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THE RELATIONSHIP OF THE MECHANICAL CHARACTERISTICS OF THE HAND GRIP EXPRESSED IN DIFFERENT MODULES OF ISOMETRICAL CONTRACTION AND PSYCHOLOGICAL CHARACTERISTICS IN ADULTS

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POVEZANOST MEHANIČKIH KARAKTERISTIKA STISKA ŠAKE ISPOLJENIH U RAZLIČITIM MODULIMA IZOMETRIJSKOG NAPREZANJA I PSIHOLOŠKIH KARAKTERISTIKA KOD ODRASLIH OSOBA

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Posvećeno mome ocu

Dedicated to my father

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THE RELATIONSHIP OF THE MECHANICAL CHARACTERISTICS OF THE HAND GRIP EXPRESSED IN DIFFERENT MODULES OF ISOMETRIC CONTRACTION AND PSYCHOLOGICAL CHARACTERISTICS IN ADULTS

ABSTRACT

This dissertation examines the quantitative relationship between handgrip strength parameters (maximal force, rate of force development, endurance, and time-related variables) and adults' psychological characteristics (Big Five, mental toughness, dark triad, and empathy). It was assumed that a higher result on the handgrip tests would be accompanied by a more positive psychological profile, i.e., a more pronounced presence of characteristics that are desirable from the point of view of functioning in stressful situations (extraversion, agreeableness, conscientiousness, openness, mental toughness, interpersonal reactivity), and a lower degree of expression of undesirable characteristics (neuroticism, positive valence, negative valence, and the dark triad). The research was conducted on a convenience sample of 205 participants, among whom 93 females and 112 males, students of the Faculty of Sport and Physical Education, University of Belgrade, University of Criminal Investigation and Police Studies in Belgrade, Academy for National Security in Belgrade and members of the general student population, as well as the working population of different professional orientations. The total sample was divided into general adult, police students, security, and athletic subsamples. Criterion variables of the Big Five personality traits, mental toughness, the dark triad, and empathy, were assessed by psychological questionnaires Big Five plus Two, Mental Toughness Index, Dark Triad Dirty Dozen and Interpersonal Reactivity Index. The predictor variables of maximal force, rate of force development, and endurance in the manifestation of force were measured using isometric dynamometry. For categorical and control variables, information was collected on gender, age, education and field of work, years of study and work experience, sports experience and achievements, as well as body weight and height. Correlation, multiple regression, and multivariate variance analysis were performed on the collected data. Numerous significant correlations were obtained between the mechanical characteristics of the handgrip and psychological characteristics and differences between members of different groups within the total and subsamples. The MANOVA for factors of mechanical characteristics of handgrip revealed significant differences in psychopathy on factor maximum rate of force development, significant interactions of maximal muscular force and maximum rate of force development with mental toughness and narcissism, as well as maximal muscular force and force impulse attained in handgrip endurance test with psychopathy. The obtained results also revealed gender-specific patterns in the research relationships. Numerous effective regression models, which can explain a significant percentage of the variance of psychological characteristics with mechanical characteristics of handgrip expressed in both impulse and classical mode of isometric contraction within general adult population subsample 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]. The results of the canonical discriminant analysis show the existence of statistically significant ($p<0.05$) discriminant functions both in female (Wilks's Λ=0.44, $\chi^2_{(22)}$=37.67) and male (Wilks's Λ=0.59, $\chi^2_{(20)}$=41.18) within athletic subsample. The resulting models, with 90% accuracy for females and 80% accuracy for males, recognize participants as well-trained or elite athletes. For the first time, this research establishes the relationship between the rate of force development and endurance in the manifestation of force with psychological characteristics. It was concluded that the obtained discriminant models are very efficient in further use in sports selection. The results affect individualizing training programs and candidate selection processes for physically demanding and stressful occupations. Also, the obtained results justify further research on this topic with the aim of better understanding the nature of the obtained correlations.

Keywords: motor behaviour, maximal force, maximal rate of force development, endurance in the manifestation of force, force impulse, personality traits, Big Five, mental toughness, dark triad, interpersonal reactivity, selection

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POVEZANOST MEHANIČKIH KARAKTERISTIKA STISKA ŠAKE ISPOLJENIH U RAZLIČITIM MODULIMA IZOMETRIJSKOG NAPREZANJA I PSIHOLOŠKIH KARAKTERISTIKA KOD ODRASLIH OSOBA

SAŽETAK

Cilj ove doktorske disertacije je bio da se istražite kvantitativne karakteristike povezanosti maksimalne sile, brzine razvoja sile, izdržljivosti u ispoljavanju sile, vremenskih parametara ispoljavanja zadatih karakteristika sile kao i indeksnih parametara stiska šake merenih u izometrijskom režimu, sa velikih pet osobina ličnosti, mentalnom čvrstinom, tamnom trijadom i empatijom kod odraslih, kao i određivanje specifičnosti ovih odnosa u različitim populacijama, zajedno sa metrološkim karakteristikama novoformiranih indeksnih varijabli. Pretpostavljeno je da će veći rezultat na testovima stiska šake biti praćen pozitivnijim psihološkim profilom, odnosno izraženijim prisustvom karakteristika koje su poželjne sa stanovišta funkcionisanja u stresnim situacijama (ekstraverzija, saradljivost, savesnost, otvorenost, mentalna čvrstina, empatija) odnosno manjim stepenom izraženosti nepoželjnih karakteristika ličnosti (neuroticizam, potitivna valencija, negativna valencija i tamna trijada). Istraživanje je sprovedeno na uzorku od 205 ispitanika, među kojima 93 ženskog i 112 muškog pola, studenata Fakulteta sporta i fizičkog vaspitanja Univerziteta u Beogradu, Kriminalističko-policijskog Univerziteta i Akademije za nacionalnu bezbednost, pripadnici opšte studentske populacije, kao i radno aktivno stanovništvo različitih profesionalnih orijentacija. Ukupni uzorak je takođe podeljen na sledeće subuzorke: opšta odrasla populacija, studenti policijiskih studija, bezbednostna populacija kao i sportisti. Kriterijumske varijable velikih pet crta ličnosti, mentalna čvrstina, tamna trijada i empatija procenjivane su psihološkim upitnicima Velikih 5+2, Inventar mentalne čvrstine, Prljavih dvanaest tamne trijade i Indeks intrepersonalne reaktivnosti. Prediktorske varijable maksimalne sile, maksimalne brzine stvaranja sile i izdržljivosti u ispoljavanju sile biće merene uz pomoću metode izometrijske dinamometrije. Kao kategoričke i grupišuće varijable prikupljene su informacije o: polu, uzrastu, obrazovnom i profesionalnom usmerenju, godini studija i radnom stažu, sportskom iskustvu i postignućima, kao i telesnoj masi i visini. U obradi podataka korišćena je korelaciona analiza, analiza višestruke regresije i multivarijantna analiza varijanse. Na osnovu rezultata dobijene su brojne značajne korelacije između mehaničkih karakteristika stiska šake i psiholoških karakteristika, kao i razlike između pripadnika različitih grupa u ukupnom uzorku kao i u poduzorcima. Rezultati MANOVA za faktore mehaničkih karakteristika stistka šake pokazali su da postoje značajne razlike u psihopatiji na faktoru maksimalne brzine razvoja sile, značajne interakcije maksimalne mišićne sile i maksimalne brzine razvoja sile sa mentalnom čvrstinom i narcizmom, kao i maksimalne mišićne sile i postignutog impulsa sile u testu izdržljivosti stiska šake sa psihopatijom. Dobijeni rezultati su takođe pokazali rodno specifične obrasce istraživanih odnosa. Otkriveni su brojni efikasni regresioni modeli, koji mogu objasniti značajan procenat varijanse psiholoških karakteristika sa mehaničkim karakteristike stiska šake izražene u pulsnom i klasičnom modusu izometrijske kontrakcije kod poduzorka opšte odrasle populacije [inicijalno: agresivnost (R^2=0,95), ekstraverzija (R^2=0,74), neuroticizam (R^2=0,82), negativna valencija (R^2=0,75), otvorenost (R^2=0,62), pozitivna valencija (R^2=0,62), mentalna čvrstina (R^2=0,75), makijavelizam (R^2=0,56), psihopatija (R^2=0,56), narcizam (R^2=0,78), tamna trijada (R^2=0,69]. Rezultati kanonske diskriminantne analize pokazuju postojanje statistički značajne ($p<0,05$) diskriminantne funkcije kod žena (Wilksov Λ=0,44,

$\chi^2_{(22)}$=37,67) i muškarac (Wilksov Λ=0,59, $\chi^2_{(20)}$ =41,18) unutar sportskog poduzorka. Rezultirajući modeli sa 90% tačnosti za žene i 80% tačnosti za muškarce prepoznaju učesnike kao dobro trenirane ili elitne sportiste. Ovo istraživanje po prvi put uspostavlja vezu između brzine razvoja sile i izdržljivosti u ispoljavanju sile sa psihološkim karakteristikama. Zaključeno je da su dobijeni diskriminantni modeli veoma efikasni kada je u pitanju dalja upotreba u selekciji u sportu. Rezultati imaju implikacije na individualizaciju programa obuke i procesa selekcije kandidata za fizički naporna i stresna zanimanja. Takođe, dobijeni rezultati opravdavaju dalja istraživanja na ovu temu sa ciljem boljeg razumevanja prirode dobijenih korelacija.

Ključne reči: motorno ponašanje, maksimalna sila, maksimalna brzina razvoja sile, izdržljivosti u ispoljavanju sile, impuls sile, crte ličnosti, velikih pet, mentalna čvrstina, tamna trijada, interpersonalna reaktivnost, selekcija

Naučna oblast: Fizičkog vaspitanje i sport

Uža naučna oblast: Nauke fizičkog vaspitanja, sporta i rekreacije

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1 INTRODUCTION

If we consider behaviour as the actions and reactions of living organisms interacting with each other and their external environment, then understanding, predicting, and modifying human behaviour is one of the most important goals of the social and humanistic sciences. Faithfully imitating patterns of human behaviour is an admirable goal for researchers and practitioners across various technical and technological disciplines.

Motor behaviour, a specific aspect of behaviour, refers to the execution of any movement involving any part of the body in social contexts (Adolph & Franchak, 2017). The movement of the body in terms of motor behaviour can ultimately be described by the interaction of external and internal forces, with a particular focus on the muscular force that a person can consciously control. However, the functioning of muscular force cannot be explained entirely by biomechanics alone. Moving the body, even involuntarily, relies on cognitive systems responsible for data collection and processing. The quality of motor behaviour is primarily determined by the efficiency of these cognitive systems (Keen, 2011; Latash & Turvey, 1996).

Movement is a crucial element and driving force behind early cognitive development (Piaget, 1954). Patterns of movement not only enable the formation of broader behavioural patterns, but these behavioural patterns also influence the establishment and modification of movement patterns. Therefore, it is both valid and necessary to conduct integrative observations, studies, and analyses of movement expression and regulation within the broader context of behaviour regulation and the interplay between the two systems. This assertion is supported by empirical studies that demonstrate a correlation between essential morphological and psychological characteristics (Crewther et al., 2024; Faith et al., 2001; Magee et al., 2013; Stefanovic et al., 2021; Stephan et al., 2022; Sutin & Terracciano, 2016 a,b). Furthermore, evolutionary psychology suggests that movement is the primary reason for the emergence of the nervous system in organisms, with its primary function being the control of movement, that is, behaviour (Cosmides & Tooby, 1997). This assumption implies that the structures and indicators of movement regulation may be linked to specific behavioural tendencies and attributes.

Based on this premise, it was hypothesized that there is a relationship between the mechanical characteristics of skeletal muscles and personality traits and attributes. This assumption has been validated through various empirical studies (Anestis, 2005; Brito et al., 2023; Gallup et al., 2007; Fink et al., 2016; Frederick & Haselton, 2007; Kerry & Murray, 2018; Leigh et al., 2008; Mueller et al., 2016, 2018; Stephan et al., 2022; Shuai et al., 2023; Sutin, 2018; Tolea et al., 2012).

In this context, the arms, particularly the hands, are of great significance. Throughout human evolution, the hands have developed distinct functions, allowing for a wide range of activities, including communication, hunting, gathering fruits, cultivating land, crafting, working, and fighting. The human use of hands is exceptional compared to other species, in the same way as the psychic apparatus. Comprising 27 bones, 27 joints, 34 muscles, and over 100 ligaments and tendons, innervated by numerous peripheral nerves, the upper limbs—especially the hands—occupy a significant portion of the sensory and motor cortex (Penfield & Rasmussen, 1950; Grodd et al., 2001; Saadon-Grosman et al., 2020), nearly equivalent to the rest of the body, excluding the head (Figure 1).

As a result, it is not surprising that numerous studies have connected various mechanical characteristics of the hand, as measured through handgrip tasks, with different indicators of lifestyle and health. For example, handgrip strength provides valuable information about nutritional status (Norman et al., 2011), the risk of potential heart failure (Chung et al., 2014; Izawa et al., 2009; Oreopoulos et al., 2010), and postural stability (Trajkov et al., 2018). Additionally, the maximum force generated during an isometric handgrip test has been found to predict certain behaviours, including aggressive and sexual tendencies (Gallup et al., 2007) and socially dominant behaviour (Gallup et al., 2010). Handgrip mechanical characteristics have also been used to assess individuals' fighting ability (Muñoz-Reyes et al., 2012) and overall formidability (Kerry & Murray, 2018).

Given the unique role of hands in human behaviour, they serve as a key area for research into the relationship between the mechanical characteristics of skeletal muscles and behavioural tendencies and attributes. Numerous studies have supported this relationship (Gallup et al., 2007, 2010; Fink et al., 2016; Kerry & Murray, 2018; Mueller et al., 2016; Muñoz-Reyes et al., 2012; Stephan et al., 2022; Sutin, 2018).

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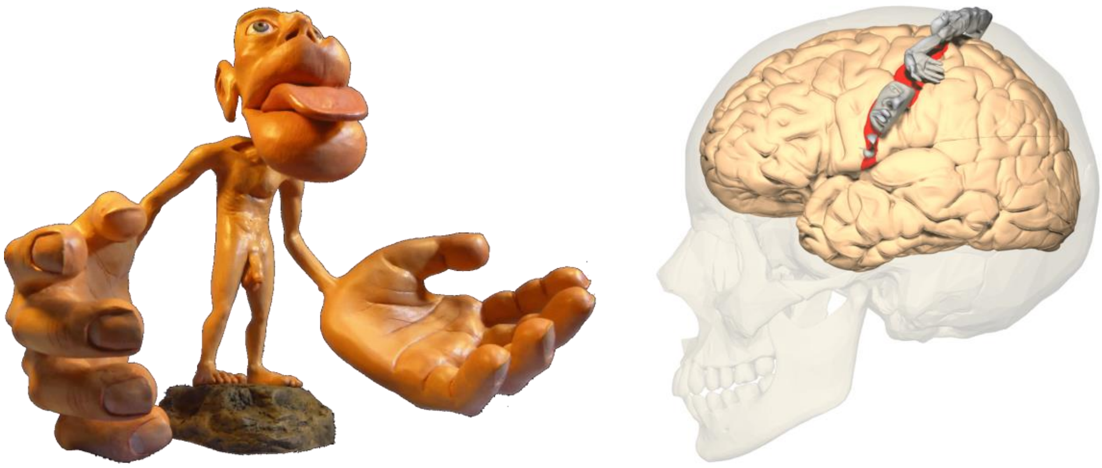


Figure 1. Representation of the body in the sensory cortex (Mpj29, BA312)

Numerous studies have established connections between the mechanical characteristics of the hand and Big Five personality traits (Fink et al., 2016; Kerry & Murray, 2018; Mueller et al., 2016; Stephan et al., 2022; Sutin, 2018). However, this area remains underexplored. Many aspects of handgrip mechanics have not been thoroughly investigated, and specific characteristics of different populations have not received adequate attention. Furthermore, there is significant potential for future research to examine the relationship between the mechanical properties of the handgrip and psychological constructs beyond the Big Five model. This topic has not been widely addressed in current research practices. Addressing these issues will require an interdisciplinary approach and collaboration (Momtazmanesh et al., 2021).

The primary objective of the upcoming review is to present the findings of the studies mentioned, along with their theoretical implications and opportunities for further research in this field.

2 THEORETICAL APPROACH TO THE RESEARCH PROBLEM

After the introductory considerations, this section will clarify the theoretical foundations of the research problem. To explore the links between the mechanical characteristics of handgrips and psychological traits and attributes, we will first present key theories from the psychology of individual differences and those suggesting a biological basis for personality.

Following this analysis, we will provide an overview of research that has tested hypotheses regarding the biological foundations of personality. Next, we will connect psychological characteristics with the mechanical properties of the hand by reviewing studies on the physiological mechanisms that underlie the mechanical characteristics of skeletal muscles, such as maximal force, rate of force development, and endurance in force production. Special attention will be directed toward neural mechanisms that are linked to behaviour regulation.

Furthermore, we will summarize research that validates both the direct and indirect connections between the mechanical characteristics of skeletal muscles and psychological traits, explaining the potential mechanisms through which these connections operate. A particular focus will be placed on studies investigating the mechanical features of muscle force during maximum handgrip.

Finally, we will consider how the findings from previous research can be practically applied, expanding the scope of investigation for future studies.

2.1 Psychological Characteristics as a Behaviour Management System

In the following section, we will present, describe, and define key psychological concepts important for understanding psychological characteristics' role in managing behaviour. This analysis will be the first step in identifying potential for future research, i.e., posing a research question.

The psychology of individual differences is a branch of psychology that studies the differences and variations among individuals in tendencies towards behaving, thinking, or feeling coherently in various situations and over a long period (Ashton, 2013). Studying only specific types of psychological processes, states, abilities, and even traits is not enough to understand a person's psychological life as a whole. It is crucial to study their entire behaviour. It is crucial to study their entire behaviour. By studying the behaviour of each individual, it is possible to observe regularity or consistency in behaviour. Individuals exhibit consistent behaviors, allowing identification of characteristics such as laziness, diligence, cheerfulness, or withdrawal. The psychology of individual differences examines behavior patterns and their broader organizational structures. Broader organizational structures that manifest through similar tendencies in behaviour are called traits or personality traits, while the overall organizational characteristic of the behaviour of each individual is called personality. More precisely, “[p]ersonality is the dynamic organization within the individual of those psychophysical systems that determine his characteristic behavior and thought" (Allport, 1961, p. 28). It is important to note that the founders of the theory of personality traits, in their initial definition in the first half of the last century, also studied the physical component of the personality.

The psychology of individual differences is one of the most prolific branches of psychology in terms of theory development. Within this framework, various personality theories have been created to describe personality in terms of its structure, dynamics, and development. Based on the answers to these questions, personality theories can be classified into several influential schools of thought: psychodynamic, social-psychological, self-theories, and trait theories.

In modern practice, particularly in the assessment of personality and the use of test results for purposes such as selection, education, and management, trait theories have emerged as the most influential (Ashton, 2013). The fundamental assumption of personality trait theory is that a limited number of key traits can represent the vast range of human behavioural tendencies. These traits reflect the specific functioning of the body and organs, primarily the nervous system (Rush, 1992).

Hans Eysenck was one of the pioneers who explained this hypothesis (Eysenck, 1967). The co-authors of the influential theory pertaining to the Big Five personality traits also support this viewpoint. However, they do not delve into the details as extensively as Eysenck does. They assert that the five factors represent basic dimensions of personality for several reasons: "(a) longitudinal and cross-sectional studies indicate that all five factors are enduring traits that manifest in behaviour patterns; (b) traits associated with each factor can be found across various personality systems and correspond to natural language descriptors; (c) the factors are present in diverse age, gender, racial, and linguistic groups, even though they may be expressed differently across cultures; and (d) evidence of heritability suggests a biological basis for all five factors" (Costa & McCrae, 1992, p. 653).

These theoretical propositions are supported by classic empirical studies (Eysenck & Eysenck, 1967) as well as more recent research (Brumbaugh et al., 2013; Brito et al., 2023).

In the theoretical part of our work, emphasis will be placed on hypotheses and research on biological aspects of personality. This fact does not dispute the importance of environmental factors or the individual's experience in building personality traits, motor abilities, and skills. This procedure can be justified if we consider, first of all, the peculiarities of the subject of interest of this dissertation and the necessity of an interdisciplinary approach in its research. Namely, the theoretical concepts will be simplified, reducing them to the simplest shared content to keep the focus of the research in sports sciences and motor behaviour.

However, before presenting theoretical concepts and research results concerning the biological basis of personality, one must familiarize oneself with several basic concepts from the psychology of individual differences, which will be important for this work.

2.1.1 Basic concepts: The Big Five, Mental Toughness, Dark Triad and Empathy

About the described breadth of the study of the psychology of individual differences, that is, the study of the role of personality characteristics in the management of human behaviour, in this part, only some of the influential concepts of this field will be selected to establish the focus of the research.

One of the fundamental questions of the psychology of individual differences is the basic structure of the personality that is, identifying the essential elements that can be used to describe and predict an individual's behaviour validly. The answer to this question depends on the theoretical approach from which it is approached, that is, its epistemological and methodological frameworks (Čolović et al., 2014). The Big Five personality traits model is currently one of the most influential answers to this question (Saucier & Srivastava, 2015).

The Big Five model outlines the range of traits that a comprehensive personality assessment should evaluate, identifying them as neuroticism, extraversion, openness, agreeableness, and conscientiousness (Costa & McCrae, 1992). Neuroticism represents a general tendency to experience adverse effects, that is, a degree of emotional stability. Extraversion refers to the degree of sociability. Openness determines the degree to which a person is open to new experiences. Agreeableness is the tendency to be cooperative and compassionate, while conscientiousness represents the degree of discipline and spontaneity.

While often linked to the foundational work of Costa & McCrae (1992), the Big Five model emerged from diverse lines of research that consistently identified similar dimensions characterizing human personality (Digman, 1990). When the model was validated across various linguistic and cultural contexts, researchers found that while it remained robust, many identified five dimensions of personality that closely aligned with the Big Five yet also proposed alternative frameworks or additional traits. Consequently, this has led to the emergence of nuanced models such as the big 4+1, 5+1, and 5+2. In a notable study involving a Serbian sample, the traditional Big Five model was further enriched by incorporating dimensions of positive and negative valence (Čolović et al., 2014). Here, positive valence encapsulates a favorable self-image and narcissistic tendencies, while negative valence reflects a detrimental self-image coupled with manipulative behaviors. These findings, while largely supporting the Big Five model, illuminate the opportunity to extend the personality assessment domain. It has been suggested that although the Big Five is widely recognized as one of the most effective models for explaining personality (Saucier & Srivastava, 2015), it may fall short in capturing the intricate variations of human behavior and experience. Critics argue it is too broad, lacking specificity when it comes to predicting a range of phenomena (Boyle et al., 2008). Consequently, scholars have proposed extensions to this model that aim to provide deeper insights, especially in predicting stress-related behaviors and emotional responses (Papageorgiou et al., 2019). The first construct proposed to enhance the Big Five models for predicting stress reactions is mental toughness, which will be defined and elaborated on in the following text.

