecting neuromuscular adaptations induced by predominant unilateral use. At the morphological level, although most parameters showed relatively well-preserved symmetry, significant discrepancies were observed in forearm and arm length and circumference, suggesting localized structural adaptation, most likely due to daily activity. Gender differences were also evident: the male group showed higher values across all segmental dimensions and grip strength, whereas in the female group, stronger correlations were observed between morphological characteristics and functional performance.

Interestingly, although subjects in the male group had significantly greater strength, subjects in the female group demonstrated more consistent and significant correlations between segmental dimensions (forearm circumference, palm width) and grip strength. This aspect suggests a more predictable functional model in the female group, where morphological development is more closely linked to functional performance. In contrast, in the male group, strength appears influenced by additional factors, possibly neurophysiological or hormonal, that are not directly reflected in anthropometric dimensions.

The study results validate the research hypothesis regarding the link between morphological characteristics and functional performance, offering an essential scientific foundation for using anthropometric evaluations in predicting grip strength. Therefore, Table 4 not only supports the inclusion of gender and laterality differences in predictive models of neuromuscular function but also highlights an essential functional asymmetry that must be considered in ergonomics, sports medicine, and rehabilitation.

The results of this study offer a detailed perspective on bilateral asymmetries [40,41] of the upper limbs among university students not involved in organized sports activity. Although specialized literature tends to emphasize symmetry as a functional and morphological ideal in healthy populations [42,43], our data indicate statistically significant discrepancies, especially in functional parameters (grip strength) and, to a lesser extent, in some morphological parameters, such as forearm and arm circumferences.

The most prominent form of asymmetry observed was functional, reflected in grip strength differences between upper limbs [34,44,45]. This observation is in accordance with specialized literature, which emphasizes that manual dominance leads to preferential use of one limb, inducing functional hypertrophy and, consequently, greater strength in the dominant limb [1,46–48]. Thus, differences of approximately 2 kg on average in dynamometry tests between left and right limbs support the hypothesis of systematic and constant functional asymmetry among non-athlete subjects. It is noteworthy that these differences are not significantly influenced by the biomechanical testing position (extended arm vs. bent arm), suggesting that the determining factors are neuromuscular rather than strictly biomechanical.

In contrast to functional parameters, most morphological parameters did not show significant bilateral differences. Notable exceptions were forearm length and forearm and arm circumferences (both relaxed and flexed), where differences of up to 0.5–0.8 cm were observed between limbs. These discrepancies, although relatively small in absolute terms, are statistically significant and indicate differentiated muscular adaptation in the dominant limb, likely associated with repetitive, sustained use in daily activities.

These results are consistent with those reported by [23], who observed a similar pattern of lateralized functional hypertrophy in athletes and the general population. However, unlike studies focused on performance athletes, where morphological differences are much more pronounced [49,50], the population studied in this case presents relatively well-preserved structural symmetry, indicating a moderate influence of daily behavior on segmental morphology.

Gender analysis revealed clear differentiation regarding both morphological and functional parameters. The male group recorded significantly superior values for all strength indicators and for most segmental dimensions (forearm, arm, palm). This result aligns with recent meta-analyses that confirm physiological and hormonal gender differences in muscle mass and strength performance [26,34].

A central aspect emerging from current literature is the influence of asymmetric use on neuromuscular and morphological development of the upper limbs. Even in untrained populations, such as those investigated in this study, manual dominance determines differential stimulation of the musculature, with measurable effects on local strength and tone. It has been demonstrated that laterality significantly influences grip performance and that this difference directly correlates with segmental circumferences, especially at the forearm level, in healthy young people. This finding supports our results regarding the localized character of functional adaptations [26].

Additionally, the analysis of sex differences in the present study is in accordance with the literature, suggesting a differentiated distribution of muscle mass and gender-specific neuromuscular recruitment. Studies also emphasize that female and male group use different strategies during muscular effort, even within upper-limb muscle groups [51]. Thus, our results, which indicate a more predictable relationship between morphology and strength in the female group, can be explained by more linear neuromuscular control and a more uniform distribution of muscle mass involved in gripping actions. In contrast, in the male group, factors such as neural impulse, joint stiffness, or anabolic hormones may play a more important role in force generation, independent of morphology.

Beyond the explanatory dimension, these findings also have applicative implications in the field of ergonomics and rehabilitation. Grip strength, as an easily evaluated parameter, can serve as an early indicator of neuromuscular imbalances or risk of dysfunctions associated with excessive unilateral use. A specialized study highlights the need to assess strength by position and by professional activity, showing that position differences can have a reduced impact in the presence of marked functional dominance, as our data indicate [52]. We consider that dynamometric and segmental anthropometric evaluations can constitute a valuable tool for evaluating correlations between anthropometric and motor parameters, as predictive elements of body symmetries and harmonious physical development in young people [53–57].

#### *4.1. Practical Implications of the Study*

The identification and quantification of these functional and morphological asymmetries has major practical importance. In the context of physical education and the prevention of postural imbalances, these results can guide personalized interventions to balance functional loads on the upper limbs. Additionally, in ergonomics and occupational medicine, these data can serve as a basis for adapting repetitive tasks (e.g., typing, lifting objects, desk work) to be evenly distributed between limbs, thereby reducing the risk of unilateral overload and musculoskeletal dysfunctions. At the same time, in neuromuscular rehabilitation and sports medicine, evaluating these asymmetries can inform the development of differentiated training or recovery protocols that account for laterality, gender-related morphological variation, and segmental muscular adaptations.

#### *4.2. Limitations and Future Directions*

The study has several limitations that must be considered. First, the investigated population consisted exclusively of young, healthy students, limiting the generalizability of the results to other age groups or clinical populations. Second, electromyographic or imaging measurements were not included to highlight differences in muscle activation or

tissue composition. In the future, integrating these methods could provide a more detailed picture of the mechanisms underlying the identified functional asymmetries. Additionally, the direct influence of daily activities or a history of physical exercise on symmetry was not analyzed, an aspect that could be explored in future longitudinal research. Evaluation of other body segments is also necessary to understand whether the asymmetry pattern is localized or generalized.

## 5. Conclusions

The research results partially confirmed the initial hypothesis: general morphological asymmetry is reduced and does not significantly influence functional parameters, but specific muscle segments and local circumferences clearly correlate with grip strength. Paired analyses showed constant functional asymmetry in favor of the right side, where grip strength was approximately 2 kg greater, both in the female group and male group. In parallel, forearm circumference (at rest and in contraction) presented significant differences between left and right, with moderate effects. Pearson correlations revealed positive links between forearm and arm circumference and grip strength, especially in the female group. Regarding gender differences, the male group recorded higher values for all segmental dimensions and grip strength, confirming evident functional and morphological differences between genders. However, in the female group, correlations between morphological and functional parameters were more consistent, indicating a closer relationship between structure and performance.

The study confirms that bilateral structural asymmetry (lengths and widths) does not significantly affect functional performance, whereas muscular asymmetry, especially at the forearm level, directly influences grip strength. These findings validate the research hypothesis and support the proposed title, highlighting that the influence of morphology on strength is localized and functional rather than global. The results can contribute to better understanding of the relationship between morphology and function in young semi-active populations. They can support preventive or rehabilitation programs oriented toward functional balancing of the upper limbs. Additionally, the study contributes to filling the scientific gap regarding the relationship between the bilateral morphology of the upper limbs and their functionality among the semi-active student population. These results can form the basis for preventive or corrective interventions that address functional and structural imbalances from the early stages of adult life.

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