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Testing the Grip Strength of Individual Fingers of the Hand in Relation to the Grip Strength of the Whole Hand

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Abstract. This paper investigates the grip strength of individual fingers, utilising a medical dynamometer to measure the force exerted by each finger and both hands across multiple series of tests. The objective of this study is to provide a comprehensive analysis of finger grip strength among different groups, segmented by centile, gender, activity levels, and BMI. The scope includes detailed measurements of each finger's strength, aggregate hand strength, and statistical processing of the data to compute mean values, standard deviations, confidence intervals, and Student's t-distributions for the various centile groups. Results highlight significant variations in grip strength, correlated with physical activity and BMI. This detailed data set is critical for indexing, abstracting, and retrieval purposes, offering valuable insights for fields such as ergonomics, physical therapy, and sports science.

Key words: grip strength, finger strength measurement, centile, physical activity, BMI, statistical analysis

Introduction

Modern design of technical equipment requires not only innovative technological solutions, but also a deep understanding of human physiological capabilities. One of the key parameters that has a significant impact on the ergonomics and safety of machine operation is finger grip strength. Measuring this force provides valuable data necessary for creating equipment tailored to the actual abilities of operators, both in industry and in everyday use. At the same time, there is a noticeable lack and need for such knowledge in manually operated machines [1, 2]. A particular group of devices that work with the hand are wheelchair drive systems. In the case of these devices, the strength of the handshake translates into the efficiency [3, 4] of the drive operation and its accessibility [5, 6] for people with disabilities. Knowledge of hand grip strength allows engineers and designers to optimize tools and machines to minimize the risk of injury and fatigue to users, while maximizing work efficiency . Understanding grip strength is also crucial in designing assistive devices that support people with limited manual dexterity, enabling them to use everyday equipment safely and comfortably [7, 8]. Parameterizing handshake strength is a difficult research problem for the entire population of potential users of technical devices because the value of handshake strength depends on the individual physical capabilities of the user. For example, on age [9], health status [10] and gender [11]. Grip strength is a measure of the hand muscles' ability, and actually the entire arm, as muscles of the arms are engaged to increase the force generated, to exert pressure. Physical activity has a direct and significant impact on hand grip strength, being one of the key factors that can improve it [12]. Regular exercise that engages the muscles of the hands, forearms and arms, such as weightlifting, climbing, weight training or sports that require a precise grip (e.g., tennis, gymnastics), leads to the strengthening of the muscles responsible for grip strength. These exercises increase the strength and endurance of the hand muscles and improve neuromuscular coordination, resulting in a better and stronger grip [13].

Most articles focus on the study of grip strength in relation to various factors. The most common of those are gender and age [14]. With the researchers focusing mainly on analysing the strength of the whole handshake. There are publications describing the grip strength of individual fingers [15]. However, they take into account hand clenching shapes corresponding to common hand tools and only present results in terms of grip strength. Given the complexity of the anatomical structure of the hand and the muscular system that supports it, as well as the individual physical capabilities of people, it is a complex research problem to describe the grip strength of individual fingers into a catalogue as input for the design process.

With this in mind, the research problem was formulated to determine the percentage of individual fingers in the total grip strength and the correlation of finger grip strength with BMI and physical activity. Solving such a research problem will allow the research objective of being able to calculate the grip strength of individual fingers on the basis of a single measurement of the whole hand grip with a dynamometer. This idea can be applied to the design process of personalised technical devices and the development of design methodologies.

1. Material and method

The research and experimental protocols has been positively evaluated by Bioethical Commission at the Karol Marcinkowski Medical University in Poznań Poland, Resolution No. 1100/16 of 10 November 2016, under the guidance of Prof. MD P. Chęciński for the research team led by Wieczorek B. The authors obtained the written informed consent of the examined person for the publication of research results with their participation. The data was presented in such a way as to ensure their complete anonymity. The measurement method and data acquisition were carried out in accordance with the directives of the Bioethics Commission at the Karol Marcinkowski Medical University in Poznań Poland, which are in line with the guidelines Declarations of Helsinki.

The subjects of this study were 9 people, 3 male and 6 female. All were of Central European nationality, aged 21-22 and right-handed. Their dominant hands and fingers were measured using anthropometric measure tape as shown in Fig. 1.