There is currently no consensus on the description and definition of mental toughness. One perspective, presented by Clough and Stricharczik (2012), views mental toughness as a personality trait that determines how individuals respond to challenges, stress, and pressure. According to this viewpoint, mental toughness is combined with the ability to consistently achieve optimal results, utilizing one's maximum capabilities, regardless of the circumstances at hand (Clough et al., 2002). Thus, mental toughness is considered a vital aspect of understanding personality functioning in stressful situations.

Conversely, some authors emphasize the development of mental toughness through individual activity. In this context, mental toughness is defined as a psychological construct, akin to a state, that equips individuals with the skills necessary to pursue their goals despite difficulties (Gucciardi et al., 2015; Gucciardi, 2017). This perspective suggests that mental toughness can be cultivated over time and enhanced through specific intervention programs (Gucciardi et al., 2015; Stamatis et al., 2016 a). This thesis will primarily explore mental toughness from this developmental perspective, which aligns with the experiences of master strength and conditioning coaches (Stamatis et al., 2021b). Furthermore, a series of studies have provided empirical evidence supporting the theoretical perspective of mental toughness (Gucciardi et al., 2015). These studies challenge the conceptualization of mental toughness as a multidimensional construct, especially highlighting that direct assessments often outperform indirect approaches (Clough et al., 2002), where individual facets of mental toughness are evaluated. This method has become a prevalent research practice in subsequent years (Cowden, 2017; Gucciardi et al., 2016, 2017; Giles et al., 2018; Milošević et al., 2022; Stamatis et al., 2016 a, 2021a, b; Van der Mark et al., 2020).

Although the nature of mental toughness continues to be a topic of debate, most researchers agree that it is a psychological resource that enables individuals to perform optimally despite various stressors (Gucciardi et al., 2015; Hardy et al., 2014; Stamatis et al., 2016 a). Mental toughness has been shown to predict academic and professional outcomes (Lin et al., 2017). Additionally, it is associated with perceived stress (Papageorgiou et al., 2019), which helps in understanding and predicting the effects and reactions to chronic stress (Gershon et al., 2009). Research indicates that individuals with higher levels of mental toughness tend to demonstrate better stress-coping mechanisms (Gerber et al., 2013). In sports studies, it was shown that mental toughness is linked to differences in indicators of performance (Cowden, 2017). Among many others, positive correlation with 800-meter distance running speed (Cooper et al., 2020), perseverance in a specific aerobic test (Gucciardi et al., 2016 b; Giles et al., 2018) and even placement in elite sports events (Van der Mark et al., 2020) were reported.

All of the above points to the conclusion that more profound research into mental toughness in its relationship to the mechanical properties of skeletal muscle is justified. One could hypothesize a direct link to those characteristics related to muscular endurance and stamina, as well as an indirect one through the tendency to develop superior mechanical characteristics through rigorous training. These assumptions align with results from previous studies (Crust, 2005; Nabilpour & Agababa, 2018).

The dark triad was the second construct proposed in addition to the Big Five model to increase its efficiency in predicting stress reactions. We will briefly describe and define it in the following text.

The dark triad, consisting of the personality traits of narcissism, Machiavellianism, and psychopathy, is defined as a tendency towards a lack of empathy, manipulation and exploitation of others, absence of morals, antisocial behaviour, impulsiveness, selfishness and the like (Paulhus & Williams, 2002). The dark triad represents the dark core of the personality (Moshagen, 2012), a propensity for malicious behaviour. "Narcissism is characterized by a grandiose sense of self, entitlement, dominance, and superiority; Machiavellianism by manipulativeness, callous affect, strategic planning, and superior impulse regulation; and psychopathy by thrill-seeking, lack of empathy and remorse, superficial charm, low anxiety proneness, and a lack of long-term goals" (Dinić et al., 2018, p. 18). Aspects of the dark triad share many common traits (Gordon & Platek, 2009) and overlap (Paulhus, 2014), so they should also be studied as a whole.

Empathy plays a crucial role in positive outcomes and the functioning of groups and teams. Broadly defined, empathy involves how individuals react to the perceived experiences of others (Davis, 1983) or the ability to view situations from another person's perspective (Baron-Cohen et al., 2015). It encompasses both affective and cognitive responses to the emotions of others (Hawk et al., 2013).

The cognitive aspect of empathy includes two components: perspective-taking, which is the ability to understand others' viewpoints, and fantasy, which involves identifying with fictional characters in media or the arts (Davis, 1983). In contrast, the affective dimension consists of empathic concern, which is feeling sympathy for those in need, and personal distress, a self-oriented adverse emotional reaction to others' suffering (Davis, 1983).

Although Davis established this framework in the 1980s, it continues to receive widespread support (Baker-Eck et al., 2020; Davis, 1983; Inzunza et al., 2022; McLellan & McKinlay, 2013; Millie & Hirschler, 2023). Empirical research has shown that empathy provides essential information that enhances existing models, assisting in the prediction of various behaviours and events (Milošević et al., 2024; Ristić & Milošević, 2019; Pepping & Timmermans, 2012).

Studies on collective creativity indicate that, in highly creative but selectively chosen groups, the quality of the final product is influenced by the level and quality of interaction and communication among members (Ristić et al., & Mandić, 2016). Furthermore, empathy is crucial for effective communication and collaboration in group work (Sawyer & DeZutter, 2009). Therefore, it is unsurprising that empathy is a more reliable predictor of group creativity than evaluations of individual members' creative abilities (Ristić & Milošević, 2019).

For the same reason, empathy can be a unique asset for young theatre artists during the educational process at the academies. Although high creativity is a prerequisite for success in artistic work, highly developed empathy is necessary to actualize this ability in a group setting. Things are similar in team sports such as basketball. A high level of technical-tactical skills and physical abilities are prerequisites for achieving high results; empathy is necessary for the abilities and skills to be maximally manifested on the court. This conclusion is drawn from the significant review study "Oxytocin and the biopsychology of performance in team sports" (Pepping & Timmermans, 2012), which shows that oxytocin is involved in stimulating bio-psychological processes associated with more excellent team performance in sports, among which empathy has a key role. These assumptions were validated in the recent empirical study (Milošević et al., 2024).For our research, it is important to note that the existence of correlations between Big Five personality traits, mental toughness, dark triad and interpersonal reactivity is very well documented (for instance: Baker-Eck et al., 2020; Čolović et al., 2014; Dinić et al., 2018; Millie & Hirschler, 2023; Milošević et al., 2024; Papageorgiou, 2019) The reasons why exactly these theoretical concepts of the psychology of individual differences were chosen for this dissertation, even though they are sketched and indicated here, will be elaborated in more detail in the final segment of the theoretical part of the work, when the needs and possibilities for expanding previous research on this topic as well as their possible theoretical and practical implication will be analyzed. Once we have familiarized ourselves with the basic terms, we can move on to a deeper analysis of the assumption about the biological basis of personality characteristics and traits.

2.1.2 Hypothesis on the Biological Basis of Personality Characteristics and Traits

As already mentioned, the biological basis of personality is only one of the possible theoretical explanations, which was chosen as the theoretical basis of this research due to the specificity of the topic. In this part, these theories will be presented in more detail.

When considering the hypothesis that different tendencies in behaviour are actually an expression of the biological peculiarities of people, the differences in the functioning of the nervous system are the first thing that comes to mind. However, at the very beginning of development of such idea, the nervous system was not given much importance in the control of human behaviour , which would have been reflected in the peculiarity of temperament. Around the fourth century BC, the Greek philosopher Hippocrates of Kos put forward a theory about the four temperaments, which are an expression of the excess or deficiency of some of the bodily fluids (Hall & Lindsey, 1998).

According to Hippocrates' typology, the first type of temperament is called choleric, it is characterized by strong emotions, quickness to action, and frequent excitement. With this temperament, reactions are sudden and strong, and characteristic moods are anger and rage. An imbalance of body fluids in this temperament causes bile. The second type is sanguine, which is characterized by a quick reaction to feelings that are not strong and do not last long. Cheerful moods are characteristic, while the manifestations of character are expressive. In this type, the behaviour is caused by an imbalance associated with the blood. The third type of temperament according to Hippocratic theory is the melancholic temperament, whose behaviour is associated with a bodily fluid called black bile. A melancholic rarely reacts, but when he does, it does so with intense feelings that last a long time. Characteristic moods include sadness and worry. In the fourth type, the phlegmatic temperament, behaviour is associated with the amount of phlegm in the body. In this type, reactions are rare, slow, and weak. Characteristic moods include calmness and composure. Although later research did not lead to the validation of the assumption about the connection between the levels of bodily fluids and personality traits, Hippocrates' typology of the description of temperaments influenced future thinkers and researchers for a long time, to the extent that numerous similarities with many more modern typologies of personality traits can be observed (Ruch, 1992).

The Russian physiologist Ivan Pavlov, known for his research on the conditioned reflex, proposed a theory at the beginning of the twentieth century on three basic properties of the nervous system that cause typical differences in behaviour between people (Ashton, 2013). These include strength, balance, and mobility of the process of excitation and inhibition of the nervous system. In this theory (Strelau, 1983), the strength of excitation refers to the functional capacity of the central nervous system. This property refers to the ability to endure intense or long-lasting stimulation without transitioning into transmarginal inhibition[1]. On the other hand, the strength of inhibition represents the ability to maintain a state of conditioned inhibition in situations where the unconditioned stimulus is delayed, or it needs to be differentiated from related stimuli and the like. In individuals with weak inhibition power, it is impossible to maintain conditioned inhibitions for a longer period of time. Balance as a property of the nervous system represents the ratio of the power of excitation and the power of inhibition in each individual. Functionally, this feature represents the ability to inhibit excitations, which enables the adaptation of reactions to the moment and the environment. The mobility of nervous processes represents the ability to adequately respond to continuous changes in the environment. Manifest forms of combinations of these features of the nervous system, according to Pavlov (Ruch, 1992) can also be classified into four types of character. The first type is a weak character, who is inhibited, anxious, and easily upset. The second type is strong, unbalanced, characterized by excitability, hyperactivity, and irritability. The third type is strong, balanced, static and calm, consistent, and difficult to get excited, while the fourth is strong, balanced, mobile, lively, quick, and full of desires and old age. In the description of these characters, it is possible to find many similarities with Hippocrates' typology, which was the subject of later empirical studies (Ruch, 1992).

The British psychologist Hans Eysenck developed his well-known theory of personality dimensions based on observations of individuals in military hospitals during World War II. He termed these dimensions extraversion and neuroticism (Eysenck, 1947). Later, through his observations of patients in psychiatric hospitals, he revised this theory and introduced a third dimension known as psychoticism (Eysenck & Eysenck, 1985).

According to Eysenck's theory, the fundamental differences among individuals stem from the strength of their nervous system's reactions to stimulation—that is, the information received from the senses. He referred to this trait as the excitability of the nervous system. Those with high sensitivity to stimulation often experience discomfort in highly stimulating environments, leading them to withdraw from or avoid such situations. In contrast, individuals with low sensitivity may

[1] Transmarginal inhibition is a phenomenon in classical conditioning when a conditioned reaction caused by a conditioned stimulus due to long-term and intense stimulation can lead to a paradoxical reduction of the conditioned reaction.

feel bored when there is a lack of stimulation, resulting in a constant desire for new and intense experiences.

People who are sensitive to stimulation tend to shy away from large groups, social events, and crowded environments, preferring quieter activities and settings. Eysenck named these individuals as introverts. Conversely, those with low sensitivity actively seek out new situations characterized by high levels of people and noise; Eysenck referred to these individuals as extroverts.

Eysenck also believed that the differences in levels of extraversion were linked to a specific part of the brain that he called the ascending reticular activating system. Additionally, he observed varying reactions to stress among individuals. Some people show weak responses to stressful stimuli and situations, which allows them to maintain emotional stability.

On the other hand, some people are far more sensitive to stressful stimuli and are characterized by increased anxiety. Eysenck called this dimension of personality neuroticism and believed that the structures of the limbic system were responsible for individual differences in neuroticism. Finally, Eysenck noticed differences in people's tendency toward aggressive, cruel behaviour versus compassion and concern for others. He called this personality dimension psychoticism and believed that testosterone levels were responsible for its manifestation. Even with this typology, it is not difficult to find similarities with previously described personality typologies (Ruch, 1992). Eysenck's detailed and explicit biological assumptions make his theory easy to test experimentally. Because of this, it has been the subject of numerous studies, the results of which have supported it to some extent, which will be discussed in more detail soon. However, most research today indicates that the necessary number of dimensions to describe personality is five, rather than three (Digman, 1990; Goldberg, 1990; John, 1990; Costa & McCrae, 1992; Wiggins, 1996; McCrae & Costa, 2003). Two of Eysenck's factors, extraversion and neuroticism, are among the Big Five, and the third factor, psychoticism, appears to be a combination of the remaining three factors (Griggs, 2010).

Personality trait theories, often referred to as factor theories, derive the fundamental dimensions of personality from a list of adjectives that describe human behaviours through statistical methods, particularly factor analysis. The number of dimensions identified in this analysis depends on the level of abstraction chosen.

Gordon Allport initially condensed a list of about 18,000 words into 200 clusters (Allport & Odbert, 1936). Raymond Cattell further refined personality description using 16 distinct factors (Cattell, 1965). Eysenck employed a similar methodology but identified only three factors, which can be viewed as higher-order factors compared to Cattell's 16 (Digman, 1990).

By the end of the last century, there was a broad consensus around the five-factor model. This model has been extensively tested across various social contexts, and its structure appears consistent, with only minor variations reflecting local specificities and methodologies (McCrae & Costa, 1997, 2001). Notably, the Serbian model of the Big Five was enriched by including dimensions of positive and negative valence (Colović et al., 2014), showcasing one such localized adaptation.

It is also important to note that the heritability of approximately 50% of the variance in the Big Five traits has been empirically validated (Loehlin et al., 1998), indicating a biological basis. Despite this consensus, the discussion over the number of personality dimensions remains open, with recent research (DeYoung, 2006; DeYoung, 2013) suggesting potential for further abstraction of the Big Five model, which will be explored shortly. In addition to the aforementioned theories that were chosen for a detailed review because of their historical role, as well as their impact on the psychology of individual differences and the practice of assessing personality characteristics and traits, numerous other hypotheses and theories about their biological basis exist. William Sheldon assumed the connection between somatotype (mesomorph, ectomorph, and endomorph) and temperament. Robert Cloninger assumed the connection between neurotransmitters (serotonin, dopamine, and norepinephrine) and personality dimensions (novelty seeking, punishment avoidance and reward dependence). Jeffrey Gray, in his theory of sensitivity to reinforcement, assumed that certain regions of the brain were responsible for behaviour al control (behaviour al activation system, behaviour al inhibition system, the fight or flight system), and that personality traits and the like depend on their activity. However, as will soon be seen, many of the aforementioned assumptions did not fully pass the test of empirical validation.

2.1.3 Validation of the Assumption on the Biological Basis of Personality Characteristics and Traits

Of course, the theories presented in previous part of the text also have their empirical validation through the results of previous studies, which will be presented in more detail in this part.

Hippocrates' idea, which was later elaborated by Galen, that the typical behaviour s of certain characters are related to the system of bodily fluids, remained influential and popular until the Middle Ages, after which it was rejected in scientific circles (Ashton, 2013). As for Pavlov, his theory was largely based on experiments on dogs, while validation of these hypotheses on humans was absent. What was the subject of research was the similarity of the three-character typologies of Hippocrates, Pavlov, and Eysenck. Using the negative personality inventories created on the basis of these theories, a relative similarity of the three typologies, i.e., the high correlation between individual types was confirmed (Strelau, 1983; Strelau et al., 1990; Ruch, 1992).

In a classic experiment called the Lemon Juice Test (Eysenck & Eysenck, 1967), the hypothesis about the sensitivity of the nervous system as the basis of introverted and extraverted behaviour was tested. The researchers put a few drops of lemon juice on the subject's tongue and measured the amount of saliva that the subject produced in response. The assumption that those who were more sensitive to stimulation, that is, subjects who produced more saliva in such an experiment, would be those who leaned towards introverted patterns of behaviour , has been confirmed.

Similar results were obtained in Geen's (Russell Geen) study (1984) with the preferred level of noise and the body's response to it. Geen not only demonstrated that extroverts preferred higher environmental noise levels than introverts, even in learning tasks, but also that they responded to the same noise levels with a lower heart rate and lower psychogalvanic reflex than introverts, regardless of whether the noise was raised or lowered.

On the other hand, Gray (1970) believed anxiety and impulsivity to be more fundamental traits than Eysenck's neuroticism and extraversion because they have a clearer biological basis. Carrying out laboratory research on rats, he came to important findings that contributed to the understanding of the role of the hypothalamus and the septohippocampal system in the regulation of emotions (Mitrović et al., 2008). Although both Eysenck's and Gray's personality theories are considered to be controversial at the very least, they are still the subject of empirical studies (e.g., LeBlanc et al., 2004; Mitrović et al., 2008; Küssner, 2017), while Eysenck alone was cited nearly 2,500 times in 2022 (over 16,000 citations in the last 5 years)[2].

[2] https://scholar.google.com/citations?user=FZzaeRsAAAAJ&hl=en. Retrieved March 1, 2023.

Technological advancements have provided new opportunities for empirical validation of hypotheses regarding the biological basis of personality characteristics and traits. A recent study (LeBlanc et al., 2004) investigated the relationship between stress reactions and Eysenck's dimensions of extraversion and neuroticism. Participants were subjected to physical stress and discomfort by being exposed to strong, cold winds directed at their faces. During this time, the autonomic nervous system's response was measured by monitoring heart rate and catecholamine levels in blood plasma before, during, and after the experimental exposure.

The results indicated that individuals with higher levels of extraversion experienced increased heart rates and more significant responses to noradrenaline, as well as intensified feelings of discomfort. In contrast, neuroticism was found to have a negative correlation with these variables, aligning with Eysenck's theoretical framework. Interestingly, extraverted individuals would respond more strongly to the stimulation of the wind, as it could be viewed as a form of enhancement rather than merely a stressor. However, the findings suggest that introverts, who generally have reduced sensitivity to stimulation, reacted with less discomfort and showed lower autonomic responses, supporting Eysenck's assumptions. The biological and physiological bases of the influence of the Big Five personality traits on the quality and intensity of emotional reactions have also been the subject of empirical research (Brumbaugh et al., 2013). Heart rate, psychogalvanic reflex, and breathing rate were measured in response to watching different emotionally colored video clips. Although general patterns of response to the emotional tone of the scenes were observed, personality traits were associated with the intensity of these responses. Extraversion and neuroticism were positively related to the strength of the autonomic arousal response, although neuroticism to a lesser extent. These line results were also obtained in the previously described study.

Structural magnetic resonance imaging (sMRI) was used to verify the association between the size of brain parts and the Big Five personality traits (DeYoung et al., 2010). The results showed that there is such a connection for as many as four out of five traits from the model, namely: extraversions with the volume of the brain region involved in the processing of reward information (medial orbitofrontal cortex), neuroticism with the volume of the brain regions associated with threat, punishment, and negative feelings, agreeableness with volume in regions that process information about the intentions and mental states of others, and conscientiousness with volume regions involved in planning and voluntary control of behaviour (lateral prefrontal cortex). The two mentioned neural structures, and especially the lateral prefrontal cortex, play an important role in motor learning as well as in the control of voluntary movements (Lee et al., 2020).

Suppose the intercorrelations of the factors of the Big Five model are taken into account. In that case, it is possible to extract two higher-order factors: α - stability (cooperativeness, conscientiousness, and neuroticism) and β - plasticity (extraversion and openness), which are also assumed to be biologically conditioned (DeYoung, 2006). Namely, individual differences in the functioning of the serotonergic system, which regulates the stability of emotions and behaviour, are expressed through the α factor, while individual differences in the functioning of the dopaminergic system, which governs research behaviour and cognitive flexibility, refer to the β factor. Research by Jang et al. (1998) and DeYoung (2006, 2013) has confirmed the functioning of a system involving two neurotransmitters and the genetic inheritance of α and β factors. However, this theory does not dismiss the existence of the Big Five personality traits, nor does it simplify all biological mechanisms of behaviour regulation to just these two systems. The assumption is, in fact, that peculiarities in the functioning of serotonin and dopamine, which act very broadly in the brain as neuromodulators, are responsible for the mutual correlations of the Big Five personality traits (DeYoung, 2006) and, therefore, represent broad targets of personality traits. After nearly a century of research into personality traits and their biological basis, it seems as if the circle is closed, i.e., the new model of two meta-factors is very similar to Eysenck's original idea of two dimensions of personality. At this point, for the topic of this paper, it is important to recall the role of serotonin and dopamine in the management and coordination of movement, as well as their activation during strenuous physical and mental actions (Sesboüé & Guincestre, 2006; Korchounov et al., 2010; Spencer & Hu, 2020). Regarding the biological basis of mental toughness, the dark triad, and empathy, although not studied in nearly as much detail as the Big Five model, it appears to be at least partially confirmed in inheritance studies (Vernon et al., 2009; Horsburgh et al., 2009; Warrier, et al., 2018).

However, recent studies are not completely unanimous when it comes to the biological basis of personality characteristics and traits. Studies in which the connections between personality traits and the level of arousal of different brain segments were examined gave rather complex results, which can only be partially explained by the presented theories of personality traits (Zuckerman, 2005; Canli, 2006). Research aimed at a better understanding of this topic is still needed, and likely new theories into which their findings will fit in a valid way.

After all that has been stated, it seems that, nowadays, the biological and physiological basis of personality, although insufficiently known, remains, nevertheless, unquestioned. Furthermore, numerous structures that are associated with the manifestations of personality characteristics and traits have their role in learning, performing, initiating, and controlling movement. This conclusion provides grounds for supposing that some mechanical characteristics of movement could be related to personality characteristics and traits. Moreover, it could be assumed that, through the study of these connections, something more could be learned about the very nature of the biological basis of personality characteristics and traits.

2.2 Mechanical Characteristics of Skeletal Muscles as an Indicator of the Quality of Control and Execution of Movements

When we got acquainted in more detail with psychological characteristics and their role in managing behaviour , it is time to get acquainted with the mechanical characteristics of skeletal muscles. In this part of the text, mechanical characteristics will be presented and defined through the prism of different dimensions of muscle force. Due to the specificity of the researched topic, these characteristics will be considered as indicators of the quality of control and execution of movements.

