Klemen Krejač[1]*
Milan Žvan[1]
Stanislav Peharec[2]
Milan Čoh[1]

CORRELATION OF HANDGRIP STRENGHT WITH VERTICAL AND HORIZONTAL PLYOMETRIC JUMPS

POVEZANOST MOČI STISKA PESTI Z VERTIKALNIMI IN HORIZONTALNIMI PLIOMETRIČNIMI SKOKI

ABSTRACT

Handgrip strength is a good general indicator of physical fitness. It has long been used as a diagnostic tool, the results of which are related to eating habits, rotator cuff weakness, fatigue, and general physical fitness. We did not find any research of correlation of handgrip with the jumping force, so we wanted to test this in our study. We expected correlations between these two areas of power. The study included vertical and horizontal plyometric jumps, handgrip strength, and some body characteristics. Relationships were verified by correlation analysis. The study included 64 students of the Faculty of Sport, who performed 9 plyometric tests, a handgrip test, and measurements of body characteristics. The results in the participants show the dominance of the right hand and a significant correlation between the strength of the handgrip and body weight. Plyometric jumps show large differences between men and women. In men, there was only the significant correlation of handgrip strength with the test standing triple jump (HG_L/STJ: r=0.33; HG_R/STJ: r=0.35). In women, the force of the handgrip is correlated with the standing triple jump (HG_L/STJ: r=-0.57; HG_R/STJ: r=-0.55) and horizontal jumps on one leg (HG_L/HJOL_L: r=0.60; HG_R/HJOL_L: r=0.56; HG_L/HJOL_R: r=0.62; HG_R/HJOL_R: r=0.58). Handgrip strength is only correlated with some plyometric jumps. Small number of correlations is most likely due to large differences in neuromuscular mechanisms, as handgrip involves isometric, absolute strength, and plyometric jumps involve relative strength, where subjects must overcome their own body weight. However, it is also necessary to consider the low number of subjects, especially female, which reduced the variability of the sample and the possibility of generalization to the wider population. As expected, of the body characteristics, body weight is most correlated to the handgrip strength.

Keywords: handgrip, plyometrics, vertical jumps, horizontal jumps, physical fitness

[1]University of Ljubljana, Faculty of Sport, Ljubljana, Slovenia

[2]Polyclinic of Physical Medicine and Rehabilitation, Pula, Croatia

IZVLEČEK

Moč stiska pesti je dober splošen pokazatelj telesne pripravljenosti. Že dalj časa se uporablja kot diagnostično orodje, katerega rezultati so povezani s prehranskimi navadami, šibkostjo rotatorne manšete, utrujenostjo in splošno telesno sposobnostjo. Nismo zasledili proučevanja povezanosti moči stiska pesti z odrivno močjo, zato smo to želeli preveriti v naši študiji. Pričakovali smo statistično pomembne povezave teh dveh prostorov moči. V raziskavo smo vključili vertikalne in horizontalne pliometrične skoke, moč stiska obeh pesti in nekatere telesne značilnosti. Povezanosti smo preverjali s korelacijsko analizo. V raziskavo je bilo vključenih 64 študentov Fakultete za šport, ki so opravili 9 pliometričnih testov, testa stiska pesti in meritev telesnih značilnosti. Rezultati pri merjencih kažejo dominantnost desne roke in zmerno pozitivno povezanost moči stiska pesti s telesno težo. Pri pliometričnih skokih se kažejo velike razlike med moškimi in ženskami. Pri moških je bila povezana moč stiska pesti samo s testom troskok z mesta (HG_L/STJ: r=0,33; HG_R/STJ: r=0,35). Pri ženskah pa je moč stiska pesti povezana s testoma troskok z mesta (HG_L/STJ: r=-0,57; HG_R/STJ: r=-0,55) in horizontalni skoki po eni nogi (HG_L/HJOL_L: r=0,60; HG_R/HJOL_L: r=0,56; HG_L/HJOL_R: r=0,62; HG_R/HJOL_R: r = 0,58). Moč stiska pesti je povezana samo z nekaterimi pliometričnimi skoki. Malo število povezanosti je najverjetneje zaradi velikih razlik v nevro-mišičnih mehanizmih, saj gre pri stisku pesti za izometrično in absolutno moč, pri pliometričnih skokih pa za relativno moč, kjer morajo merjenci premagovati lastno telesno težo. Upoštevati pa je potrebno tudi nizko število merjencev, še zlasti merjenk, kar je znižalo variabilnost vzorca in možnost posploševanja na širšo populacijo. Pričakovano, je od telesnih značilnosti, z močjo stiska pesti najbolj povezana telesna teža.

Ključne besede: stisk pesti, pliometrija, vertikalni skoki, horizontalni skoki, telesna pripravljenost

Corresponding author:*
Klemen Krejač,
University of Ljubljana,
Ljubljana, Slovenia.
E-mail: klemen.krejac@fsp.uni-lj.si

INTRODUCTION

Many human activities require a high degree of activation of the wrist and hand flexor muscles. As an evolutionary phenomenon during human development, these muscles were involved in gripping power. Various sports such as judo, wrestling, tennis, weightlifting, hockey, basketball, baseball, as well as everyday tasks such as hanging the laundry, opening doors, working in the garden, require a certain handgrip strength (Smith et al., 2006). Tennis players can risk the development of lateral epicondylitis, called tennis elbow, without adequate handgrip strength (Budoff, 2004; Yasuo et al., 2005). Handgrip strength is often overlooked but is crucial in preventing injuries and developing holistic strength (Fry et al., 2006).

