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Dynamics of changes and sexual dimorphism in dynamometric strength of stronger hand based on Cracow Longitudinal Growth Study

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Original article

Abstract

The aim of this study was to analyse 18-year changes in dominant handgrip strength and assess sexual dimorphism in this trait among a group of participants from the Cracow Longitudinal Growth Study (KLGS) born between 1970 and 1972. The study was conducted twice—in 2004 (age 32–34) and in 2022 (age 50–52)—among a group of 84 participants (35 women and 49 men).

Handgrip strength was measured using the JAMAR dynamometer, and basic somatic characteristics were also calculated: body mass, body height, BMI (Body Mass Index) and upper limb circumference. The degree of sexual dimorphism was determined using the Mollison Index.

The results showed a significant decrease in mean gripstrength over the 18-year period—by nearly 3 kG in women and over 4 kG in men—with a simultaneous increase in body mass and BMI in both groups. High stability of individual differences in grip strength was found ($r \approx 0.65$), meaning that individuals who were stronger at age 32 remained relatively stronger at age 50. Sexual dimorphism, while still evident, was slightly weakened. In women at age 50, the best correlate of grip strength was forearm circumference, while in men, it was body height.

The obtained results confirm that handgrip strength is a stable indicator of strength potential in adulthood, and its decline is a natural part of the aging process. The relationships between strength and somatic characteristics change with age and differ among women and men.

Keywords

- dynamometric strength
- somatic characteristics
- women
- men
- longitudinal study

Contribution

A – Preparation of the research project
B – Assembly of data
C – Conducting of statistical analysis
D – Interpretation of results
E – Manuscript preparation
F – Literature review
G – Revising the manuscript

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Conflict of interest

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Introduction

Muscle strength is an important indicator of current health status and a reliable predictor of age-related disease and disability. Handgrip strength—measured with an isometric dynamometer—is a convenient, feasible and widely used method in the assessment of muscle strength among individuals of all ages.[1] Strength, as a motor skill, is "the ability to overcome or counteract external resistance at the cost of muscular effort".[2]

Motor skills are individual, psychophysical characteristics of a person that determine their level of movement capabilities.[3] It is a set of predispositions that—to predominantly varying degrees—are genetically established and shaped by environmental factors. Within this set of predispositions, we can distinguish, among others, fitness abilities (strength, endurance).[4] Developing muscle strength plays an essential role in improving athletic performance as well as maintaining and increasing overall physical fitness.[5] Among the forms of externalising strength, we can distinguish static strength – the ability to resist external resistance through active muscle tension, without changing their length.[6]

The strength of muscle contraction depends on the number of activated motor units, which—when stimulated—contract with full force. This stimulation is short-lived and occurs in anaerobic conditions.[7] When developing muscle strength, it is important to note that excessively intense and unilateral training can lead to subpathological or pathological changes. Maximum strength loads should only be applied after the static-motor system has fully developed, which typically occurs after the age of 17–18.[8]

In literature on the subject, it is emphasised that the key determinants of muscle strength include: genetic predisposition, age, gender, hormonal balance, nutrition and the specificity of the applied training.[9,10].People with a predominance of fast-twitch fibres (type 2) have greater potential to generate force, which translates into higher predispositions in strength sports.[9] In turn, environmental factors, such as systematic physical activity undertaken early in life and the availability of sports infrastructure, play a significant role in optimising the development of strength abilities.

Strength training—particularly resistance training—is one of the most effective tools in developing muscle strength. A carefully designed exercise programme promotes increased muscle tone, induces hypertrophy and contributes to improved neuromuscular coordination.[11] The appropriate selection of training methods is also a crucial element of the training process. The use of isometric, dynamic and explosive techniques allows for the development of various strength components. Therefore, the training strategy should take both the objective and the current level of athletic preparation into account.[12]

A balanced diet plays a key role in the recovery process and muscle mass development. Consuming protein, B vitamins and minerals supports protein synthesis and accelerates post-workout recovery.[13] Hormonal balance—especially with regard to testosterone, growth hormone and insulin levels—also directly impacts strength training results. Declining levels of these hormones, particularly during middle age, can make maintaining muscle strength significantly more difficult.[14]