The mechanical characteristics of skeletal muscles represent those properties that can be measured and described by mechanical quantities, such as force, speed, power, and the like (Zatsiorsky, 2000). The mechanical properties of muscles are a complex subject of study in numerous scientific disciplines, with the aim of understanding the structure and function of the neuromuscular system, as well as describing and predicting the level of muscle abilities. The subject of interest of this paper is specific in relation to most research that deals with the mechanical characteristics of muscles. Namely, the focus will be on an attempt to understand better the relationships and the place of the movement control system on the broader behaviour control system through the research of mechanical characteristics. In this sense, two basic mechanisms are observed: the force level control mechanism (Latash & Gottlieb, 1991) and the time control mechanism in which the force is created (Goodbody & Wolpert, 1998). Muscle contraction is a condition for movement of the body (in terms of motor behaviour) or its parts. Under natural conditions, in order for muscle contraction to occur, it is necessary for nerve impulses to reach the muscle through the nerve fibers of the motor neuron. After the arrival of the nerve impulse, motor units whose muscle fibers begin to produce force are recruited. The muscle force produced is directly proportional to the frequency of nerve impulses arriving in the muscle, as well as the number of active (recruited) motor units (Bartlett, 2005).

When it comes to the relationship between the muscle and the external force that the muscle opposes, it is possible to distinguish between concentric, eccentric, and isometric contractions, in which the muscle creates force by the exact mechanism (at the molecular level). However, its length is shortened, lengthened, or unchanged depending on whether it is a force produced greater than, less than, or equal to an external force. Regardless of the type of contraction, force-length relations (dependence of muscle force on muscle length), force-speed (dependence of muscle force on the speed of muscle shortening), and force-time (dependence of muscle force on the degree of muscle activation) represent mechanical relations that describes the mechanism of muscle contraction (Bartlett, 2005). However, in the isometric mode of muscle contraction, in which the muscle force is equal to the external force, and its length does not change, force-length and force-speed ratios are constant. They can be abstracted, which significantly facilitates the research process. Although this is by no means the most common case in actual conditions of movement, this approach to studying the mechanical properties of muscles makes it much easier to measure and find out the fundamental mechanisms that have not yet been sufficiently explored. In contrast, research in dynamic conditions should follow as the next step. When it comes to the mechanical properties of the hand, it should be emphasized that numerous important functions of the hand in real life are performed in isometric (or at least approximately isometric) mode. For example, when it comes to fighting or handling aids and body extensions (such as props, aids, tools, implements, weapons, etc.), the primary function of the hand is to provide a solid striking surface (fist) or fixation (either the opponent or the tool), while the rest of the body provides the necessary force through eccentric and concentric contractions. Because of this, the research approach described earlier is additionally justified when it comes to researching the mechanical properties of the hand.

The maximal force will serve as an indicator of the force control mechanism, while the maximal rate of force development and endurance in the manifestation of force will serve as indicators of the time control mechanism, the basics of which will be briefly presented, primarily from the point of view of the interest of this work, i.e., the discovery of possible relationships with the behaviour control system.

For our research is important to note that, the existence of correlations between the mechanical characteristics of maximal force, maximal rate of force development and endurance of hand-grip is very well documented (for instance: Gerodimos et al, 2017; Dopsaj et al, 2018, 2019, 2021, 2022; Innes, 1999; Ivanović & Dopsaj 2012; Trajkov et al, 2018).

2.2.1 Maximal Force

The first, from the point of view of this research, the key mechanical characteristic that will be presented in this part of the text is the maximal force.

As explained earlier, under the influence of nerve impulses, muscles generate force. However, the creation of force is not instantaneous; instead, it develops over time, which is explained by the force-time relation. Put (according to Feher, 2012), the action potential that passes from the nerve to the muscle causes a twitch and then relaxation in the muscle fiber. Nevertheless, the action potential in the nerve fiber does not cause a twitch in the muscle immediately, but with a delay of about 10 ms, which is necessary for biochemical processes to take place. If the next action potential reaches the muscle before complete relaxation has occurred, the next twitch in the nerve fiber will follow, which will manifest itself as the sum of the produced force of the two twitches. Through this process, an increase in muscle strength can be obtained by increasing the frequency of nerve impulses that reach the muscle. Another mechanism is an increase in the number of active muscle fibers that produce force at the same time. Activation is achieved by the mechanism of strengthening the nerve signal - simultaneous delivery of a more significant number of nerve impulses to the muscle. The resulting muscle force will again be the sum of the forces produced in the simultaneously active muscle fibers. However, this process cannot last forever. At one point, the voluntary maximal force is reached, followed by its decline. Maximal force is actually the highest point that force intensity can reach in the described time cycle of muscle contraction.

What is interesting about the topic of this paper is that both described mechanisms by which muscle force is produced have an important neural basis. Furthermore, the amount of nerve impulses that the central nervous system sends to the muscles is approximately equal to only one-third of the nerve impulses that actually reach the muscles under regular conditions in which a person is trying to produce maximal force. This fact is explained by inhibitory mechanisms that, among other things, are carried out by the Golgi tendon organ and Rensch cells, protecting the body from injury.

The most commonly used variable for assessing the maximum intensity of the handgrip force in isometric conditions is the maximal force. The maximal force in the handgrip test is reached up to about a maximum of 3 seconds of contraction duration, on average about 1.5 seconds, regardless of hand dominance (Dopsaj et al., 2022). Its validity is based on the assumed similarity with the maximal force that the muscle can exert in different activities (Dopsaj et al., 2021). The force of the handgrip is the result of the adequate flexion of the joints of all fingers with the voluntary maximum strain that a person can apply in normal biokinetic conditions.

Over 50% of the variance in maximal handgrip strength can be attributed to hereditary factors (Frederiksen et al., 2002), while the rest can be explained by general body condition, lifestyle, or training adaptations. Maximum muscle force is generally directly proportional to the cross-sectional size of the muscle (Jarić et al., 2005; Dulac et al., 2016). The findings of recent studies suggest a possible role of serotonin in the growth of skeletal muscles (Chandran et al., 2012), the role of nerve stimulation in muscle hypertrophy (Alix-Fages, 2020), and the modulatory role of neural motor control in relation to muscle compared to hypertrophy and strength, are important for the topic of this paper (Reggiani & Schiaffino, 2020). The assessment of the intensity of the handgrip force is applied in various areas of research activity, which will be discussed in more detail soon.

2.2.2 Maximal Rate of Force Development

The second, from the point of view of this research, the key mechanical characteristic that will be presented in this part of the text is the maximal rate of force development.

When the time dimension is added to muscle force as a mechanical characteristic, we get, among other things, the rate of force development. The rate of force development is a term that is widely used in scientific literature in the broadest possible sense of the field of sports and human movement sciences. It represents the ability of the neuromuscular system to increase the level of contractile force when there is an intention or need to activate the muscles as quickly as possible. This is why it is one of the most important abilities when it comes to movements in which time for force production is limited (Rodriguez-Rosell et al., 2018). Of course, sports and sports competitions abound in such situations. However, in everyday life, especially in crises, a higher rate of force development can be the key to successful reaction, adaptation and, therefore, survival.

In an influential overview study of the physiological aspects of the rate of force development from 2018 (Rodriguez-Rosell et al., 2018), the most important neural factors upon which this ability depends stand out: motor unit discharge rate, the appearance of doublet discharges, and the synchronization of motor units. Motor unit discharge rate refers to the number of action potentials produced by motor neurons per unit of time. Duplicated discharge represents the appearance of a pair of action potentials at an interval of less than 5 ms, which probably arises as a result of delayed depolarization in the dendrites of spinal motoneurons. Synchronization of the operation of motor units refers to the level of coordination of the production of action potentials of simultaneously active motor units. In addition to the aforementioned neural factors, numerous structural factors, in addition to movement characteristics, are mentioned as important for the rate of force development. Moreover, depending on the time interval in which the force is produced, numerous factors listed will be decisive for the speed of the individual's force generation. Although the rate of force development is insufficiently investigated for now, the results of previous studies lead to the conclusion that the relative contribution of neural versus muscle properties may vary during the time course of force growth, where the early phase of force generation is dominated by neural stimulation. In contrast, maximal muscle forces influence the late phase more. However, there is a simultaneous neural influence in that phase.

Analyzing the aforementioned factors that determine the rate of force development (Del Vecchio et al., 2019) suggests that, although previous research has shown that the recruitment and increase in the discharge rate of motor units determines the speed of force change (Milošević et al., 2014; 2020), it is not known until the end whether the properties of the motor units determine the individual variability among individuals in the maximal rate of force development. Therefore, the question arises: Are human movements as fast as the motor neurons that drive them? The starting assumption in this study is that the rate of recruitment and the total maximal rate of discharge of motor neurons will determine the maximal rate of force generation in humans. Before this study, there was much circumstantial evidence that pointed to this assumption. Namely, when external electrical stimulation is performed, the rate of force development really depends on the stimulation frequency (Deutekom et al., 2000).

Furthermore, after several months of ballistic training, the increase in the rate of force generation was accompanied by an increase in the discharge rate of motor units (Van Cutsem et al., 1998). Moreover, the finding that ageing reduces the discharge rate of motor neurons and, at the same time, the rate of force generation should be taken as evidence (Klass et al., 2008) and similar. By applying a new approach for precisely identifying the activity of motor neurons using high-resolution electromyography decomposition while simultaneously measuring the rate of force development, the behaviour of relatively large (10 and 20 times larger than in previous similar studies) populations of motor neurons was recorded during rapid contractions. The obtained results show that the peak of the discharge rate of the motor unit occurs before the very moment of force generation. Meanwhile, after this moment, the discharge rates decrease, which is why they are significantly higher during the initial phase of the contraction compared to the plateau of the explosive contraction. The maximum discharge rate of the motor unit was related to the force generation rate variables (R^2=0.72, p=0.001).

Furthermore, supraspinal drive, i.e., the cortical input of impulses to motor neurons during the initial phase of the motor task, which was measured as the speed of recruitment of motor units until the moment of generating an afferent feedback reaction, was significantly related to both the rate of force development and the speed of discharge of the motor unit. As such, for the first time, the connection between the nerve drive of the muscles and the maximal rate of force development is explicitly demonstrated. It is concluded that the results obtained in this study show that the variability of the maximal rate of force development in human muscle is determined by the neural activation that precedes force generation.

However, the presented study and its results had a significant limitation. Namely, due to the unknown variance in the speed of individual motor unit contractions among the subjects, it was not possible to assess the relative importance of nervous and contractile parameters when it comes to the rate of force development. Therefore, the same group of researchers is launching a study with the aim of investigating the neural and muscular determinants of maximal force generation velocity using a realistic computational model of ballistic isometric contraction (Dideriksen et al., 2020). This model allowed for systematic variation of motor unit discharge rate (including the possibility of doublets), motor unit recruitment rate, and single motor unit contraction time. The analysis showed that the effective neural drive to the simulated muscle had a lower bandwidth than the contraction range of the average motor unit. This fact indicates that the bandwidth of the motor output, and thus the capacity for the rate of force generation, is limited mainly by neural properties. The simulated rate of force development increased by 1,050% from the longest to the shortest recruitment interval. This effect was more than four times greater than the effect of increasing the discharge rate, more than five times greater than the effect of increasing the chance of doublets, and more than six times greater than the effect of decreasing single contraction time. The simulation results suggest that the physiological variation in the rate at which motor units are recruited during ballistic contractions is a significant determinant of the variability in the rate of force generation between humans.

The studies presented so far have provided much information about the neurological basis of the rate of force development (Del Vecchio et al., 2019; Dideriksen et al., 2020; Rodriguez-Rosell et al., 2018; Van Cutsem et al., 1998). They also provide evidence that fast muscle contractions allow insight into the maximal rate of recruitment, as well as the maximal rate of discharge of motor units in vivo. What remains unknown is the origin of the input impulses that underlie the maximal rate of recruitment and discharge of motor units.

A study from Baudry and Duchateau (2021) seeks to answer these questions. By using transcranial magnetic stimulation and peripheral nerve stimulation, an attempt is made to compare the specific modulation of the cortex and spinal cord excitability during the preparatory phase (the last 500 ms before the onset of contraction) of fast (ballistic) and gradual contractions. The results indicate that changes at the cortical level occur earlier than at the spinal level during the preparatory phase of both types of contractions. However, these adjustments occur later in fast (last 200-100 ms) compared to slow contractions (last 300-200 ms). These results also suggest a higher rate of rise in the excitatory input before the onset of fast contractions. In addition, an apparent increase in the excitability of spinal cord motor neurons was recorded, starting at 200 ms before the gradual contraction.

In comparison, only a very moderate increase was recorded in the last 100 ms during the fast contraction. The obtained data indicate that the recorded early increase in the change in neuromotor excitability during fast contractions reflects changes at the level of the cortex and not at the level of neurons of the spinal cord. In conclusion, this study clearly demonstrates that the time course of changes in cortical and spinal cord excitability during the preparatory phase of a voluntary contraction is specific to the planned rate of force development of the upcoming movement.

Complementary results, when it comes to the role of the cortex and subcortical centres in the rate of force development were offered by recently published studies (Škarabot et al., 2022; Colomer-Poveda et al., 2023) with the use of sudden and startling stimuli as cues for the initiation of fast movements. Namely, although the exact mechanism and reason are not yet known, it has been known for a long time (Valls-Solé et al., 1999) that startling stimuli lead to a shortening of reaction time and an increase in muscle force output. This phenomenon is thought to represent the involuntary realization of a pre-planned movement stored in subcortical centres, probably in the pontomedullary reticular formation. Therefore, responses to startling stimuli are suitable for investigating reticulospinal contributions to human locomotion. Similar to the previously presented studies, the activity of motoneurons was monitored with the help of high-resolution electromyograms. The obtained results showed that the reaction time was significantly shorter in response to startling stimuli compared to visual and visual-auditory stimuli. The startling stimulus further elicited faster neuromechanical responses, including a higher motor unit discharge rate and a higher maximal rate of force generation. No differences were noted between the other two types of stimuli. Consequently, it was also explicitly demonstrated for the first time that the increase in the rate of force development could be, at least partially, initiated by subcortical structures. As such, the contribution of subcortical pathways to the maximum output of α motoneurons in humans is suggested, which results in faster recruitment and higher discharge rates of motor units.

Taking all the presented results into account, the role of the primary motor cortex in the performance of fast contractions was clearly demonstrated (Baudry et al., 2021). Additionally, it has been observed that there is a wide network of cortico-reticular connections (Škarabot et al., 2022) so that, in response to a startling stimulus, a cortical input of impulses is likely to be enhanced by signals from reticulospinal neurons, leading to greater output in motoneurons. The presented data suggest that different neural pathways and mechanisms, both cortical and subcortical, probably act synergistically, and contribute to the rapid recruitment and high discharge rate of motor units during the performance of fast movements.

Taking everything into account, one can observe the peculiarity of the physiological mechanism of the maximum rate of force development in relation to the maximal force, which justifies its further study. Moreover, from the point of view of the interest of this paper, the rate of force development acts as a more relevant parameter than the maximal force.

2.2.3 Endurance in the Application of Force

The third, from the point of view of this research, the key mechanical characteristic that will be presented in this part of the text is the endurance in the application of force.

Similar to the mechanism of the rate of force development described just now, by adding a time component to the force, but with the aim of making that time last as long as possible and not as short as possible, we gain endurance in the manifestation of force. This property is also fundamental from the point of view of the possibility of connecting psychological and mechanical characteristics. Questions are raised about the limits of human endurance: How are they determined, and what is the nature of fatigue that leads to cessation of activity? Numerous studies describe the physiological limits of the human body, after which physical activity is stopped (Allen al., 2008; Amann & Calbe, 2008), while those in the field of sports endurance research primarily refer to muscle fatigue and limits (Quarta et al., 2009). However, recent research suggests that the physiological exhaustion of the nervous system (Morales-Alamo et al., 2015) should be taken into account when researching this topic, and that means at all levels, from sensory input through the spinal cord and brain to autonomic functions and effector output. (Taylor et al., 2016). Mental fatigue is defined as a mental state caused by prolonged, demanding cognitive activity (Van Cutsem et al., 2017). It refers to the physiological changes caused by the activity, as well as to the psychological interpretation (Giboin et al., 2017). The negative influence of both of these components of mental fatigue on the ability to exercise has been documented (Pires et al., 2018a).

An increase in the range of theta waves in the prefrontal cortex (mentioned earlier in connection with the conscientiousness personality trait) is an indicator of the onset of mental fatigue (Wascher et al., 2014). It is assumed that mental fatigue is associated with reduced activation of the prefrontal cortex due to an increase in ATP hydrolysis and adenosine concentration in the brain (Brietzke et al., 2020; Pires et al., 2018a), which impairs the ability to tolerate aversive stimuli (Latini et al., 2001). This occurrence ultimately leads to the inhibition of activity. However, the finding that mentally exhausted athletes improved their performance after caffeine intake did not affect the change in activity in the prefrontal cortex (Franco-Alvarenga et al., 2019), even in placebo sessions (Pires et al., 2018b; Brietzke et al., 2020), shows that, when explaining the phenomenon of activity inhibition due to mental fatigue, the psychological component must also be taken into account. Theoretical assumptions that explain mental fatigue with emotional processes, whose role is to protect the body and preserve homeostasis (Noakes, 2012), and cognitive processes of self-control (Giboin et al., 2019) can explain the aforementioned controversial findings, as well as the phenomenon that athletes do not provide their maximums, that is, they give up on a strenuous task even when physiological limits have not been reached (Morales-Alamo et al., 2015).

Studies on the effects of direct transcranial stimulation (tDCS) represent a new experimental method that should enable the elucidation of the neuroanatomical and neurophysiological bases of conative abilities and processes, as well as the causal links between them and sports achievement (Quarta et al., 2020). After anodal stimulation of the primary motor cortex in experimental conditions on healthy adult subjects, a significant increase in endurance was obtained, which was associated with increased corticospinal excitability of the knee extensor muscles and reduced effort perception (Angius et al., 2018). Similar findings were obtained in studies on athletes (Vitor-Costa et al., 2015). The finding that after direct transcranial stimulation of the temporal and insular cortex, which are connected to the autonomic nervous system and responsible for awareness of information from the body related to emotions, also occurred as a validation of the modulatory role of the psychological component of mental fatigue in the regulation of activity duration, leading to changes in the perception of effort in subjects and better results on endurance tasks (Okano et al., 2015).

Another important theoretical model is related to endurance in physical tasks. Based on the findings of empirical studies that show that limits in energy production cannot fully describe the limits of human capacity for endurance (Calbet et al., 2003), the central control theory postulates the role of subconscious processes taking place in the brain in limiting human performance through adjusting the number of active motor units (Noakes et al., 2005).

Moreover, when it comes to persistence in activities, most of the concepts and theoretical assumptions come from the corpus of personality traits theories. Resistance to stress, vulnerability, resilience, and mental toughness are some of the most influential theoretical concepts from this field, which share a relatively permanent predisposition of the personality to cope with problems, threats, and challenges, i.e., acute and chronic stress to a greater or lesser extent. It was found that the primary physiological mediators of mental toughness and resistance to stress versus vulnerability are resistance to depletion of catecholamines in the brain, increased peripheral availability of catecholamines, and increased sensitivity of beta receptors, which is manifested by a low general level of physiological arousal. In contrast, in stressful situations, it manifests through an intense but short-term response of the autonomic nervous system via catecholamines and the suppression of responses via cortisol (Dienstbier, 1989). These physiological parameters are related not only to the efficiency of functioning under stress but also to characteristics of temperament and the immune system. The hippocampus also plays a role in the described processes, through which the described responses of the autonomic nervous system to stress are inhibited through a feedback loop. A study in rats showed that hippocampal brain-derived neurotrophic factor (BDNF) plays a crucial role in resistance to chronic stress. At the same time, its reduced expression in youth induces prolonged corticosteroid secretion (Taliaz et al., 2011). A recent study in mice showed that GABA (B1) but not GABA (B2) receptor activity within the infralimbic cortex in the medial prefrontal cortex plays an important role in resilience and vulnerability to stress (Zou al., 2021). All described mechanisms can be interpreted as somatic adaptations to environmental conditions, which are primarily determined through genetic predisposition (Dienstbier, 1989). However, the role of environmental influence and personal experience as a potential for systematic positive influence can also be clearly observed.

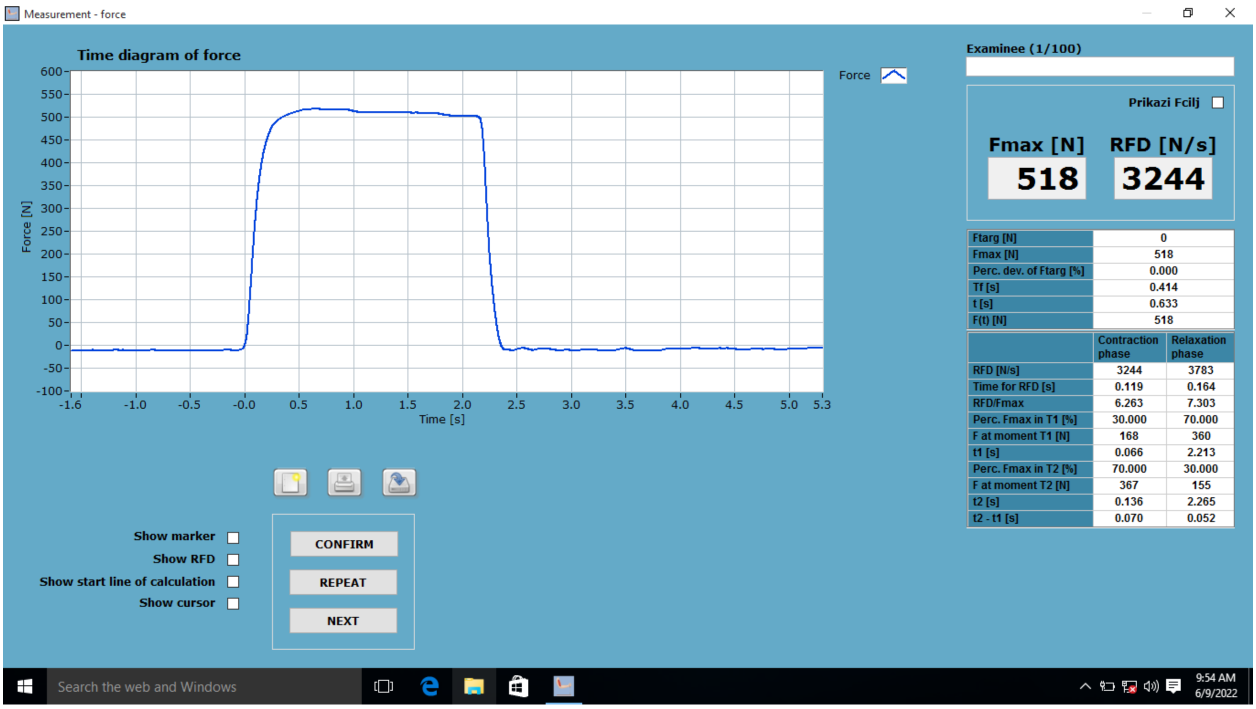
From the domain of cognitive learning theories comes the aforementioned Gray's theory of sensitivity to reinforcement, which can also be linked to resistance to stress and persistence in physically demanding tasks. According to this model, the initiation and termination of behaviour are influenced by two systems: the reward sensitivity system and the punishment sensitivity system (Gray, 1970). The reward sensitivity system is a neurological system of the dopamine reward pathway that involves sending impulses from the substantia nigra and ventral tegmental area (VTA) to the dorsal and ventral striatum and then to the prefrontal cortex (McNaughton & Corr, 2004). The punishment sensitivity system is further divided into two subsystems: the anterior cingulate and prefrontal ventral pathways (Corr, 2004), which are activated during threat perception, and the septo-hippocampal, posterior cingulate, and prefrontal dorsal pathways (Gray & McNaughton, 2000), which are activated when approaching aversive charms and stimuli. There is ample, albeit circumstantial, evidence that greater sensitivity to rewards leads to more excellent resistance to stress and mental toughness, while increased sensitivity to punishments has the opposite effect (Bell, 2012). Possible relationships between the mechanical properties of skeletal muscles and personality characteristics and traits, as well as their common physiological basis can be most clearly observed when it comes to endurance in the exercise of force. Therefore, further study into it is more than justified.