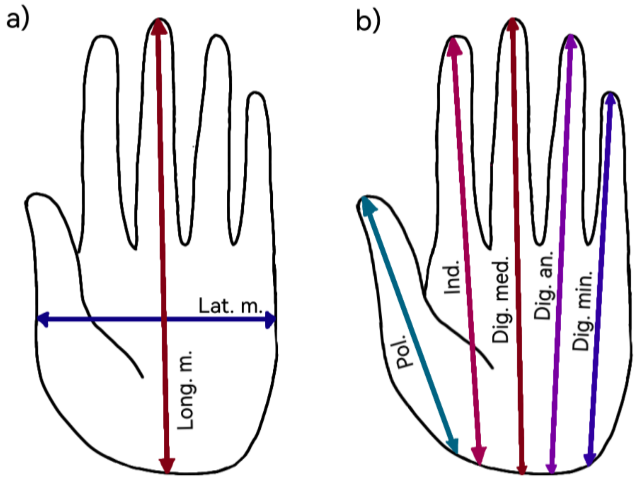

Fig. 1. - Measurement of a) length and width of the hand b) length of the fingers: Pollex – Pol., Index – Ind., Digitus medius – Dig. med., Digitus annularis – Dig. an., Digitus minimus – Dig. min., Latitudo manus - Lat. m., Longitudo manus - Long. m.

Using measurements, subjects were divided into hand size centile groups [16]. On the basis of the measurements taken, three subjects were allocated to the 50th centile group of women, three to the 5th centile of women and three to the 50th centile of men. The results of the hand measurements by centile group are shown in Table 1.

Table 1. Right hand sizes of subjects in each centile group

Subject	***Lat. m.* [mm]**	***Long. m.* [mm]**	***Long. Ind* [mm]**	***Long. Dig. med.* [mm]**	***Long. Dig. an.* [mm]**	***Long. Dig. min.* [mm]**	***Long. Pol.* [mm]**
5 centile (female)							
Woman 1	80	160	145	160	150	127	105
Woman 2	87	170	165	170	161	135	120
Woman 3	78	170	164	170	154	135	114
50 centile (female)							
Woman 4	97	176	173	176	164	139	128
Woman 5	97	178	176	178	168	139	129
Woman 6	97	179	166	179	171	143	121
50 centile (male)							
Man 1	109	188	175	188	176	151	140
Man 2	105	189	188	189	183	154	149
Man 3	109	199	187	199	188	156	139

Subjects were also split into groups by their physical activity levels (4 were active, 5 not active) and by BMI categories (4 in healthy range, 5 overweight). Person was considered active if they reported exercising at least 3 times a week. Participants' activity levels and BMIs are presented in Table 2.

Table 2. Activity levels and BMI of subjects in each centile group

Subject	Activity level	BMI
5 centile (female)		
Woman 1	not active	27.7 (overweight)
Woman 2	active	21.7 (healthy)
Woman 3	not active	24.9 (healthy)
50 centile (female)		
Woman 4	active	23.3 (healthy)
Woman 5	not active	29.1 (overweight)
Woman 6	not active	29.4 (overweight)
50 centile (male)		
Man 1	active	25.9 (overweight)
Man 2	not active	24.2 (healthy)
Man 3	active	26.8 (overweight)

Force measurement was performed using a medical dynamometer (Fig. 2) with a measuring range of up to 130 kg and a measurement accuracy of 100 g. The dynamometer had a grip span of 64 mm and an empty weight of 0.3 kg. Standard measuring tools such as an anthropometric tape, an anthropometer and an anthropometric compass were used to measure the anthropometric dimensions of the hands.

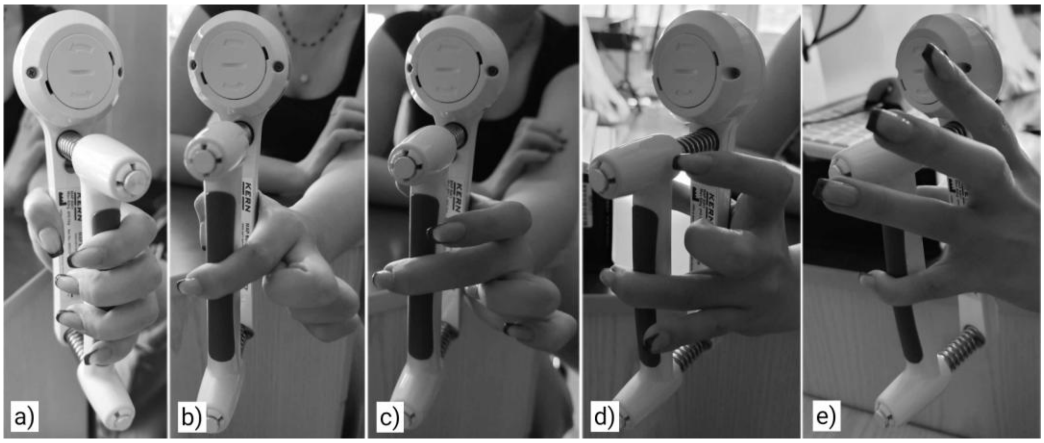

Fig. 2. - Method of measuring the grip strength of a: a) Mns, b) Ind., c) Dig. med., d) Dig. an., e) Dig. min.

