DOI 10.26773/jaspe.251002

JASPE Journal of Anthropology of Sport and Physical Education

ORIGINAL SCIENTIFIC PAPER

The Relationship of the Neuromuscular Characteristics of the Handgrip Expressed in Different Modules of Isometric Contraction and Psychological Characteristics in Adults - Proof of Concept

Miloš M. Milošević[1], Vladimir Kitanović[2], Miloš R. Mudrić[3], Milivoj Dopsaj[3]

[1]Faculty of Physical Education and Sports Management, Singidunum University, Belgrade 11000, Serbia, milosmilosevic80@yahoo.com, [2]Serbian Institute for Sport and Sports Medicine, Belgrade 11000, Serbia, vladimirkitanovic@gmail.com, [3]Faculty of Sport and Physical Education, University in Belgrade, Belgrade 11000, Serbia, milos.mudric@fsfv.bg.ac.rs, milivoj.dopsaj@gmail.com

Abstract

This study aimed to explore the interplay of handgrip neuromuscular, morphological, and psychological characteristics in well-trained and elite athletes. The research was conducted on a sample of 25 adults. For Handgrip Neuromuscular characteristics, the sliding device that measures isometric finger flexor force was used in both the classic and the impulse mode of isometric testing. Psychological Characteristics were assessed using a shortened version of Big Five Plus Two, Mental Toughness Index, and Dark Triad Dirty Dozen test questionnaires. Numerous significant correlations were obtained both in the classic and the impulse mode of isometric testing. Numerous effective regression modes, which can explain a significant percentage of the variance of psychological characteristics with mechanical characteristics of handgrip expressed in both impulse and classical mode, were obtained [initially: aggression (R^2=0.95), extraversion (R^2=0.74), neuroticism (R^2=0.82), negative valence (R^2=0.75), openness (R^2=0.62), positive valence (R^2=0.62), mental toughness (R^2=0.75), Machiavellianism (R^2=0.56), psychopathy (R^2=0.56), narcissism (R^2=0.78), Dark triad (R^2=0.69)]. It was concluded that obtained discriminant modes are very efficient when it comes to their further use in selection in sports. Also, the obtained results justify further research on this topic with the aim of better understanding the nature of the obtained correlations.

Keywords: *Big Five, Dark Triad, Maximal muscle force, Mental Toughness, Rate of force development*

Introduction

The handgrip strength (HGS) test is a highly lateralized measurement procedure (Gallup et al., 2007), a reflection of both muscular force and neural activity (i.e., neuromuscular characteristics) (Liu et al., 2005). Correlations of HGS with various psychological characteristics and behaviours are documented in previous research (Hegerstad et al., 2019). Among other correlations with the Big Five dimensions of personality were reported (Stephan et al., 2022; Sutin et al., 2018). However, this topic should be explored further.

First, studies so far reached HGS as one solid variable, the level of the force exerted by the flexor and extensor muscles of the hand on the measuring device. Since force is produced in time, it can also be analyzed according to the force-time curve

Correspondence:

Montenegro Sport

Miloš Miloševiće
Singidunum University, Danijelova 32, Belgrade 11000, Serbia
Tel.: +381645622961
E-mail: milosmilosevic80@yahoo.com

produced in the HGS task. This method is reliable and has been used frequently in research (Cronin et al., 2017). In this way, parameters of the maximal force (Fmax), maximum rate of force development (RFD), the time needed for achieving Fmax (tFmax), and the time needed for achieving RFD (tRFDmax) can be obtained. This fact is important since different physiological mechanisms are responsible for the manifestation of the mentioned characteristics (Baudry & Duchateau, 2021; Dideriksen et al., 2020). Moreover, studies of the effect of immobilization showed non-uniform loss of isometric muscle strength and neuromuscular characteristics, with different outcomes between upper and lower limbs, attributed to different degrees of central neural control (Campbell et al., 2019), which justifies the expansion of research into neuromuscular characteristics.

Second, in testing neuromuscular characteristics, the results obtained can be expanded with verbal instructions given by the researcher. The instruction "perform the test as fast as you can" resulted in different values contrary to the instruction "perform the test as hard and fast you can" (Sahaly et al., 2001). The second instruction refers to the classical mode of isometric testing, which is the golden standard (Andersen & Aagaard, 2006; Marković et al., 2020). However, the second instruction referring to the impulse mode of isometric testing proves to have excellent metric characteristics (Dopsaj, Klisaric, et al., 2021) and advantages when it comes to assessing neuromuscular characteristics related to RFD (Suzović & Nedeljković, 2009). This justifies the expansion of the investigation in both modes of muscle contraction.

Third, it has been shown that the Big Five, although one of the most commonly used models, does not capture sufficient variation across the whole spectrum of personality when it comes to the prediction of various phenomena. In order to effectively predict reactions related to stress, its extension with Mental Toughness (MT) and the Dark Triad (DT) was proposed (Papageorgiou et al., 2019). For this reason, the research on the relationship between neuromuscular and psychological characteristics should be expanded with MT and DT. This fact justifies the expansion of the investigation into the field of psychological characteristics.

Expanding the research described should provide a deeper understanding of investigated relationships and find application in the practice of selecting individuals for various occupations associated with stress and physical effort.