Thirty-five muscles are involved in the movement of the forearm and arm, most of which are involved in handgrip. While gripping, the flexor muscles allow a firm grip, and the extensor muscles ensure the stability of the wrist (Waldo, 1996). There are four main joints of the hand: carpometacarpal, intermetacarpal, metacarpophageneal, and interphalangeal. These are joint with 9 external muscles crossing the wrist and 10 internal muscles with distal attachments to the wrist (Stewart and Hall, 2006). These muscles include the pronator radii teres, flexor carpi radialis, flexor carpi ulnaris, flexor sublimis digitorum, and palmaris longus on the external side. Flexor profundus digitorum, flexor pollicis longus, pronator quadratus, flexor pollicis brevis, and abductor pollicis brevis are present on the palmar side (Weineck, 1990). Each one of these muscles is involved in handgrip.

A German scientist in the field of sports, Jurgen Weinick (1990), found that the characteristics of the hand are related to gripping function. The ability to grip is made possible by the fact that the thumb can move opposite to the other fingers - the fingers and thumb act as a versatile pair of pliers. The palm is needed as a flat base on which an object can be held tightly (Weineck, 1990). The anatomy of the hand is, therefore, oriented more towards flexion than extension. Li, Zatsiorsky, and Latash (2001) concluded that the strength of finger flexors is 62% stronger than the strength of finger extensors during isometric tasks.

Handgrip dynamometry, as a diagnostic method, is used to measure the muscular force created by bending the hand and forearm. There are three main categories of hand dynamometers: spring, air, and hydraulic dynamometers. We use a hand dynamometer to measure the maximum strength of wrist flexors. The hand dynamometer came into use in the late 19th century and was developed by American neurologists. It is still used in various ways as a diagnostic tool and a tool for predicting human health (Mafi, Mafi, Hindocha, Griffin, & Khan, 2012). Handgrip is associated with a variety of poor health conditions, including chronic illness, functional disorders, and mortality (McGrath, Kraemer, Snih, & Peterson, 2018). Grip is a force, not pressure, so it is measured in kilograms. The most accurate choice is a hydraulic dynamometer (Waldo, 1996). When measuring the force of handgrip, it is usually necessary to normalize the results according to body weight. Testing protocols should be coordinated according to the time of day, posture, body characteristics, and dynamometer settings. Posture and elbow position play an important role during handgrip strength testing. Various studies have shown that with less elbow flexion, the force of handgrip is greater (Kuzala and Vargo, 1992; Su, Lin, Chien, Cheng and Sung, 1994; Momiyama, Kawatani, Yoshizaki and Ishihama, 2006). Body characteristics such as body height, body weight, finger length, and circumference may also affect the result of the handgrip strength test. Smith et al. (2006) found a direct association between handgrip strength and overall muscle strength in older women. Fry et al. (2006) also found an association between handgrip strength and performance in American youth weightlifters. The study showed an association between handgrip strength and a variety of other physical abilities, including nutritional habits, rotator cuff weakness, fatigue, and general physical ability.

To determine an athlete's physical fitness, it is recommended to measure handgrip force using a hydraulic dynamometer (Kurz, 2001). This information provides the trainer with valuable data regarding the athlete’s training status. If the strength of the athlete's handgrip, with respect to body weight, is below the result of the previous measurement, this may indicate fatigue. If the opposite is true, the athlete is adequately rested, and performance can be increased. This theory is similar to the findings of studies conducted by Hunt, Rowlands, and Johnston (1985), Michiko, Yoko, Naoko, Akinobu, and Toshio (1999), and Frederiksen et al. (2002). In these studies, a hand dynamometer was used to assess physical fitness. The findings of these studies linked lower handgrip strength scores to fatigue and poorer physical performance scores. Improving an athlete’s ability to apply force to an object or performance with a particular pattern of movement is multifactorial. These factors include technical ability (coordination of movements, sequence and timing), physical ability (strength, flexibility, neuromuscular function during reaction time), physical composition and tactical ability (monitoring and responding to the opponent) (Cronin, Lawton, Harris, Kilding, & McMaster, 2017).

The state of body nutrition is also related to handgrip strength. Kenjle, Limaye, Ghugre, and Udipi (2005) found that handgrip strength is a strong indicator of an individual’s nutritional status. These findings have some common traits with the findings of body characteristics studies. Nutritional status leads to certain bodyweight levels. Research has found this status to be directly related to handgrip strength. This simple method of non-invasive measurement can provide nutritionists and healthcare professionals with valuable data before further, more invasive, testing. Handgrip strength can be a reliable indicator of physical fitness, even health, and depends on general strength training, especially lifting free weights, where a firm handgrip is essential.