The measurement procedure involved measuring the grip strength of each finger in 10 repetitions, with the measurement series separated by a recovery break. During the measurements, the patient was in a seated position. Their forearm was supported on a table so that a 90-degree angle was maintained between the arm and forearm. The wrist and hand extended beyond the edge of the table, and the wrist was not subjected to any rotations, flexions, or deviations.. The results measured according to the above procedure were averaged, and for each mean value, a confidence interval was calculated using a confidence level of p = 0.05, applying the Student's t-distribution.

2. Results and discussion

Averaged values of grip strength for individual fingers, categorized by percentile dimension groups, are presented in Tables 3 - 6. For the entire study population of women (5 and 50 centiles) (Table 6) it was found that the hand grip generates an average force of 199.3±11.8 N for the right hand and 176.7±13.7 N for the left. This represented a difference of 12.8% between the dominant and non-dominant limb. This trend was also observed among men (Table 5) in this case, for the right hand, the grip strength was measured at 418.2±24.0, which was 82.7% the difference from women of the same centile group (50 centile) (Table 4). The conducted research showed that regardless of the centile dimension of the hand and the sex of the patient, the largest grip force is generated by the index and the smallest digitus minimus. An interesting relationship was observed for the second in the order of the strongest finger. In the case of the centile group 50, it was the index, while for women from the centile group 5 digitus medius. For women with palm dimensions of 50 centile (Table 3) digitus medius achieved a huge value of 86.4±9.7 N and an index of 74.4±7.0 N, which was a difference of 16.1%, greater than between the left and right hands. Analysing the average percentage difference between the fingers of the right hand and the left hand, it was found that not all fingers of the dominant hand generate greater grip strength than the fingers of the non-dominant hand (for the examined patients, the left hand). For example, for men with 50 centile dimensions of length the highest grip strength for a single finger was measured for the digitus medius left hand (non-dominant hand) 155.7±13 N, which was 16.5% higher than on the right hand. Similar differences in the greater grip strength were observed for digitus minimus and digitus annularis, where the difference between dominant and non-dominant hands was 13.9% and 29.7%. In turn, for the manus and index slightly larger values were examined for the right hand. The value of the grip force for the entire right hand was 418.2±24 N, and for the left hand 397.4±27.7 N, which gave a difference of 5.2% in the results. Similarly, for the index fingers, the pressure in the right hand was 5.7% greater than in the other hand.

Table 3. Measurement results for women in the 5 centile

Parameters	Grip strength (right hand), [N]					Grip strength (left hand), [N]				
	Dig. min.	*Dig. an.*	*Dig. med.*	*Ind*	*Mns*	*Dig. min.*	*Dig. an.*	*Dig. med.*	*Ind*	*Mns*
Mean	39.44	62.36	86.36	74.39	169.71	34.89	61.97	73.9	63.11	146.46
Standard deviation	9.75	25.46	27.02	19.46	40.46	10.11	15.79	19.12	16.99	58.52
Confidence interval	3.49	9.11	9.67	6.96	14.48	3.62	5.65	6.84	6.08	20.94

Table 4. Measurement results for women in the 50 centile

Parameters	Grip strength (right hand), [N]					Grip strength (left hand), [N]				
	Dig. min.	*Dig. an.*	*Dig. med.*	*Ind*	*Mns*	*Dig. min.*	*Dig. an.*	*Dig. med.*	*Ind*	*Mns*
Mean	31	32.47	50.39	85.54	228.87	27.6	37.15	51.04	73.38	206.99
Standard deviation	8.74	6.77	13.42	16.46	31.45	3.63	9.11	6.67	17.29	25.28
Confidence interval	3.13	2.42	4.8	5.89	11.25	1.3	3.26	2.39	6.19	9.05

Table 5. Measurement results for men in the 50 centile

Parameters	Grip strength (right hand), [N]					Grip strength (left hand), [N]				
	Dig. min.	*Dig. an.*	*Dig. med.*	*Ind*	*Mns*	*Dig. min.*	*Dig. an.*	*Dig. med.*	*Ind*	*Mns*
Mean	58.17	81.59	133.61	127.53	418.17	66.28	105.78	155.68	117.43	397.4
Standard deviation	15.82	25.55	50.46	33.4	67.05	19.47	38.79	45.56	36.22	69.13
Confidence interval	5.66	9.14	18.06	11.95	23.99	6.97	13.88	16.3	12.96	24.74

Table 6. Measurement results for men in the 50 centile

Parameters	Grip strength (right hand), [N]					Grip strength (left hand), [N]				
	Dig. min.	*Dig. an.*	*Dig. med.*	*Ind*	*Mns*	*Dig. min.*	*Dig. an.*	*Dig. med.*	*Ind*	*Mns*
Mean	35.22	56.37	59.42	79.97	199.29	31.24	56.51	55.52	68.24	176.73
Standard deviation	10.17	21.22	33.38	18.86	46.78	8.42	13.29	23.71	17.89	54.3
Confidence interval	2.57	5.37	8.44	4.77	11.84	2.13	3.36	6	4.53	13.74

The analysis of the percentage share showed that the largest percentage of the total strength of the handshake is index and digitus medius. For men with 50 centile (C50), the largest percentage of the total strength of the handshake was digitus medius and it was 31.9% (Fig. 5). A similar relationship was observed for women with 5 percentile (C5) because in this group also the largest percentage share of 50.9 % had digitus medius (Fig. 3). The exception was a research group of women with 50 percentile of hand dimensions. In this group, the largest percentage share was index and it was 37.3% (Fig. 4).

