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EXPLORING THE INTERPLAY OF HANDGRIP NEUROMUSCULAR, MORPHOLOGICAL AND PSYCHOLOGICAL CHARACTERISTICS IN WELL-TRAINED AND ELITE ATHLETES: GENDER-SPECIFIC PATTERNS AND DISCRIMINANT MODELS

Miloš M. MILOŠEVIĆ[1], Nenad KOROPANOVSKI[2], Marko VUKOVIĆ[3], Branislav BOŽOVIĆ[4], Filip KUKIĆ[5], Miloš R. MUDRIĆ[4] and Milivoj DOPSAJ[4]

[1] *Faculty of Physical Education and Sports Management, Singidunum University, Belgrade Serbia*
[2] *Department of Criminalistics, University of Criminal Investigation and Police Studies, Belgrade, Serbia*
[3] *Academy for National Security, Belgrade, Serbia*
[4] *Faculty of Sport and Physical Education, University in Belgrade, Belgrade, Serbia*
[5] *Faculty of Physical Education and Sports, University of Banja Luka, Banja Luka, Bosnia and Herzegovina*

ABSTRACT

This study aimed to explore the interplay of neuromuscular characteristics of handgrip and morphological characteristics, along with personality traits, in well-trained and elite athletes. The research involved a sample of 155 well-trained and elite athletes. A cross-sectional design was employed. A sliding device that measures isometric finger flexor force was used to assess handgrip neuromuscular characteristics. Key morphological characteristics, including body height, body mass and body mass index, were measured using a portable stadiometer and the InBody 720 device. Personality traits were evaluated using the Big Five plus Two Questionnaire. The study found numerous significant correlations, among which the positive association of positive valence and maximum force of the dominant (r=0.77) and non-dominant (r=0.82) hand in a group of female elite athletes stand out. The results revealed gender-specific patterns in the relationships examined. Canonical discriminant analysis indicated the presence of statistically significant discriminant functions for all variables assessed, both in female (Wilks's Λ=0.44, $\chi^2(22)$=37.67) and male samples (Wilks's Λ=0.59, $\chi^2(20)$=41.18), with 90% accuracy for females and 80% accuracy for males when discriminating between elite and well-trained athletes. The results support the need for further research in this area to enhance our understanding of the identified correlations.

Keywords: Athlete selection; Big Five model; Body mass index; Handgrip strength test; Maximal force of handgrip; Maximal rate of force development of handgrip.

INTRODUCTION

The handgrip strength (HGS) test has been used as a simple and robust marker of overall body strength (Bohannon, 2001; Cronin *et al.,* 2017) and health status (Sayer & Kirkwood, 2015;

McGrath *et al*., 2018; 2020; Mey *et al.,* 2022). It is both a highly gender dimorphic and a lateralised measurement (Kamarul *et al.*, 2006; Gallup *et al.,* 2007a), as well as a reflection of muscular force and neural activity (i.e., neuromuscular characteristics) (Innes, 1999; Liu *et al.,* 2005). This test has been used in the testing and selection of athletes (Dopsaj *et al.,* 2019b; Ivanović & Dopsaj, 2012). To this day, there are well-documented correlations between HGS and various psychological characteristics and personality traits (Crust & Clough, 2005; Gallup *et al.,* 2010; Atkinson *et al.,* 2012; Goldberg *et al.,* 2017; Hegerstad *et al.,* 2019), such as negative correlations with neuroticism (Fink *et al.,* 2016; Mueller *et al.,* 2016; 2018; Kerry & Murray, 2018; Stephan *et al.,* 2022), positive correlations with extraversion (Fink *et al*., 2016; Mueller *et al.,* 2016; 2018; Kerry & Murray, 2018; Stephan *et al.,* 2022), positive correlations with openness (Mueller *et al.,* 2016; Stephan *et al.,* 2022), positive correlations with agreeableness (Mueller *et al.,* 2016) and positive correlations with conscientiousness (Mueller *et al.,* 2016; Sutin *et al.,* 2018; Stephan *et al.,* 2022). In these studies, different versions of the inventories for assessing the Big Five personality traits were used. The Big Five model of personality, often associated with the foundational work of Costa and McCrae (1992), actually evolved from various lines of research that consistently identified similar dimensions of human personality. When validated across different linguistic and cultural contexts, researchers found that the model remained robust (Costa & McCrae, 1992). However, many also identified five dimensions of personality closely aligned with the Big Five, while proposing alternative frameworks or additional traits. As a result, nuanced models such as the Big 4+1, 5+1 and 5+2 have emerged (Čolović, *et al.,* 2014). The Big 5+2 model is obtained when positive and negative valence are added to the essential five personality traits, which is important in understanding self-appraisals and social evaluations (McCrae & Costa, 1995). It should be noted that aggressiveness, which is often found in such models, can be seen as the opposite of agreeableness, that is, a negative part of this dimension.

Gender, age and occupation-based specificities of the correlations mentioned above have also been documented (Fink *et al.,* 2016; Kerry & Murray, 2018; Stephan *et al.,* 2022; Milošević *et al.,* 2025). However, all prior research has been conducted on the general population, and it is not known whether these relationships exist or whether they are specific in strictly selected populations that are characterised by a long-term and strenuous process of physical exercise, such as athletes. In other words, since physical exercise affects neuromuscular characteristics, the question posed is whether the mentioned relationships between HGS and personality traits would still be present among a population of well-trained or elite athletes? Furthermore, the studies thus far have not analysed the mentioned relationships according to the force–time curve produced in the HGS task. This method is reliable and widely used in the testing of athletes (Innes, 1999; Cronin *et al.,* 2017). 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 by analysing the force–time curves produced in the HGS task. Moreover, indexes of dimorphism and excitation, which are important for athletic success (Ivanović & Dopsaj, 2012; Dopsaj *et al.,* 2019b; Marković *et al.,* 2020), can be calculated and researched from those measures. This is important for research as various physiological mechanisms, such as neural drive, motor unit discharge rate, the occurrence of double discharge, the synchronisation of the motor units, muscle fibre volume and body composition, are responsible for the manifestation of different neuromuscular characteristics (Baudry & Duchateau, 2021; Del Vecchio *et al.,* 2019; Dideriksen *et al.,* 2020; Rodríguez-Rosell *et al.,* 2018). Additionally, since hands have different functional roles in different sport-specific movements, different neuromuscular characteristics such as Fmax and RFD of handgrip will play a decisive role in sports performance in different sports (Cronin *et al.,* 2017).