2.2.4 Classic and Impulse Mode of Muscle Contraction

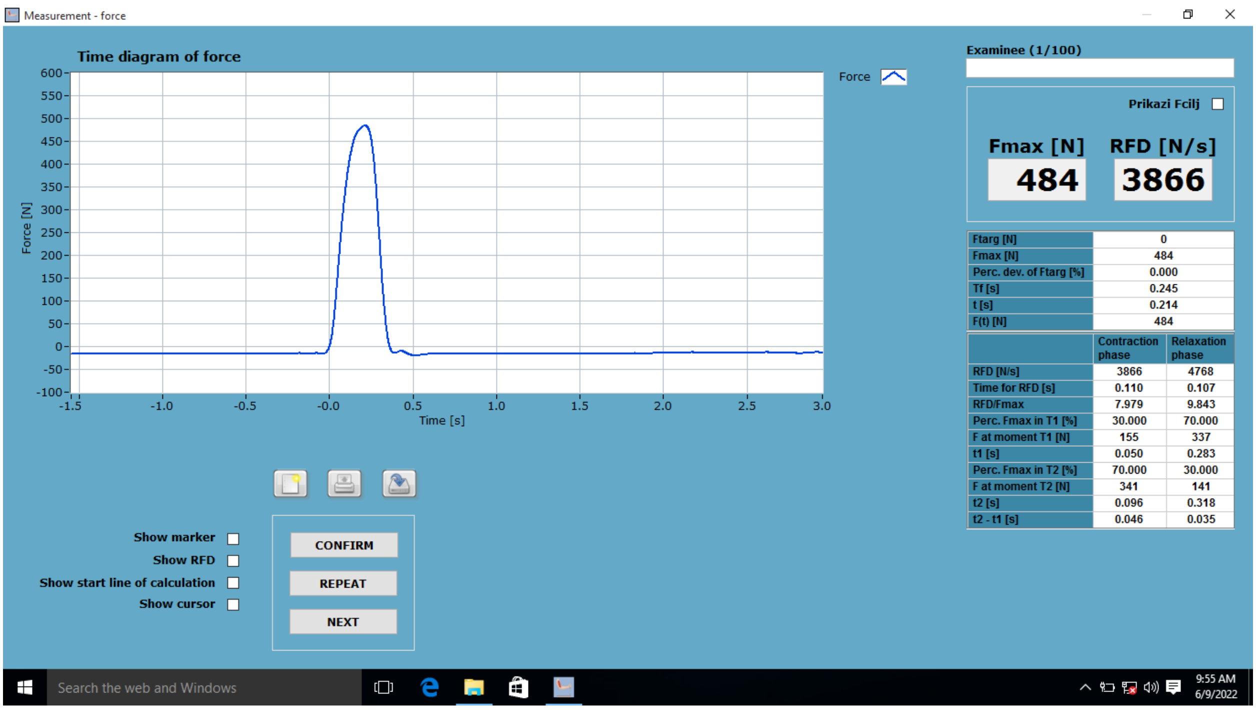
Mechanical characteristics presented so far have different characteristics and manifestations depending on the modality of muscle contraction. In this chapter, they will be presented in more detail classic and impulse mode of muscle contraction which have not received much attention in previous research, but they represent a promising avenue for future research.

An interesting phenomenon related to the mode of muscle contraction has been observed in recent empirical studies. The values of the mechanical characteristics of maximum muscle force and maximum rate of force development can be changed depending on the content of the verbal instructions given to the subjects. In the flexor muscles in the elbow joint and the flexors in the knee joint, the instruction Perform the test as fast as you can result in higher values of the maximum rate of force development ($F = 40.8$, $p < 0.001$) compared to the instruction Perform the test as hard and as fast as you can (Bemben et al., 1990; Sahaly et al., 2001). Differences in the neural activation pattern could explain this phenomenon, typical of the two contraction modalities (Mirkov et al., 2004; Holtermann et al., 2007; Suzović & Nedeljković, 2009).

Although the initial validation studies on the mechanical characteristics of skeletal muscles during impulse contraction did not yield satisfactory results due to moderate generalization across different muscle groups (Suzović & Nedeljković, 2009), recent findings (Koznic et al., 2022) suggest that using impulse contraction is valid for the handgrip test (Dopsaj et al., 2021). This approach demonstrates high reliability, and by varying the verbal instructions, significantly different mechanical properties were observed between the two types of contractions (Graphs 1 and 2).



Graph 1. Record of the force-time curve in the classical modality of isometric muscle contraction of the hand (Dopsaj et al., 2021)



Graph 2. Record of the force-time curve in the impulse modality of isometric muscle contraction of the hand (Dopsaj et al., 2021)

In comparison to the classic contraction method, the impulse contraction produced both lower maximal force and a higher maximal rate of force development (Dopsaj et al., 2021; Koznic et al., 2022). The time taken to reach maximal force was drastically different; it required over 400% less time achieving maximal force with the impulse contraction. Considering the mechanisms involved, particularly the rate of force development, these differences seem to primarily reflect variations in the speed of motor unit recruitment and the firing rate of motoneurons. The described differences suggest that, behind the manifestation of the mechanical characteristics of the hand in different contraction modes, lie somewhat different (in quantitative terms) physiological processes, therefore, further research into the mechanical characteristics manifested in different modes of isometric contraction in the light of the topic of this work is also justified.

2.3 Relationships of the Mechanical Characteristics of the Handgrip with Psychological Characteristics and Behaviour al Patterns

After a more detailed introduction to the basic theoretical concepts, we will directly address our topic relationships of the mechanical characteristics of the handgrip with psychological characteristics and behavioural patterns.

As mentioned earlier, the use of the hand and its functions in the human species are unique in the living world, similar to psychological functioning. The importance of the hand for daily life and the survival of humankind are reflected in its neural representation, wherein the motor and sensory cortex centres associated with the control of the hand occupy approximately the same place as the rest of the body (excluding the head).

The isometric handgrip test is a useful predictor of various life outcomes, including postoperative complications, the length of recovery periods, and decline in physical functionality, the likelihood of requiring social care, and mortality rates (Bohannon, 2001). Although these findings primarily pertain to clinical and elderly populations, the test also correlates with total body strength in adults (Marković et al., 2020) as well as in children and adolescents (Wind et al., 2010). Additionally, the handgrip test is valuable in the assessment and selection of athletes (Ivanović & Dopsaj, 2012). For police officers, this test holds particular significance in specific job-related scenarios, such as precise pistol shooting (Kaihan et al., 2013) and evaluating fitness readiness and the risk of injury while performing police duties (Tomes et al., 2020). It should be emphasized that isometric handgrip strength is both a highly sexually dimorphic and a lateralized measurement (Gallup et al., 2007; Kamarul et al., 2006), a reflection of muscular force and neural activity (i.e., neuromuscular characteristics) (Innes, 1999; Liu et al., 2005). It is influenced by personal and training history, that is, environmental influences and individual activities (Gallup et al., 2007; Innes, 1999; Kamarul et al., 2006). Also, since we talk about muscle force and its influences, it should be noted that force produced in handgrip, as well as any other muscular force under the influence of body dimensions (Dulac et al., 2016; Jarić et al., 2005; Trajkov et al., 2017).

The relationship between hand characteristics and personality has been a focus of research since its inception. Eysenck (1947) reported a correlation between handwriting and personality traits, suggesting that it is possible to distinguish between the dimensions of neuroticism and extraversion based on handwriting analysis. Building on Eysenck's work, Roush (1950) conducted a study using handgrip strength and endurance tests to examine the effects of hypnosis on these personality traits. Roush concluded that subjects demonstrated increased strength and endurance when under hypnosis, attributing this enhancement to the absence of inhibitory mechanisms during the hypnotic state.

In the male population, in recent research, the handgrip test is a predictor of the aggression and sexual behaviour of students (Gallup et al., 2007), as well as socially dominant behaviour (Gallup et al., 2010). Given that, in the aforementioned studies, correlations were found only in men, the obtained results could be explained by previously observed relationships between testosterone levels and handgrip strength (Alibhai et al., 2010; Hansen et al., 1999).

A study on women showed that handgrip strength, paired with voice pitch, also predicted reproductive success in women from African tribes (Atkinson, 2012). This study can also be interpreted as a validation of the assumptions of evolutionary psychology where, with the elimination of the influence of modern society, the connections between biological characteristics and behavioural characteristics can be more clearly observed.

Research on the relationship between handgrip strength and levels of sensation seeking suggests that the demonstrated relationships can be extended to the personality domain (Fink et al., 2010). Namely, maximum handgrip force correlates positively with the total score on the sensation-seeking scale (SSS-V) and the thrill and adventure-seeking subscale. Such results support the assumption that physically stronger men display physical and social characteristics that women prefer (Gallup, White & Gallup, 2007; Frederick & Haselton, 2007).

The results of the presented studies were the reason for a deeper investigation into the relationship between maximum handgrip strength and personality traits, specifically the Big Five model (Costa & McCrae, 1992). In a sample of 160 British women and men aged 18–42, maximum handgrip strength correlated negatively with neuroticism, positively with extraversion in men, and negatively with cooperativeness in women (Fink et al., 2016). The correlation with neuroticism in men remained significant even after partializing age and body mass index influences.

Starting from the documented connection of physical strength with the dynamics of everyday social interactions, as well as the occurrence of social behaviour disorders in mammals (Anestis, 2005; Leigh et al., 2008), the hypothesis of the existence of such a connection in humans was tested (Kerry & Murray, 2018). In two samples of about 500 American students, negative correlations were found between maximum handgrip strength and neuroticism in both men and women. Other dimensions of the Big Five personality model were not significantly related to maximum handgrip force.

Handgrip strength is widely recognized as a reliable indicator of physical strength and overall health (Vaara et al., 2012; Wind et al., 2010). Additionally, numerous studies have established connections between personality traits, health outcomes, and life expectancy (Chapman et al., 2007; Mroczek & Spiro, 2007; Ziegler, 2015). This result suggests a potential relationship between the mechanical characteristics of hand muscles and psychological traits.

Guided by this premise, a study was conducted involving 1,232 participants aged 65 to 88 (Mueller et al., 2016). The findings revealed that individuals with higher morbidity and lower maximal handgrip strength exhibited higher levels of neuroticism. Furthermore, lower maximal handgrip strength was associated with less openness, diminished positive changes in extraversion, decreased cooperativeness, and a more pronounced age-related decline in conscientiousness.

In a subsequent study, the same research team (Mueller et al., 2018) used auto- and cross-effects continuous time course models to analyze 13 years of longitudinal data from the Berlin Aging Study, which included 516 subjects aged 70 to 103. This study examined the relationships between personality traits and indicators of functional health, mainly focusing on maximum handgrip strength. The results indicated that neuroticism had a more significant predictive effect on functional health in younger individuals compared to older ones. Additionally, changes in health status could be used to predict shifts in neuroticism. The decrease in extraversion was also found to predict declines in functional health.

Using continuous time models, the researchers demonstrated that the magnitude of these effects varies based on the time interval analyzed. Overall, the findings highlight a close interplay between personality traits and functional health. While the above-described studies had an older population as their subject, the question arises of the existence of similar relationships in other populations. It is known that personality traits and conscientiousness contribute to better health through behavioural (Turiano et al., 2015) and physiological (Friedman et al., 2014) mechanisms. A similar relationship was obtained in a study with 12,188 participants (Sutin, 2018), where four out of the six aspects of conscientiousness (self-control, organization, diligence, and responsibility) were positively associated with nearly all health markers: lower body fat percentage, healthier metabolism, cardiovascular and inflammatory markers, as well as a higher maximal force of the handgrip.

The studies that examine the relationship between handgrip strength and the Big Five personality traits (Fink et al., 2016; Kerry & Murray, 2018; Mueller et al., 2016, 2018; Sutin, 2018) present somewhat inconsistent results. Several studies found a negative correlation between neuroticism and maximum handgrip strength (Kerry & Murray, 2018; Mueller et al., 2016, 2018). However, one study indicated that this correlation was only valid for men (Fink et al., 2016).

Additionally, some studies observed a positive relationship between greater extraversion and higher maximal handgrip strength (Mueller et al., 2016, 2018), while others found this association only applicable to men (Fink et al., 2016; Kerry & Murray, 2018). Some findings suggest a positive correlation between openness and maximal handgrip strength (Mueller et al., 2016), but other studies refute this (Fink et al., 2016; Kerry & Murray, 2018).

Agreeableness shows a positive correlation with maximum handgrip strength in some studies, but this is observed only in women, whereas other studies show no significant relationship (Kerry & Murray, 2018). Conscientiousness also demonstrates a mixed association; some studies report a positive relationship with handgrip strength (Mueller et al., 2016; Sutin, 2018), while others do not support this finding (Fink et al., 2016; Kerry & Murray, 2018).

Due to these inconsistencies, a comprehensive metastudy was conducted in 2022, analyzing data from various national databases. This study processed measures of maximum handgrip strength and Big Five personality traits for over 40,000 adults of all ages (Stephan et al., 2022). The results of this extensive study confirmed relationships between personality traits and maximal handgrip force exerted under isometric conditions: neuroticism exhibited a negative correlation, while extraversion, openness, and conscientiousness demonstrated positive associations with maximum handgrip strength.

Moreover, these findings align with the earlier results of the Baltimore longitudinal study involving 1,220 participants (Tolea et al., 2012). The study found that the maximal force of knee muscles exerted in isometric conditions was negatively correlated with neuroticism and almost all its aspects. Simultaneously, it identified a positive association with extraversion and its components, such as warmth, action, and positive emotions, independent of age, sex, race, or body mass index. The presented results provide the basis for the assumption that the research into other mechanical characteristics of the handgrip, such as maximal rate of force development, force impulse, time for which maximal force is manifested, time of maximal rate of force development, maximum endurance in force, as well as various indices, could be associated with the psychological characteristics of adults. Understanding the importance of such research will be greater after consideration of the possible nature of the aforementioned relationships.

2.3.1 The Nature of the Relationship between Mechanical Characteristics of the Hand and Psychological Characteristics

After reviewing research results suggesting a connection between the mechanical and psychological characteristics of skeletal muscles, we will explore possibilities for a deeper explanation of the nature of the observed relationships.

Although it is clear from the previous presentation that there is a well-documented connection between the mechanical characteristics of the handgrip, primarily the maximum strength, and the psychological characteristics of adults (Fink et al., 2016; Kerry & Murray, 2018; Mueller et al., 2016, 2018; Stephan et al., 2022; Sutin, 2018), the question arises: what is the nature of the obtained connections? First of all, it should be noted that this is still a new research area, which is why the description of the nature of the aforementioned connections is more in the domain of speculation and less based on unequivocal results of empirical studies.

One possible explanation for the obtained and hypothesized connections is the evolutionary paradigm. Masculine qualities that make men attractive to women as partners for making and rearing offspring, i.e., prolonging the species, can be seen as a combination of numerous interconnected components. At the same time, maximum handgrip strength is one such component (Fink et al., 2016). Namely, maximum handgrip strength in men is positively associated with sensation seeking (Fink et al., 2010) and negatively with neuroticism (Fink et al., 2016; Kerry & Murray, 2018; Mueller et al., 2016, 2018). It can be assumed that women prefer men who show more excellent sensation-seeking and low neuroticism as partners (Fink et al., 2016), while the maximum handgrip strength is expressed precisely in people with both traits. As such, the described connections between the mechanical characteristics of the handgrip and psychological characteristics could be explained by evolutionary mechanisms of adaptation and natural selection.

The documented relationship between personality traits and physical health outcomes (Brenes et al., 2005; Krueger et al., 2006) can be understood through models that explain the development of pathology and disability (Nagy, 1965; Verbrugge & Jette, 1994). According to these models, particularly Nagy's (1965) model, the development of disability occurs progressively: active pathology leads to impairment, which then leads to functional limitation and ultimately to disability. Damage, identified as the second step in this process, refers to an abnormality or loss in one of the body's systems, such as the musculoskeletal system. A decrease in muscle strength during contractions further limits mobility and reduces the range of activities that can be performed, impacting one's ability to maintain health (Rantanen, 2003).

Personality can influence the development of movement-related pathology in two key ways (Verbrugge & Jette, 1994). First, personality traits can affect the likelihood of developing chronic or acute diseases, which may trigger a process leading to musculoskeletal damage. Second, if pathology is already present, personality can either accelerate or slow down the progression from pathology to disability. Empirical studies provide support for these notions, showing that traits like neuroticism, extraversion, and conscientiousness are reliable indicators of physical activity levels, making them at least as significant as other external factors (Rhodes & Smith, 2006). Specifically, aspects of extraversion, particularly activity and sensation-seeking, are positively correlated with higher levels of physical activity (De Moor et al., 2006). On the other hand, a meta-analysis of conscientiousness and health-related behaviour studies on a sample of 194 studies shows that it and some of its aspects are strongly positively related to the level of physical activity (Bogg & Roberts, 2004). Therefore, the connection between specific personality characteristics and traits and level of physical activity could explain the already-described connections between the mechanical characteristics of skeletal muscles (primarily maximal force) and psychological characteristics. This assumption was tested in the aforementioned Baltimore longitudinal empirical study (Tolea et al., 2012), in which a partial mediating effect of the level of physical activity on the association between mechanical characteristics of skeletal muscles and psychological characteristics was confirmed.

The assumption that the psychological, behavioural, and biological profiles of individuals with specific personality traits can explain their connection to handgrip strength was examined in a previously presented meta-analysis (Stephan et al., 2022). The results of this study indicate that the relationship between neuroticism and maximum handgrip strength is primarily influenced by psychological factors, particularly the presence of depressive symptoms. Conversely, individuals who are extraverted, open, and conscientious tend to exhibit fewer depressive symptoms and higher levels of physical activity, which may help explain the link between these traits and maximum handgrip strength.

Additionally, the biological profile of conscientious individuals may also contribute to the association between this trait and maximum handgrip strength, as they tend to have lower levels of C-reactive protein (CRP). The research also found that body mass index (BMI) mediates the relationship between conscientiousness and maximum grip strength. Specifically, greater conscientiousness is associated with lower BMI, which in turn is linked to lower handgrip strength. However, the psychological, behavioural, and biological factors studied only partially mediate the relationship between personality traits and the mechanical properties of skeletal muscles, indicating that further research is needed in this area.

Previous studies have established correlations between handgrip strength and psychological characteristics, but further research is needed to explore potential physiological mechanisms that may contribute to these relationships. Here, first of all, we should emphasize the observed similarity of some neural structures responsible for the manifestation of both motor behaviour and personality characteristics. In this sense, the role of the lateral prefrontal cortex should be highlighted, which plays an important role in both motor learning and the control of voluntary movements, while its volume positively correlates with the presence of dimensions of the Big Five personality traits (DeYoung et al., 2010; Lee et al., 2020). Furthermore, the role of individual differences in the functioning of the serotonergic and dopaminergic systems should be highlighted, both in the manifestation of α (agreeableness, conscientiousness and neuroticism) and β (extraversion and openness) personality meta factors, as well as in the management and coordination of movement (DeYoung, 2006, 2013; Jang et al., 1998; Korchounov et al., 2010; Sesboüé & Guincestre, 2006; Spencer & Hu, 2020).

If the presented physiological peculiarities of the mechanical characteristics of skeletal muscles are considered, the assumed hypothetical connections with the psychological characteristics could be explained by several more hypothetical physiological mechanisms. The connection with the rate of force development could be interpreted by the peculiarities of the neuro-muscular mechanism underlying the manifestation of this characteristic and, above all, the speed of recruitment of motor units, as well as the speed of discharge of motoneurons (Baudry et al., 2021; Del Vecchio et al., 2019; Dideriksen et al., 2020; Rodriguez-Rosell et al., 2018; Van Cutsem et al., 1998). This hypothesis could be further tested through the analysis of the connection between the mechanical characteristics of the handgrip manifested in the impulse and classical modalities of muscle contraction (Mirkov et al., 2004; Holtermann et al., 2007; Suzović & Nedeljković, 2009; Dopsaj et al., 2021; Koznic et al., 2022). Endurance in the exercise of force could be interpreted as a central resistance to the physiological exhaustion of the nervous system (Morales-Alamo et al., 2015), which is manifested through the strategies of turning on and off motor units (Calbet et al., 2003; Noakes et al., 2005). As such, the role of the prefrontal cortex (Wascher et al., 2014), the primary motor cortex (Quarta et al., 2020), and the dopamine reward pathway system (McNaughton & Corr, 2004) should be singled out.

The contribution of the muscular and nervous components of the enumerated mechanical characteristics of the handgrip could be further analyzed by analyzing the time dimension of the manifestation of the given characteristics. In this way, the variability in the manifestation of mechanical characteristics could be positioned closer to the neural or muscular component, depending on whether the analyzed measure relies more on force or time. The contribution of genetics to the external component(environmental influences, training, lifestyle, and similar) could be analyzed in more detail through the different ratios of manifestation of the mechanical characteristics of the handgrip with the dominant and non-dominant hand. Finally, analyzing the mediating and moderating effect of gender, age, field of work, and level of physical activity will contribute to more precise insights into the nature of the analyzed connections.