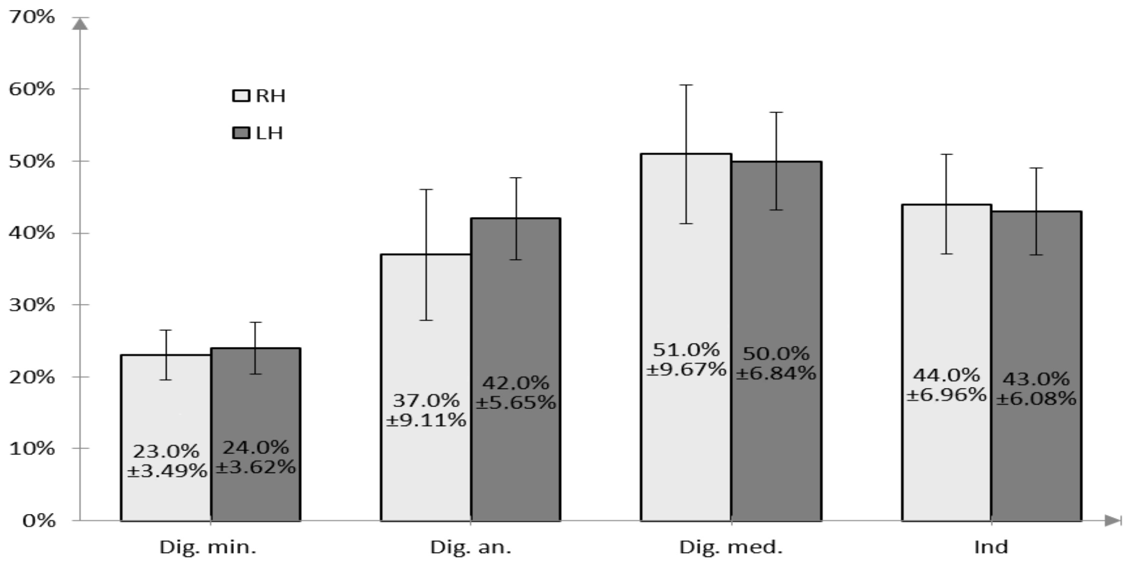

Fig. 3. - Graph of the percentage of grip strength for women in the 5 centile

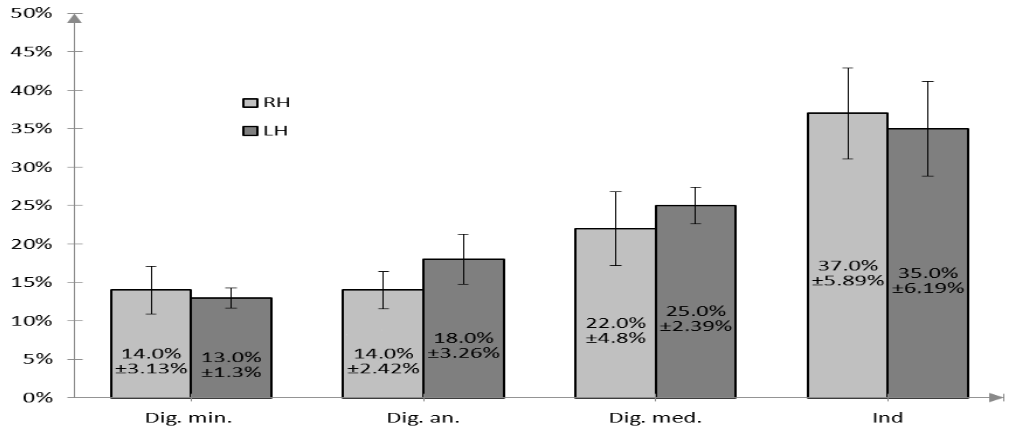

Fig. 4. - Graph of the percentage of grip strength for women in the 50 centile

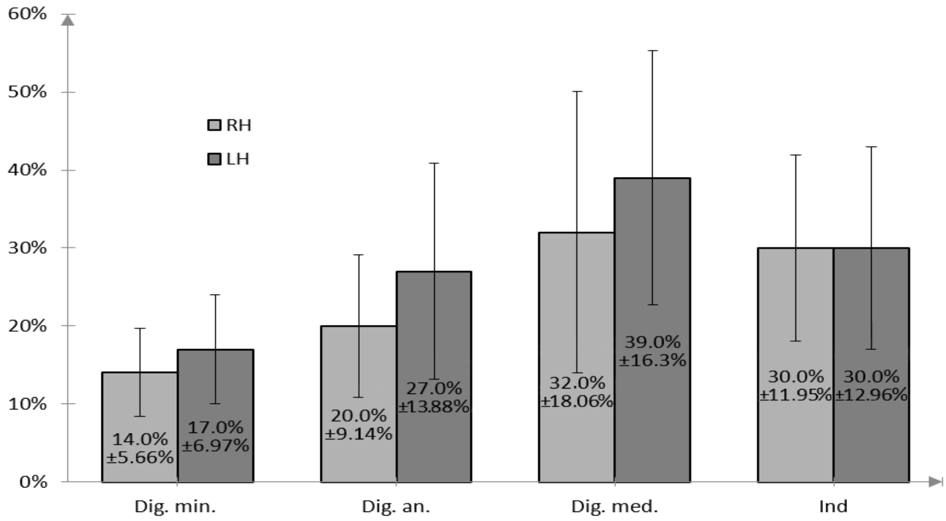

Fig. 5. - Graph of the percentage of grip strength hand for men in the 50 centile

Meanwhile, for all groups, the digitus minimus achieved the lowest result. Thepercentage grip strength for this finger was similar for women and men in 50 percentile (C50) and are respectively 13.9% (Fig. 4) and 13.5% (Fig. 5). For 5 centile of women (C5) digitus minimus has the lowest percentage of grip strength, it is, 23.2% (Fig. 3). However, compared to the group of 50 centile women and men, we notice more than 10% difference for 5 centile and other groups.

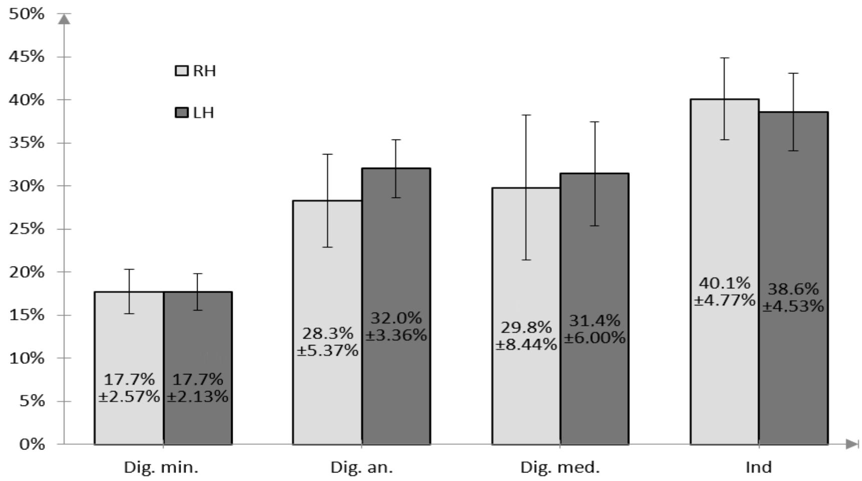

Fig. 6. - Graph of the percentage of grip strength hand for women in the 50 centile

Below (Fig. 3 to 6), a graphical interpretation of the results is presented in the form of charts for each centile group.

Other studies have shown similar results despite experimental groups varying in size and type and different testing methods being used. Mühldorfer-Fodor et al [17] in the study used cylinders of 3 different sizes, obtaining an average result of the percentage of the force of individual fingers: Ind. - 35%, Dig. med. - 33%, Dig. an. - 22%, Dig. min. - 12%. Obtained percentages are the result of combining the measurements of the group of men with the measurements of the group of women. Amis [18] used 6 cylinders of different sizes in their research obtaining the following results: Ind. - 30%, Dig. med. - 30%, Dig. an. - 22%, Dig. min. - 18%. The group in these studies