Essential morphological characteristics of body height (BH), body mass (BM) and body mass index (BMI) are important in understanding and predicting athletic success (Bankovic *et al.,* 2018; Pilis *et al.,* 2019; Reale *et al.,* 2020; Zarić *et al.,* 2020). They highly correlate with the neuromuscular characteristics of various body parts (Jaric *et al.,* 2005; Tan *et al.,* 2024), as well as with the HGS (Morlino *et al.,* 2021; Wen *et al.,* 2022). Moreover, morphological characteristics are related to personality traits such as conscientiousness, neuroticism, extraversion, agreeableness and openness (Faith *et al.,* 2001; Magee *et al.,* 2013; Sutin & Terracciano, 2016a; 2016b; Stefanovics *et al.,* 2021), and further mediate several of the already mentioned relationships of HGS and psychological characteristics and personality traits (Stephan *et al.,* 2022). Although some research has been carried out on male adolescent athletes (Crewther *et al.,* 2024), relationships between morphological and personality traits in various groups of athletes (female or elite athletes, for example) have not been sufficiently investigated thus far.

Based on what has been described so far, a gap in the literature could be identified. Although well documented in previous studies, the relationships between neuromuscular characteristics of handgrip and morphological characteristics along with personality traits have not been sufficiently investigated in populations characterised by daily strenuous physical exercise, such as athletes. Furthermore, when the relationships are described, most studies have dealt exclusively with HGS. At the same time, research on other neuromuscular parameters, such as the time in which forces are generated or RFD, has not been conducted. Finally, since the Big 5 model also has local variations, the question arises whether its application will yield results that are in line with previous studies. This research focus is essential because the aforementioned versions of the Big 5 model and the questionnaires derived from them are widely used in the practice of psychological assessment and selection of athletes, but also beyond. The theoretical contribution of this research does not relate exclusively to the verification and description of previously known relations in a specific population. A more detailed investigation of neuromuscular characteristics, which is expanding the domain of research from strength to force and time parameters, will provide a clearer picture of the nature of the relationships investigated. While this is only an exploratory study, its results may warrant further, more comprehensive research on the subject. Moreover, this research has an applied value for the selection and training of athletes through the description of differences and even the recognition (discrimination) of athletes of differing levels of sports performance based on the specificity of the investigated relationships, as recommended in previous talent identification multifactorial approach research (Robertson *et al.,* 2022).

PURPOSE OF RESEARCH

This study aimed to explore the existence and specificities of relationships between neuromuscular characteristics of handgrip and morphological characteristics along with personality traits in well-trained and elite athletes. The first hypothesis (H1) was that superior handgrip neuromuscular and morphological characteristics would be associated with positive psychological characteristics in both well-trained and elite athletes. Since achieving sports results requires a superior level of all three groups of characteristics, the second hypothesis (H2) was that in elite athletes, the studied relationships would be in the same direction but of greater intensity compared with well-trained athletes. The third hypothesis (H3) was that elite athletes have superior handgrip neuromuscular, morphological and psychological characteristics than well-trained athletes and can be accurately recognised according to them.

METHODS

Study design and setting

A non-experimental, cross-sectional, correlational research study design was followed. The research was conducted in the Laboratory for Motoric Research of the Faculty of Sport and Physical Education, University of Belgrade.

Participants

The research was conducted on a sample of students from all levels of study at the Faculty of Sport and Physical Education, University of Criminal Investigation and Police Studies and Academy for National Security, Belgrade, Serbia. This population is strictly selected based on, among others, superior physical abilities and level of physical fitness (Dopsaj *et al.,* 2019a; Papadakis *et al.,* 2021; Koropanovski *et al.,* 2022). In order to successfully finish their studies, maintaining a high level of physical fitness is required. The highest level of physical fitness was the first criterion for inclusion in the sample. The respondents were expected to have been involved in physical training at least three times a week for at least 5 years and to have trained at least five times a week in the last year, while competitive experience was not a criterion for inclusion. Although the level of the physical is a necessary criterion in order to enrol and actively study at the faculties selected for the sample of respondents, professors and instructors working with the population from which the sample was selected at the faculties additionally confirmed this criterion for each respondent individually. The second inclusion criteria for participation were voluntary registration and the absence of any health problems before and during the study. Winning a medal at a national or international competition, as well as membership of national teams, were criteria for the selection of elite athletes. Any history of arm injury, as well as the failure to perform all the tests, were exclusion criteria. The total sample included 155 participants, of which 60 were female (age 20.7±3.2 years, BH 171.4±6.8 cm, BM 64.7±8.9 kg, BMI 22.2±2.8 kg·m^2) and 94 male (age 22.2±6.2 years, BH 182.9±7.3 cm, BM 79.5±8.2 kg, BMI 24.1±2.0 kg·m^2). The female sample had 5.8±5.7 years of athletic experience, while the male sample has 8.63±6.3 years of athletic experience. Among the participants were 46 national champions and members of national selections (13 females and 23 males) who constituted the elite athletes subsample. In contrast, the rest of the sample constituted the subsample of well-trained athletes. Among athletic disciplines, the most frequent were athletics (*n*=6), basketball (*n*=14), dancing (*n*=6), gymnastics (*n*=5), handball (*n*=4), football (*n*=33), combat sports and martial arts (*n*=23), tennis (*n*=5), swimming (*n*=6) and volleyball (*n*=20), as well as bodybuilding and weight lifting (*n*=12).

Procedures

All testing procedures were conducted within two sessions. During the first session, participants filled out the questionnaire to record their sociodemographic status, as well as the Big 5+2 questionnaire, with no time limit. The second session was performed the next day and included the BH and BM measurements, as well as the performance of the HGS test. In order to avoid injuries and achieve optimal performance, the test was preceded by a standard warm-up routine (Woods *et al.,* 2007): they performed 5 min of an upper-body exercise routine (Amako *et al.,* 2003) and 3 min of exercises that activate tested muscle groups, which included superficial and deep finger flexor muscles (holding a 10 kg dumbbell, 5–10 s hang on a pull-up bar, 3–5 inverted rows). 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 between the warm-up trials was 1–2 min, while the rest between the warm-up trials and actual testing procedures was about 5 min. HGS for dominant and non-dominant hands were performed in random order. All chosen tests have proven valid and have been used in numerous previously published studies concerning the neuromuscular characteristics of the handgrip, morphological characteristics, and personality traits (Gallup *et al.,* 2007a; Ivanović & Dopsaj, 2012; Čolović *et al.,* 2014; Bankovic *et al.,* 2018; Dopsaj *et al.,* 2018; 2019b; 2019a; 2021; Trajkov *et al.,* 2018; Rakić *et al.,* 2019; Marković *et al.,* 2020; Zarić *et al.,* 2020; Milošević *et al.,* 2025).