One can see the space for further research by analyzing the studies and possible theoretical explanations. First of all, it is imperative to check the replicability of the obtained results, that is, to check the external validity of the relationship between the mechanical characteristics of the handgrip and the psychological characteristics in the local Serbian context.

Next, it is possible to expand the subject of research, both in the domain of mechanical as well as psychological characteristics.

First of all, all reported studies researched handgrip mechanical properties as one solid variable, i.e. handgrip strength, which primarily concerns the force exerted by the flexor and extensor muscles of the hand on the measuring device. However, since force is produced in time, it can be analyzed according to the force-time curve produced in the handgrip strength task. This method is promising and reliable (Innes, 1999), and with the decrease in the cost of the equipment required for its use, it has been used more and more frequently in research (Cronin et al., 2017). Analyzing the force-time curves produced in the handgrip strength task, parameters of the maximal force, maximum rate of force development, the time needed for achieving maximal force, and the time needed for achieving the maximum rate of force development can be obtained. Moreover, indexes of dimorphism and excitation, which are important for athletic success (Dopsaj et al., 2019; Ivanović & Dopsaj, 2012; Marković et al., 2020), can be calculated and researched from those measures. All of this is important for research because different physiological mechanisms 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). Since 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 higher degrees of central neural control of upper limb musculature (Campbell et al., 2019), the proposed additional analysis seems justified.

Second, although an important mechanical characteristic of the handgrip, isometric grip endurance, which measures the ability to sustain muscle contraction of finger flexors at 50% of maximal force and the stability of contraction (i.e., oscillations around 50% of maximal force (Ivanovic & Dopsaj, 2012; Trajkov et al., 2018) it has not yet been linked to psychological characteristics in research. An exception is the study on police officers, which shows the existence of a correlation between isometric grip endurance and mental toughness (Hegerstad et al., 2019), which points to additional space for the expansion of previous research on the relationship of the mechanical characteristics of the handgrip and psychological characteristics.

In the end, the impulse mode of isometric testing, where the emphasis is on the speed of force production, proves to have excellent metric characteristics (Dopsaj et al., 2021) and advantages when it comes to assessing mechanical characteristics related to the rate of force development (Sahaly et al., 2001; Suzović & Nedeljković, 2009), also was not researched in the context of a relationship with psychological characteristics. Furthermore, comparing the rate of force development obtained in impulse and the classical mode of isometric contraction, we can assess another important mechanical characteristic of the handgrip, i.e. the ability to generate more force in less or the same time in impulse compared to the classical mode, which can also be interpreted as an indicator of the possibility of creating more nerve impulses when needed but also efficient execution of the movements. This fact justifies expanding the investigation of links between psychological and mechanical characteristics manifested in classical and impulse muscle contraction modes.

While the mechanical properties, in addition to the maximal force, can be further complemented by the maximal rate of force development, endurance in the manifestation of force, the time in which the mentioned force characteristics are manifested, different index indicators of laterality and the relationship of the essential characteristics, as well as different modules of the manifestation of force, the possible expansion of the research subject about the psychological characteristics will be analyzed below from the aspect of possible applicability of the obtained results, which primarily refer to the different populations in which the research can be conducted.

2.4 The Importance of the Relationship between Mechanical and Psychological Characteristics in Different Populations

The previous part pointed out the well-documented relationship between the mechanical characteristics of the skeletal muscles, especially the handgrip, and the psychological characteristics. However, all prior research had been conducted on the general population. It is unknown whether these relationships exist or whether they are specific in strictly- selected populations characterized by a long-term and strenuous process of physical exercise, such as athletes, tactical athletes and similar. In other words, since physical activity, exercise, and training affect the mechanical characteristics of skeletal muscles, would the relationships between HGS and psychological characteristics still be present among the population of well-trained, elite or tactical athletes?

Moreover, physically demanding jobs, such as police, military and similar, and sports, are vivid examples where research into the relationship between the mechanical characteristics of skeletal muscles and psychological characteristics, in addition to the theoretical, could have important practical implications. These jobs are characterized by exposure to extreme physical efforts, tasks dangerous to life and health, and criticism from superiors and the public, which represent risk factors for the negative impact of stress both on the efficiency of performing tasks and on physical and mental health and behaviour as a whole (Ilić et al., 2018; Kukić et al., 2021, 2022). Due to all of the above, an extensive and rigorous prevention system has been developed, from selection through training to regular monitoring of health status, as well as work quality (Milošević & Milošević, 2014), which includes the analysis and monitoring of both physical and psychological conditions and characteristics.

When it comes to the mechanical characteristics of skeletal muscles, what should be considered is that the aforementioned jobs require a high level of physical preparation (Milošević et al., 2014, 2020; Maupin et al., 2018). Previous studies have demonstrated that some police departments (e.g., the Special Forces) have a much higher level of physical fitness than elite athletes

(Aharoni et al., 2008). Several tests provide valuable information about physical fitness (Marins et al., 2019; Maupin et al., 2018), including the handgrip test (Orr et al., 2021).

However, despite the rigorous selection, training and monitoring of police officers, maladaptive reactions and stress-related behaviours are rare (Alang et al., 2020; Grassi et al., 2019). In general, the level of occupational stress has a different effect on the performance of individuals (Gutshall et al., 2017; Nisar & Rasheed, 2020; Regehr et al., 2008), while the results of studies suggest a connection between the level of physical preparation and stress response (Anderson et al., 2002; Gershon et al., 2009). In order to analyze this topic in more detail, it is important to find all available relationships between these components.

Moreover, when it comes to sport, sport-specific movements determine which mechanical characteristics will play a decisive role in sports performance (Cronin et al., 2017). This fact gives the basis for the assumption that a more detailed investigation of the relationship between mechanical and psychological characteristics in different populations of athletes could find a practical application in their selection.

Although the relationship between mechanical and psychological characteristics has been the subject of numerous studies, as already mentioned, this relationship within a specific police-security or athletic population has not been sufficiently researched so far.

Mental toughness enables individuals to cope and thrive under stress and pressure (Clough & Strycharczyk, 2012; Gucciardi et al., 2014). Also, empirical studies in athletes validate such conceptualization by revealing positive correlations with self-confidence and negative with cognitive and somatic anxiety (Mojtahedi, 2023). Physical fitness levels play a similar role (Neumann et al., 2022). That is why a positive correlation between mental toughness and mechanical characteristics of handgrips can be expected. Nevertheless, studies on tactical athletes do not fully support this assumption (Beitia et al., 2022).

Closely related to the above is the possibility of expanding the research domain on the relationship between the mechanical characteristics of handgrip and the psychological characteristics, not only to specific groups and populations but also in the domain so far not sufficiently in this context investigated psychological characteristics. Namely, in order to better understand and predict the prolonged stress reaction, based on the results of empirical studies, the proposal was made to expand the domain of personality assessment to date with the most widespread personality models, such as the Big Five, by adding the assessment of mental toughness and the dark triad (Papageorgiou et al., 2019). Both mental toughness and the dark triad have also been shown to help predict important life outcomes, such as income and academic performance (Lin et al., 2017) or, on the other hand, plagiarism, aggression following threats to the ego, bullying others, and retaliatory acts, fantasy (Furnham et al., 2013). Both mental toughness and the dark triad play a significant role in coping with stress, stress tolerance, and stress responses (Gerber et al., 2013; Lyons et al., 2019). Furthermore, mental toughness and the dark triad carry valuable information about perceived stress (Papageorgiou et al., 2019), which is crucial for understanding and predicting the effects and reactions to prolonged exposure to stress (Gershon et al., 2009).

Since mental toughness and the dark triad directly influence an individual's ability to cope with cumulative life stressors and can contribute to the development of mental distress (Lyons et al., 2019), the cumulative impact of both the mental toughness and the dark triad constructs, as behavioural determinants, can exert a significant influence on the stress levels experienced by police-security officers, athletes and similar, and ultimately become determinants of their decision-making processes. In line with this perspective, higher levels of mental toughness combined with lower levels of dark triad may characterize individuals who are more resilient to stress and possess stronger moral values, ultimately resulting in enhanced job performance, wellbeing, and overall health. This fact is the reason why the inclusion of mental toughness and dark triad in this study as job performance and overall wellbeing predictors is justified. A recent study investigating the impact that perceived stress has on handgrip muscle strength and endurance (Bhattacharjya, 2023) shows another possibility of connecting mental toughness and the dark triad with the mechanical characteristics of the hand grip since all of them are associated with perceived stress.

In the previous text, we have shown a relationship between the mechanical characteristics of skeletal muscles and psychological characteristics. Previous studies showed that the mechanical characteristics of the hand, expressed in handgrip tasks, are of particular interest to researchers on this topic. Possible physiological, evolutionary and life experience-related mechanisms behind the described relationships are also presented and analyzed in detail. We also presented studies that showed the connection between mental toughness and the dark triad with other psychological characteristics, behaviours, and habits. Their role in experiencing and responding to stress has also been shown. They have even been shown to be linked to sports performance. Due to all of the above, one can see the possibility of a relationship between mental toughness, the dark triad, and the mechanical characteristics of the handgrip.

Taking into account the accelerated social changes in the twenty-first century, which bring with them the changed role and way of performing the duties of the police and security structures, as a mandatory part of the selection of members of these structures, the assessment of empathic capacities and characteristics is proposed (Kammersgaard, 2021). Empathy has been widely theorized as one of the most important abilities in professions characterized by frequent conflict situations and interpersonal contacts (Inzunza et al., 2022), such as police or security. It is important to interact with the public under challenging circumstances (Skogan, 2006) to understand others' perceptions of complex situations and, at the same time, regulate one's perception (Inzunza, 2015), which is necessary for acting professionally. Also, empathy is a necessary ability when working with crime victims (Inzunza et al., 2022) for establishing and maintaining rapport during interviews (Baker-Eck et al., 2020), which is crucial for successful information-gathering. Furthermore, empathy, as one of the foundations of successful communication, is necessary for successful teamwork (Milošević et al., 2024). Police students consider empathy to be the most important ability in gaining tremendous respect and engagement, as well as the most excellent moral value of police work (Millie & Hirschler, 2023). For similar reasons, Danish police emphasized empathy in the process of selection and training of police officers, which resulted in more significant support and trust of the community and more efficient police work while strengthening democratic traditions (Bloksgaard & Prieur, 2021).

Nevertheless, although there is agreement on the importance of empathy for the performance of police and similar jobs, it has not been sufficiently empirically examined in the police and similar populations to date. In order to successfully fit empathy into the existing system of selection and training of future police and security officers, it is necessary to research the relationships of empathy with the basic dimensions of the current selection system of police and security workers (Koropanovski et al., 2022; Papadakis et al., 2021), that is psychological and mechanical characteristics.

Considering the robustness of the aforementioned mechanical and psychological characteristics, attempts to integrate these two principles with the aim of improving selection, training, and performance in physically demanding tactical professions have been on the rise (Pynes, 2001; Gnacinski et al., 2015; Bloksgaard & Prieur, 2021; Beitia et al., 2022). One of the underlying ideas of such an approach is that the relationship between mechanical characteristics and behavioural tendencies may be used as indicators of personality suitable for both job performance in stressful environments and coping with chronic stress. To that end, it is necessary to investigate the relations as well as possible effects between indicators and mechanisms of mechanical characteristics, namely handgrip characteristics and behavioural tendencies.

Based on everything presented, it is reasonable to expect documentation of numerous relationships between mechanical and psychological characteristics in this research. In this way, our research deepens the existing knowledge on this topic, as well as the possibility of its use. Handgrip variables can prove to be an effective predictor of some psychological characteristics or at least an informative supplement to existing predictive models. This result is especially anticipated for the population already selected according to mechanical characteristics of skeletal muscles and psychological characteristics. The observation and description of the specifics of the connection between mechanical and psychological characteristics in different subsamples can also be interpreted in the light of the nurture vs. nature debate. Although the boundary cannot be drawn clearly, when it comes to the muscular component, the influence of environment and activity is more significant than that of the neural component of muscle contraction, where hereditary factors have a more significant influence. The different mechanical characteristics that will be examined have different levels of influence on the muscular and neural components in their manifestation. The same can be said for the athletic and security population; in their case, the influence of the environment and the individual's activity in building the mechanical characteristics of skeletal muscles should obviously have a more significant influence than in the general population. In this way, this research could have important practical implications for training and the selection system for different physically demanding professions and sports. Therefore, it can have a direct positive impact on the wellbeing of future police officers, soldiers, and athletes, as well as the corporate selection system and similar.

On the other hand, this research has more profound theoretical implications. For the psychology of individual differences, this research can be interpreted as an indirect checking of the assumption about the physiological basis of personality characteristics and traits and the expansion of knowledge on this topic. The obtained results could also be interpreted as a contribution to the verification of the central regulation model. In this way, aspects of motor behaviour and control could be positioned more precisely within the broader scope of behaviour. Due to all of the above, this research represents a step forward towards the greater integration of police, sports, and physical activity studies with psychology.

2.5 Explication of theoretical assumptions

In this closing section of the theoretical framework for our research, we will summarize and clarify our theoretical assumptions before moving on to the methodological considerations.

Our research utilizes a cross-sectional design and has primarily exploratory objectives. It serves as an extension of existing studies in the field that examine the relationships between bodily functions and psychological characteristics. Specifically, this research expands upon a substantial body of work focused on the connections between the mechanical properties of skeletal muscles and personality traits, particularly in relation to handgrip strength.

The relationship between the mechanical characteristics of handgrip and personality traits is well-documented. Existing research primarily explains this connection through evolutionary mechanisms and through personal histories of behavior and development, which influence the manifestation of both mechanical and psychological characteristics. Additionally, we consider the possibility of shared physiological mechanisms that may account for the expression of both domains.

In our study, we aim to investigate these known relationships within specific groups and to broaden the scope of personality traits examined by introducing concepts that have not yet been explored in this context. The correlations among these psychological concepts, as well as their linkages to specific mechanical characteristics of skeletal muscles, particularly handgrip strength, provide a theoretical foundation for this expansion. Moreover, previous research will help extend our understanding of the domain of mechanical characteristics as well.

Our primary objective will be to identify whether existing relationships are present or absent among the groups studied, along with their specific nature. While our findings will shed light on these relationships, providing definitive answers regarding their nature will be speculative and beyond the scope of this research.

Once we have thoroughly described and justified the novelty of this research compared to prior studies, and outlined the expansions on existing work, we will then determine the methodological solutions that are appropriate for this type of research based on the preceding theoretical exposition.

3 PROBLEM, SUBJECT, GOAL AND RESEARCH TASKS

3.1 The Problem of Research

Relationship between the mechanical characteristics achieved during the handgrip and the psychological characteristics has not been sufficiently investigated to date. Based on this, it is possible to formulate the problem of this research as follows. Are there and, if so, what is the nature of the relationship between the mechanical characteristics of the handgrip and psychological characteristics in adults?

Moreover, in relation to the stated problem, there is the problem of the existence of differences in the mentioned relations in different populations, that is, the problem of their specificity in strictly selected and homogeneous populations, such as the athletic, police and security, when compared to the general population.

3.2 Research Subject

The subject of this doctoral dissertation was investigation of the relationship between mechanical characteristics, specifically maximal force, rate of force development, endurance in the manifestation of force, time parameters of manifestation of given force characteristics, as well as index parameters of handgrip measured in isometric contraction with psychological characteristics, specifically the Big Five personality traits, mental toughness, dark triad and empathy in adults. Furthermore, the subject of this research is the determination of the specificity of these relationships in different populations of adults, more precisely, in the athletic, police-security and general population.

3.3 Research Goals

The goal of this doctoral dissertation were to explore the quantitative characteristics of the association of maximal force, rate of force development, endurance in the manifestation of force, time parameters of manifestation of given force characteristics, as well as index parameters of handgrip measured in isometric contraction, with the Big Five personality traits, mental toughness, dark triad, and empathy in adults, then determining the specificity of these relationships in different populations, as well as the metrological characteristics of the newly formed index variables.

3.4 Research Tasks

In order to fulfill the set goals of the research, it is necessary to fulfill the following tasks:

1. Define the sample selection criteria and form the sample and subsamples of participants based on them.

2. Collect information on the socio-demographic status of the participants.

3. Collect information on the sports and training history, experience, level of achievement and performance as well as status of the participants.

4. Assess the psychological characteristics of the Big Five personality traits, mental toughness, dark triad, and empathy of the participants.

5. Perform an assessment of the morphological status of the examinee, i.e., the measurement of body height and weight.

6. Measure force and time parameters in the impulse and classic modality of isometric contraction of the hand for both the dominant and the non-dominant hand.

7. Based on the measured parameters, determine the maximal force, the maximum rate of force development, the time required for the production of maximal force and the maximum rate of force development.

8. Determine 50% of the maximal force.

9. Measure the maximum endurance in force, i.e., the maximum time in which the force can be maintained at 50% of the maximal force of the hand.

10. Based on the measurement of endurance in force, calculate the force impulse.

11. Normalize force parameters for body mass.

12. Based on all measured and calculated parameters, form new index indicators.

13. Perform data processing.

14. Perform a statistical analysis of the obtained data.

15. Present and interpret findings.

16. Draw conclusions; analyze the possibility for practical application of the obtained findings as well as further research of the treated topic.

4 RESEARCH HYPOTHESES

Based on the results of previous research on this topic, as well as the observed problem, the chosen subject, the set goals, and objectives of the research, it is possible to put forth the following hypotheses.

4.1 Central Hypothesis

H: There are associations between the mechanical characteristics of the handgrip and psychological characteristics, and which are specific to the different populations of adults. It is assumed that a higher result on the handgrip tests will be accompanied by a more positive psychological profile, i.e., a more pronounced presence from the point of view of functioning in stressful situations of desirable ones (extraversion, aggression, conscientiousness, openness, mental toughness, interpersonal reactivity), i.e., a lower degree of expression of undesirable personality characteristics (neuroticism, positive valence, negative valence and dark triad). It is also expected that these relationships are more pronounced among the athletic, police and security population compared to the general population.

4.2 Auxiliary Hypotheses

h1: There is an association between the characteristics of the maximum handgrip force and the psychological characteristics of the participants.

h2: There is an association between the characteristics of the maximum rate of force development of handgrip and the psychological characteristics of the participants.

h3: There is an association between the characteristics of endurance in the manifestation of handgrip force and the psychological characteristics of the participants.

h4: The association between the mechanical characteristics of the handgrip and the psychological characteristics of the participants follow the same trend in different subsamples, but are more intense in the athletic and police-security group compared to the general population.

h5: Mechanical characteristics of handgrip are predictors of psychological characteristics.

h6: There are moderating effects of belonging to a certain subpopulation and the factor of the manifestation of the mechanical characteristics of the handgrip as well as the interaction of these factors on the psychological characteristics of the participants.

5 RESEARCH METHODS

5.1 Sample of Participants

The research was conducted on a convenience sample of 205 participants, among whom 93 females and 112 males. 12 participants were left handed and 1 ambidexter while all others where right-handed. Participants were students of Faculty of Sport and Physical Education, University of Belgrade, University of Criminal Investigation and Police Studies i Belgrade, Academy for National Security in Belgrade. This population is strictly selected based among others on superior physical abilities and level of physical fitness (Dopsaj et al., 2019b; Koropanovski et al., 2022; Papadakis et al., 2021). In order to successfully finish their studies, maintaining hi level of physical fitness is demanded. Rests of the sample were members of the general student population, as well as the working population of different professional orientations. Descriptive parameters of the sample are presented in Table 1.

The criteria for participation were voluntary registration and the absence of any health problems before and during the study. Any history of arm injury was exclusion criteria. Taking into account that this was exploratory research, such a sample enabled both the observation and description of the basic relationships of the researched variables, as well as the comparison of different populations.

Convenience sampling is more of necessity in low financed research such this one than choice which can be justified. However, by dividing the sample into subpopulations, providing sufficiently large groups and subgroups, power analysis, we tried to compensate to some extent this obvious limit of our study. Thus, some subgroups, primarily athletic (such as elite athletes or tactical athletes), have reached a number rarely seen in fundamental research such as this. Also, a number of other techniques were applied to control for grouping and confounding variables and effects, which will be discussed in more detail later.

The total sample was divided into subsamples according to gender (female-male) and occupation (the general adult population, police students, security, and athletes). The division into sub-samples was also caused by the limited resources for this research, so only part of the measurements and assessments were done for the whole sample (Big Five, mental toughness, dark triad and handgrip in classical mode of isometric contraction), while individual sub-samples also did additional measurements (empathy, handgrip endurance and handgrip in impulse mode of isometric contraction).

The general adult population subsample included 25 participants [age = 30.4 ± 10.1 years, body high (BH) = 177.1 ± 9.9 cm, body weight (BW) = 77.4 ± 13.5 kg, and body mass index (BMI) = 24.5 ± 2.8], from which 10 were females and 15 males.

The police students subsample included 65 cadets from University of Criminal Investigation and Police Studies i Belgrade, among who were 32 males (Age = 19.9 ± 0.8 years, BH = 181.4 ± 4.6 cm, BM = 78.9 ± 6.3 kg; mean ± SD) and 33 females (Age = 19.5 ± 0.8 years, BH = 171 ± 6 cm, BM = 63.2 ± 5.8 kg; mean ± SD).

The security subsample included 136 participants, students of University of Criminal Investigation and Police Studies i Belgrade, Academy for National Security in Belgrade, from which 54 were females (Age = 19.6 ± 0.8 years) and 82 males (Age = 19.9 ± 0.7 years). Other descriptive parameters of the subsamples are presented in Table 19.

The athletes subsample included 155 participants, students from all levels of study on the Faculty of Sport and Physical Education, University of Belgrade, University of Criminal Investigation and Police Studies i Belgrade, Academy for National Security in Belgrade, from which 60 were females (Age = 20.7 ± 3.2 years, BH = 171.4 ± 6.8 cm, BM = 64.7 ± 8.9 kg, BMI = 22.2 ± 2.8) and 94 males (Age = 22.2 ± 6.2 years, BH = 182.9 ± 7.3 cm, BM = 79.5 ± 8.2 kg, BMI = 24.1 ± 2.0). Female subsample has 5.8 ± 5.7 years of athletic experience, while subsample sample have 8.63 ± 6.3 years of athletic experience. Among participants were 46 national champions and members of national selections (13 females and 23 males) who constitute elite athletes subsample, while rest of the sample constitute well-trained athletes subsample. Among athletic disciplines the most frequent were track and fields (6), basketball (14), dancing (6), gymnastics (5), handball (4), football (33), combat sports and martial arts (23), tennis (5), swimming (6), volleyball (20) as well as body building and weight lifting (12).