This study aimed to explore the relationship between neuromuscular characteristics of the hand grip expressed in different modules of isometric contraction and psychological characteristics. The first hypothesis (H1) was that the handgrip neuromuscular characteristics would be associated with psychological characteristics. The second hypothesis (H2) was that the handgrip neuromuscular characteristics can serve as a good predictor of various psychological characteristics.

Materials and Methods

Participants

The research was conducted on a sample of adults of various professional orientations who volunteered to participate in the research after an ad posted by the researchers on social media. The criteria for participation were voluntary registration and the absence of any health problems. Any history of arm injury was exclusion criteria. The total sample included 25 participants [age=30.4±10.1 years, body height =177.1±9.9 cm, body mass =77.4 ±13.5 kg, and body mass index =24.5±2.8], from which 10 were females and 15 male.

The study was conducted in accordance with the European Commission's General Data Protection Regulation, the American Psychological Association-prescribed Ethical Principles and Code of Conduct, as well as the Helsinki Declaration. The study design was approved by the Ethical Board (number 484-2) of the Faculty of Sport and Physical Education, University of Belgrade.

Procedures

All testing procedures were conducted within two sessions. During one session, participants filled out the questionnaire to record their socio-demographic status as well as psychological questionnaires, with no time limitation. The second session, performed on another day, included a performance of HGS tests in classical and impulse modes of muscular contraction. Tests were preceded by a standard warm-up routine, including 5 min of upper-body exercises and 3 min of dynamic exercises that activate tested muscle groups, which included superficial and deep finger flexor muscles. During the last part of the warm-up, each participant performed two HGS trials with a gradual increase of muscle force until Fmax and two maximally strong and fast trials. The rest of the rest between the warm-up trials and actual testing procedures, as well as between the classical and impulse modes, was about 5 min. The order of sessions, psychological questionnaires, HGS for dominant and non-dominant hands, and classical and impulse modes were randomized.

Handgrip neuromuscular characteristics

The HGS was assessed using a custom-made device (SMS HG system) and software system (Isometrics Lite, ver. 3.1.1, Isometrics SMS All4Gym, Belgrade). This system was shown to be valid and reliable for this type of testing compared to the Jamar Handgrip Dynamometer (dominant hand ICC=0.98, non-dominant hand ICC=0.97) (Marković et al., 2020). It allows the adjustment of each participant's hand grip size. The HGS device was attached to the force transducer that measured the isometric force of finger flexors. The standard potentiometric probe with a measurement precision of ±0.01 N was connected to the force reader. The force-time signal was sampled at 1000 Hz and low-pass filtered (10 Hz) using a fourth-order (zero-phase lag) Butterworth filter (Knezevic et al., 2014). RFD was calculated as the maximal slope of the force-time curve (over the first derivative of the force-time curve) in regard to the force onset (Knezevic et al., 2014). Prior to measurement, the device was calibrated. The onset of the contraction was defined as the point in time when the first derivative of the force-time curve exceeded the baseline by 3% of its maximal value.

Participants performed the HGS test according to previously reported procedures (Dopsaj et al., 2019b; Gallup et al., 2007). The test was performed with participants in a sitting position with an extended arm beside the body (angle in the elbow joint of 180°) with mild abduction (5-10 cm) for dominant and non-dominant hands. Participants were not allowed to lean the hand and the device on the thigh or another solid object. Two types of testing were performed; for the first (classical mode), a verbal instruction was given: "grip the gauge maximally hard and fast as you can, and hold it for 1 to 2 seconds", while for the second (impulse mode), a different verbal instruction was given: "grip the gauge maximally hard and short as you can". This procedure has also been reported and proven to be valid (Dopsaj, Klisaric, et al., 2021; Suzovic & Nedeljkovic, 2009).

Since muscular force results increase by 50% with body size, standard allometric partialization will be performed for the obtained force by dividing it by body mass scaled to 2/3 (Dulac et al., 2016).

The force output was projected on the screen, and participants were verbally encouraged to obtain the best result. From the HGS test, Fmax [$N/kg^{2/3}$], tFmax [s], RFD [$N/kg^{2/3}/s$], tRFD [s] of dominant (D) and non-dominant (ND) hand, as well as for classical (C) and impulse (P) mode were collected. From the obtained values, Neural reserve indexes (NRI) for both D and ND hands were calculated in the following way:

NRI=CRFD/PRFD

Psychological characteristics

To assess psychological characteristics, a shortened version of the Big Five Plus Two (BF+2), Mental Toughness Index (MTI), and Dark Triad Dirty Dozen test (DTDD) questionnaire was used.

BF+2 is composed of 70 items which assess five basic dimensions: neuroticism (Nrt), extraversion (Ext), openness (Opn), conscientiousness (Cns), and aggression (Agr), as well as two additional dimensions: positive (PV) and negative valence (NV) (Čolović et al., 2014). Responses to each item are scored on a 5-step Likert scale, ranging from "strongly disagree" (1) to "strongly agree" (5). The total score on each of the dimensions is calculated as the average of the scores on the scales. The BF+2 has been widely used in scientific research and clinical practice (Vukmirovic et al., 2020) due to its good psychometric characteristics (Čolović et al., 2014). In previous studies, reliability estimates for BF+2 scores were ≥0.81 (Čolović et al., 2014).