Morphological characteristics

BH was measured with a portable stadiometer (Swiss Instruments, Zurich, SU), while BM was measured on the InBody 720 device in accordance with a standardised procedure (Gába *et al.,* 2015). From the obtained values, BMI was calculated.

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 with the Jamar Handgrip Dynamometer [dominant hand intraclass correlation coefficient (ICC) 0.98, non-dominant hand ICC 0.97] (Marković *et al.,* 2020). It allows the adjustment of each participant's handgrip size. The HGS device was attached to the force transducer that measured the isometric force of finger flexors. The standard tensiometric 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 (Gallup *et al.,* 2007a; Ivanović & Dopsaj, 2012; Trajkov *et al.,* 2018; Dopsaj *et al.,* 2019a). In short, participants were in a sitting position, holding the measuring device in their hand, with the arm extended next to the body while the other arm was resting alongside the body. They were not allowed to change their position during the test or to lean the hand and the device on the thigh or another solid object.

For the HGS test, participants were instructed to squeeze the device as powerfully and as fast as possible. The test was performed twice with a 2-min between-trial rest. Their force output was projected on the screen, and they were verbally encouraged to obtain the best result. From the HGS test, Fmax (N), tFmax (s), RFD (N/s), tRFDmax (s) of dominant (D) and non-dominant (ND) hand were collected. From these values, the Dimorphism index (DI) of Fmax (DIF) and RFD (DIRFD) and Excitation indexes (EI) for both D and ND hands, and sum (S) were calculated in the following way:

- DIF=FmaxD/FmaxND
- DIRFD=RFDD/RFDND

Personality traits

A shortened version of the Big Five Plus Two (BF+2) questionnaire was used to assess personality traits. The instrument is composed of 70 items that assess five basic dimensions: neuroticism (Nrc), 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 five-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 (Tasic *et al.,* 2020; Vukmirovic *et al.,* 2020) due to its good psychometric characteristics (Čolović *et al.,* 2014).

Statistical analysis

The sample size was determined after applying a power analysis. For two-tail *t*-tests – correlation: point biserial model, two tails, with α=0.05, power 1-β=0.80, and effect size ρ=0.50 – the sample size should comprise at least 26 participants, while for the effect size ρ=0.30, the total sample size should comprise at least 80 participants. For f tests – ANOVA: fixed effects, omnibus, one-way, with α=0.05, power 1-β=0.80, effect size f=0.4 and two groups – the sample size should be 52 participants at least. 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, NY, USA). Statistical significance was defined at the level of 95% probability for the value of $p<0.05$ and the level of 99% probability for the value of $p<0.01$. Descriptive statistical analysis was performed, including mean (M), standard deviation (SD), minimal (Min) and maximal (Max) values, and coefficient of variation (CV). The Kolmogorov–Smirnov test was used to assess the normality of distribution.

Spearman's correlation analysis was performed to discover the relationship between the morphological and handgrip neuromuscular characteristics with personality traits (H1 and H2). 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 discover the differences between well-trained and elite athletes (H3), the Mann–Whitney U test was performed. For the purpose of evaluating the potential of recognising well-trained and elite athletes according to the handgrip neuromuscular, morphological and psychological characteristics (H3), canonical discriminant analysis was performed. In the case of normality violation, normalisation (square, cube root, logarithmic transformation) of the variable was performed. In this case, after applying statistical methods for score distribution, the normalisation normality of the distributions was still violated; those variables were not used for further analyses.

Ethical considerations

Participants were informed about the study aims and procedures and they provided written consent for their voluntary participation. 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 and the Declaration of Helsinki. The study design was approved by the Ethical Board (number 484-2) of the Faculty of Sport and Physical Education, University of Belgrade, Serbia.

RESULTS

Table 1 presents a descriptive statistical analysis of the female sample. The non-parametric Kolmogorov–Smirnov test showed significant deviations from the normal distribution for the variables Nrt, NV, tRFDmaxD, and EID in the well-trained athletes subsample. According to the CV, both subsamples showed high variability on the Agr, Nrt, tFmaxND, and tFmaxD.

Table 2 presents the descriptive statistical analysis results for the male sample. The non-parametric Shapiro–Wilk test showed significant deviations from the normal distribution for the variables Nrt, NV, tRFDmaxND, tFmaxD, tRFDmaxD and EIND in the well-trained athletes subsample. Similarly to women, according to CV, both the well-trained and elite male athletes showed high variability on the Agr, Nrt, tFmaxND and tFmaxD.

The correlation analysis (Table 3) revealed a weak positive association of Ext with EIND and Cns with DIRFD, as well as a weak negative association of Ext with RFDND, Nrt with EIS and NV with DIRF among the well-trained female athletes. Regarding the elite female athletes, there was a positive strong correlation of PV with FmaxND. Positive moderate correlations of Agr with tFmaxD, Ext with BMI and tFmaxND; Opn with FmaxND, RFDND and FmaxD; PV with FmaxND, RFDND and FmaxD; and Cns with BMI, FmaxND and RFDND were also revealed.