All participants voluntarily participate in the research. They were informed in advance about the tasks and procedures, that the data were used exclusively anonymously, and that they can withdraw from the research at any time without any consequences. Participants provided written consent for their voluntary participation. The study was conducted in accordance with the European Commission's General Data Protection Regulation, and the American Psychological Association-prescribed Ethical Principles and Code of Conduct. The study design was approved by the Ethical Board (number 484-2) of the Faculty of Sport and Physical Education, University of Belgrade.

The total samples as well as subsamples sizes were determined using power analysis.

For two-tail t-test - Correlation: with probability of making a type 1 error $\alpha = 0.05$, power $1-\beta = 0.80$ and medium effect size $\rho = 0.30$, the sample size should include at least 82 participants. For two-tail t-tests - Correlation: Point biserial model, with $\alpha = 0.05$, power $1-\beta = 0.80$, and effect size $\rho = 0.50$, the sample size should comprise at least 26 participants. 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 t-test - Linear multiple regression: with probability of making a type 1 error $\alpha = 0.05$, power $1- \beta = 0.80$, expected effect size ($f^2 = 0.15$), the sample size should be at least 56 subjects.

For two-tails t tests - Means: Wilcoxon-Mann-Whitney test, with Parent distribution: logistic, $\alpha = 0.05$, power $1-\beta = 0.80$, effect size d = 0.55, and Allocation ratio N2/N1 = 1.5, the sample size should be 122 participants at least.

For f tests - ANOVA: Fixed effects, omnibus, one-way, with $\alpha = 0.05$, power $1-\beta = 0.80$, effect size f = 0. 4 and 2 groups the sample size should be 52 participants at least. For two-tail t-tests – Linear multiple regression, with $\alpha = 0.05$, power $1-\beta = 0.80$, effect size f2 = 0.50, and 18 predictors the sample size should comprise at least 25 participants.

For f tests - MANOVA special effects and interactions, with $\alpha = 0.05$, power $1- \beta = 0.80$ and medium effect size ($f^2 = 0.06$), 4 groups, 3 predictor variables and 15 outcome variables, the sample size should be at least 165 participants. For f tests - MANOVA: special effects and interactions, with $\alpha = 0.05$, power $1-\beta = 0.80$, effect size f2 = 0.14, 3 groups, 3 predictors, and 5 response variables the sample size should be 50 participants at least. 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 measurement and correlation among repeated measurement 0.7 the sample size should be 22 participants at least.

Power analyses were performed using G-power 3.1.9.6 (Franz Faul, Univesitat Kiel, Germany).

5.2 Variables

All the measured and assessed variables used in this research can be divided into three groups: the mechanical characteristics of the handgrip are the predictor variables, the psychological characteristics are the criterion variables, while the control and grouping variables are related to the socio-demographic characteristics and morphological characteristics of the participants.

5.2.1 Predictor Variables

The mechanical characteristics of the handgrip in classical mode of isometric contraction were measured through:

- $F_{max}D$ – maximal force of the dominant hand [N]
- $F_{max}ND$ – maximal force of the non-dominant hand [N]
- $F_{max}S$ – the sum of the maximal force of the dominant and non-dominant hand [N]
- $F_{rel}D$ – maximal force of the dominant hand normalized for body weight [$N/kg^{2/3}$]
- $F_{rel}ND$ – maximal force of the non-dominant hand normalized for body weight [$N/kg^{2/3}$]
- $F_{rel}S$ – the sum of the maximal force of the dominant and non-dominant hand normalized for body weight [$N/kg^{2/3}$]
- $tF_{max}D$ – time required to reach the maximal force of the dominant hand [s]
- $tF_{max}ND$ – time required to reach the maximal force of the non-dominant hand [s]
- $tF_{max}S$ – the sum of the time required to achieve the maximal force of the dominant and non-dominant hand [s]
- $RFD_{max}D$ – maximal rate of force development of the dominant hand [N/s]
- $RFD_{max}ND$ – maximal rate of force development of the non-dominant hand [N/s]
- $RFD_{max}S$ – the sum of the maximal rate of force development of the dominant and non-dominant hand [N/s]

• $RFD_{rel}D$ – maximal rate of force development of the dominant hand normalized for body weight [$N/s/kg^{2/3}$]

• $RFD_{rel}ND$ – maximal rate of force development of the non-dominant hand normalized for body weight [$N/s/kg^{2/3}$]

• $RFD_{rel}S$ – the sum of the maximal rate of force development of the dominant and non-dominant hand normalized for body weight [$N/s/kg^{2/3}$]

• $tRFD_{max}D$ – the time required to achieve the maximal rate of force development of the dominant hand [s]

• $tRFD_{max}ND$ – the time required to reach the maximal rate of force development of the non-dominant hand [s]

• $tRFD_{max}S$ – the sum of the time required to achieve the maximal rate of force development of the dominant and non-dominant hand [s]

• $F_{imp}50\%D$ – force impulse for maximum endurance at 50% of the maximal force of the dominant hand [Ns]

• $F_{imp}50\%ND$ – force impulse for maximum endurance at 50% of the maximal force of the non-dominant hand [Ns]

• $F_{imp}50\%S$ – the sum of force impulse for maximum endurance at 50% of the maximal force of the dominant and non-dominant hand [Ns]

• $F_{imp}50\%SD_{rel}$ –force impulse for maximum endurance at 50% of the maximal force of the dominant hand normalized for body weight [$Ns/kg^{2/3}$]

• $F_{imp}50\%SND_{rel}$ –force impulse for maximum endurance at 50% of the maximal force of the non-dominant hand normalized for body weight [$Ns/kg^{2/3}$]

• $Fimp50\%S_{rel}$ – the sum of force impulse for maximum endurance at 50% of the maximal force of the dominant and non-dominant hand normalized for body weight [$Ns/kg^{2/3}$]

• $tF_{imp}50\%D$ –the maximum time for which the force can be maintained at the level of 50% of the maximal force of the dominant hand [s]

• $tF_{imp}50\%ND$ –the maximum time for which the force can be maintained at the level of 50% of the maximal force of the non-dominant hand [s]

• $tF_{imp}50\%S$ – sum of the maximum time for which the force can be maintained at the level of 50% of the maximal force of the dominant and non-dominant hand [s]

The mechanical characteristics of the handgrip in impulse mode of isometric contraction were measured through:

- $IF_{max}D$ – maximal impulse force of the dominant hand [N]
- $IF_{max}ND$ – maximal impulse force of the non-dominant hand [N]
- $IF_{max}S$ – the sum of the maximal impulse force of the dominant and non-dominant hand [N]
- $IF_{rel}D$ – maximal impulse force of the dominant hand normalized for body weight [$N/kg^{2/3}$]
- $IF_{rel}ND$ – maximal impulse force of the non-dominant hand normalized for body weight [$N/kg^{2/3}$]
- $IF_{rel}S$ – the sum of the maximal impulse force of the dominant and non-dominant hand normalized for body weight [$N/kg^{2/3}$]
- $ItF_{max}D$ – time required to reach the maximal impulse force of the dominant hand [s]
- $ItF_{max}ND$ – time required to reach the maximal impulse force of the non-dominant hand [s]
- $ItF_{max}S$ – the sum of the time required to achieve the maximal impulse force of the dominant and non-dominant hand [s]
- $IRFD_{max}D$ – maximal impulse rate of force development of the dominant hand [N/s]
- $IRFD_{max}ND$ – maximal impulse rate of force development of the non-dominant hand [N/s]
- $IRFD_{max}S$ – the sum of the maximal impulse rate of force development of the dominant and non-dominant hand [N/s]
- $IRFD_{rel}D$ – maximal impulse rate of force development of the dominant hand normalized for body weight [$N/s/kg^{2/3}$]
- $IRFD_{rel}ND$ – maximal impulse rate of force development of the non-dominant hand normalized for body weight [$N/s/kg^{2/3}$]
- $IRFD_{rel}S$ – the sum of the maximal impulse rate of force development of the dominant and non-dominant hand normalized for body weight [$N/s/kg^{2/3}$]
- $ItRFD_{max}D$ – the time required to achieve the maximal impulse rate of force development of the dominant hand [s]
- $ItRFD_{max}ND$ – the time required to reach the maximal impulse rate of force development of the non-dominant hand [s]
- $ItRFD_{max}S$ – the sum of the time required to achieve the maximal impulse rate of force development of the dominant and non-dominant hand [s]

Derived index variables:

• Maximal force dimorphism index (ratio of the maximal force of the dominant and non-dominant hand):

$DIF=F_{max}D/F_{max}ND$
$DIF_{rel}=F_{rel}D/F_{rel}ND$

• Dimorphism index of maximal rate of force development (ratio of maximum rate of force development of dominant and non-dominant hand):

$DIRFD=RFD_{max}D/RFD_{max}ND$
$DIRFD_{rel}=RFD_{rel}D/RFD_{rel}ND$

• Excitation index (the ratio between maximal force and maximal rate of force development) for dominant and non-dominant hand as well as sum.

$EID=F_{max}D/RFD_{max}D$
$EIND=F_{max}ND/RFD_{max}ND$
$EIS= EID+ EIND$
$EID_{rel}=F_{rel}D/RFD_{rel}D$
$EIND=F_{rel}ND/RFD_{rel}ND$
$EIS_{rel}= EID_{rel}+ EIND_{rel}$

• Neural reserve index (the ratio between the maximum rate of force development in classical and impulse mode of isometric contraction) for dominant and non-dominant hand as well as sum:

$NRID=RFD_{max}D/IRFD_{max}D$
$NRIND=RFD_{max}ND/IRFD_{max}ND$
$NRIS= NRID+ NRIND$
$NRID_{rel}=RFD_{rel}D/IRFD_{rel}D$
$NRIND=RFD_{rel}ND/IRFD_{rel}ND$
$NRIS= NRID_{rel}+ NRIND_{rel}$

5.2.2 Criterion Variables

Psychological characteristics were assessed through:

• Nrt – neuroticism

• Ext - extraversion

• Opn - openness

• Agr –aggression

•Cns – conscientiousness

• PV – positive valence

• NV- negative valence

• MT – mental toughness

• Mch - Machiavellianism

• Psc – psychopathy

• Nrc – narcissism

• PT – perspective taking

• Fnt – fantasy

• EC – empathic concern

• PD – personal distress

5.2.3 Categorical and Control Variables

The variables whose potential influence were investigated or controlled are the following:

•gender

•age

• faculty or field of work

• year of study or work experience

- level of physical activity
- BW - body weight [kg]
- BH - body height [cm]
- BMI - body mass index [kg/m2]

5.3 Design and Procedures

A cross-sectional design was used to investigate maximal force, maximal rate of force development, endurance in the exercise of force, time parameters of exercise of given maximal force characteristics as well as index parameters of handgrip measured in isometric contraction, along with the Big Five personality traits, mental toughness, dark triad, and empathy in different student populations.

A device that measures the isometric force of the finger flexors, standardized by the manufacturer, was used to measure the predictor variables of handgrip strength (Dopsaj et al., 2018; Marković et al., 2020). A standard tensiometric probe with a measurement accuracy of ± 0.01 N was connected to the force reader. A specially designed software-hardware system (Isometrics Lite, ver. 3.1.1, Isometrics SMS, Belgrade) was used for data collection and processing. The force-time signal was sampled at 1,000 Hz and low-pass filtered (10 Hz) using a fourth-order Butterworth filter. The onset of contraction was defined as the moment at which the first derivative of the force-time curve exceeded the baseline by 3% of its maximum value. The measured force was instantly calculated, after which the rate of force development was found as a measure of the maximal force development in a certain period of time (F/t). The maximum duration of the handgrip was defined as 50% of the maximal force sustained during the time period [N • s]. Predictor variables were measured separately for the dominant hand, the non-dominant hand, and the sum of the dominant and non-dominant hand values were also presented. Furthermore, predictor variables were measured in the classical and impulse modality of muscle contraction. On the basis of the obtained parameters, index values were further calculated: index of maximal force dimorphism (ratio of maximal force of dominant and non-dominant hand), index of dimorphism of maximal rate of force development (ratio of maximal rate of force development of dominant and non-dominant hand), index of dimorphism of endurance of force expression (ratio of endurance of exercise dominant and non-dominant hand forces), neural reserve index (ratio between the maximal rate of force development in classical and impulse stress modules), excitation index (ratio between maximal force, and maximal rate of force development).

The Interpersonal Reactivity Index (IRI), version of Big Five Plus Two (BF+2), Mental Toughness Index (MTI), Dark Triad Dirty Dozen test (DTDD) questionnaire was used to assess Psychological characteristics. In order to make it easier to compare the scores on different questionnaires and subscales, they were calculated as average values of respondents' answers to all items concerning one questionnaire or subscale. These procedures prove to be valid in previous studies (Hawk et al., 2013).

Criterion variables of the Big Five personality traits were assessed by the Serbian short version of BF+2 questionnaire (Čolović et al., 2014), which consists of 70 statements on which the degree of agreement is expressed using a five-point Likert-type rating scale. BF+2 assess five standard personality traits: Aggressiveness, Openness, Conscientiousness, Extraversion, and

Neuroticism, with the addition of positive and negative valences. Scores are expressed as the arithmetic mean of the scores on each subscale, and range from a minimum of 1 (poorly developed) to a maximum of 5 (extremely developed). BF+2 is widely used in scientific research and clinical practice (Tasić et al., 2020; Vukmirović et al., 2020), due to its sound psychometric characteristics (Čolović et al., 2014).

The criterion variable mental toughness were assessed with the Serbian version of a Mental Toughness Index - MTI questionnaire (Gucciardi et al., 2015), which provides a reliable one-dimensional assessment of mental toughness. The instrument consists of eight items, and the level of agreement with the participants' statements is expressed by seven-point Likert-type evaluation scales. The total score is calculated as the average value of the responses and can vary from a minimum of 1 (poorly developed) to a maximum of 7 (extremely developed). The Mental Toughness Index has solid psychometric properties that have been empirically confirmed (Gucciardi et al., 2015, Stamatis et al., 2021a, Milošević et al., 2022), and is widely used in psychological testing (Cowden, 2016; Gucciardi et al., 2016 a,b).

Criterion variables of the dark triad were assessed with the Dirty 12 test of the dark triad - DTDD (Dinić et al., 2018; Jonason & Webster, 2010), which consists of 12 statements answered using seven-point Likert-type rating scales. The questionnaire assesses an individual's dark triad traits through three socially undesirable traits: Machiavellianism, psychopathy, and narcissism. The results are calculated as the average value of the responses on the subscales and on the entire questionnaire in total, and vary from a minimum of 1 (weakly present) to a maximum of 7 (extremely present). This questionnaire is also widely used in scientific research and clinical practice (Jonason & Davis, 2018; Sabouri et al., 2016), due to its good psychometric characteristics (Dinić et al., 2018; Milošević et al., 2022).

Criterion variables of empathy were assessed with the questionnaire Interpersonal Reactivity Index - IRI (Davis, 1980), which consists of 25 items answered with the help of five-point Likert-type assessment scales. It assesses the individual's empathy through four sub dimensions: taking another's perspective, fantasy, empathic care, and personal concerns. Scores are expressed as the arithmetic mean of the scores on each subscale, and range from a minimum of 1 (poorly developed) to a maximum of 5 (extremely developed). The questionnaire was constructed and validated in 1980 (Davis) and, due to its sound metric characteristics, is widely used in scientific research and clinical practice (Bonfils et al., 2017; Ristic & Milošević, 2019).

For categorical and control variables, the impact of which were investigated and controlled through sample selection and statistical data processing procedures, information were collected on: gender, age, field of work, year of study, work experience, sports experience, sports achievements, as well as body weight and height. All the mentioned information, except for body height and weight, were collected using a questionnaire with open and closed questions.

The measurement of anthropometrics characteristics (body height and body weight) were performed according to the principles of the International Biological Program (Weiner & Lourie, 1981). Body height was measured with a Martin anthropometer (Seca Instruments Ltd., Hamburg, Germany). During the measurement, the subject, barefoot and in underwear, stand in an upright position on a firm surface. The examinee's head was in such a position that the Frankfurt plane is horizontal. The subject arched back as far as possible while bringing his feet together. The examiner stood on the left side of the subject and controlled whether the anthropometer was placed directly vertically along the back of the body, then lowers the metal ring so that the horizontal bar comes to the top of the head. Then he read the result on the scale at the height of the upper side of the triangular ring. The result was read within an accuracy of 0.1 cm.

Body weight was measured using an electronic scale placed on a horizontal surface following the built-in spirit level on the left side. The barefoot subject in underwear, stand still in the upright position in the middle of the scale. The body weight value was read on the display. The result was recorded within an accuracy of 0.1 kg.

Based on body height and body weight, body mass index were calculated according to standardize procedure of the International Biological Program (Weiner & Lourie, 1981).

5.4 Method of Data Collection and its Analysis

The research was conducted in two phases in the amphitheaters, sports hall, and motor research laboratory of the University of Criminal Investigation and Police Studies, Academy for National Security and the Faculty of Sports and Physical Education at the University of Belgrade. In the first phase, body height and body weight were measured, and then each participant was asked to fill out a questionnaire consisting of items related to socio-demographic status, sports experience, and four psychological questionnaires. The psychological questions were given in randomized order. Filling out the questionnaires were carried out without time limit.

In the second phase, participants performed handgrip tests. Before the test begins, participants completed a general warm-up of 10 minutes, a practice test to familiarize themselves with the test procedure, after which each participant was complete two trials with a 2-minute break in between before data is recorded. Both the maximal force and the maximum rate of force development were recorded for both the dominant and non-dominant hand twice, while the order of the dominant and non-dominant hand was random. The better score for each hand was used for data analysis. The subjects repeated the entire procedure twice, once in classical and once in impulse mode of muscle contraction (Vukadinović et al, 2024), while the order of classical and impulse mode was randomized.

After this measurement, there was a 24-hour rest, during which time the subjects are suggested to refrain from training and strenuous physical work. After the rest, in the same space, using the same equipment, a test of the maximum duration of the handgrip was conducted. Subjects were asked to maintain handgrip force for as long as possible at 50% of the maximal force previously achieved with each hand, in random order, as previously described. Throughout the duration of the test, the examinees had visual feedback on the computer screen both about the current force level and about the set force level that needs to be maintained. Due to possible fatigue, only one handgrip endurance test was recorded.

After collection, with the goal of performing further analysis, the data were coded and transformed into a numerical matrix. The data from the first part of the questionnaire was transformed into nominal and ordinal scales according to the participants' answers. Answers to statements from psychological questionnaires were converted into total scores and scores on subscales according to the participants' answers. Data on morphological status and handgrip tests were added to this data.

Since the results of F_{max}, RFD_{max} and F_{imp} increase by 50% with body size, allometric partialization was performed for the mentioned variables by dividing by body weight scaled to 2/3 (Jarić et al., 2005; Dulac et al., 2016; Trajkov et al., 2017). In this way we try to put under control to some extent subpopulation differences regarding gender and body dimensions.

Division in to the subsamples, statistical testing of smaller but also larger groups too, as well as compering various groups of participants, enable to some degree control of population differences but also analyzing their effect on our topic.

The collected and processed data in the manner described so far, were subjected to further statistical analyses.

All statistical analyses were performed using SPSS 20 (IBM Corp., Armonk, N.Y., USA) and JAMOVI 1.2 (The jamovi project, 2020. Retrieved from https://www.jamovi.org). Statistical significance was defined at the level of 95% probability, for the value of $p < 0.05$ and at the level of 99% probability, for the value of $p < 0.01$ s well as 99.9% probability, for the value of $p < 0.001$. 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 the case of normality violation non parametric statistical methods were used. Also, normalization (square, cube root, logarithmic transformation) of the variable was performed. In case that after applying statistical methods for scores distribution normalization normality of the distributions still was violated, those variables were not used for further analyses where parametric statistical methods were used.

To discover the relationship between handgrip neuromuscular characteristics and behaviour al determinants, Pearson's and Spearman's correlation analysis was performed. 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 of evaluating potential of handgrip neuromuscular model in predicting psychological characteristics multiple linear regression analysis, backward stepwise selection, with criterion: probability of F to remove ≥ 0.10, was performed. To address concerns about model overfitting, outlier analysis adjusted R^2 were 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.

For the purpose of evaluating potential of recognizing well-trained and elite athletes according to the handgrip neuromuscular, morphological and psychological characteristics canonical discriminant analysis was performed.

In order to reveal gender as well as occupational and athletic level differences, non-parametric Mann-Whitney U-Test was performed. Effect size was calculated according to the formula:

$$r = |z|/\sqrt{N}$$

where r is effect size, z is z statistic, and N is number of the observations. The criterion for evaluation of the effect size was: $r < (0.2)$ – small effect, $(0.2) < r < (0.8)$ – medium effect, and $r > (0.8)$ – large effect (Sawilowsky, 2009).

In order to determine the differences between the classical and impulse regime isometric characteristics repeated measurements MANOVA was used. Partial eta squared (ηp^2) was calculated for the MANOVA effect size. The criterion for evaluation of the effect size in MANOVA was: η^2 (0.01) = small, η^2 (0.06) = medium, η^2 (0.14) = large (Sawilowsky, 2009).

In order to reveal the effects and interactions of mechanical characteristics of handgrip on psychological characteristics, multiple analysis of variance (MANOVA) was performed. For this purpose, participants were allocated to three equal groups using the 33rd and 66th percentiles as cut-off points. Accordingly, participants were allocated to High, Average, and Low groups. Variables entering the MANOVA were tested for homogeneity of variance and non-multicollinearity assumptions. In a case of significant main effects, Bonferroni pairwise post-hoc test with mean difference (MD) calculation was applied. Partial eta squared (η_p^2) was calculated for the MANOVA effect size. The criterion for evaluation of the effect size in MANOVA was: η^2 (0.01) = small, η^2 (0.06) = medium, η^2 (0.14) = large (Sawilowsky, 2009).

6 RESULTS

For the sake of easier review, comparison, but also more valid drawing of conclusions, the results will be presented through sub-chapters concerning the results of both the entire sample and sub-samples.

6.1 Total Sample

Descriptive statistical analysis of age, morphological and psychological characteristics for the whole sample is presented in Table 1. The nonparametric Kolmogorov–Smirnov test showed significant deviations from the normal distribution for Age, Nrt, NV, Cns, MT, Mch and Psc.