consisted mostly of women, however their results were combined with the results obtained by the men studied. Radhakrishnan [19] and Lee [20] also used 4 cylinders of different diameters in their research and obtained the following results: Ind. - 31%, Dig. med. - 33%, Dig. an. - 22%, Dig. min. - 14%. [19] and Ind. - 33%, Dig. med. - 30%, Dig. an. - 23%, Dig. min. - 15% [20]. Additionally, both studies did not specify the gender of the study participants. Other studies of the percentage of individual finger strength were conducted using dynamometers, similar to this study. Both Hazelton [21] and Talsania [22] used dynamometers to conduct the measurements. For the first of these studies [21], the study group consisted of 30 men who obtained the following results: Ind. - 26%, Dig. med. - 33%, Dig. an. - 22%, Dig. min. - 17%. In the case of subsequent studies [22], the research group consisted of both men and women, again the results obtained are the result of combining the measurements of both groups: Ind. - 25%, Dig. med. - 35%, Dig. an. - 26%, Dig. min. - 15%. The results we obtained for the male group are consistent with the results obtained in previous studies: Ind. - P 30%, Dig. med. - 32-39%, Dig. an. - 20-27%, Dig. min. - 14-17%. In the case of the entire group of women studied (combination of the C5 and C50 groups), the results obtained are slightly higher for some fingers compared to previous studies: Ind. - 38,6-40,1%, Dig. med. - 29,8-31,4%, Dig. an. - 28,3-32%, Dig. min. - 17,7%. This may be due to the higher results obtained by the woman's C5 group: Ind. - 43-44%, Dig. med. - 50-51%, Dig. an. - 37-42%, Dig. min. - 23-24% compared to the woman's C50 group: Ind. - 35-37%, Dig. med. - 22-25%, Dig. an. - 14-18%, Dig. min. - 13-14%.