Table 1. **DESCRIPTIVE STATISTICAL ANALYSIS HANDGRIP NEUROMUSCULAR, MORPHOLOGICAL AND *PSY*-CHOLOGICAL CHARACTERISTICS FOR FEMALE PARTICIPANTS**

	Well-trained (*n*=47)						Elite (*n*=13)					
	Min	**Max**	**M**	**SD**	**CV**	**KSZ**	**Min**	**Max**	**M**	**SD**	**CV**	**SWW**
Aggression	1.00	4.10	2.24	0.75	33.71	0.78	1.60	3.80	2.58	0.77	29.75	0.43
Extraversion	2.50	5.00	4.10	0.62	15.20	0.95	2.90	4.50	3.92	0.54	13.65	0.85
Neuroticism	1.00	4.30	1.76	0.85	48.12	1.41*	1.00	2.90	1.49	0.59	39.31	0.83
Negative Valence	1.00	2.30	1.35	0.37	27.39	1.60*	1.00	2.10	1.33	0.36	27.16	1.00
Openness	3.00	4.90	4.17	0.53	12.71	0.75	2.70	5.00	4.02	0.58	14.32	0.67
Positive Valence	1.80	5.00	3.61	0.78	21.54	0.68	3.10	5.00	3.97	0.49	12.23	0.59
Conscientiousnes	2.40	5.00	4.31	0.62	14.36	0.92	3.70	5.00	4.55	0.40	8.72	0.78
Body Height*	1.58	2	1.71	0.07	4.16	0.94	1.65	1.85	1.74	0.05	3.16	0.62
Body Weight*	44	104	63.65	8.78	13.79	0.96	53	82	68.90	8.69	12.61	0.49
Body Mass Index	17.63	36.85	22.03	2.89	13.11	1.21	19.32	25.83	22.70	2.19	9.65	0.46
FmaxND	188	387	291.74	44.92	15.40	0.57	220	460	313.92	60.52	19.28	0.74
RFDND	1283	2654	1910.85	352.30	18.44	0.60	1374	2938	2073	429.24	20.71	0.61
tFmaxND	0.31	1.75	0.83	0.32	38.73	0.75	0.40	2.42	1.06	0.59	55.78	0.87
tRFDmaxND	0.09	0.16	0.12	0.01	12.04	0.85	0.10	0.14	0.11	0.01	10.83	0.59
FmaxD**	231	427	312.51	44.12	14.12	0.52	274	503	359.69	61.03	16.97	0.51
RFDD*	1203	3118	1970.43	364.19	18.48	0.54	1468	3483	2298.46	526	22.88	0.68
tFmaxD	0.25	1.79	0.99	0.37	37.49	0.57	0.40	2.33	1.05	0.51	48.38	0.55
tRFDmaxD	0.09	0.28	0.13	0.03	24.06	1.68**	0.11	0.14	0.12	0.01	7.67	0.51
DIF*	0.86	1.43	1.08	0.13	11.85	1.02	1.03	1.31	1.15	0.08	6.86	0.59
DIRFD	0.65	1.50	1.04	0.16	15.02	0.35	1.00	1.24	1.11	0.08	7.62	0.90
EIND	0.12	0.20	0.15	0.02	12.99	0.47	0.13	0.17	0.15	0.02	10.11	0.59
EID	0.11	0.31	0.16	0.03	18.87	1.39*	0.14	0.19	0.16	0.01	9.44	0.49
EIS	0.24	0.50	0.32	0.04	13.90	0.63	0.26	0.35	0.31	0.03	8.89	0.54

Note: *$p<0.05$, **$p<0.01$. CV = coefficient of variation; DIF = Dimorphism index of maximal force; DIRFD = Dimorphism index of maximum rate of force development; EID = Excitation index dominant; EIND = Excitation index non-dominant; EIS = Excitation index sum; FmaxD = Maximal force dominant; FmaxND = Maximal force non-dominant; KSZ = Kolmogorov–Smirnov z statistic; M = mean; Max = maximum; Min = minimum; RFDD = maximum rate of force development dominant; RFDND = maximum rate of force development non-dominant; SD = Standard deviation; SWW = Shapiro–Wilk w statistic; tFmaxD = time needed for achieving Fmax dominant; tFmaxND = the time needed for achieving Fmax non-dominant; tRFDmaxD = the time needed for achieving RFD dominant; tRFDmaxND = the time needed for achieving RFD non-dominant.

Table 2. **DESCRIPTIVE STATISTICAL ANALYSIS OF HANDGRIP NEUROMUSCULAR, MORPHOLOGICAL AND PSYCHOLOGICAL CHARACTERISTICS FOR MALE PARTICIPANTS**

	Well-trained (*n*=72)						Elite (*n*=23)					
	Min	**Max**	**M**	**SD**	**CV**	**KSZ**	**Min**	**Max**	**M**	**SD**	**CV**	**SWW**
Aggression*	1.00	4.10	2.02	0.72	35.80	1.16	1.10	4.30	2.46	0.90	36.51	1.28
Extraversion	1.40	5.00	4.05	0.70	17.37	0.85	3.30	5.00	4.22	0.44	10.47	0.64
Neuroticism	1.00	3.40	1.61	0.69	42.83	1.96***	1.00	3.30	1.77	0.81	45.71	0.90
Negative Valence	1.00	3.50	1.47	0.54	37.03	1.66**	1.00	3.70	1.73	0.74	42.72	1.10
Openness	2.60	5.00	4.02	0.55	13.79	0.84	2.90	5.00	4.26	0.53	12.49	0.95
Positive Valence	1.60	5.00	3.56	0.74	20.67	0.66	2.20	4.90	3.83	0.70	18.28	0.93
Conscientiousnes	2.40	5.00	4.28	0.75	17.58	1.55*	2.90	5.00	4.18	0.66	15.77	0.93
Body Height	1.65	2.00	1.82	0.08	4.17	1.01	1.75	2.00	1.85	0.06	3.18	0.59
Body Weight	60.40	97.00	78.49	7.83	9.98	0.39	68.00	101.00	82.55	8.74	10.59	0.49
Body Mass Index	19.99	28.00	23.96	1.85	7.72	0.55	19.86	27.16	24.34	2.25	9.26	0.75
FmaxND	284	702	492.86	91.66	18.60	0.50	283.00	704	505.61	92.53	18.30	0.74
RFDND	1782	4734	3285.22	628.76	19.14	0.62	1767.00	4789	3379.96	668.83	19.79	0.80
tFmaxND	0.27	2.13	0.92	0.46	49.66	1.24	0.24	2.39	0.83	0.49	59.10	0.71
tRFDmaxND	0.10	0.24	0.12	0.02	16.31	1.47*	0.09	0.18	0.12	0.02	14.92	1.16
FmaxD	294	735	520.65	96.95	18.62	0.52	349.00	720	517.09	88.28	17.07	0.57
RFDD	2011	5215	3432.26	775.14	22.58	0.72	1990.00	4990	3395.65	632.78	18.64	0.44
tFmaxD	0.22	3.59	0.99	0.61	61.49	1.34*	0.34	1.48	0.81	0.36	44.35	0.66
tRFDmaxD	0.10	0.33	0.12	0.03	26.94	2.28***	0.09	0.15	0.11	0.01	11.75	0.70
DIF	0.83	1.42	1.07	0.11	10.56	0.68	0.75	1.29	1.03	0.11	10.99	0.56
DIRFD	0.73	1.49	1.06	0.16	14.88	0.39	0.83	1.56	1.02	0.16	15.35	1.04
EIND	0.12	0.21	0.15	0.02	10.54	0.92	0.12	0.25	0.15	0.03	18.11	0.99
EID	0.12	0.25	0.15	0.02	15.70	1.19	0.13	0.18	0.15	0.01	9.52	0.61
EIS	0.25	0.42	0.31	0.04	11.62	0.83	0.26	0.40	0.31	0.03	11.03	0.91