Table 1. Descriptive statistical analysis of age, morphological characteristics and psychological characteristics

	M	SD	CV	Min	Max	KS Z
Age	22.91	7.41	0.32	18.1	65	3.88***
BH	1.76	0.09	0.05	1.51	1.97	1.03
BW	73.02	13.04	0.18	42.5	136.7	0.54
BMI	23.47	2.91	0.12	15.71	37.08	0.75
Agr	2.22	0.76	0.35	1	4.3	1.34
Ext	4.08	0.61	0.15	1.4	5	1.39
Nrt	1.67	0.72	0.43	1	4.3	2.50***
NV	1.43	0.49	0.34	1	3.7	2.70***
Opn	4.06	0.56	0.14	2.2	5	1.33
PV	3.56	0.75	0.21	1.3	5	0.82
Cns	4.27	0.67	0.16	2.4	5	2.06***
MT	6.21	0.62	0.1	3.75	7.13	1.39*
Mch	2.04	1.09	0.54	1	6.17	2.45***
Psc	2.13	1.1	0.52	1	7	2.18***
Nrc	3.13	1.45	0.46	1	6.25	1.26
DT	2.38	0.97	0.41	1	6.17	1.34

Note: *p<0.05, **p<0.01, ***p<0.001

According to CV sample is heterogeneous on variables: Age, Agr, Nrt, NV, Mch, Psc, Nrc, and DT.

Descriptive statistical analysis of mechanical characteristics of the handgrip for the whole sample is presented in Table 2. The nonparametric Kolmogorov–Smirnov test showed significant deviations from the normal distribution for $F_{max}ND$, $RFD_{max}ND$, $tF_{max}ND$, $tRFD_{max}ND$, $F^{max}D$, $tF_{max}D$, $tRFD_{max}D$, $F_{max}S$, $RFD_{max}S$, $tRFD_{max}S$, EID, $F_{rel}ND$, and EID_{rel}.

According to CV sample is also heterogeneous on variables: $F_{max}ND$, $RFD_{max}ND$, $tF_{max}ND$, $F_{max}D$, $RFD_{max}D$, $tF_{max}D$, $tRFD_{max}D$, $F_{max}S$, $RFD_{max}S$, and $tF_{max}S$.

Table 2. Descriptive statistical analysis of mechanical characteristics of the handgrip

	M	SD	CV	Min	Max	KS Z
$F_{max}ND$	394.27	131.81	0.33	180	721	1.79**
$RFD_{max}ND$	2596.44	924.96	0.36	950	4819	1.38*
$tF_{max}ND$	0.88	0.43	0.48	0.24	2.42	1.53**
$tRFD_{max}ND$	0.12	0.02	0.15	0.09	0.24	2.13***
$F_{max}D$	419.25	133.45	0.32	206	735	1.40*
$RFD_{max}D$	2715.35	962.16	0.35	957	5215	1.35
$tF_{max}D$	0.94	0.48	0.51	0.22	3.59	1.58*
$tRFD_{max}D$	0.12	0.03	0.22	0.09	0.33	2.91***
$F_{max}S$	813.52	261.32	0.32	392	1427	1.52**
$RFD_{max}S$	5311.79	1840.96	0.35	2277	9779	1.42*
$tF_{max}S$	1.83	0.76	0.42	0.58	5.66	1.21
$tRFD_{max}S$	0.24	0.04	0.16	0.19	0.46	2.51***
DIF	1.08	0.13	0.12	0.75	1.8	1.06
DIRFD	1.06	0.17	0.16	0.65	1.59	0.72
EIND	0.15	0.02	0.13	0.11	0.25	1.22
EID	0.16	0.03	0.16	0.11	0.31	1.39*
EIS	0.31	0.04	0.13	0.24	0.5	1.23
$F_{rel}ND$	22.24	5.78	0.26	11.63	36.67	1.56*
$RFD_{rel}ND$	146.34	41.76	0.29	68.45	248.86	1.24
FrelD	23.73	5.71	0.24	13.42	38.67	1.09
$RFD_{rel}D$	153.29	43.32	0.28	61.79	279.34	1.14
FrelS	45.96	11.21	0.24	26.46	73.02	1.19
$RFD_{rel}S$	299.63	81.99	0.27	149.31	520.02	1.08
DIF_{rel}	1.08	0.13	0.12	0.75	1.8	1.06
$DIRFD_{rel}$	1.06	0.17	0.16	0.65	1.59	0.71
$EIND_{rel}$	0.15	0.02	0.13	0.11	0.25	1.21
EID_{rel}	0.16	0.03	0.16	0.11	0.31	1.39*
EIS_{rel}	0.31	0.04	0.13	0.24	0.5	1.23

Note: *p<0.05, **p<0.01, ***p<0.001

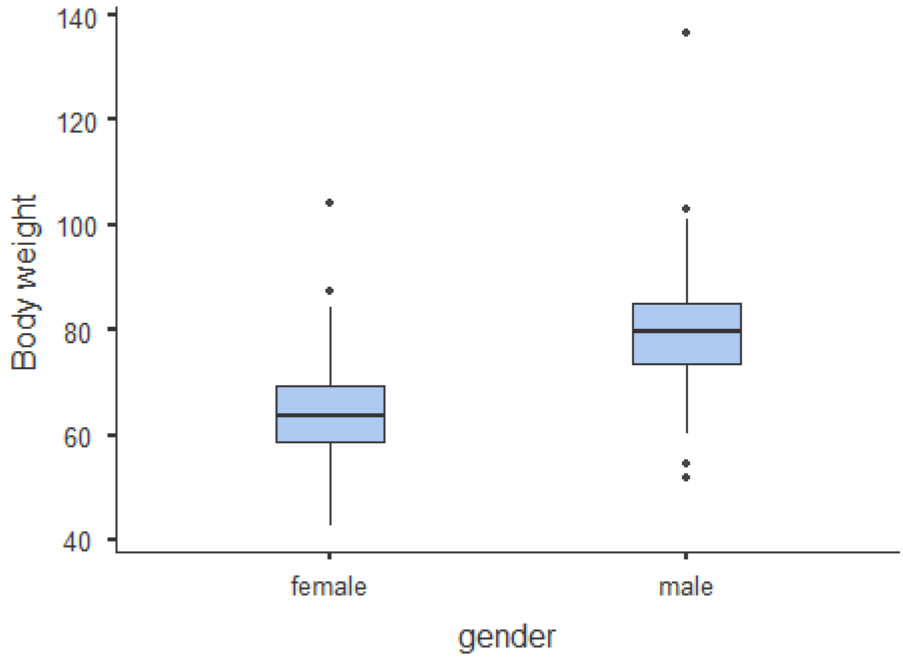
Descriptive statistical analysis of age, morphological and psychological characteristics according to gender for the whole sample is presented in Table 3.

Table 3. Descriptive statistical analysis of age, morphological characteristics and psychological characteristics according to gender

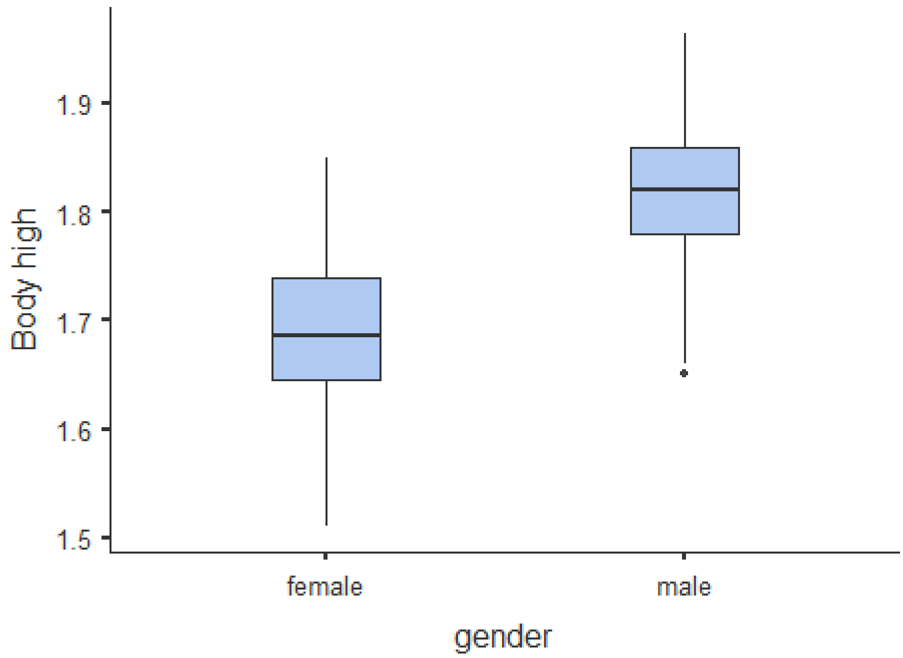
	Female (n=93)				Male (n=112)			
	M	SD	Min	Max	M	SD	Min	Max
BH***	1.69	0.06	1.51	1.85	1.82	0.06	1.65	1.97
BW***	64.25	9.76	42.5	104	80.3	10.76	51.6	136.7
BMI***	22.51	3.07	15.71	36.85	24.27	2.53	18.73	37.08
Agr**	2.38	0.72	1	4.1	2.08	0.78	1	4.3
Ext	4.04	0.57	2.5	5	4.12	0.64	1.4	5
Nrt	1.71	0.72	1	4.3	1.64	0.72	1	3.8
NV	1.34	0.33	1	2.3	1.51	0.58	1	3.7
Opn	4.05	0.54	2.5	5	4.07	0.58	2.2	5
PV	3.53	0.76	1.3	5	3.59	0.75	1.6	5
Cns	4.26	0.6	2.4	5	4.28	0.72	2.4	5
MT**	6.07	0.65	3.75	7	6.32	0.57	3.88	7.13
Mch	1.87	0.9	1	4.75	2.17	1.21	1	6.17
Psc**	1.88	0.88	1	4.5	2.34	1.22	1	7
Nrc	3.03	1.4	1	6	3.22	1.5	1	6.25
DT	2.21	0.78	1	4.33	2.52	1.08	1	6.17

Note: *p<0.05, **p<0.01, ***p<0.001

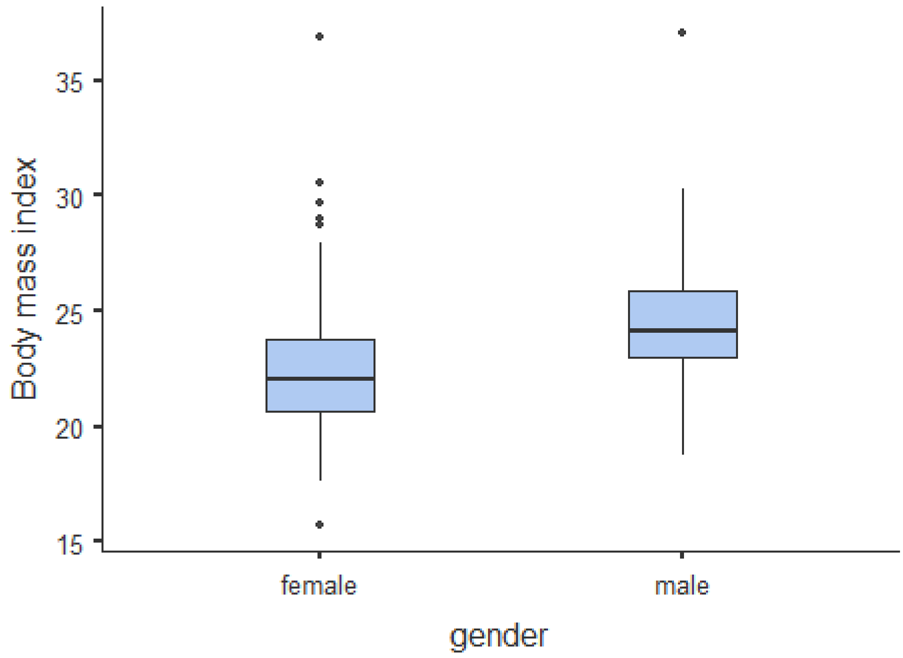
The non-parametric Mann-Whitney U test reveals significant differences between the female and male participants in: BH (U=810.5, z=-10.4, p<0.001), BW (U=1172, z=-9.5, p<0.001), BMI (U=2960, z=-5.3, p<0.001), Agr (U=3885, z=-3.1, p<0.01), MT (U=4019, z=-2.8, p<0.01), and Psc (U=4029, z=-2.8, p<0.01) which are illustrated in the Graphs 3, 4, 5, 6, 7 and 8.



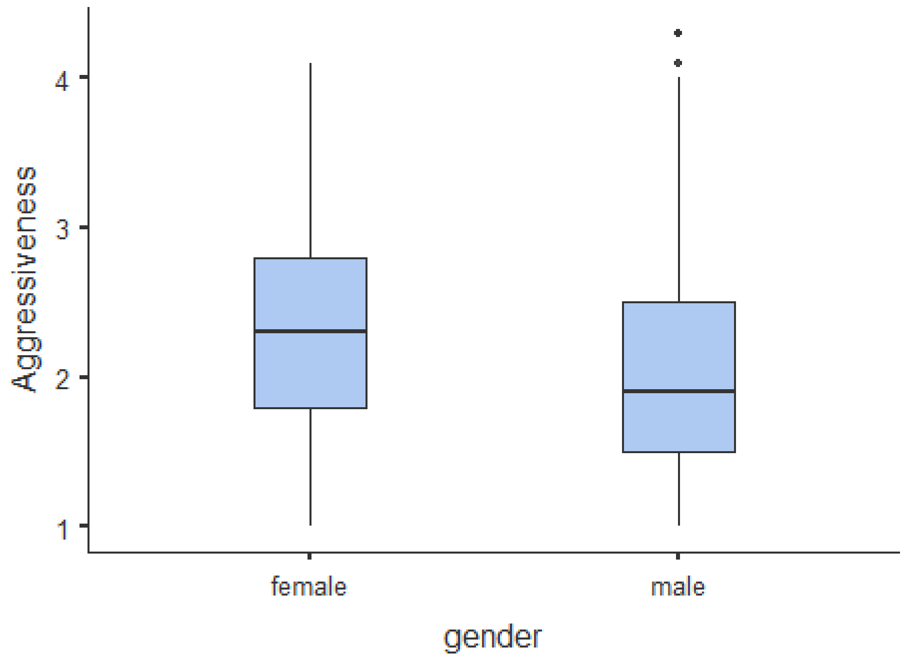
Graph 3. Box plot of differences in body weight according to gender



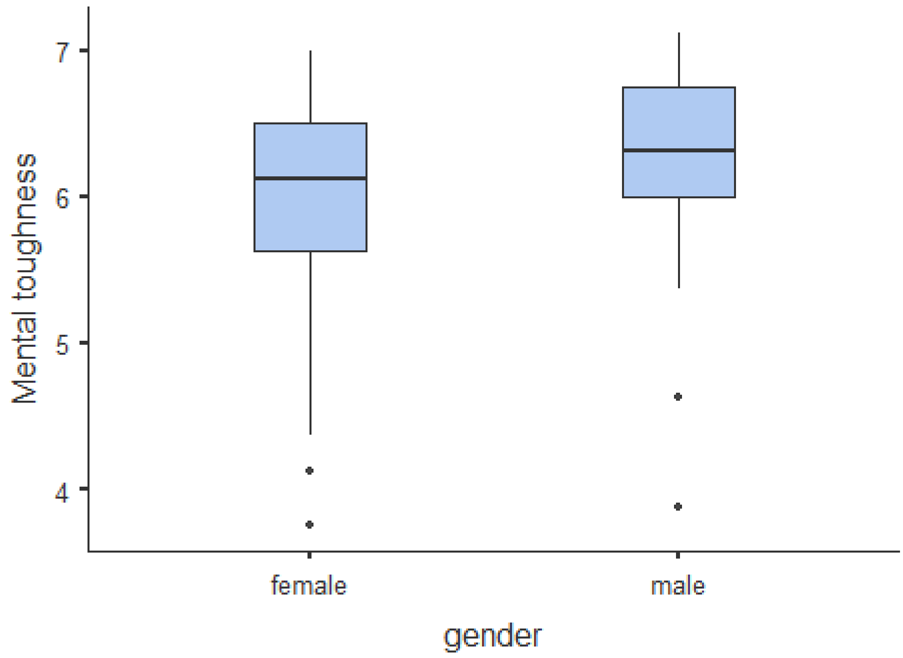
Graph 4. Box plot of differences in body high according to gender



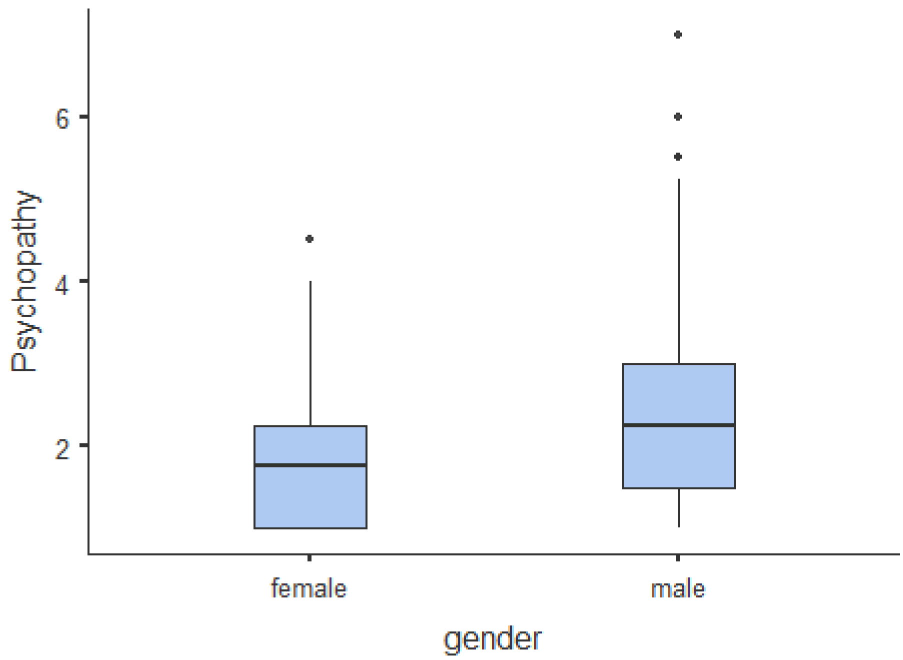
Graph 5. Box plot of differences in body mass index according to gender



Graph 6. Box plot of differences in aggressiveness according to gender



Graph 7. Box plot of differences in mental toughness index according to gender



Graph 8. Box plot of differences in psychopathy according to gender

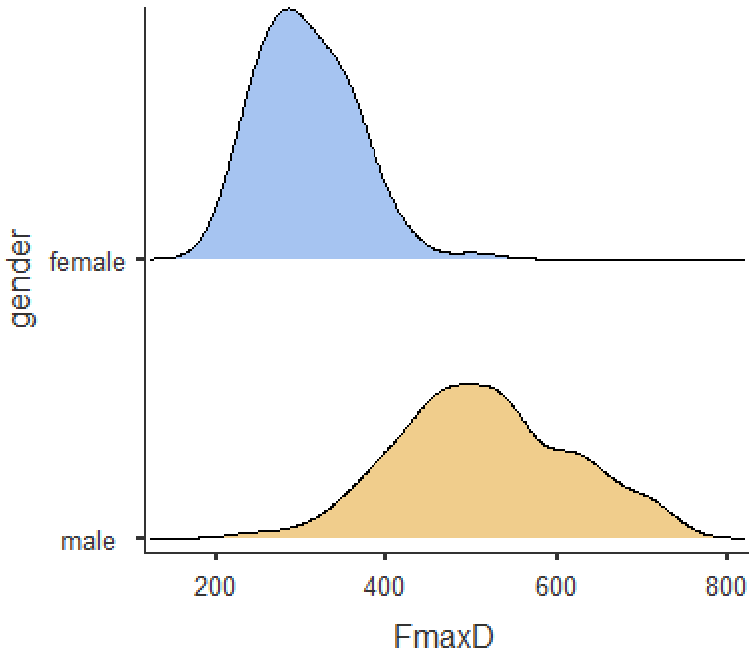
Descriptive statistical analysis of mechanical characteristics of the handgrip according to gender for the whole sample is presented in Table 4.