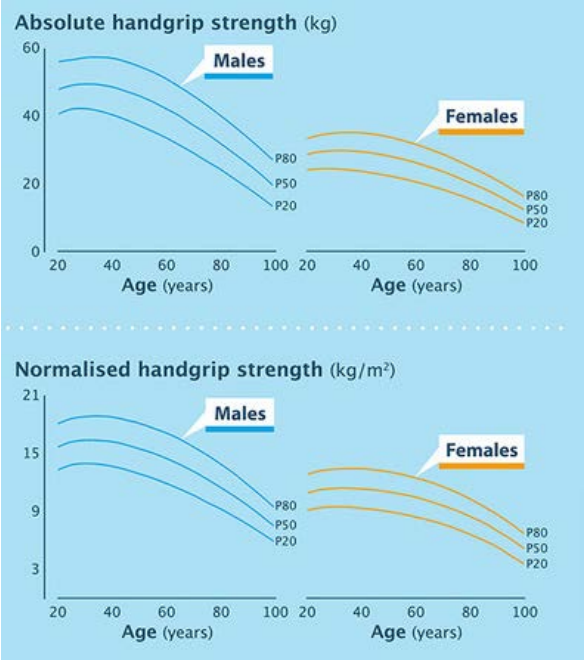

Figure 1. Handgrip strength standards[1]

Muscle strength increases after the age of 20, with peak strength in both sexes occurring between 30 and 40 years of age (Figure 1). Muscle strength in women is lower than in men at all ages, which is caused by the influence of androgens on the development of male muscle tissue, primarily in the trunk and upper limb muscles, and to a lesser extent, in the lower limb muscles.[15]

Among the tests implemented to assess strength capacity,[16] dynamometers are used. Dynamometry is one of the most popular methods for evaluating muscle strength. In this case, strength was measured using a dynamometer, and the main purpose of this technique was to calculate the force generated by muscles during their contraction.

The aim of this study was to analyse changes in dynamometric strength of the stronger hand and to assess the size of sexual dimorphism based on data from the Cracow Longitudinal Growth Study (KLGS).

It was determined how strength of the dominant hand changed in women and men born in 1970 and 1972 and examined in 2004 and 2022.

Material and methods

The research material consists of data from the Cracow Longitudinal Growth Study (KLGS) on the somatic development and physical fitness of people born in 1970 and 1972, conducted in Cracow in the years 1976–2022 (KLGS 1976-2022) by research teams of the Department of Anthropology, Institute of Biomedical Sciences at the University of Physical Education in Krakow (currently the University of Physical Culture in Krakow):

- 1st series of annual examinations in the years 1976–1988 (age 6–18);
- 2nd series of annual examinations in the years 1980–1990 (age 8–19);
- two combined series (1st and 2nd) of women and men examined in 2004 (age 32–34);
- re-examination, after 18 years, of the same women and men in 2022 (age 50–52).

Healthy individuals who accepted the invitation to participate in the study were included. All examinations were conducted after obtaining the participants' written, informed consent. The approval of the Bioethics Committee at the Regional Medical Chamber in Cracow was also obtained for the examination in 2022 (Consent No. 65/KBL/OIL of April 11, 2022). All procedures contributing to the study complied with the ethical standards of the relevant national and institutional committees on human experimentation and the 1975 Declaration of Helsinki,[17] as revised in 2008.

In total, 103 females and 122 males participated in the 2004 study, and in 2022, 47 and 67, respectively. Of these participants, 35 females and 49 males were present for both measurements in 2004 and 2022. The decrease in the number of participants in subsequent studies is typical for longitudinal studies, despite repeated invitations to participate. No morphological selection of the women or men who participated in the 2022 study was observed in comparison to the 2004 trial, as the height of 103 females examined in 2004 was 165.2 cm, and 37 examinees were 164.4 cm tall; and, respectively, 178.1 cm for 122 and 178.3 cm for 53. In terms of body mass, the values were 59.8 kg and 58.5 kg for the females, and 80.7 kg and 79.6 kg for the males.