Analyzing the changes in the strength of the grip of the fingers for all sex and centile groups (Fig. 7) it was found that the percentage of the grip force of individual fingers decreases as the pollex moves away towards the digitus minimus. On the basis of this comparison, a universal mathematical model (1) was derived, on the basis of which it is possible to determine the approximate percentage of the finger grip force kF(i) in the grip strength of the whole hand.

$$k_F(i) = 0.172652 + 0.150211 \cdot i \tag{1}$$

where i is the finger number matching the key: 1 – digitus minimus, 2 – digitus anularis, 3 – digitus medius, 4 – index.

The model is a universal tool that allows you to determine the kF coefficient, which is enough to multiply with an easy to measure grip force of the entire Fh hand and obtain an approximate value of the grip force of a single finger Fi (2).

$$F_i = F_h k_F(i) = F_h(0.172652 + 0.150211 \cdot i\,) \tag{2}$$

where Fi - single finger grip strength with key number i,

Fh – whole hand grip force measured by dynamometer,

kF(i) – single finger grip strength percentage ratio, whole hand grip strength,

i – finger number matching key: 1 – digitus minimus, 2 – digitus annularis, 3 – digitus medius, 4 – index.

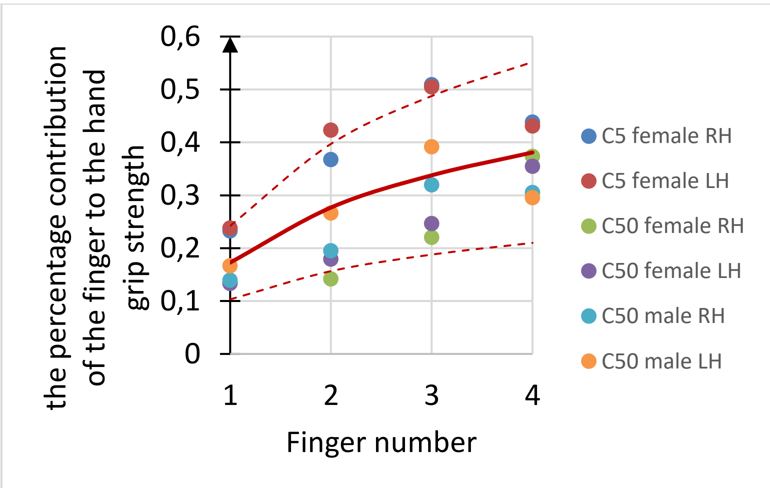

Fig. 7. - Graph of the percentage of grip strength hand for all the women

In addition to distinguishing centile groups, the subjects were divided into BMI and physical activity groups. Due to the insufficient size of the men's groups, they were not considered in the following summary. Two groups of physical activity were distinguished: low and high physical activity. The criterion for the latter was working out or practising sports at least 3 times a week. Statistic analysis was also performed for both measurements. Analysis of physical activity showed that in the group of women studied, the effect of physical activity on the equalization of grip strength between the right (dominant) limb and the left limb could be observed (Table 7, Fig. 8). In the group of physically active women, the difference in grip strength was 1.1%. In comparison, in the group of women with low physical activity the difference was already 16.1%. The reason for such differences is the symmetrical development of musculoskeletal organs in physically active people, as opposed to people with low physical activity who perform most activities with the dominant limb, thus replacing the other non-dominant limb. The numerical values (Table 7) of the analysis of the impact of physical activity are only the basis for determining the percentage differences in the grip force generated by the two limbs. The calculated average values take into account in each group different dimensional centiles therefore also different physical predisposition and muscle mass.