Note: *$p<0.05$, **$p<0.01$, *** $p<0.00$. CV = coefficient of variation; DIF = Dimorphism index of maximal force; DIRFD = Dimorphism index of maximum rate of force development; EID = Excitation index dominant; EIND = Excitation index non-dominant; EIS = Excitation index sum; FmaxD = Maximal force dominant; FmaxND = Maximal force non-dominant; KSZ = Kolmogorov–Smirnov z statistic; M = mean; Max = maximum; Min = minimum; RFDD = maximum rate of force development dominant; RFDND = maximum rate of force development non-dominant; SD = Standard deviation; SWW = Shapiro–Wilk w statistic; tFmaxD = time needed for achieving Fmax dominant; tFmaxND = the time needed for achieving Fmax non-dominant; tRFDmaxD = the time needed for achieving RFD dominant; tRFDmaxND = the time needed for achieving RFD non-dominant

Table 3. **CORRELATION ANALYSIS OF HANDGRIP NEUROMUSCULAR AND MORPHOLOGICAL WITH PSYCHOLOGICAL CHARACTERISTICS FOR FEMALE PARTICIPANTS**

	Well-trained (n=47)							Elite (n=13)						
	Agr	**Ext**	**Nrt**	**NV**	**Opn**	**PV**	**Cns**	**Agr**	**Ext**	**Nrt**	**NV**	**Opn**	**PV**	**Cns**
Body Height	0.09	0.03	0.11	0.14	0.05	0.03	-0.13	0.12	-0.18	-0.11	0.01	0.32	0.12	0.04
Body Weight	0.16	-0.09	0.00	0.13	-0.22	0.04	-0.04	-0.15	0.20	-0.27	-0.08	0.44	0.46	0.46
Body Mass Index	0.14	-0.24	0.03	0.12	-0.27	-0.12	-0.02	-0.37	0.61*	-0.38	-0.17	0.37	0.30	0.61*
FmaxND	0.16	-0.16	0.04	0.13	-0.11	-0.09	-0.16	-0.2	-0.04	-0.36	-0.27	0.67*	0.82**	0.58*
RFDND	0.26	-0.37*	0.20	0.23	-0.21	-0.17	-0.2	-0.18	0.16	-0.08	-0.09	0.57*	0.63*	0.65*
tFmaxND	-0.01	0.09	0.10	0.01	-0.08	-0.09	0.03	-0.13	0.55*	-0.37	-0.17	0.21	0.18	0.3
tRFDmaxND	-0.02	0.12	-0.29	-0.06	0.03	0.16	0.15	-0.25	-0.07	-0.11	-0.3	-0.14	0.19	-0.29
FmaxD	0.15	-0.12	-0.03	-0.02	-0.1	-0.15	0.04	-0.13	-0.13	-0.22	-0.15	0.62*	0.77**	0.53
RFDD	0.17	-0.24	0.14	0.01	-0.24	-0.16	0.01	-0.28	0.2	-0.14	-0.09	0.55	0.54	0.67*
tFmaxD	-0.06	0.03	0.13	0.16	0.01	-0.09	-0.05	0.56*	-0.01	-0.02	0.41	0.31	-0.02	0.16
tRFDmaxD	-0.07	0.15	-0.20	0.05	0.13	0.16	-0.05	0.13	-0.34	-0.21	-0.14	0.03	-0.06	-0.3
DIF	-0.03	0.03	-0.11	-0.20	0.00	-0.08	0.25	0.28	-0.21	0.33	0.38	-0.23	-0.23	-0.16
DIRFD	-0.11	0.15	-0.07	-0.31*	-0.03	-0.04	0.32*	-0.47	0.32	-0.01	-0.02	-0.20	-0.25	-0.06
EIND	-0.18	0.32*	-0.23	-0.14	0.06	0.12	-0.01	-0.42	0.05	-0.24	-0.3	-0.27	-0.26	-0.39
EID	-0.07	0.16	-0.28	-0.07	0.06	-0.02	-0.01	0.24	-0.4	-0.14	0.07	-0.04	-0.19	-0.3
EIS	-0.18	0.28	-0.32*	-0.14	0.11	0.09	0.04	0.05	-0.27	-0.17	-0.08	-0.10	-0.27	-0.27

Note: *p<0.05, **p<0.01. Agr = Aggression; Cns = conscientiousness; CV = coefficient of variation; DIF = Dimorphism index of maximal force; DIRFD = Dimorphism index of maximum rate of force development; EID = Excitation index dominant; EIND = Excitation index non-dominant; EIS = Excitation index sum; Ext = extraversion; FmaxD = Maximal force dominant; FmaxND = Maximal force non-dominant; Nrt = neuroticism; Opn = openness; PV = positive valence; RFDD = maximum rate of force development dominant; RFDND = maximum rate of force development non-dominant; SD = Standard deviation; SWW = Shapiro–Wilk w statistic; tFmaxD = time needed for achieving Fmax dominant; tFmaxND = the time needed for achieving; Fmax non-dominant; tRFDmaxD = the time needed for achieving RFD dominant; tRFDmaxND = the time needed for achieving RFD non-dominant.