The study included data on handgrip strength of the stronger hand and morphological characteristics of the 35 females and 49 males who participated in these two series of tests in 2004 and 2022. The following anthropometric measurements were taken:

- body height—measured according to Martin's technique using an anthropometer (GPM, Switzerland, to the nearest 1 mm);
- body mass—assessed using a body composition analyser, Tanita TBF-300 (Japan), to the nearest 0.01 kg
- mid-upper-arm (MUAC, in relaxation) and the largest forearm circumferences measured with a non-stretchable anthropometric tape.

Hand grip strength was measured using the "JAMAR" hand dynamometer (Figure 1).

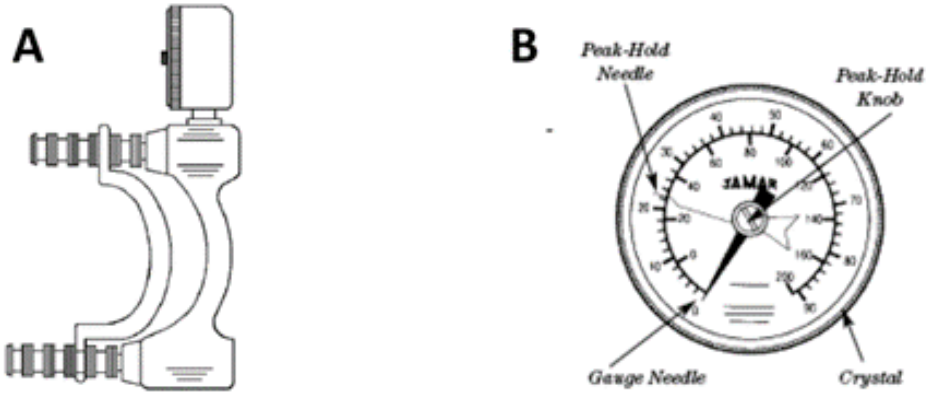

Figure 2. Handheld dynamometer. A – general view, B – dynamometer dial[18]

Two measurements were taken with the right and left hands, and the greater measurement was recorded. In the work, the result of the stronger hand is taken into account. Body mass index (BMI) was calculated as the proportion of body mass in kilogrames to body height expressed in metres squared.

The level of sexual dimorphism was calculated via Mollison's Index[19] (MI): MI = (Xf − Xm)/SDm, where: Xf means the value of the parameter for females, Xm is the value of the parameter for males and, SDm means the standard deviation of the parameter for males.

Basic descriptive statistics (means and measures of variability) were calculated. The statistical significance of the differences between the analysed sexes was estimated using the Student's *t*-test. The relationship between the results of the stronger hand grip strength and somatic characteristics was determined using the Pearson correlation coefficient. The calculations were performed with the Statistica 13.0 package.

Results

Analysing the grip strength of both hands, the dominant hand was determined as the one with the greater grip strength value.

Table 1. Comparison of hand dominance in 2004 and 2022 by gender (KLGS)

Sex	Year	No. of subjects	Right hand stronger	Left hand stronger	% of right dominance
Female	2004	35	32	3	91.4
	2022	35	33	2	94.3
Male	2004	49	45	4	91.8
	2022	49	42	7	85.7

Table 2. Arithmetic means and measures of variability regarding somatic characteristics and strength of stronger hand among females examined in 2004 and 2022 (N = 35, KLGS)

Characteristic	$\bar{x}$		SD		x_{min}		x_{max}	
	2004	2022	2004	2022	2004	2022	2004	2022
Body height (cm)	164.22	164.0	6.01	5.99	152.0	152.0	175.9	175.8
Body mass (kg)	58.57	66.06	7.14	10.81	44.4	49.2	80.0	94.3
BMI (kg/m^2)	21.71	24.56	2.46	3.92	17.7	17.9	28.8	35.5
Resting arm circumference (cm)	26.37	28.46	2.32	3.06	21.0	21.5	32.5	36.0
Largest forearm circumference (cm)	23.66	24.27	1.38	1.92	21.0	20.0	26.0	29.0
Strength of stronger hand (kG)	37.40	34.43	3.87	4.50	29.0	26.0	46.0	43.0