MT was assessed by the Mental Toughness Index (MTI) (Gucciardi et al., 2015). The instrument consists of 8 items that were answered using the seven-point Likert-type assessment scales. The total score varies from a minimum of 1 (False, 100% of the time) to a maximum of 7 (True, 100% of the time). The construct validity of the MTI has been supported by studies involving participants from various cultures (Stamatis et al., 2022). In previous studies, reliability estimates for MTI scores were ≥0.86 (Stamatis et al., 2022).

DT traits were assessed by DTDD (Dinić et al., 2018a), which consists of 12 items that were answered using seven-point Likert-type assessment scales. The DTDD assesses an individual's overall DT through three socially malevolent traits: Machiavellianism (Mch), psychopathy (Psc), and narcissism (Nrc). The scores vary from a minimum of 1 (poorly present) to a maximum of 7 (extremely present). In previous studies, reliability estimates for DTDD scores were ≥0.77 (Jonason & Webster, 2010; Dinić et al., 2018a).

Statistical analysis

The sample size was estimated after applying a power analysis. For two-tail t-tests - Correlation: Point biserial model, with $\alpha=0.05$, power $1-\beta=0.80$, and effect size $\rho=0.55$, the sample size should comprise at least 21 participants. For f tests - MANOVA: Repeated measures, within factor, with $\alpha=0.05$, power $1-\beta=0.80$, effect size f=0.25, 2 groups, 2 measurements and correlation among repeated measurement 0.7. The sample size was estimated to be 22 participants at least. For two-tail t-tests – Linear multiple regression, with $\alpha=0.05$, power $1-\beta=0.80$, effect size $f^2=0.50$, and 18 predictors, the sample size should comprise at least 25 participants. Power analyses were performed using G-power 3.1.9.6 (Franz Faul, Universitat Kiel, Germany).

All statistical analyses were performed using SPSS 20 (IBM Corp., Armonk, N.Y., USA). The statistical significance at the present study was set to value $p<0.05$. Descriptive statistical analysis was performed, including mean (M), standard deviation (SD), minimal (Min) and maximal (Max) values. The Kolmogorov–Smirnov test was used to assess the normality of distribution. In order to examine the differences between the classical and pulse regimes, isometric characteristics were used, and repeated measurements of MANOVA were used. Partial eta squared (ηp^2) was calculated for the MANOVA effect size. The criterion for evaluation of the effect size in MANOVA was: $\eta^2(0.01)$=small, $\eta^2(0.06)$=-medium, $\eta^2(0.14)$=large (Sawilowsky, 2009).

Pearson's correlation analysis was performed to discover the relationship between handgrip neuromuscular and psychological characteristics (H1). The effect size of correlation coefficients was defined as weak =0.20–0.49, moderate =0.50–0.80, or strong ≥0.80 (Sullivan & Feinn, 2012). In order to evaluate the potential of the handgrip neuromuscular model in predicting psychological characteristics (H2), multiple linear regression analysis, backward stepwise selection, with criterion: the probability of F to remove ≥0.10, was performed. To address concerns about model overfitting, outlier analysis adjusted R^2 was used to determine if extreme values are skewing results and verify model stability. Due to the small sample, cross-validation was performed on 75% of randomly selected respondents (n=19) to confirm the model's reliability.

Results

Descriptive statistical analysis of psychological characteristics [aggression (Agr), extraversion (Ext), neuroticism (Nrt), negative valence (NV), openness (Opn), positive valence (PV), conscientiousness (Cns), Mental Toughness (MT), Machiavellianism (Mch), psychopathy (Psc), narcissism (Nrc), Dark Triad (DT)] and handgrip neuromuscular [maximal force (Fmax), maximum rate of force development (RFD), time needed for achieving Fmax (tFmax), the time needed for achieving RFD (tRFDmax), neural reserve index (NRI)] characteristics for both dominant (D) and non-dominant (ND) hand, in classic (C) and pulse (P) mode of isometric contraction for the whole sample is presented in Tables 1 and 2. The nonparametric Kolmogorov–Smirnov test did not show significant deviations from the normal distribution for any variable. Outlier analysis revealed that only one out of 750 scores was outside the scope of M±3*SD (tRFDmaxND=0.19) but did not significantly skew the distribution.

Table 1. Descriptive Statistical Analysis of Psychological Characteristics

	Agr	Ext	Nrt	NV	Opn	PV	Cns	MT	Mch	Psc	Nrc	DT
Min	1.60	3.10	1.00	1.00	3.40	2.20	2.50	4.13	1.00	1.00	1.00	1.00
Max	3.90	4.60	3.20	2.20	5.00	4.80	5.00	6.88	3.33	3.75	6.00	3.42
M	2.34	3.88	1.98	1.43	4.19	3.42	4.06	5.94	1.94	1.82	3.13	2.21
SD	0.59	0.46	0.69	0.32	0.42	0.70	0.61	0.63	0.76	0.88	1.51	0.72

Note. Agr: aggression, Ext: extraversion, Nrt: neuroticism, NV: negative valence, Opn: openness, PV: positive valence, Cns: conscientiousness, MT: Mental Toughness, Mch: Machiavellianism, Psc: psychopathy, Nrc: narcissism, DT: Dark Triad, Min: minimum, Max: maximum, M: mean, SD: standard deviation

Analysis of variance revealed significant differences with large effect size between classic and impulse mode of isometric contraction for FmaxND ($F=22.3$, $p<0.001$, $\eta_p^2=0.48$), RFDND ($F=10.1$, $p<0.01$, $\eta_p^2=0.30$), tFND ($F=52.8$, $p<0.001$, $\eta_p^2=0.69$), FmaxD ($F=20.6$, $p<0.001$, $\eta_p^2=0.46$), RFDND ($F=10.3$, $p<0.01$, $\eta p2=0.30$), tFND ($F=74.5$, $p<0.001$, $\eta_p^2=0.76$).