Table 4. **CORRELATION ANALYSIS OF HANDGRIP NEUROMUSCULAR AND MORPHOLOGICAL WITH PSYCHOLOGICAL CHARACTERISTICS FOR MALE PARTICIPANTS**

	Well-trained (n=72)							Elite (n=22)						
	Agr	**Ext**	**Nrt**	**NV**	**Opn**	**PV**	**Cns**	**Agr**	**Ext**	**Nrt**	**NV**	**Opn**	**PV**	**Cns**
BH	0.03	-0.07	0.02	-0.12	-0.04	0.21	0.02	-0.14	-0.51*	-0.11	0.22	-0.27	-0.29	-0.59**
BW	0.11	-0.13	0.01	0.03	-0.11	0.10	0.05	0.01	-0.57**	0.22	0.33	-0.29	-0.11	-0.43*
BMI	0.14	-0.14	0.03	0.12	-0.16	-0.04	0.01	0.08	-0.45*	0.22	0.3	-0.08	-0.03	-0.2
FmaxND	0.31**	-0.23*	0.13	0.10	-0.16	0.03	-0.03	-0.07	-0.09	0.27	0.39	0.17	-0.18	-0.24
RFDND	0.30*	-0.32**	0.17	0.08	-0.13	0.00	-0.02	0.07	-0.42*	0.56**	0.46*	0.11	-0.22	-0.42*
tFmaxND	0.06	-0.06	-0.07	0.06	0.00	0.05	-0.01	0.08	-0.04	-0.1	0.38	0.21	0.12	0.03
tRFDmaxND	0.16	-0.06	0.13	0.13	-0.04	0.01	-0.05	-0.26	0.25	-0.2	-0.42*	-0.14	-0.08	0.14
FmaxD	0.32**	-0.26*	0.14	0.15	-0.08	0.1	-0.06	-0.01	-0.4	0.47*	0.38	0.04	-0.27	-0.41
RFDD	0.31**	-0.32**	0.26*	0.15	-0.08	-0.02	-0.14	0.08	-0.41	0.32	0.34	0.07	-0.09	-0.3
tFmaxD	-0.26*	0.15	-0.12	-0.05	0.16	-0.04	0.02	0.11	0.27	-0.15	0.27	0.46*	0.22	-0.01
tRFDmaxD	0.06	0.07	-0.02	-0.04	0.06	0.20	0.10	-0.18	0.15	0.19	-0.32	-0.04	-0.07	0.14
DIF	-0.05	0.03	-0.02	0.13	0.06	0.12	-0.09	0.33	-0.52*	0.38	0.11	0.03	0.06	-0.24
DIRFD	-0.02	0.05	0.13	0.14	0.06	-0.02	-0.18	0.05	-0.12	0.07	-0.08	0.04	0.11	-0.01
EIND	-0.04	0.19	-0.03	0.04	0.04	0.08	-0.01	-0.19	0.30	-0.10	-0.02	-0.01	0	0
EID	-0.03	0.16	-0.14	0.05	0.05	0.18	0.06	-0.03	-0.09	0.37	0.09	-0.04	-0.23	-0.28
EIS	-0.07	0.22	-0.12	0.05	0.09	0.15	0.06	-0.18	0.19	0.02	0	-0.03	-0.17	-0.01

Note: *p<0.05, **p<0.01. Agr = Aggression BH = Body height BMI = Body Mass index BW = Body weight Cns = conscientiousness CV = coefficient of variation DIF = Dimorphism index of maximal force DIRFD = Dimorphism index of maximum rate of force development EID = Excitation index dominant EIND = Excitation index non-dominant EIS = Excitation index sum Ext = extraversion FmaxD = Maximal force dominant FmaxND = Maximal force non-dominant KSZ = Kolmogorov–Smirnov z statistic M = mean Max = maximum Min = minimum Nrt = neuroticism Opn = openness PV = positive valence RFDD = maximum rate of force development dominant RFDND = maximum rate of force development non-dominant SD = Standard deviation SWW = Shapiro–Wilk w statistic tFmaxD = time needed for achieving Fmax dominant tFmaxND = the time needed for achieving Fmax non-dominant tRFDmaxD = the time needed for achieving RFD dominant tRFDmaxND = the time needed for achieving RFD non-dominant.

The results of correlation analysis (Table 4) revealed a weak positive association of Agr with FmaxND, RFDND, FmaxD and RFDD, as well as a weak negative association of Agr with tFmaxD, Ext FmaxND, RFDND, FmaxD and RFDD, among the well-trained male athletes. Regarding the elite male athletes, positive moderate correlations of Nrt with RFDND and FmaxD, NV with RFDND and Opn with tFmaxD, as well as negative moderate correlations of Ext with BH, BW and RFDND, Nv with tRFDmaxND, and Cnx with BH, BW, RFDND were also revealed.

The nonparametric Mann–Whitney U test revealed significant differences between the female well-trained and elite athletes in BH (U=177.5, z=-2, *p*=0.049), BW (U=163.5, z=-2.2, *p*=0.026), FmaxD (U=160.5, z=-2.6, *p*=0.009), RFDD (U=178.5, z=-2.3, *p*=0.023) and DIF (U=169, z=-2.4, *p*=0.014). In the male sample, the non-parametric Mann–Whitney U test revealed significant differences between the well-trained and elite athletes only in Agr (U=562.0, z=-2.3, *p*=0.021). Regarding gender differences, the non-parametric Mann–Whitney U test did not reveal significant differences between the male and female well-trained male and female elite athletes for personality traits.

After applying statistical methods for score distribution normalisation, the normality of Nrc and tRFDmaxD in female smaple, as well as NV in male samples, was not improved. This is why they were not included in further analyses. The results of the canonical discriminant analysis showed the existence of statistically significant discriminant functions both in the female (Wilks's Λ=0.44, $\chi^2(22)=37.67$, *p*=0.020) and male samples (Wilks's Λ=0.59, $\chi^2(20)=41.18$, *p*=0.004). Canonical correlations were 0.75 for the female and 0.64 for the male sample. The resulting models, with 90% accuracy for females and 80% accuracy for males, recognised participants as well-trained or elite athletes. The discriminant function for the female sample had the largest relationship with FmaxD, RFDD, BW and DIF. In contrast, the discriminant function for the male sample has the largest relationship with Agr, BW, NV, Opn and PV (Table 5).

DISCUSSION

In this study, we aimed to investigate the relationships between the neuromuscular characteristics of HGS and various morphological characteristics with personality traits among well-trained and elite athletes. Our findings revealed several significant associations that supported our first hypothesis. However, not all the correlations were in the expected positive direction for superior handgrip neuromuscular and morphological with positive psychological characteristics, which mean the first hypothesis cannot be entirely accepted. The obtained correlations of unexpected direction were most pronounced in male athletes.