There is very little research effort related to studying the relationship between handgrip force and jumping force represented by vertical and horizontal jumps. Vertical jumps include the squat jump (SJ), counter movement jump (CMJ), and drop jump (DJ). Horizontal jumps include the standing broad jump (SBJ), standing triple jump (STJ), drop-distance standing triple jump (DSTJ), consecutive horizontal jumps (CHJ_5), and horizontal jumps on one leg (HJOL). The listed jumps are often used as a measure of the explosive power of the lower extremities. Vertical jumps can be defined as a complex series of ballistic multi-joint actions in which the muscles of the ankle, knee, and hip joints work together and create complex patterns of movement (Rodano, Squadrone, and Mingrino, 1996). The effectiveness of vertical jumps depends on the correct order of involvement of individual muscle groups. This is related to the principle of the proximal-distal muscle chain (Mackala, Stodoka, Siemienski, and Čoh, 2013).

Sports situations usually present modalities that require eccentric - concentric muscle action. A typical representative of this action is a counter movement jump. Performance has been shown to be more effective when we use counter movement. A jump with counter movement can be 10 to 15% higher than a jump from a 90° squat (Bobbert, Gerritsen, Litjens, and Van Soest, 1996). Drop jumps involve vertical jumps immediately after landing from a predetermined height (Young, Pryor, and Wilson, 1995). Plyometric exercises are a commonly used movement task for strength training. Performing plyometric exercises uses a cycle of stretching and shortening. In the stretching cycle, the muscle is stretched just before it explosively contracts (Walsh, Arampatzis, Schade, and Brüggemann, 2004). The basic exercises of plyometric training, which aim to improve the strength of the lower extremities and the height of the jump, are drop jumps. They can be performed using different techniques, which significantly affect jump variables (Struzik, Juras, Pietraszewski, and Rokita, 2016). When performing drop jumps, it is important to provide the same stimulus for both legs and thus allow for the balanced development of the lower extremities (Ball, Stock, and Scurr, 2010). Preactivation of the tibial muscles or motor control before landing is important for the effectiveness of drop jumps (Horita, Komi, Nicol, and Kyröläinen, 2002). Horita et al. (2002) found that pre-centrally programmed activity and associated elasticity in the knee joint during the force transfer phase in conjunction with the contractile property of the muscles play an important role in the regulation of performance during the drop jump.

In the present study, we set out to determine the extent to which correlations between handgrip strength and jump power of the lower extremities exist. The explosive power of the lower extremities is represented by a battery of vertical and horizontal plyometric jumps. Hypothetically, we expect statistically significant correlations between these two areas of power. Additionally, we want to explore the correlation between body characteristics and handgrip strength.

METHODS

Sample of subjects

Our study involved 44 male and 20 female second-year University students attending the Faculty of Sport. The participants were aged between 20 and 27. They were all active athletes. The average height of male students was 182.2 ± 1.95 cm, and 166.8 ± 2.48 cm for the female students. The average body weight of male and female students was 78.5 ± 2.41 kg and 62.2 ± 3.29 kg, respectively. The subjects had no injuries to the locomotor system at the time of the measurements. They were informed of the purpose and objectives of the research, they gave informed consent, in accordance with the Helsinki Declaration (2013), to participate in the study voluntarily and that they could terminate their participation at any time. The study was approved by the Ethics Commission of the Faculty of Sport, University of Ljubljana.

Sample of variables

We measured body weight (BW), body height (BH), skeletal muscle mass (SMM) and fat mass (FM). Following tests were performed: handgrip – left (HG_L), handgrip – right (HG_R), squat jump (SJ), counter movement jump (CMJ), drop jump from 30 cm – men (DJ_30), drop jump from 60 cm – men (DJ_60), drop jump from 20 cm – women (DJ_20), drop jump from 40 cm – women (DJ_40), standing broad jump (SBJ), standing triple jump (STJ), drop-distance standing triple jump (DSTJ), 5 consecutive horizontal jumps (CHJ_5), horizontal jumps on one leg – left (HJOL_L) and horizontal jumps on one leg – right (HJOL_R).

Measurement procedure

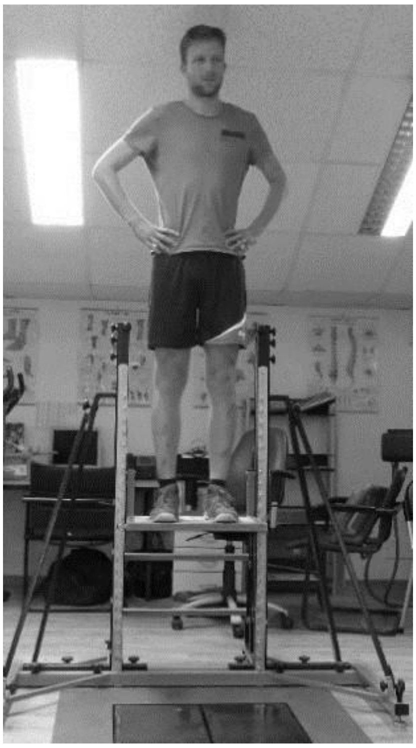
Measurements took place at the Faculty of Sports. In one set of tests (approx. 1 hour), the subjects were able to perform a maximum of 3 tests. After a 15-minute warm-up, subjects were first briefed on the course of the test and were shown a demonstration of the tasks involved. Each test was performed three times. The better result was chosen for statistical analysis. Participants had a 2-3 minute break between repetitions. Breaks between tests were 5-10 minutes. We performed the testing in the gym of the Faculty of Sport, where climatic conditions were optimal, and the floor surface in the gym was tartan. Measurements of morphological variables were performed using InBody measuring instruments (InBody 720, InBody CO., LTD. USA).