Table 2. Descriptive statistical analysis of Handgrip Neuromuscular Characteristics in Classic (C) and Impulse (P) mode of Isometric Contraction

	CFmaxND	CRFDND	CtFmaxND	CtRFDND	CFmaxD	CRFDD	CtFmaxD	CtRFDD	NRID
Min	14.60	77.62	0.34	0.09	15.71	82.84	0.37	0.09	0.73
Max	32.59	220.48	1.88	0.19	36.27	249.93	1.39	0.17	1.10
M	22.86	152.02	0.85	0.12	24.71	163.09	0.77	0.12	0.95
SD	5.62	44.81	0.40	0.02	6.29	48.07	0.27	0.02	0.08
	PFmaxND	PRFDND	PtFmaxND	PtRFDND	PFmaxD	PRFDD	PtFmaxD	PtRFDD	NRIND
Min	13.50	100.11	0.20	0.09	11.45	94.89	0.15	0.10	0.71
Max	29.91	219.68	0.41	0.13	31.54	241.57	0.43	0.14	1.14
M	21.27	160.39	0.27	0.11	22.75	171.32	0.26	0.11	0.94
SD	4.92	38.33	0.06	0.01	6.00	43.88	0.08	0.01	0.10

Note. C: classical mode of isometric contraction, P: impulse mode of isometric contraction, D: dominant hand, ND: non-dominant hand, Fmax: maximal force, RFD: maximum rate of force development, tFmax: time needed for achieving Fmax, tRFDmax: the time needed for achieving RFD, NRI: neural reserve index, Min: minimum, Max: maximum, M: mean, SD: standard deviation

The correlation analysis (Table 3) revealed a weak positive association of NV with CFmaxND, CRFDND, and CRFDD; Psc with CFmaxND, CRFDND, CFmaxD, and PFmaxDL and DT with PFmaxND, NRID; as well as weak negative association of Agr with CFmaxND CRFDND, PFmaxND, PRFDND, NRIND; Ext with CRFDND, CFmaxD, PFmaxND, and PFmaxD. The correlation analysis also revealed a strong positive association of NV with CFmaxD, PFmaxND, PRFDND, and Psc with CRFDD, PFmaxND, PRFDND, and PRFDD.

Table 3. Correlation Analysis of Handgrip Neuromuscular with Psychological Characteristics

	Agr	Ext	Nrt	NV	Opn	PV	Cns	MT	Mch	Psc	Nrc	DT
CFmaxND	-0.42*	-0.36	0.11	0.47*	-0.01	-0.29	-0.03	0.20	0.33	0.45*	0.26	0.39
CRFDND	-0.48*	-0.40*	0.12	0.43*	-0.01	-0.26	0.05	0.22	0.23	0.44*	0.21	0.32
CtFmaxND	-0.10	0.13	-0.33	-0.10	0.20	0.04	0.14	0.19	-0.14	-0.16	-0.28	-0.25
CtRFDND	0.19	0.20	-0.22	-0.19	-0.16	-0.01	-0.13	0.12	0.03	-0.15	-0.14	-0.10
CFmaxD	-0.36	-0.42*	0.14	0.50*	-0.05	-0.23	0.01	0.15	0.15	0.49*	0.14	0.31
CRFDD	-0.36	-0.35	0.12	0.41*	-0.06	-0.24	0.05	0.12	0.12	0.54**	0.19	0.32
CtFmaxD	-0.09	-0.13	0.07	0.08	0.20	-0.13	-0.01	-0.24	-0.08	-0.05	0.00	-0.04
CtRFDD	0.14	0.36	-0.06	-0.18	0.10	0.23	-0.20	0.07	-0.14	-0.33	-0.07	-0.12
PFmaxND	-0.42*	-0.42*	0.18	0.53**	-0.02	-0.26	-0.07	0.19	0.25	0.52**	0.26	0.40*
PRFDND	-0.41*	-0.38	0.18	0.50*	-0.01	-0.20	0.00	0.20	0.26	0.50*	0.26	0.39
PtFmaxND	0.20	0.25	0.18	0.20	0.10	0.13	-0.09	0.09	0.07	-0.08	-0.03	-0.01
PtRFDND	0.10	0.36	-0.15	-0.24	0.05	0.13	0.01	-0.12	-0.22	-0.19	-0.09	-0.17
PFmaxD	-0.36	-0.41*	0.14	0.39	-0.09	-0.29	0.02	0.18	0.14	0.47*	0.12	0.25
PRFDD	-0.40*	-0.36	0.12	0.39	-0.15	-0.28	0.03	0.15	0.10	0.50*	0.10	0.25
PtFmaxD	-0.12	-0.06	0.15	0.07	0.10	-0.06	0.01	0.22	-0.09	-0.01	-0.07	-0.10
PtRFDD	0.31	0.28	0.13	-0.23	0.22	0.34	-0.12	0.06	0.06	-0.22	0.08	0.01
NRIND	-0.48*	-0.35	-0.13	0.09	-0.03	-0.35	0.14	0.23	0.07	0.16	0.02	0.03
NRID	0.03	-0.17	0.09	0.29	0.30	0.01	0.08	-0.09	0.20	0.37	0.40	0.41*