The correlations observed in elite athletes were similar in direction but greater in intensity than those seen in well-trained athletes, lending support to our second hypothesis. Nevertheless, caution is warranted before concluding that the second hypothesis is entirely accepted, as the elite group, particularly among women, was relatively small, making it difficult to draw definitive conclusions.

Table 5. **THE STRUCTURE MATRIX OF THE DISCRIMINANT FUNCTIONS FOR FEMALE AND MALE PARTICIPANTS**

Female	Function	Male	Function
FmaxD	-0.34	Agr	0.35
RFDD	-0.28	BW	0.27
BW	-0.22	NV	-0.24
DIF	-0.22	Opn	0.21
tRFDmaxND	0.19	PV	0.20
BH	-0.17	BH	0.19
PV	-0.17	Cns	-0.17
DIRFD	-0.17	DIF	-0.17
Agr	-0.16	tFmaxDN	-0.14
tRFDmaxDN	-0.16	Ext	0.11
Opn	0.16	DIRFD	-0.11
tFND	-0.16	BMI	0.11
FmaxND	-0.15	tFmaxND	-0.10
RFDND	-0.14	RFDND	0.09
Cns	-0.14	tRFDmaxND	0.08
Nrt	0.11	FmaxND	0.08
Ext	0.10	EIND	-0.03
BMI	-0.09	EIND	0.03
tFmaxD	-0.06	RFDD	-0.01
EINS	0.04	EIS	0.00
EIND	0.03	FmaxD	0.00
EIND	0.02		

Agr = Aggression BH = Body height BMI = Body Mass index BW = Body weight Cns = conscientiousness CV = coefficient of variation DIF = Dimorphism index of maximal force DIRFD = Dimorphism index of maximum rate of force development EID = Excitation index dominant EIND = Excitation index non-dominant EIS = Excitation index sum Ext = extraversion FmaxD = Maximal force dominant FmaxND = Maximal force non-dominant KSZ = Kolmogorov–Smirnov z statistic M = mean Max = maximum Min = minimum Nrt = neuroticism Opn = openness PV = positive valence RFDD = maximum rate of force development dominant RFDND = maximum rate of force development non-dominant SD = Standard deviation SWW = Shapiro–Wilk w statistic tFmaxD = time needed for achieving Fmax dominant tFmaxND = the time needed for achieving Fmax non-dominant tRFDmaxD = the time needed for achieving RFD dominant tRFDmaxND = the time needed for achieving RFD non-dominant

We also recorded differences in the neuromuscular, morphological, and psychological characteristics between athletes of varying performance levels, primarily favouring the elite group. This finding supports our third hypothesis. Ultimately, the presence of significant discriminant functions in both female and male samples affirmed the validity of our third hypothesis.

Before discussing the explored relationships, it is important to describe our sample to interpret accurately the results obtained. Based on the descriptive indicators presented in Tables 1 and 2, we first compare the morphological characteristics, particularly BMI. The average BMI for females in our sample was 22.2 kg/m², while for males it was 24.1 kg/m². In comparison with the general population, as reported in previous studies (Dopsaj *et al.,* 2018; Rakić *et al.,* 2019; Dopsaj *et al.,* 2021), where the average BMI falls into the overweight category (female 23.9 kg/m², male 26.4 kg/m²), we can conclude that our participants represent a population that is above average in physical fitness and health (Van Dyke & Drinkwater, 2014).

Values of all handgrip neuromuscular variables (Tables 1 and 2) were above or at least in line with average compared with the students and even athletes (Ivanović & Dopsaj, 2012; Dopsaj *et al.,* 2018; 2019a). In our study, the maximum force of the dominant hand for female participants in our sample was 322.7 N, while it was 519.79 N for males. In comparison, female students exhibited an Fmax of 272.1 N, and male students had an Fmax of 508.9 N. Additionally, in our sample of elite female athletes, the Fmax of the dominant hand was recorded at 359.69 N, compared with 381.87 N for top-level female athletes. Our group outperformed several others in various sports disciplines, including taekwondo (357.73 N), swimming (323.33 N), and table tennis (304.00 N).

For psychological indicators, all four subsamples were characterised by weakly present Nrc and NV, moderate Agr, moderately high PV, and highly present Ext, Opn and Cns. When compared with the general population (Dinić *et al.,* 2018; Tasic *et al.,* 2020; Vukmirovic *et al.,* 2020), the obtained psychological profile can be described as healthy and stress resilient since Ext, Opn and Cns are positively correlated while Nrc is negatively correlated with stress resilience (Campbell-Sills *et al.,* 2006; Eley *et al.,* 2013; Oshio *et al.,* 2018; De La Fuente *et al.,* 2021).

The observed positive correlations with Opn and Cns, as well as negative correlations with Nrt (Tables 3 and 4), align with prior research (Fink *et al.,* 2016; Goldberg *et al.,* 2017; Kerry & Murray, 2018; Sutin *et al.,* 2018; Stephan *et al.,* 2022) on the existence and direction, as well as gender specificity, of relationships of handgrip neuromuscular and psychological characteristics. The same applies to the obtained negative correlations of BMI and Cns (Stefanovics *et al.,* 2021; Crewther *et al.,* 2024).

The biggest surprise was RFDND, which correlated positively with Nrc and negatively with CNS in male elite athletes. This finding suggests that the innate ability to generate nerve impulses outweighs the training adaptations of muscles in elite athletes when it comes to RFD manifestations in ND hands. This finding is the first specificity of the male elite athletes subsample compared not just to the general population but also to the other subsamples of this research regarding researched relationships. Adding to this numerous positive correlations of handgrip neuromuscular variables with Agr only in the male well-trained subsample, some gender specifics in the athletic population are unfolded. A similar link between HGS and aggressive behaviour (Gallup *et al.,* 2007b), as well as HGS and testosterone levels (Page *et* *al.,* 2005), and testosterone levels and Cns (Crewther *et al.,* 2024) only in males was found in previous studies. Considering results of previous studies our results can be interpreted as follows: greater inherent capacity to produce maximal voluntary activation in the early phase of an explosive contraction (Maffiuletti *et al.,* 2016) is followed by less emotional stability and less tendency towards being responsible and hard-working, which are also largely hereditary (Jang *et al.,* 1996). However, these studies also leave a considerable portion of the variance in the manifestation of the described characteristics that would be influenced by personal activity and environment. This part could be interpreted as the inheritance of superior neuromuscular characteristics in male elite athletes actually hindering the development of the Cns because high results can be achieved with less effort. Since women are traditionally not expected to have physical strength (Gallup *et al.,* 2007b; Gallup *et al.,* 2010; Atkinson *et al.,* 2012), in order to reach the high level of physical fitness demonstrated by our participants, they had to go through more rigorous training (Nuzzo, 2023). Even a lack of understanding of the environment (Bryson, 1983) contributed to the development of CNS; moreover, since they were weaker than men (Nuzzo, 2023), women did not associate their Agr with physical strength. Furthermore, superior neuromuscular characteristics flow with greater PV in elite female athletes, while in men with more prominent NV. This finding also speaks to gender differences, as well as the relationship between physical characteristics and positive and negative behavioural tendencies.