The first test performed was a handgrip measurement. For each individual, the hand dynamometer needed to be adjusted according to the participant's finger length and hand. A hydraulic hand dynamometer (Camry SCACAM-EH10117) was used to test handgrip strength. It can be observed in Figure 1. The participants were in a neutral standing position, the inactive arm was held next to the body, turned neutrally, with the forearm and wrist in a neutral position (Šimenko et al., 2016). Clear instructions were given to squeeze and hold the test stand as firmly as possible and to gradually release after 3 seconds. During the test, the subjects were not verbally encouraged. After relaxation, each participant had 30 seconds of rest. No movement was allowed during the test. Three experiments were performed, according to the protocol, and the best result was considered for analysis.

Figure 1. Handgrip measurement and Camry dynamometer

Vertical jumps were performed on a bipedal tensiometric plate (Kistler Type 9286B; Kistler Instruments AG, Winterthur, Switzerland). The data acquisition frequency was 1000 Hz. We measured the jump height based on jump speed and flight duration. They performed four vertical and six horizontal jump tests. Participants performed three SJs, three CMJs, and two DJs from each height; men from 30 and 60 cm and women from 20 and 40 cm onto a tensiometric plate. For the SJ, a precise explosive movement from the 90° squat is only important in the vertical direction. The hands are placed on hips for the entire duration of the task. For the CMJ, the starting position is the normal standing position, and the goal is to get into the 90° squat as fast as possible and to jump again, as explosively as possible, vertically with hands on hips. For these two jumps, it is important that the movements are done in the correct order and, at the same time, in a continuous chain from ankle to hip. In drop jumps, the subject needed to jump-off vertically as fast and as high as possible immediately after landing. The participants were also instructed to keep their hands on their hips during the entire drop jump test. Drop jump measurement can be observed in Figure 2.

Figure 2. Drop jump (from 60 cm) measurement



Horizontal jumps were performed last. For the standing broad jump, it is important that the test participants stand upright on the line, jump with both feet, and try to land as far away from the starting line as possible. The jump is performed with free hands. The distance from the line to the first footprint is measured. In a standing triple jump, the subject must stand with both feet at the starting line, and the test is performed by jumping with both legs, landing on one foot, jumping, landing on the other foot, jumping again and landing on both feet. The result is the sum of the three jumps. The drop-distance standing triple jump is similar to the standing triple jump, but that the first jump is performed from a height of 25 cm. It can be observed in Figure 3. The jump is carried out with both legs simultaneously, landing first on one foot and then on the other, then jumping again and landing on both feet. The result is the distance from the starting position to the landing. In consecutive horizontal jumps, the subject is placed on the starting line with both feet and then performs five consecutive jumps in the horizontal direction. The result is the distance from the starting line to the first footprint of the fifth landing. Horizontal jumps on one leg followed, first with one leg and then with the other. The test participant is positioned at the starting line with the left/right foot. They push off with the left/right foot and try to cover the distance of 10 meters in one-legged jumps in the shortest possible time. The result is measured with two pairs of electronic photocells (Brower, USA). The time recording is accurate to 1/100 of a second.

Figure 3. Drop-distance standing triple jump measurement

Statistical data analysis

The SPSS software package (Version 26, SPSS Inc., Chicago, Illinois, USA) was used for statistical processing of the results. Basic statistical parameters were calculated for all tests. Correlation analysis was used to determine the correlation of handgrip strength with vertical and horizontal jumps. The characteristics of the correlations were determined at 1% and 5% risk level.

RESULTS

Table 1 shows the basic statistics of selected morphological measures. We can see large differences in the heights of men and women. The maximum height for men was 184.14 cm and, on average, they are 15.41 cm taller than women, who had a maximum height of 169.26 cm. The heaviest man weighs 80.90 kg and the heaviest woman 65.52 kg. On average, men were 16.26 kg heavier than women. Men had 7.36% more skeletal muscle mass on average, while women had 10.33% more fat mass on average.

Table 1. Basic statistics of body characteristics

		N	Min	Max	M	SD
body height (BH) [cm]	men	44	169.00	196.00	182.19	6.43
	women	20	154.50	176.50	166.78	5.29
body weight (BW) [kg]	men	44	60.40	97.60	78.49	7.94
	women	20	49.00	78.50	62.23	7.02
skeletal muscle mass (SMM) [%]	men	42	46.65	55.39	51.71	1.85
	women	20	38.80	49.89	44.35	2.46
fat mass (FM) [%]	men	42	4.85	17.52	10.01	2.77
	women	20	12.64	29.73	20.34	4.44

N – count; Min – minimum; Max – maximum; M – arithmetic mean; SD – standard deviation

Both groups squeezed harder with their right hand, men, on average, 18.1 kg more than women. With the left hand, women squeezed, on average, 17.6 kg less than men, which is shown in Table 2.