Note. Agr: aggression, Ext: extraversion, Nrt: neuroticism, NV: negative valence, Opn: openness, PV: positive valence, Cns: conscientiousness, MT: Mental Toughness, Mch: Machiavellianism, Psc: psychopathy, Nrc: narcissism, DT: Dark Triad, C: classical mode of isometric contraction, P: impulse mode of isometric contraction, D: dominant hand, ND: non-dominant hand, Fmax: maximal force, RFD: maximum rate of force development, tFmax: time needed for achieving Fmax, tRFDmax: the time needed for achieving RFD, NRI: neural reserve index, $*p<0.05$, $**p<0.01$

Table 4. The resulting models of multiple linear regression analysis of Handgrip Neuromuscular Characteristics (standardized coefficients) as predictors of Psychological Characteristics

	Agr	Eks	Nrt	NV	Opn	PV	Cns	MT	Mch	Psc	Nrc	DT
R2	0.94	0.18	0.74	0.71	0.46	0.46	0.14	0.46	0.44	0.29	0.70	0.55
Adjusted R2	0.90	0.14	0.58	0.47	0.19	0.32	0.06	0.35	0.21	0.26	0.55	0.40
F	23.10***	5.01*	4.48*	2.96*	1.71	0.28	1.78	4.24*	1.90	9.34*	4.63*	3.64*

(continued on next page)

(continued from previous page)

Table 4. The resulting models of multiple linear regression analysis of Handgrip Neuromuscular Characteristics (standardized coefficients) as predictors of Psychological Characteristics

	Agr	Eks	Nrt	NV	Opn	PV	Cns	MT	Mch	Psc	Nrc	DT
CFmaxND	1.4***	-	-	-	-0.9	-1.5**	-	-	0.7	-	-	-
CRFDND	-4.1***	-	-2.3**	-	5.8	-	-	-	-	-	-1.5*	-1.3
CtFmaxND	-0.3**	-	-5 0.8***	-0.4*	0.3	-	-	0.4*	-	-	-	-
CtRFDND	-	-	-0.4	0.3	-	-	1.1	0.5*	0.6	-	-	-
CFmaxD	-	-	-	3.0**	-	-	-	-	-	-	-2.7**	-1.4*
CRFDD	0.7**	-	-	-7.2*	-1.1*	1.3	-	-	-4.6	0.53**	8.1**	2.8**
CtFmaxD	0.3*	-	0.9**	0.6	-	-	-	-0.6**	-	-	-	-
CtRFDD	-0.6***	-	-	-	-	-	-	-	-	-	-	-
PFmaxND	-	-0.4*	2.1**	-	-	-	-1.1	-	-	-	-	-
PRFDND	0.7*	-	-	-	-3.1	1.7*	-	-	-	-	3.5***	2.5**
PtFmaxND	0.1	-	0.4*	0.4*	-	-	-	-	0.2	-	-0.3	-
PtRFDND	-1.4***	-	-0.7*	-	-	-	-	-	-0.5	-	-	-
PFmax_D	_	-	-	-2.4*	-	-1.4*	-	-	-	-	-	-
PRFDD	_	-	-	4.5*	-	-	-	-	3.5	-	-6.2*	-1.9*
PtFmaxD	_	-	-	0.5	0.3	-	-	-	-	-	-	-
PtRFDD	0.8***	-	0.5**	-0.3	-	0.8**	-	-	-	-	0.7**	0.5*
NRIND	_	-	-	-	-1.9	-	-	0.7**	-	-	-	
NRID	_	-	-0.3	1.1*	0.9**	-	-	-	1.4	-	-1.2	-

Note. Agr: aggression, Ext: extraversion, Nrt: neuroticism, NV: negative valence, Opn: openness, PV: positive valence, Cns: conscientiousness, MT: Mental Toughness, Mch: Machiavellianism, Psc: psychopathy, Nrc: narcissism, DT: Dark Triad, R2:coefficient of determination, F: F statistic, C: classical mode of isometric contraction, P: impulse mode of isometric contraction, D: dominant hand, ND: non-dominant hand, Fmax: maximal force, RFD: maximum rate of force development, tFmax: time needed for achieving Fmax, tRFDmax: the time needed for achieving RFD, NRI: neural reserve index, *p<0.05, **p<0.01, ***p<0.001

The multiple linear regression analysis started with all handgrip neuromuscular variables as predictors for Agr (R^2=0.95), Ext (R^2=0.74), Nrt (R^2=0.82), NV (R^2=0.75), Opn (R^2=0.62), PV (R^2=0.62), MT (R^2=0.75), Mch (R^2=0.56), Psc (R^2=0.56), Nrc (R^2=0.78), DT (R^2=0.69), where only a Agr model was significant ($p<0.05$). Performing backward stepwise selection resulted in more efficient models (Table 4).