Table 3. Arithmetic means and measures of variability regarding somatic characteristics and strength of stronger hand among males examined in 2004 and 2022 (N = 49, KLGS)

Characteristic	$\bar{x}$		SD		x_{min}		x_{max}	
	2004	2022	2004	2022	2004	2022	2004	2022
Body height (cm)	178.55	178.33	5.41	5.42	166.8	189.4	166.8	189.4
Body mass (kg)	79.49	88.22	10.78	16.44	54.6	53.8	106.2	146.5
BMI (kg/m^2)	24.79	27.70	2.91	4.80	18.90	18.80	32.1	42.30
Resting arm circumference (cm)	30.84	32.29	2.53	3.82	25.0	26.0	35.5	44.0
Largest forearm circumference (cm)	28.02	28.74	1.66	2.39	24.0	24.0	32.0	37.0
Strength of stronger hand (kG)	60.24	55.86	6.88	7.42	43.0	38.0	77.0	70.0

From Table 1, it results that both among women and men, the vast majority demonstrated greater right hand strength. In 2024, the respondents were 32–34 years old, and in 2022, 50–52 of age.

The mean body height of the studied women (Table 2) was within the average for the Polish population, and BMI was within the normal range, but the maximum values suggest overweight and obesity. The difference in strength of the dominant hand between the minimum and maximum values was 17 kG, demonstrating significant functional differentiation within a group of women, homogeneous in terms of age.

Compared to the research conducted 18 years earlier (Table 2), body mass increased by almost 8 kg, BMI increased by 3 units and circumference by 1–2 cm, while the strength of the stronger hand decreased by about 3 kg, and there were practically no changes in body height (difference of 0.2 cm). The Student's t-test values for dependent samples between the hand strength results of stronger women were $t = -4.82$, df = 34, $p = 0.000031$.

The mean body height totalled 178 cm, which is typical for adult men in Poland. Body mass variability was significant—52 kg in 2004 and 93 kg in 2022, and BMI ranged from 18.9 to 32.1 kg/m^2 and 18.8 to 42.3 kg/m^2, respectively, indicating a range from normal to class 1 and 3 obesity. Both upper arm and forearm circumferences showed moderate variability, suggesting varying levels of muscularity. The distribution of body height was fairly uniform, with a small SD = 5.4 cm.

Compared to the study from 18 years earlier (Table 3), body mass increased by nearly 9 kg, BMI by 3 units, circumference by 0.7–1.45 cm, strength of the stronger hand decreased by more than 4 kg, while body height remained practically unchanged (difference of 0.2 cm). The Student's t-test values for dependent samples between the hand strength results of stronger men were: $t = -4.24$, df = 48, $p = 0.00018$.

Table 4. Pearson's r correlation coefficients and level of significance between grip strength and selected body characteristics of women (N = 35) and men (N = 49) examined in 2004 and 2022 (KLGS)

Variable	Correlation coefficient for women		Correlation coefficient for men	
	2004	2022	2004	2022
Body height (cm)	0.39 (0.021)	0.36 (0.034)	0.26 (0.071)	0.39 (0.006)
Body mass (kg)	0.07 (0.689)	0.33 (0.053)	0.34 (0.017)	0.29 (0.043)
BMI (kg/m^2)	−0.16 (0.359)	0.18 (0.301)	0.28 (0.051)	0.17 (0.243)
Resting arm circumference (cm)	0.13 (0.457)	0.36 (0.034)	0.32 (0.025)	0.30 (0.036)
Largest arm circumference (cm)	0.27 (0.117)	0.38 (0.024)	0.44 (0.002)	0.31 (0.030)

The strongest correlation in the 2004 study of women was between body height and grip strength ($r = 0.39$, $p = 0.02$). Neither body mass nor BMI correlated significantly with handgrip strength, suggesting that body composition, and especially muscle mass, is more important than body mass alone. The higher correlation coefficient between grip strength and forearm circumference and not upper arm circumference confirms that the muscles located in the forearm play a key role in generating hand strength. However, in 2022, the strongest correlation among women was between grip strength and forearm circumference, which is anatomically justified, as it is the muscles in this area that contribute most to generating grip strength. There is a relatively weak correlation with BMI, suggesting that excess body mass does not necessarily translate into strength unless accompanied by muscle mass. The circumference of the largest forearm is therefore an indicator of hand strength potential.