Table 2. Basic statistics of handgrip

		N	Min	Max	M	SD
handgrip – left (HG_L) [kg]	men	44	38.10	62.60	50.31	6.48
	women	20	25.20	44.50	32.72	4.64
handgrip – right (HG_R) [kg]	men	44	41.30	68.20	53.03	6.39
	women	20	27.40	49.30	34.94	4.98

N – count; Min – minimum; Max – maximum; M – arithmetic mean; SD – standard deviation

The best jumping results were achieved by both men and women in counter movement jumps. The average height of the drop jumps was very similar for both genders in the lower and upper initial jump heights. The measured drop jump heights were the lowest of all the vertical jumps. The squat jump was on average, 5.3 cm higher for men and 5.6 cm higher for women than the drop jump and 4.8 cm lower for men and 4.8 cm lower for women than the counter movement jump.

Table 3 shows the average and extreme values of the vertical jumps by gender. Men dominated the horizontal jumps. For the standing broad jump, on average, men jumped 34 cm further than women. The longest standing broad jump for men was 58 cm longer than the longest jump for women. Men also achieve shorter times in horizontal jumps on one leg, where the aim is to jump as fast as possible.

Table 3. Basic statistics of vertical and horizontal jump tests

		N	Min	Max	M	SD
squat jump (SJ) [m]	men	44	0.19	0.48	0.35	0.06
	women	20	0.18	0.41	0.26	0.05
counter movement jump (CMJ) [m]	men	44	0.27	0.56	0.38	0.07
	women	20	0.20	0.44	0.29	0.05
drop jump (DJ) [m] - 30/20 cm	men	44	0.14	0.38	0.29	0.06
	women	20	0.13	0.31	0.23	0.05
drop jump (DJ) [m] - 60/40 cm	men	44	0.18	0.42	0.29	0.06
	women	20	0.16	0.32	0.25	0.04
standing broad jump (SBJ) [cm]	men	44	232.00	308.00	261.61	17.90
	women	20	198.00	240.00	215.35	9.50
standing triple jump (STJ) [m]	men	44	6.60	8.85	7.45	0.54
	women	20	5.30	6.96	6.15	0.38
drop-distance standing triple jump (DSTJ) [m]	men	44	6.27	8.73	7.41	0.55
	women	20	5.30	7.04	6.36	0.41
horizontal jumps on one leg – left (HJOL_L) [s]	men	44	2.08	2.73	2.34	0.14
	women	20	2.47	3.18	2.73	0.20
horizontal jumps on one leg – right (HJOL_R) [s]	men	44	2.07	2.72	2.34	0.15
	women	20	2.42	3.04	2.72	0.18
5 consecutive horizontal jumps (CHJ_5) [m]	men	44	10.74	15.45	13.12	0.94
	women	20	9.35	12.00	10.78	0.65

N – count; Min – minimum; Max – maximum; M – arithmetic mean; SD – standard deviation

After analyzing the basic statistics, we further compared the correlation of body characteristics and the results of the handgrip tests in men. In Table 4, we report the statistically significant degrees of correlation, denoted by * ($p < 0.05$) and ** ($p < 0.01$). The Pearson correlation coefficients were statistically significant only in the ratio of body weight to handgrip strength. The association of handgrip strength with bodyweight was positively weak and moderate. There was found a weak positive correlation between handgrip strength and skeletal muscle mass percentage as well as a weak negative correlation between handgrip strength and fat mass percentage. The latter findings were not statistically significant.

Table 4. Correlation of body characteristics and handgrip strength in men

		body height (BH) [cm]	**body weight (BW) [kg]**	**skeletal muscle mass (SMM) [%]**	**fat mass (FM) [%]**
handgrip – left (HG_L) [kg]	r	0.10	**0.41****	0.30	-0.19
handgrip – right (HG_R) [kg]	r	0.12	**0.38***	0.20	-0.09

r – Pearson correlation coefficient; * – $\alpha < 0.05$; ** – $\alpha < 0.01$

For women, the correlation between the body characteristics and the results of the handgrip strength test is shown in Table 5. Statistically significant correlation rates are indicated by * ($p < 0.05$) and ** ($p < 0.01$). The Pearson correlation coefficient was statistically significant in the correlation of left handgrip strength with body weight and fat mass percentage. The correlation of left handgrip strength with body weight and fat mass percentage was strong. There was also a moderate correlation of left handgrip strength with the percentage of muscle mass, but this finding was not statistically significant ($p = 0.07$).

Table 5. Correlation of body characteristics and handgrip strength in women

		body height (BH) [cm]	**body weight (BW) [kg]**	**skeletal muscle mass (SMM) [%]**	**fat mass (FM) [%]**
handgrip – left (HG_L) [kg]	r	0.10	**0.65****	-0.41	**0.54***
handgrip – right (HG_R) [kg]	r	-0.25	0.36	-0.30	0.36

r – Pearson correlation coefficient; * – $\alpha < 0.05$; ** – $\alpha < 0.01$

Since the main purpose of the study was to determine the correlation between vertical jumps and handgrip strength, a correlation table was created. Table 6 shows the correlation between vertical and horizontal jumps with handgrip strength in men. Only for the standing triple jump were the Pearson's correlation coefficients (HG_L/STJ: r = 0.33; HG_R/STJ: r = 0.35), at the level of p <0.05 (marked with "*"), statistically significant. The standing triple jump had a weak and positive correlation with handgrip strength.