Cross-validation on 75% of randomly selected respondents revealed the following models Agr (R^2=0.96), Ext (R^2=0.41), Nrt (R^2=0.79), NV (R^2=0.76), MT (R^2=0.45), Psc (R^2=0.37), Nrc (R^2=0.78), DT (R^2=0.70), where Agr, Ext, Nrt, Psc, Nrc, and DT models were significant ($p<0.05$).

Discussion

This study aimed to investigate the relationship between neuromuscular characteristics of the hand grip expressed in different modules of isometric contraction and psychological characteristics. Our findings have illuminated numerous significant associations, thereby corroborating the first hypothesis. Numerous effective regression models, which can explain a significant percentage of the variance of psychological characteristics (over 90% in Agr), supporting the second hypothesis, were also documented.

Before discussing explored relationships and comparing the morphological characteristics to the general population (Dopsaj, Pajic, et al., 2021), it could be stated that participants come from an average, physically prepared and healthy population. According to descriptive indicators (Table 2), all handgrip neuromuscular variables are also near average (Dopsaj et al., 2019b, 2019a). A similar can be concluded by comparing the psychological characteristics of the sample (Table 1) to the general population (Dinić et al., 2018b).

The results of the MANOVA confirm the findings of previous studies (Dopsaj, Klisaric, et al., 2021; Suzovic & Nedeljkovic, 2009) in the manifestation of neuromuscular characteristics in the classic and impulse mode of isometric contraction, which supports the conclusions of the difference in physiological mechanisms responsible for their manifestation.

The observed correlations (Table 3) also mainly align with prior research (Stephan et al., 2022) when it comes to the existence and direction of relationships between handgrip neuromuscular and psychological characteristics. The most significant deviation is a negative correlation with Ext, which could be explained by the documented inconsistency of findings of previous studies (Stephan et al., 2022). Namely, the difference in correlations is documented when they are examined separately for women and men or altogether. In our study, the sample is composed of persons of both sexes. However, unlike the previous research, allometric partialization enabled the partialisation of the effect of the body mass on the production of muscle force (Dulac et al., 2016). Therefore, the obtained correlation is a valid description of the observed relationship and not the sampling artefact.

Another novelty of our research is the association between neuromuscular characteristics with MT and elements of DT. Namely, while MT, Mch and Nrc (similar to Opn, Nrt, Cns and PV) do not significantly correlate with neuromuscular characteristics, Psc positively correlates with Fmax and RFD (similar to NV). DT positively correlates with PFmaxND as well as with the ability to generate more force in less or the same time in impulse compared to the classical mode of isometric contraction for the dominant hand (NRID). We believe that NRID can also be described as an indicator of the possibility of creating more nerve impulses when needed, as well as efficient execution of the movements while maintaining neural reserve. In our opinion, this link is lacking (since bigger NRID indicate smaller reserve) ability to efficiently execute movements and tendencies of benevolent behaviour and can be potentially described as a lack of impulse control, both in the sense of motor control and behaviour in general. Adding to this negative correlation of Agr and Ext with Fmax and RFD, the hypothetical psychological profile of persons able to generate a large amount of force quickly (and vice versa) can be hypothetically described as non-aggressive introverts with a negative self-image prone to anti-social behaviour, emotional coldness, impulsive and manipulative. On the other hand, the ability to control impulses and maintain neural reserve could be a corrective mechanism which prevents the manifestation of the listed tendencies through aggression.

The difference in a relationship can be observed when comparing the non-dominant to the dominant hand, RFD to Fmax, and the impulse mode to the classical one. This result opens some new possibilities for explaining the relationships that were obtained. Although all mentioned variables represent a complex neuromuscular characteristic, because of its dependence on the speed of recruitment of motor units, RFD primarily reflects the ability of the nervous system to produce and transport impulses quickly (Baudry & Duchateau, 2021; Dideriksen et al., 2020), this is especially true for non-dominant hand in impulse mode of contraction. The possibility that some relationship between HGS and psychological characteristics can also be explained by the peculiarities of the functioning of the nervous system and not exclusively with the muscular strength factors is worth additional studies.

Regression models (Table 4) have a surprisingly high coefficient of determination, which raises concerns about overfitting. Outlier analysis showed that this cannot be attributed to skewed distributions of the scores due to extreme values. Adjusted R^2 scores showed that initial models are mainly unsteady. The exception is the Agr model, which initially showed good stability. After performing stepwise regression analyses, models gained much more stability regarding adjusted R^2.

Regarding cross-validation, the total sample that is not too large limits its performance. Therefore, one should not rush to say that even six models have been validated. Namely, although some models showed similarity in the total sample and on a sample of 75% of randomly selected respondents, cross-validation still showed that there is model instability and that some of the original models were not statistically significant in the repeated procedure. At this moment, it is difficult to judge whether any of the arguments mentioned above represent the reality of things and which are artefacts of sampling. Such findings call for caution in the interpretation of the obtained models. However, they also show that new research on this topic is justified. Furthermore, the obtained results show that conducting this research was justified and that the relationship between the handgrip and psychological characteristics was not exhausted by previous research.

However, obtained regression models (Table 4), with surprisingly high coefficient of determination, speak in favour of the justification of this research as well as the promising possibility that the results of future studies will bring numerous opportunities for practical application in addition to the theoretical value. What regression analysis brings in relation to the correlation is primarily a synergistic effect of subtle differences in the manifestation of measured neuromuscular characteristics when the psychological characteristics in question are predicted. It can be clearly noticed that the duration of the excitation has its share in explaining the variance of some psychological characteristics, not only the intensity of the excitation, as it could be concluded on the basis of correlation analysis. Regression analysis also showed unique connection patterns with neuromuscular characteristics specific to individual psychological characteristics. In this way, a more apparent connection of motor behaviour with a broader domain of behaviour government is established.