Table 7. Measurement results for men in the 50 centile

Parameters	People with high physical activity		People with low physical activity	
	Right hand grip strength [N]	Light hand grip strength [N]	Right hand grip strength [N]	Light hand grip strength [N]
Mean	191.1	188.99	203.39	170.6
Standard deviation	26.04	12.86	53.78	65.01
Confidence interval	11.41	5.63	16.67	20.15

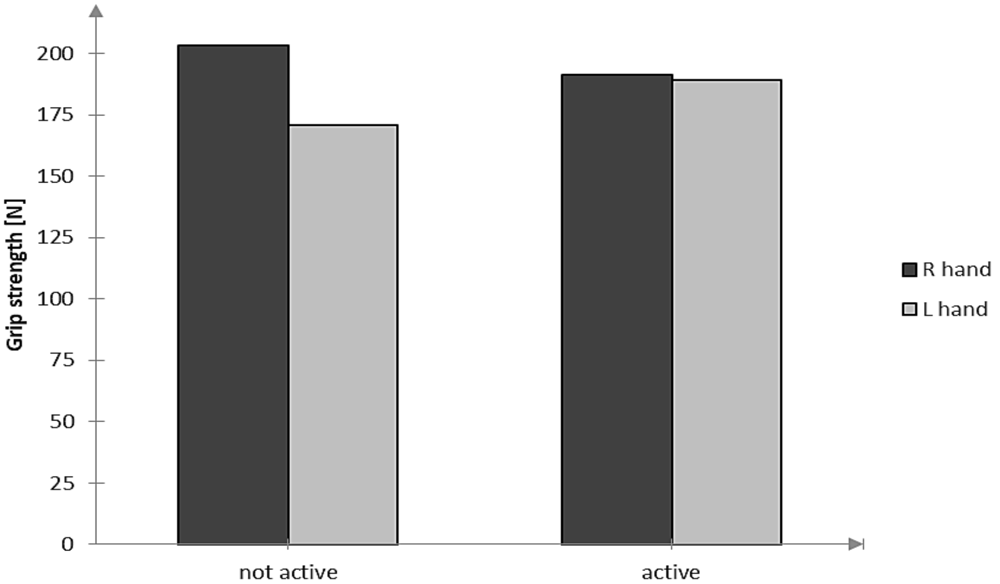

Fig. 8. - Graph of women grip strength in relation to physical activity

The analysis of the effect of BMI on the value of grip strength showed an increasing trend according to which, the strength of the hand grip increases as BMI number grows. This is a significant increase, with the slope value of the calculated trend of 82.1 degrees for right hand and 71.3 degrees for left hand (Fig. 9). For woman 2 with a BMI of 21.7, the right hand grip strength was 190.8N, and for woman 6 with a BMI of 29.4, the strength was 272.7N. This represented a 30% increase in right hand grip strength with a 16% increase in BMI. Woman 3 was deemed an outlier and was not included in the calculated trend.

Most of the articles studying the correlation between grip strength and BMI use different categories to systemise the results of the studies. For BMI range between 16,5 to 18,49 kg/m^2 the person is underweight, between 18,5 to 24,99 kg/m^2 has normal weight, and between 25 and 29,99 kg/m^2 overweight. More than that means the person is obese. In our research we had 3 women with normal BMI. Their grip strength was: Women 2 RH-169,81N and LH-182,66 N, women

4 RH-212,39 N and LH-195,32 N, women 3 RH-122,82 N and LH-66,41 N. The 3 overweight women had grip strength: women 1 RH-116,51 N and LH-190,31 N, women 5 RH- 205,03 N and LH-187,86 N, women 6 RH-269,19 N and LH-237,79 N.

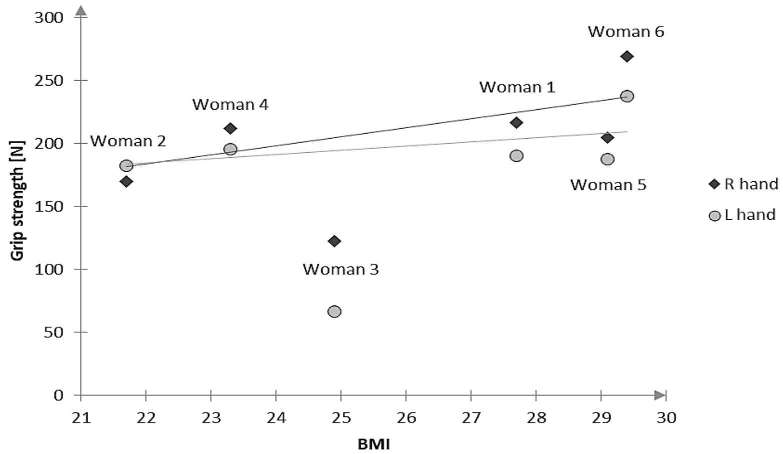

Fig. 9. - Graph of women grip strength in relation to BMI

In Lad U.P. research [23] that focused on the grip strength of the dominant hand of young adults between 18-21 years old there were three categories of BMI. The force for underweight was 265,56±44,14 N, normal weight 263,99±31,88 N and overweight 240,35±62,49 N. The results of overweight people in our study are in the range of this study, but the grip strength of normal BMI in our research is significantly lower.