Table 6. Correlation of vertical and horizontal jumps with handgrip strength in men

		handgrip – left (HG_L) [kg]	**handgrip – right (HG_R) [kg]**
squat jump (SJ) [m]	r	0.13	0.21
counter movement jump (CMJ) [m]	r	0.03	0.13
drop jump (DJ_30) [m]	r	0.02	0.09
drop jump (DJ_60) [m]	r	0.13	0.08
standing broad jump (SBJ) [cm]	r	0.19	0.18
standing triple jump (STJ) [m]	r	**0.33***	**0.35***
drop-distance standing triple jump (DSTJ) [m]	r	0.28	0.29
horizontal jumps on one leg – left (HJOL_L) [s]	r	-0.01	-0.05
horizontal jumps on one leg – right (HJOL_R) [s]	r	-0.12	-0.16
5 consecutive horizontal jumps (CHJ_5) [m]	r	0.24	0.29

r – Pearson correlation coefficient; * – $\alpha < 0.05$

The same analysis was carried out for women. In Table 7, we see the correlation between vertical and horizontal jumps with handgrip strength in women. A slightly stronger correlation between handgrip strength and horizontal jumps were observed for women, while in the case of vertical jumps, the correlation was not statistically significant. A high degree of correlation was observed for standing triple jumps (HG_L/STJ: r = -0.57; HG_R/STJ: r = -0.55), for horizontal jumps on the left leg (HG_L/HJOL_L: r = 0.60; HG_R/HJOL_L: r = 0.56) and on the right leg (HG_L/HJOL_R: r = 0.62; HG_R/HJOL_R: r = 0.58). All coefficients listed were statistically significant at the level of p <0.01, indicated by **. The correlation of the standing triple jump was strong and negative, while the correlation of the horizontal jumps on the left and right leg was strong and positive.

Table 7. Correlation of vertical and horizontal jumps with handgrip strength in women

		handgrip – left (HG_L) [kg]	handgrip – right (HG_R) [kg]
squat jump (SJ) [m]	r	-0.37	-0.13
counter movement jump (CMJ) [m]	r	-0.33	-0.04
drop jump (DJ_30) [m]	r	-0.19	0.1
drop jump (DJ_60) [m]	r	-0.05	0.26
standing broad jump (SBJ) [cm]	r	-0.21	-0.43
standing triple jump (STJ) [m]	r	**-0.57****	**-0.55****
drop-distance standing triple jump (DSTJ) [m]	r	-0.39	-0.36
horizontal jumps on one leg – left (HJOL_L) [s]	r	**0.60****	**0.56****
horizontal jumps on one leg – right (HJOL_R) [s]	r	**0.62****	**0.58****
5 consecutive horizontal jumps (CHJ_5) [m]	r	-0.17	-0.31

r – Pearson correlation coefficient; ** – $\alpha < 0.01$

DISCUSSION

The results of the study show that test participants usually have a dominant right hand. On average, men squeeze 2.72 kg (5.1%) and women 2.2 kg (6.45%) harder than with the left hand. Armstrong and Oldham (1999) found that there is a small (0.1–3%) but significant difference between the strength of the dominant and non-dominant hand. Optimal functioning of the hand in daily activities requires a preserved range of motion in all joints of the upper limbs, muscle strength and a fully functional grip (Dopsaj, Valdevit, Vučković, Ivanović, & Bon, 2019). Men are 16.26 kg heavier than women and 15.40 cm taller and stronger. On average, men have 7.36% more skeletal muscle mass, while women have, on average, 10.33% more fat mass. Perhaps the latter is also the reason why men squeeze on average 17.9 kg harder than women. We found that handgrip strength in men is statistically significantly related to body weight (HG_L/BW: $r = 0.41$; HG_R/BW: $r = 0.38$). The correlation is moderate and positive. Heavier subjects have a stronger handgrip. Women have different body composition than men. The correlation is reflected in the left-handgrip with body weight and the percentage of fat mass (HG_L/BW: $r = 0.65$; HG_L/FM: $r = 0.54$). The correlation is moderate and positive. Women with higher body weight are also stronger. This result could explain the moderately positive correlation between the handgrip and fat percentage in women. For the latter, a negative correlation between the percentage of muscle mass and handgrip strength is found at the limit of statistical significance (p = 0.07). Women with a higher percentage of muscle mass are generally thinner and simultaneously have lower body weight, all of which affects handgrip strength.

In vertical jumps, as expected, both men and women performed the highest jumps in counter-movement jumps (CMJ), since the use of elastic energy stored in the tendons and muscles is greatest in this case. Men are bigger and stronger and jump higher than women. Bobbert et al. (1996) found that people can jump higher in counter-movement jumps than in squat jumps because the latter stores less elastic energy and therefore uses less of it. Men jumped about 10 cm higher than women; their body weights and heights are also higher than women's. Men jumped significantly longer in horizontal jumps. They were stronger in bilateral and unilateral jumps. We can conclude that body characteristics are positively related to the height of jumps, which was also confirmed by Ugarkovic, Matavulj, Kukolj, and Jaric, (2002).