Since the HGS test is already in use as a robust and straightforward marker of overall body strength and health status (Cronin et al., 2017), and since explored psychological characteristics are also associated with health outcomes and life expectancy (Ziegler et al., 2015), obtained relationship can be used in practice to increase its prognostic and preventive value. Given the ease of HGS test conduction from one and all, which demonstrated direct and indirect relationships with health, it can be a very effective screening tool.

This study has certain limitations which should be taken into account when making conclusions. A convenience sampling method instead of a random one represents a limitation of its representativeness when it comes to the generalization of findings. Also, although it meets the criteria of a power analysis, this sample is not too large to claim that the findings can apply to other samples or even the general population. By applying stepwise regression, an attempt was made to increase the generability of the obtained results, but the scope of this method is still limited. In the end, correlational design limits the possibility of concluding the nature of the observed relationship.

Received: 20 June 2025 | **Accepted:** 27 August 2025 | **Published:** 15 October 2025

References

Andersen, L. L., & Aagaard, P. (2006). Influence of maximal muscle strength and intrinsic muscle contractile properties on contractile rate of force development. *European Journal of Applied Physiology*, *96*(1), 46–52. https://doi.org/10.1007/s00421-005-0070-z

Baudry, S., & Duchateau, J. (2021). Changes in corticospinal excitability during the preparation phase of ballistic and ramp contractions. *The Journal of Physiology*, *599*(5), 1551–1566. https://doi.org/10.1113/JP281093

Campbell, M., Varley-Campbell, J., Fulford, J., Taylor, B., Mileva, K. N., & Bowtell, J. L. (2019). Effect of Immobilisation on Neuromuscular Function In Vivo in Humans: A Systematic Review. *Sports Medicine*, *49*(6), 931–950. https://doi.org/10.1007/s40279-019-01088-8

Čolović, P., Smederevac, S., & Mitrović, D. (2014). Velikih Pet Plus Dva: Validacija Skraćene Verzije. *Primenjena Psihologija*, *7*(3–1), 227. https://doi.org/10.19090/pp.2014.3-1.227-254

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. https://doi.org/10.1519/JSC.0000000000002149

Dideriksen, J. L., Del Vecchio, A., & Farina, D. (2020). Neural and muscular determinants of maximal rate of force development. *Journal of Neurophysiology*, *123*(1), 149–157. https://doi.org/10.1152/jn.00330.2019

Dinić, B. M., Petrović, B., & Jonason, P. K. (2018a). Serbian adaptations of the Dark Triad Dirty Dozen (DTDD) and Short Dark Triad (SD3). *Personality and Individual Differences*, *134*(June), 321–328. https://doi.org/10.1016/j.paid.2018.06.018

Dinić, B. M., Petrović, B., & Jonason, P. K. (2018b). Serbian adaptations of the Dark Triad Dirty Dozen (DTDD) and Short Dark Triad (SD3). *Personality and Individual Differences*, *134*(June), 321–328. https://doi.org/10.1016/j.paid.2018.06.018

Dopsaj, M., Klisaric, D., Kapeleti, M., Ubovic, M., Rebic, N., Piper, D., Trikos, B., Rajkovic, A., Nikolic, D., Nikolic, M., Vasiljevic, M., & Bozovic, B. (2021). RELIABILITY AND DIFFERENCES BETWEEN THE CLASSIC AND THE IMPULSE MODEL OF ISOMETRIC TESTING IN FUNCTION OF MAXIMAL AND EXPLOSIVE STRENGTH: PILOT RESEARCH. *PHYSICAL CULTURE*, *75*(2). https://doi.org/doi: 10.5937/fizkul75-39013

Dopsaj, M., Nenasheva, A., Tretiakova, T., Syromiatnikova, Y., Surina-Marysheva, E., Marković, S., & Dopsaj, V. (2019a). HANDGRIP MUSCLE FORCE CHARACTERISTICS WITH GENERAL REFERENCE VALUES AT

CHELYABINSK AND BELGRADE STUDENTS. *Human Sport Medicine*, *19*(2), 27–36. https://doi.org/10.14529/hsm190204

Dopsaj, M., Nenasheva, A. V., Tretiakova, T. N., Syromiatnikova, Y. A., Surina-Marysheva, E. F., Marković, S., & Dopsaj, V. (2019b). Handgrip muscle force characteristics with general reference values at Chelyabinsk and Belgrade students. *Human Sport Medicine*, *19*(2), 27–36. https://doi.org/10.14529/hsm190204

Dopsaj, M., Pajic, Z., Kocic, A., Erak, M., Pajkic, Aleksandar, Vicentijevic, A., Milosevic, M., & Bozovic, B. (2021). Profile for Body Fat Percentage of Serbian Working Population, Aged from 18 to 65, Measured by Multichannel Bioimpedance Method. *Int. J. Morphol*, *39*(6), 1694–1700.