The correlation coefficient between the women's dominant hand grip strength in 2004 and grip strength in 2022 was $r = 0.66$, df = 33, $p < 0{,}001$ indicating a moderate positive correlation. This positive relationship suggests that women who had higher grip strength in 2004 retained relatively higher levels of strength, even after 18 years. Despite the natural aging process and possible decline in physical fitness, individual differences in grip strength remained relatively stable over time. This further indicates the permanence of motor characteristics such as muscle strength, which may be the result of both genetic predisposition and long-term physical activity habits.

In the case of the men studied in 2004, the strongest correlation was between the largest forearm circumference and grip strength, which is consistent with biomechanics, as the forearm muscles are primarily involved in gripping. Body mass and upper arm circumference also had impact, while height and BMI were less strongly associated with strength. The results suggest that larger body sizes promote greater strength but do not guarantee it. Among the group of men analysed in 2022, the strongest correlations with grip strength

were found for body height, upper arm circumference and the largest forearm circumference, suggesting that greater muscle mass and size may promote greater strength. BMI is not a reliable indicator of strength.

Pearson's correlation coefficient calculated between grip strength of the dominant hand in men in 2004 and 2022 equalled $r = 0.65$, df = 47, $p < 0{,}001$ and was similar to that in women, thus, its interpretation is also similar.

To assess the size of sexual dimorphism, the Mollison's Index was used, which is calculated as the difference in the mean values of women and men relative to the standard deviation of men (Table 5).

Table 5. Sexual dimorphism size according to Mollison's Index in studies from 2004 and 2022

Characteristics	Mollison's Index 2004	Mollison's Index 2022
Body height	–2.65*	–2.64*
Body mass	–1.94*	–1.35*
BMI	–1.06*	–0.66*
Resting arm circumference	–1.77*	–1.00*
Largest forearm circumference	–2.63*	–1.88*
Strength of stronger hand	–3.32*	–2.89*

* – marks statistically significant differences, $p \leq 0{,}05$.

Sexual dimorphism decreased between 2004 and 2022 across all the analysed somatic and functional traits, with the exception of a minimal decrease in body height. Although men still dominate in terms of grip strength, height and body mass, these differences begin to gradually decrease. Body mass, upper arm circumference and the largest forearm circumference demonstrated a marked reduction in gender-related differences. The greatest level of sexual dimorphism at both time points concerns grip strength of the dominant hand, as confirmed by values of Mollison's Index: –3.32 in 2004 and –2.89 in 2022. Although the difference remains significant, dimorphism in this respect also decreased, which may indicate changes in the level of physical activity between women and men, as well as the evolution of social patterns regarding physical activity.

Discussion

The upper limb plays a crucial role in everyday human life, enabling a wide range of manipulative and cognitive activities. Its dexterity allows for grasping, moving, rotating and lifting various objects. For this reason, the upper limb is of particular interest in many disciplines, such as medicine, physiotherapy, physical education and biomechanics.[20]

Physical fitness refers to the ability of the body's systems to work well together in order to support physical activity and basic self-care. One component of physical fitness is muscle strength, which is associated with overall health[21,22,23] and reflects the ability of a muscle or muscle group to generate maximum force during a single contraction.[24]

The aim of this study was to analyse changes in dynamometric strength of the stronger hand and to assess gender-related differences (sexual dimorphism) based on data from the Cracow Longitudinal Group Study (KLGS). Compared to the presented international norms1, the participants in our study achieved greater strength both at the age ranges of 30–32 and 50–52—men achieved 60.2 kG and 55.9 kG; women in the same age groups obtained 37.4 kG and 34.4 kG, compared to the norms of 49.7 kG and 46.2 kG, as well as 29.7 kG and 28.2 kG, respectively. This is similar to the results of another study25, in which men aged 30–39 and 50–59 achieved 54.1 kG and 50.3 kG, and women 34.8 kG and 31.8 kG, respectively.