The results of the drop jumps were the lowest of all the vertical jumps. Men jumped from a height of 30 and 60 cm while women jumped from heights of 20 and 40 cm. There is a negligible difference in jump height from the lower and upper starting points for both sexes. It makes sense to limit the height of the drop jumps to 20 and 40 cm if we want to investigate the effects of drop jump training (Bobbert et al., 1987). Similar jump heights can also be attributed to the lack of training or general unawareness of drop jumps and their principles. In repeated attempts or several repetitions with sufficient pause, we would most likely find a positive trend in jump height. In general, we can state that depth jumps do not show a statistically significant correlation with handgrip strength. This is true for both subsamples. The lack of correlation is probably due to various neuromuscular mechanisms. While handgrip is a general indicator of the absolute strength of the isometric principle, vertical jumps are typical representatives of the reactive elastic force (Bobbert et al., 1987).

The results of the horizontal jumps, both bilateral and unilateral, show clear differences between the two samples. This is to be expected, given the genetic potential of power in men and women. The Pearson correlation coefficient shows a low and positive correlation between the standing triple jump and handgrip strength in men (HG_L/STJ: r = 0.33; HG_R/STJ: r = 0.35). In men, there is a low and positive correlation between handgrip strength and the drop-distance standing triple jump, but this is not statistically significant (p = 0.06). In women, there is a stronger but negative correlation between handgrip strength and the standing triple jump (HG_L/STJ: r = -0.57; HG_R/STJ: r = -0.55). This result indicates that women who jump longer have less handgrip strength. This may be related to body composition, as heavier women do not jump as far as their lighter counterparts. The heavier women are also characterized by a negative correlation between horizontal jumps on one leg and handgrip strength (HG_L/HJOL_L: r = 0.60; HG_R/HJOL_L: r = 0.56; HG_L/HJOL_R: r = 0.62; HG_R/HJOL_R: r = 0.58). We can conclude that women who have a stronger handgrip achieve worse results when jumping horizontally on one leg. One-sided jumps require a pronounced relative elastic strength. Maximum handgrip is primarily produced by absolute force, with bodyweight being an important factor in success.

Limitations and strengths

The sample was small, so the results probably have to be considered with due respect. Based on the results of this study, one of the fundamental findings that the results of this study, which call for more extensive research, could include a larger number of subjects with greater physical and motor variability.

CONCLUSION

The main objective of the present study was to determine the relationship between the handgrip strength and the selected independent morphological and motor variables. Furthermore, we were interested in the correlation between body characteristics and handgrip strength. As expected, men jump further and higher than women due to genetic differences. They use elastic energy more efficiently because they have more muscle mass and tendons with greater elasticity. Men also have stronger handgrip than women. In both subsamples, a greater force of handgrip of the dominant right hand was observed. Handgrip is an indicator of the isometric strength of the absolute type. Neuromuscular mechanisms differ strongly with respect to jumps. Jumping tasks involve relative strengt; the subjects have to overcome their body weight. We can conclude that the handgrip strength test is a good indicator of physical fitness. Only some vertical and horizontal plyometric jumps are typically associated with handgrip strength. Among the morphological variables, body weight in both subsamples showed the highest correlation with handgrip strength.

Acknowledgment

Measurements of handgrip strength were performed by Jožef Šimenko, and measurements of vertical and horizontal plyometric jumps were performed by Samo Rauter, Robi Kreft, Iva Jurov and the students of the athletics program. The authors of the study would like to thank the above mentioned for their help. The study was financially supported by the Public Agency for Research of the Republic of Slovenia (ARRS).

REFERECES

Armstrong, C. A., & Oldham, J. A. (1999). A Comparison of Dominant and Non-Dominant Hand Strengths. *Journal of Hand Surgery*, 24(4), 421–425.

Ball, N. B., Stock, C. G., & Scurr, J. C. (2010). Bilateral contact ground reaction forces and contact times during plyometric drop jumping. *Journal of Strength and Conditioning Research*, 24(10), 2762–2769.

Bobbert, M. F., Gerritsen, K. G. M., Litjens, M. C. A., & Van Soest, A. J. (1996). Why is countermovement jump height greater than squat jump height? *Medicine and Science in Sports and Exercise*, 28(11), 1402-1412.

Bobbert, M. F., Huijing, P. A., & Schenau, G. J. V. I. (1987). Drop jumping. II. The influence of dropping height on the biomechanics of drop jumping. *Medicine and Science in Sports and Exercise*, 19(4), 339–346.

Budoff, J. E. (2004). The prevalence of rotator cuff weakness in patients with injured hands. *The Journal of hand surgery*, 29(6), 1154–1159.

Cronin, J., Lawton, T., Harris, N., Kilding, A., & McMaster, D. T. (2017). A brief review of handgrip strength and sport performance. *Journal of Strength and Conditioning Research*, 31(11), 3187–3217.

Dopsaj, M., Valdevit, Z., Vučkovic, G., Ivanovic, J., & Bon, M. (2019). A Model of the Characteristics of Hand Grip Muscle Force Based on Elite Female Handball Players of Various Ages. *Kinesiologia Slovenica*, 25(1), 14–26.

Frederiksen, H., Gaist, D., Petersen, H. C., Hjelmborg, J., McGue, M., Vaupel, J. W., & Christensen, K. (2002). Hand grip strength: A phenotype suitable for identifying genetic variants affecting mid- and late-life physical functioning. *Genetic Epidemiology*, 23(2), 110–122.