Dulac, M., Boutros, G. E. H., Pion, C., Barbat-Artigas, S., Gouspillou, G., & Aubertin-Leheudre, M. (2016). Is handgrip strength normalized to body weight a useful tool to identify dynapenia and functional incapacity in post-menopausal women? *Brazilian Journal of Physical Therapy*, *20*(6), 510–516. https://doi.org/10.1590/bjpt-rbf.2014.0184

Gallup, A. C., White, D. D., & Gallup, G. G. (2007). Handgrip strength predicts sexual behavior, body morphology, and aggression in male college students. *Evolution and Human Behavior*, *28*(6), 423–429. https://doi.org/10.1016/j.evolhumbehav.2007.07.001

Gucciardi, D. F., Hanton, S., Gordon, S., Mallett, C. J., & Temby, P. (2015). The Concept of Mental Toughness: Tests of Dimensionality, Nomological Network, and Traitness. *Journal of Personality*, *83*(1), 26–44. https://doi.org/10.1111/jopy.12079

Hegerstad, C., Dillern, T., Giske, R., & Shalfawi, S. (2019). BASES Conference 2019 – Programme and Abstracts, The relationship between mental toughness and physical performance test in police college students. *Journal of Sports Sciences*, *37*(sup1), 27. https://doi.org/10.1080/02640414.2019.1671688

Jonason, P. K., & Webster, G. D. (2010). The dirty dozen: A concise measure of the dark triad. *Psychological Assessment*, *22*(2), 420–432. https://doi.org/10.1037/a0019265

Knezevic, O. M., Mirkov, D. M., Kadija, M., Nedeljkovic, A., & Jaric, S. (2014). Asymmetries in explosive strength following anterior cruciate ligament reconstruction. *The Knee*, *21*(6), 1039–1045. https://doi.org/10.1016/j.knee.2014.07.021

Liu, J. Z., Yang, Q., Yao, B., Brown, R. W., & Yue, G. H. (2005). Linear correlation between fractal dimension of EEG signal and handgrip force. *Biological Cybernetics*, *93*(2), 131–140. https://doi.org/10.1007/s00422-005-0561-3

Marković, S., Dopsaj, M., & Veljković, V. (2020). Reliability of Sports Medical Solutions Handgrip and Jamar Handgrip Dynamometer. *Measurement Science Review*, *20*(2), 59–64. https://doi.org/10.2478/msr-2020-0008

Papageorgiou, K. A., Benini, E., Bilello, D., Gianniou, F., Clough, P. J., & Costantini, G. (2019). Bridging the gap: A network approach to Dark Triad, Mental Toughness, the Big Five, and perceived stress. *Journal of Personality*, *87*(6), 1250–1263. https://doi.org/10.1111/jopy.12472

Sahaly, R., Vandewalle, H., Driss, T., & Monod, H. (2001). Maximal voluntary force and rate of force development in humans—Importance of instruction. *European Journal of Applied Physiology*, *85*(3–4), 345–350. https://doi.org/10.1007/s004210100451

Sawilowsky, S. S. (2009). New Effect Size Rules of Thumb. *Journal of Modern Applied Statistical Methods*, *8*(2), 597–599. https://doi.org/10.22237/jmasm/1257035100

Stamatis, A., Morgan, G. B., Moreno, P. J. F., Pineda, L. T. B., Sanchez, A. I. A., & Torres, S. S. (2022). Multicultural Invariance and Validation of the Mental Toughness Index in North American and Mexican Athletes. *Nuevas Tendencias En Educación Física, Deporte y Recreación*, *43*, 643–650.

Stephan, Y., Sutin, A. R., Canada, B., Deshayes, M., Kekäläinen, T., & Terracciano, A. (2022). Five-factor model personality traits and grip strength: Meta-analysis of seven studies. *Journal of Psychosomatic Research*, *160*, 110961. https://doi.org/10.1016/j.jpsychores.2022.110961

Sullivan, G. M., & Feinn, R. (2012). Using Effect Size—Or Why the *P* Value Is Not Enough. *Journal of Graduate Medical Education*, *4*(3), 279–282. https://doi.org/10.4300/JGME-D-12-00156.1

Sutin, A. R., Stephan, Y., & Terracciano, A. (2018). Facets of conscientiousness and objective markers of health status. *Psychology & Health*, *33*(9), 1100–1115. https://doi.org/10.1080/08870446.2018.1464165

Suzovic, D., & Nedeljkovic, A. (2009). Short pulse contractions: Relationship between maximal forces and rate of force development. *Physical Culture*, *63*(1), 17–34.

Vukmirovic, M., Rajovic, N., Pavlovic, V., Masic, S., Mirkovic, M., Tasic, R., Randjelovic, S., Mostic, D., Velickovic, I., Nestorovic, E., Milcanovic, P., Stanisavljevic, D., & Milic, N. (2020). The Burnout Syndrome in Medical Academia: Psychometric Properties of the Serbian Version of the Maslach Burnout Inventory—Educators Survey. *International Journal of Environmental Research and Public Health*, *17*(16), 5658. https://doi.org/10.3390/ijerph17165658

Ziegler, M., Cengia, A., Mussel, P., & Gerstorf, D. (2015). Openness as a buffer against cognitive decline: The Openness-Fluid-Crystallized-Intelligence (OFCI) model applied to late adulthood. *Psychology and Aging*, *30*(3), 573–588. https://doi.org/10.1037/a0039493