The results are a little higher than the ones we achieved because the study didn't differ between women and men. Men have on average higher grip strength than women which means that the average grip strength for women is lower. There is some research which difference between dominant and non-dominant hand like the study by Kun-Hsi Liao [24], who worked with 18-27 year old people. For the women, results showed that underweight women have grip strength of RH-283,71±57,78 N and LH- 242,21±60,82 N, normal weight RH-354,44±80,15 N and LH- 323,34±76,91 N, overweight RH- 433,7±55,62 N, LH- 396,32±54,15 N. Looking at even those results we can see that in the first study the strength was decreasing by 8,95 % between normal and overweight BMI. This result is different in our and Kun-Hsi Liao study where in the latter one the trend increased by 22,36%. R. Pavlović [25] notices the same increasing tren, but far less significant. Most of the studies showed that the higher a person's BMI is, the stronger their grip strength is.

Conclusions

For women in the 5th centile, the middle finger achieved the highest pressure value. This group also exhibited significantly greater pressure strength in the little fingers of both hands compared to the other study groups. This is likely due to the necessity of holding objects using the little finger's strength, as most objects are not adapted for people with small hand sizes (5th centile women). This observation is crucial in designing ergonomic handles [26, 27] as people on the smaller centile need a specific approach when using input data on their pressure distribution. By adding value to the biomechanical data currently used [28,29], this observation complements the current knowledge about the distribution of pressure force of individual fingers. In the case of women with larger hand sizes (50th centile), they do not have this necessity, which can be seen by the highest contribution to total pressure strength from digitus anularis and index. These fingers, along with the thumb and middle finger, form the basis of many types of grips used during daily activities.

For men, the middle finger exhibited the highest strength, with strength gradually decreasing in the subsequent fingers. The middle finger is the longest finger, allowing for better distribution of force during a grip. Its central position also helps stabilise the grip [30, 31]. Based on this relationship, it can be concluded that the anatomical structure, particularly the differences in anthropometric dimensions between men and women of the same centile, should be utilised in the design of individualised and ergonomic technical devices [32, 33].

For physically active individuals, we observe similar grip strength values in both hands, whereas for the non-active group, there is a significant dominance of the dominant hand. The differences in hand strength between highly active and inactive individuals can be explained by several training-related factors. Many training programs recommend performing exercises using both hands (e.g., deadlifts, barbell presses) [34, 35]. Even unilateral exercises are often performed on both sides of the body to ensure symmetry and avoid muscle disproportions. Physically inactive individuals typically use their dominant hand for most daily activities, such as writing, eating, and opening doors. Such habits lead to greater stimulation and development of muscles in the dominant hand, resulting in a larger difference in strength between the hands.

The use of BMI to evaluate the strength of a handshake may be the biggest mistake. Weight doesn't always correlate with muscle mass, even though body mass is associated with growth [36, 37]. However, the presented research showed an upward trend according to which the increase in BMI translates into an increase in the strength of the handshake. This may be because a larger body mass often correlates with greater muscle mass. Even if part of the mass comes from adipose tissue, individuals with a higher BMI may have more muscles contributing to their heavier weight. In the future, it would be necessary to examine the relationship between grip strength and muscle mass for different BMI groups. This would provide a proper understanding of the dependency of strength on BMI.

Analysing the grip strength measurement results for men and women, we notice that it is significantly higher for men than for women. For the entire hand, the average grip strength for men is 418.17 N for the right hand and 397.4 N for the left hand, while for women, it is 199.29 N and 176.73 N, respectively ɵ the differences are more than twofold. Such a glaring disparity may be due to the fact that men typically have greater muscle mass than women. Men's arm and hand muscles are better developed, leading to greater grip strength [39–40]. Additionally, the male skeletal system is stronger and more resilient than the female skeletal system. Men have denser, stronger bones, tendons, and ligaments than women. All these factors predispose men to work involving the operation of hand-held machinery [41, 42].

The research goal of determining the percentage of individual fingers in the total adhesion strength and correlation of the finger grip strength with BMI and physical activity was successfully achieved. The findings can be applied to the design of personalised technical devices and assistive technologies. However, potential errors may have occurred during measurements such as individual changes in grip strength due to fatigue, hand positioning or environmental factors. Future research should focus on improving measurement methods, including a wider sample of the population, and on exploring other factors that may affect adhesion strength, such as regional or environmental influences. Additionally, future research should include larger testing groups in order to increase the accuracy of obtained results and decrease probability of abnormal data.

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