Fry, A. C., Ciroslan, D., Fry, M. D., LeRoux, C. D., Schilling, B. K., & Chiu, L. Z. F. (2006). Anthropometric and Performance Variables Discriminating Elite American Junior Men Weightlifters. *Journal of Strength and Conditioning Research*, 20(4), 861–866.

Horita, T., Komi, P. V., Nicol, C., & Kyröläinen, H. (2002). Interaction between pre-landing activities and stiffness regulation of the knee joint musculoskeletal system in the drop jump: Implications to performance. *European Journal of Applied Physiology*, 88(1–2), 76–84.

Hunt, D. R., Rowlands, B. J., & Johnston, D. (1985). Hand Grip Strength—A Simple Prognostic Indicator In Surgical Patients. *Journal of Parenteral and Enteral Nutrition*, 9(6), 701–704.

Kenjle, K., Limaye, S., Ghugre, P. S., & Udipi, S. A. (2005). Grip strength as an index for assessment of nutritional status of children aged 6-10 years. *Journal of Nutritional Science and Vitaminology*, 51(2), 87–92.

Kurz, T. (2001). Science of Sports Training. *Stadion Publishing Co*.

Kuzala, E. A., & Vargo, M. C. (1992). The relationship between elbow position and grip strength. *The American journal of occupational therapy: official publication of the American Occupational Therapy Association*, 46(6), 509–512.

Li, Z. M., Zatsiorsky, V. M., & Latash, M. L. (2001). The effect of finger extensor mechanism on the flexor force during isometric tasks. *Journal of Biomechanics*, 34(8), 1097–1102.

Mackala, K., Stodoka, J., Siemienski, A., & Coh, M. (2013). Biomechanical analysis of squat jump and countermovement jump from varying starting positions. *Journal of Strength and Conditioning Research*, 27(10), 2650–2661.

Mafi, P., Mafi, R., Hindocha, S., Griffin, M., & Khan, W. (2012). A Systematic Review of Dynamometry and its Role in Hand Trauma Assessment. *The Open Orthopaedics Journal*, 6(1), 95–102.

McGrath, R. P., Kraemer, W. J., Snih, S. Al, & Peterson, M. D. (2018). Handgrip Strength and Health in Aging Adults. *Sports Medicine*, 48(9), 1993–2000.

Michiko, S., Yoko, M., Naoko, K., Akinobu, F., & Toshio, F. (1999). The Correlation Between Grip Strength and Lifestyle Disease. *Sangyo Eiseigaku Zasshi*, 41, 391.

Momiyama, H., Kawatani, M., Yoshizaki, K., & Ishihama, H. (2006). Dynamic movement of center of gravity with hand grip. *Biomedical Research*, 27(2), 55–60.

Rodano, R., Squadrone, R., & Mingrino, A. (1996). Gender Differences in Joint Moment and Power Measurements During Vertical Jump Exercises. *ISBS-Conference Proceedings Archive*, 1(1), 308–310.

Šimenko, J., Škof, B., Hadžić, V., Milić, R., Zorec, B., Žvan, M., Vodičar, J., & Čoh, M. (2016). General and Specific Physical Abilities of the Members of a Special Police Unit. *Physical Education and Sport*, 14(1), 83–98.

Smith, T., Smith, S., Martin, M., Henry, R., Weeks, S., & Bryant, A. (2006). Grip Strength in Relation to Overall Strength and Functional Capacity in Very Old and Oldest Old Females. *Physical & Occupational Therapy In Geriatrics*, 24(4), 63–78.

Stewart, T. D., & Hall, R. M. (2006). Basic biomechanics of human joints: Hips, knees and the spine. *Current Orthopaedics*, 20(1), 23–31.

Struzik, A., Juras, G., Pietraszewski, B., & Rokita, A. (2016). Effect of drop jump technique on the reactive strength index. *Journal of Human Kinetics*, 52(1), 157–164.

Su, C. Y., Lin, J. H., Chien, T. H., Cheng, K. F., & Sung, Y. T. (1994). Grip strength in different positions of elbow and shoulder. *Archives of Physical Medicine and Rehabilitation*, 75(7), 812–815.

Ugarkovic, D., Matavulj, D., Kukolj, M., & Jaric, S. (2002). Standard anthropometric, body composition, and strength variables as predictors of jumping performance in elite junior athletes. *Journal of Strength and Conditioning Research*, 16(2), 227–230.

Waldo, B. R. (1996). Grip strength testing. Strength and Conditioning Journal, 18(5), 32–35.

Walsh, M., Arampatzis, A., Schade, F., & Brüggemann, G. P. (2004). The effect of drop jump starting height and contact time on power, work performed, and moment of force. *Journal of Strength and Conditioning Research*, 18(3), 561–566.

Weineck, J. (1990). Functional Anatomy in Sports. 202.

Yasuo, G., Daisaku, T., Nariyuki, M., Jun'ya, S., Toshihiko, O., Masahiko, M., & Yoshiyuki, M. (2005). Relationship between Grip Strength and Surgical Results in Rotator Cuff Tears. *Shoulder Joint*, 29(3), 559–562.

Young, W. B., Pryor, J. F., & Wilson, G. J. (1995). Effect of instructions on characteristics of countermovement and drop jump performance. *Journal of Strength and Conditioning Research* 9(4), 232–236.