Correlation analyses (Tables 3 and 4) also show that relationships between neuromuscular characteristics of handgrip and morphological characteristics along with personality traits are stronger among elite than well-trained athletes. When comparing the general population (Fink *et al.,* 2016; Kerry & Murray, 2018; Stefanovics *et al.,* 2021; Stephan *et al.,* 2022), well-trained athletes and elite athletes, we find that associations between physical fitness and athletic performance strengthen. Furthermore, in addition to the previously described parameters, we can observe that increased physical exercise and sports success are associated with a stronger body and character, leading to a more significant connection between physical attributes and personality traits. Suppose we add to this the observed superiority of RFD over Fmax when describing the relationship of handgrip neuromuscular with personality traits, where our study diverges from previous research. In that case, some new possibilities can be seen in explaining the obtained relationships. Although RFD is a complex neuromuscular characteristic, because of its dependence on the speed of recruitment of motor units, it primarily reflects the ability of the nervous system to produce and transport impulses quickly (Baudry & Duchateau, 2021; Del Vecchio *et al.,* 2019; Dideriksen *et al.,* 2020; Rodríguez-Rosell *et al.,* 2018). The possibility that features of the nervous system related to the speed of impulse generation and transport can be, to some extent, related to or even responsible for the development of psychological characteristics is worth additional study.

Further analysis revealed additional differences between well-trained and elite athletes, which are mainly in line with the findings of previous studies (Cronin *et al.,* 2017). Female elite athletes are characterised by a larger BH, BM, FmaxDH and RFDDH, while higher Agg characterises male elite athletes. Although such a finding indicates that it is not easy to differentiate well-trained and elite athletes, especially in the male sample, with the help of the examined characteristics, results of discriminant analyses convincingly show that this is not true. On the contrary, the synergistic effect of the observed characteristics and connections enables very accurate recognition of well-trained and elite athletes both among female and male samples. Taking into account the economy of the performed measurements and assessments, as well as the fact that the sample includes athletes from different sports disciplines, compared with similar earlier studies (Robertson *et al.,* 2022), the obtained discriminant models can be marked as very effective. Regarding gender differences, it can be seen (Table 5) that recognition of female athletes relies mainly on handgrip neuromuscular characteristics, recognition of male athletes relies mainly on personality traits, while morphological characteristics are equally important in both models. This finding represents the most important applied contribution of this study because it paves the way for quick and economical selection of elite athletes.

This study has certain limitations that should be considered when making conclusions. A convenience sampling method instead of a random one represents a limitation of its representativeness when generalising findings (Ross & Zaidi, 2019). Also, although it meets the criteria of a power analysis, some subsamples are too small to claim that the findings can apply to other samples or even the general population. The deliberate selection of specific cohorts in this study also introduces limitations related to the generalisability of findings (Puhan *et al.,* 2012). The findings may not readily apply to other athletic cohorts or broader populations due to the focused nature of the sample. This fact restricts the ability to make conclusions about behaviours in the broader context, mainly when influenced by sociodemographic factors. Our sample comes from the athletic and physically fit population, so the obtained differences in genders do not reflect general differences but rather the differences of these selected groups. The influence of confounding variables of training and sports history, as well as the level of physical fitness, should also be taken into account (Dopsaj *et al.,* 2018; 2019a; Rakić *et al.,* 2019). It has been brought under control to a certain extent. However, this fact should be considered when interpreting the obtained results and when thinking about the generalisation of conclusions. Also, in order to obtain a more accurate picture of the relationships that have been researched in future studies, greater control is needed.

Furthermore, psychological surveys open the door to response bias, as participants may not always provide accurate or candid responses (Krumpal, 2013). The participants, who were police, national security and sports students, might have been inclined to offer responses that aligned with social and academic norms, potentially introducing a skew in the results. Since this study was correlational, it is crucial to note that no causal relationships between the examined variables can be deduced, as correlation does not imply causation (Puhan *et al.,* 2012; Ross & Zaidi, 2019). These considerations are important for contextualising the findings and understanding the scope of their applicability beyond the specific cohort studied. For this purpose, new experimental longitudinal studies are required in order to answer the question of the nature of described relationships, as well as to validate discriminative models. On the other hand, the results obtained justify such research.

CONCLUSIONS

This study was conducted with the aim of exploring the interplay of neuromuscular characteristics of handgrip and morphological characteristics with personality traits in well-trained and elite athletes of both genders. Numerous significant correlations were obtained, as well as differences between well-trained and elite athletes of both genders. The most prominent correlations were between the PV and Fmax of the D (r=0.77) and ND (r=0.82) hand among the female elite athletes. Surprisingly, the positive correlation between the RFD and Nrc (r=0.56) and the negative correlation with Cns (r=-0.42) in male elite athletes. The biggest surprise was RFDND, which correlated positively with Nrc and negatively with Cns. Gender-specific and sports success level patterns were revealed in the relationships examined. Canonical discriminant analysis indicated the presence of statistically significant discriminant functions for all variables assessed, both in female (Wilks's Λ=0.44, $\chi^2(22)$=37.67) and male samples (Wilks's Λ=0.59, $\chi^2(20)$=41.18), with 90% accuracy for females and 80% accuracy for males when discriminating between elite and well-trained athletes.

In conclusion, the discriminant models developed in this study are highly effective and potentially valuable for sports selection. Analysing muscle contractile and time parameters as neuromuscular indicators represents a novel approach compared with previous research, showing promise for future studies in this area.

Conflicts of interest

The authors declare no conflict of interest.

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Corresponding author: Dr Miloš Miloševiće; **Email:** milosmilosevic80@yahoo.com