For the conducted research, it results that grip strength did not change to such an extent as in the case of the subjects' body mass or BMI. The results of this study confirm that handgrip strength is significantly associated with selected somatic characteristics, which is consistent with reports from other authors. In women, the observed relationships changed with age—in younger periods, the highest correlations were related to body height, while at the age of 50–52, the key predictor turned out to be the largest forearm circumference, reflecting local muscle mass. In men, the highest correlations in both 2004 and 2022 were related to the upper limb circumferences, which confirms the significant role of the development of arm and forearm musculature in generating grip strength. Similar relationships have been reported in the literature, where anthropometric parameters such as body height, muscle mass, and limb circumferences are considered major determinants of handgrip strength.[1,26,27,28] According to these studies, greater body height and larger muscle cross-section are associated with stronger grip strength, which is also evident in our research. In the context of individual differences, a significant issue is motor discrepancies based on gender.

Analysing these issues, both sexual dimorphism and differences in the functioning of the body at physiological and psychological levels should be considered. Men typically achieve better results in activities requiring high strength, reaction speed and endurance, which is confirmed in numerous studies on motor characteristics. Women, on the other hand, demonstrate greater predispositions in movement precision, fluidity, rhythmicity and flexibility.[24] Therefore, studies conducted by, among others,[1,21] as well as the results of this study, confirm that men exhibit stronger grip strength than women, and this strength changes with age.

Researchers25 from IIASA in Luxembourg also showed that—across all age groups— individuals with greater body height achieved better results in terms of grip strength.[26] In the present study, the tendency for individuals with greater body height to have strong grip strength was also observed (Table 6).

Table 6. Average grip strength of women and men in 2004 and 2022 below and above median* for height (KLGS)

Date of study	Sex	Median for body height (cm)	Average grip strength below median (kG)	Number below media	Average grip strength above median (kG)	Number above median
2004	F	165.0	35.53	17	39.35	17
	M	179.2	59.29	24	61.38	24
2022	F	164.5	32.59	17	35.94	17
	M	178.9	55.21	24	56.58	24

* – individuals whose body height value was equal to the median were not included in any of the groups.

Based on available data and analyses, the conclusion comes forth that motor skills vary depending on stage of life. The decline in muscle strength observed with age is particularly significant. Therefore, it is necessary to appropriately adapt the type of physical activity to individual body capabilities in order to support fitness and prevent the negative effects of the aging process.

Undoubtedly, the study has certain limitation. Its disadvantage is the small sample size, but its advantage is that it is a longitudinal study conducted on individuals aged 30–32 and later, aged 50–52.

Conclusions

Based on the research conducted and the analysis of the results, the following conclusions can be drawn:

1. In the majority of participants, the right hand was stronger; the number of people with a stronger left hand changed little between 2004 and 2022.
2. Grip strength declines with age were observed in both sexes, and the rate and size of the changes may indicate sexually dimorphic differences. Men achieved higher strength values at both measurement points, but also showed greater variability. Women demonstrated a more uniform rate of strength decline, suggesting a more stable muscular aging but with lower baseline strength levels.
3. The somatic feature most closely related to the current level of grip strength in women post the age of 18 is the circumference of the forearm; the larger the forearm circumference, the stronger the grip, while in men, the current level of strength is determined by body height, with taller men having greater grip strength.
4. In both women and men, a positive correlation was observed between dominant hand grip strength measurements in 2004 and 2022. This indicates the persistence of individual motor differences. Changes in body mass or BMI did not blur this pattern—individuals who were stronger earlier remained significantly stronger after 18 years.

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