Table 4. Descriptive statistical analysis of mechanical characteristics of the handgrip according to gender

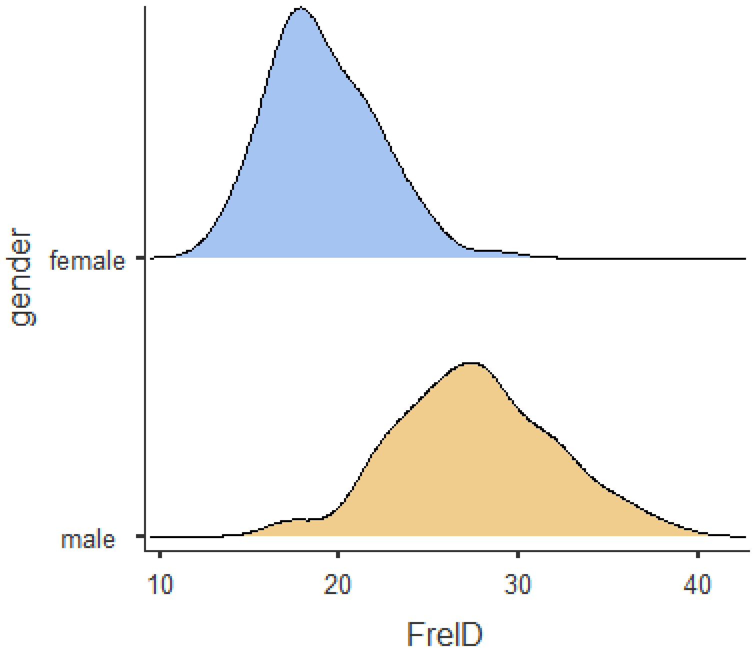
	Female (n=93)				Male (n=112)			
	M	SD	Min	Max	M	SD	Min	Max
F_{max}ND***	280.63	51.3	180	460	488.63	99.72	192	721
RFD_{max}ND***	1807.81	390.35	1037	2938	3251.29	701.64	950	4819
tF_{max}ND	0.84	0.37	0.31	2.42	0.92	0.46	0.24	2.39
$tRFD_{max}$ND**	0.12	0.02	0.09	0.19	0.12	0.02	0.09	0.24
F_{max}D***	305.02	54.68	206	503	514.1	101.21	242	735
RFD_{max}D***	1922.04	443.26	957	3483	3374.07	757.24	1472	5215
tF_{max}D	0.94	0.4	0.25	2.33	0.94	0.54	0.22	3.59
$tRFD_{max}$D***	0.13	0.03	0.09	0.28	0.12	0.03	0.09	0.33
F_{max}S***	585.66	99.63	392	963	1002.73	194.04	434	1427
RFD_{max}S***	3729.85	782.14	2277	6421	6625.37	1372.55	2422	9779
tF_{max}S	1.78	0.63	0.72	4.75	1.86	0.86	0.58	5.66
$tRFD_{max}$S***	0.25	0.04	0.19	0.43	0.24	0.04	0.19	0.46
DIF	1.1	0.15	0.76	1.8	1.07	0.11	0.75	1.42
DIRFD	1.07	0.17	0.65	1.59	1.06	0.17	0.73	1.56
EIND*	0.16	0.02	0.12	0.23	0.15	0.02	0.11	0.25
EID*	0.16	0.03	0.11	0.31	0.15	0.02	0.12	0.25
EIS*	0.32	0.04	0.24	0.5	0.31	0.04	0.24	0.42
F_{rel}ND***	17.55	2.86	11.63	26.3	26.13	4.57	13.83	36.67
RFD_{rel}ND***	112.95	21.73	68.58	173.69	174.07	33.23	68.45	248.86
F_{rel}D***	19.05	2.93	13.42	28.76	27.61	4.4	16.68	38.67
RFD_{rel}D***	119.68	23.29	61.79	199.12	181.19	35.6	91.92	279.34
F_{rel}S***	36.6	5.33	26.46	55.05	53.74	8.55	31.27	73.02
RFD_{rel}S***	232.63	41.24	149.31	367.08	355.26	63.73	171.46	520.02
DIF_{rel}	1.1	0.15	0.76	1.8	1.07	0.11	0.75	1.42
$DIRFD_{rel}$	1.07	0.17	0.65	1.59	1.06	0.17	0.73	1.56
$EIND_{rel}$*	0.16	0.02	0.12	0.23	0.15	0.02	0.11	0.25
EID_{rel}*	0.16	0.03	0.11	0.31	0.15	0.02	0.12	0.25
EIS_{rel}*	0.32	0.04	0.24	0.5	0.31	0.04	0.24	0.42

Note: *p<0.05, **p<0.01, ***p<0.001

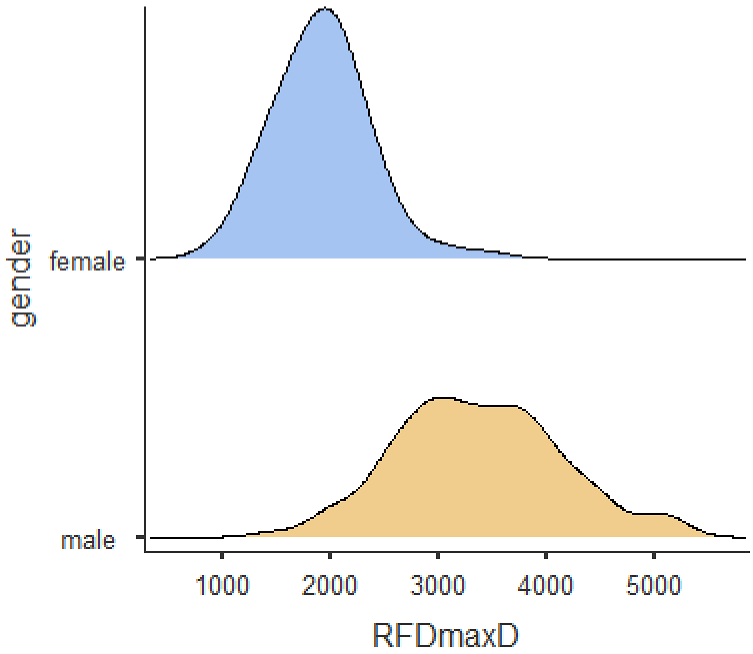
The non-parametric Mann-Whitney U test reveals significant differences between the female and male participants in: F_{max}ND (U=374.5, z=-11.4, p<0.001), RFD_{max}ND (U=458, z=-11.2, p<0.001), $tRFD_{max}$ND (U=3899.5, z=-3.1, p<0.01), F_{max}D (U=351.5, z=-11. 5, p<0.001), RFD_{max}D (U=467, z=-11.2, p<0.001), $tRFD_{max}$D (U=3148, z=-4.9, p<0.001), F_{max}S (U=323, z=-11.5, p<0.001), RFD_{max}S (U=378, z=-11.4, p<0.001), $tRFD_{max}$S (U=3348.5, z=-4.4, p<0.001), EIND (U=4276, z=-2.2, p<0.05), EID (U=4290, z=-2.2, p<0.05), EIS (U=4229, z=-2.3, p<0.05), F_{rel}ND (U=653, z=-10.8, p<0.001), RFD_{rel}ND (U=758, z=-10.5, p<0.001), F_{rel}D (U=543, z=-11, p<0.001), RFD_{rel}D (U=734, z=-10.6, p<0.001), F_{rel}S (U=513, z=-11.1, p<0.001), RFD_{rel}S (U=591, z=-10.9, p<0.001), $EIND_{rel}$ (U=4301, z=-2.1, p<0.05), EID_{rel} (U=4290, z=-2.2, p<0.05), and EIS_{rel} (U=4243, z=-2.3, p<0.05) which are illustrated in the Graphs 9, 10, 11, 12, 13 and 14.



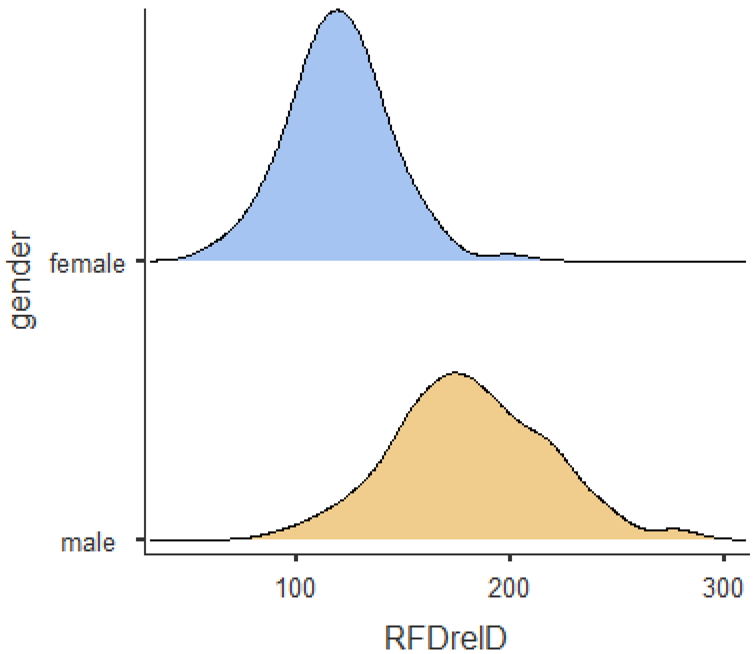
Graph 9. Density histogram of differences in maximal force of the dominant hand according to gender



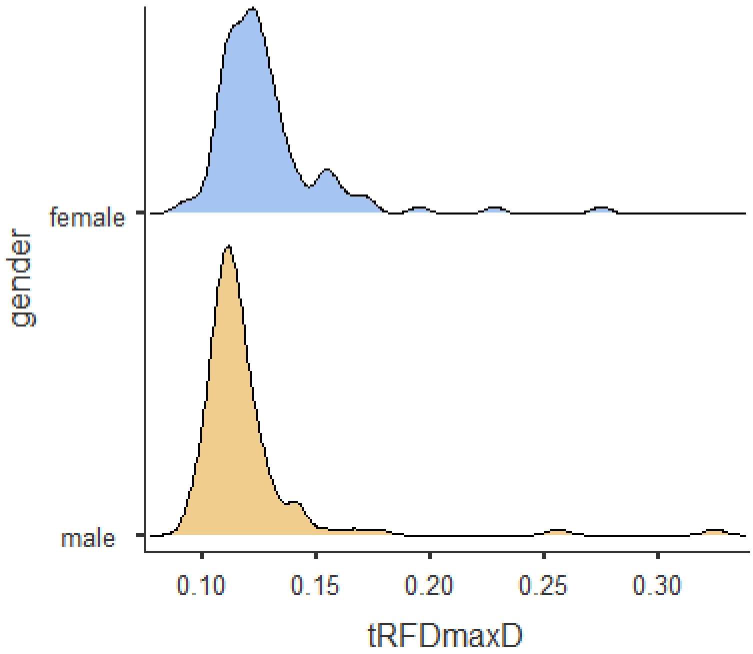
Graph 10. Density histogram of differences in maximal force of the dominant hand normalized for body weight according to gender



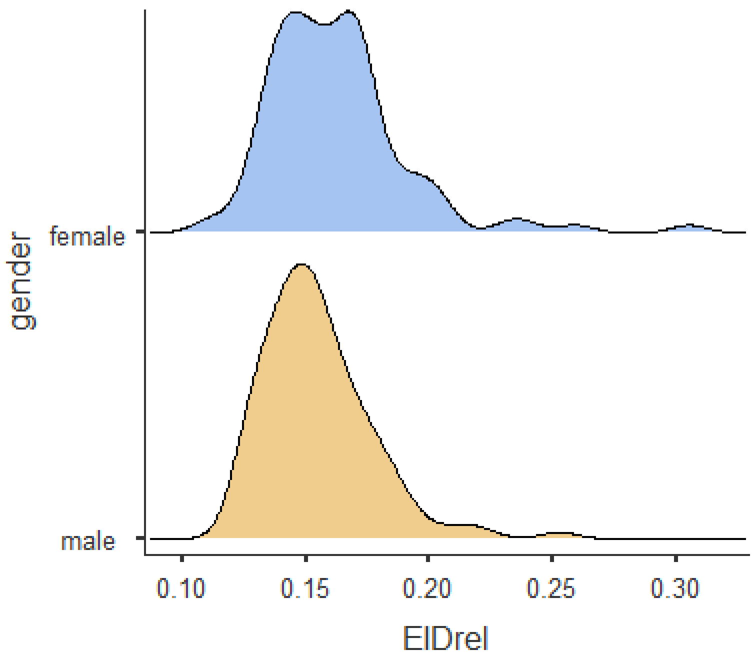
Graph 11. Density histogram of differences in maximal rate of force development of the dominant according to gender



Graph 12. Density histogram of differences in maximal rate of force development of the dominant hand normalized for body weight according to gender



Graph 13. Density histogram of differences in the time required to achieve the maximal rate of force development of the dominant hand according to gender



Graph 14. Density histogram of differences in excitation index of the dominant hand normalized for body weight according to gender

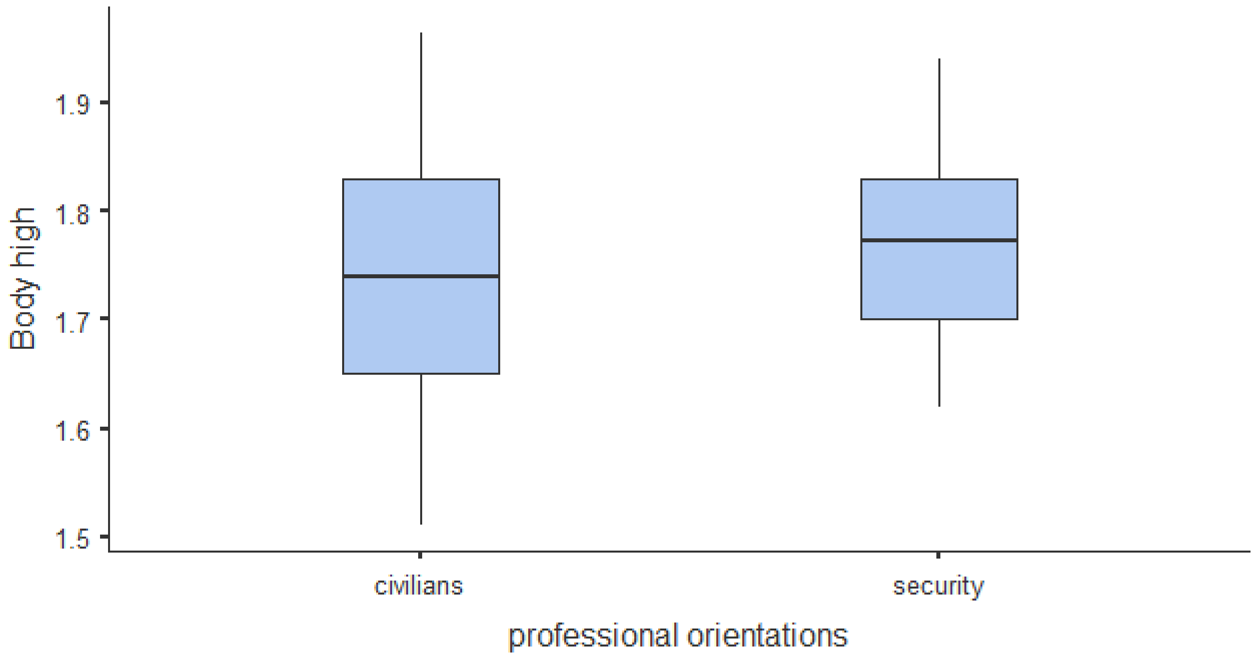
Descriptive statistical analysis of age, morphological and psychological characteristics according to professional orientations (security-civilians) for the whole sample is presented in Table 5.

Table 5. Descriptive statistical analysis of age, morphological characteristics and psychological characteristics according to professional orientations

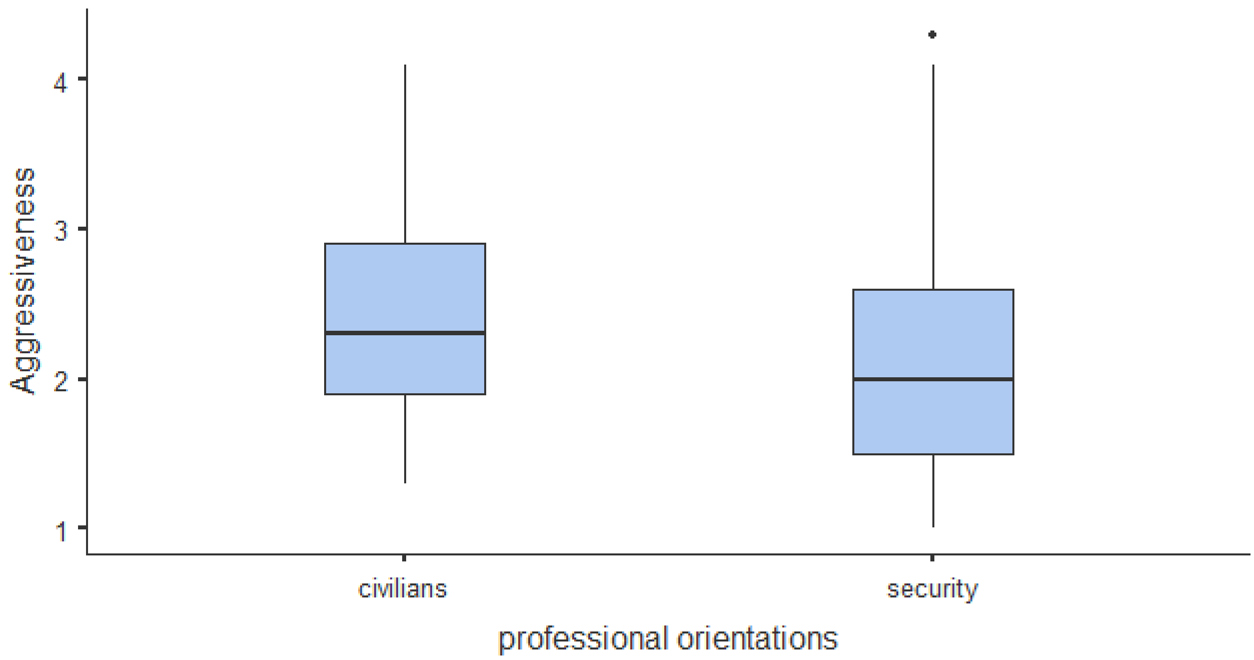
	Civilians (n=69)				Security (n=136)			
	M	SD	Min	Max	M	SD	Min	Max
BH*	1.74	0.11	1.51	1.97	1.77	0.08	1.62	1.94
BW	72.26	15.11	42.5	103	73.41	11.9	51	136.7
BMI	23.76	3.25	15.71	30.53	23.33	2.73	18.89	37.08
Agr**	2.43	0.66	1.3	4.1	2.11	0.79	1	4.3
Ext**	3.94	0.5	2.5	4.8	4.16	0.65	1.4	5
Nrt***	1.93	0.68	1	3.8	1.54	0.7	1	4.3
NV*	1.45	0.38	1	3.1	1.42	0.53	1	3.7
Opn*	3.93	0.59	2.2	5	4.13	0.54	2.6	5
PV*	3.37	0.75	1.3	4.8	3.66	0.74	1.6	5
Cns***	4.08	0.59	2.5	5	4.36	0.68	2.4	5
MT***	5.9	0.65	3.88	7	6.36	0.55	3.75	7.13
Mch	2.09	0.83	1	4	2.01	1.21	1	6.17
Psc	2.02	0.85	1	4.25	2.19	1.21	1	7
Nrc	3.13	1.39	1	6	3.13	1.49	1	6.25
DT	2.3	0.74	1	4	2.42	1.06	1	6.17

Note: *$p<0.05$, **$p<0.01$, ***$p<0.001$

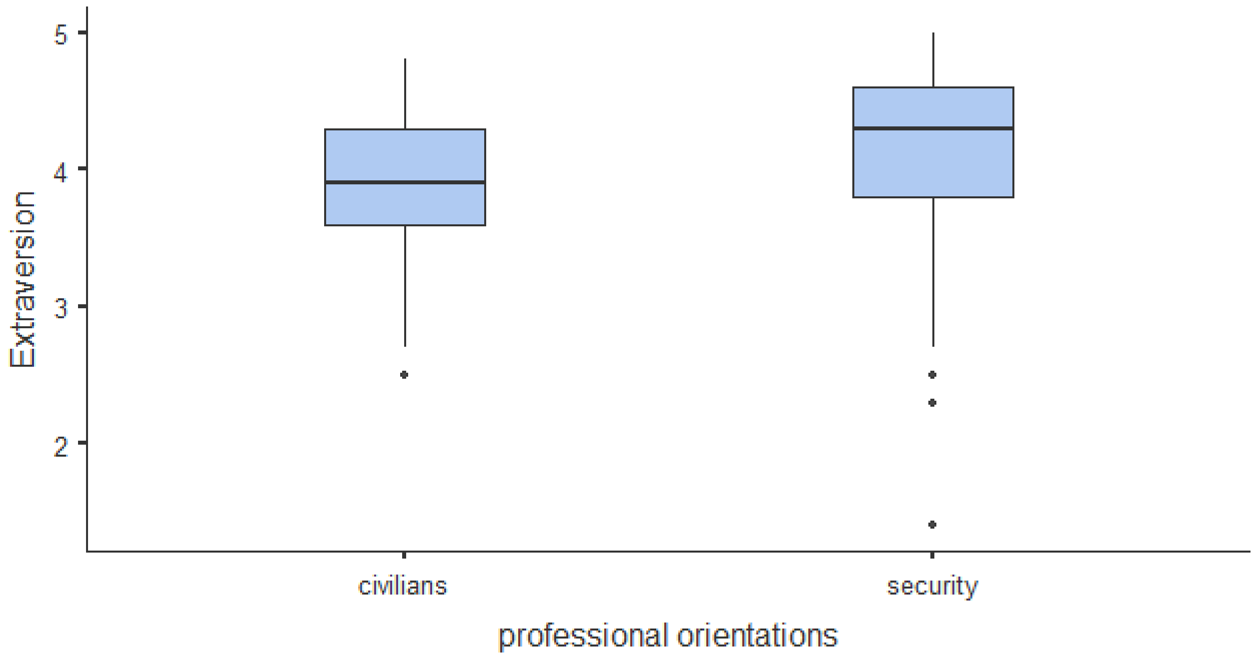
The non-parametric Mann-Whitney U test reveals significant differences between the civilians and security population of participants in: BH (U=4605, z=-2.3 , $p<0.05$), Agr (U=3331, z=-3.4 , $p<0.01$), Ext (U=342.5, z=-3.2, $p<0.01$), Nrt (U=2792.5, z=-4.8, $p<0.001$), NV (U=3840, z=-2.1, $p<0.05$), Opn (U=3772, z=-2.3, $p<0.05$), PV (U=3730.5, z=-2.4, $p<0.05$), Cns (U=3175, z=-3.8, $p<0.001$), and MT (U=2697, z=-4.9, $p<0.001$) which are illustrated in the Graphs 15, 16, 17, 18, 19, 20, 21, 22, and 23.



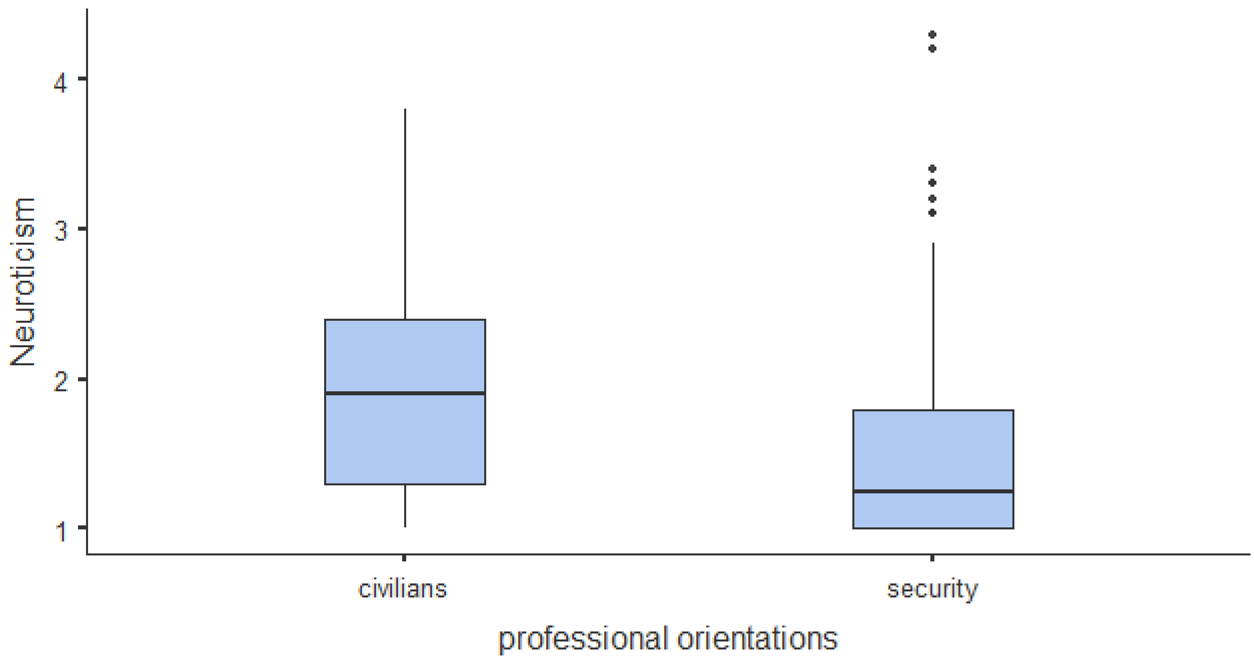
Graph 15. Box plot of differences in body height according to professional orientation



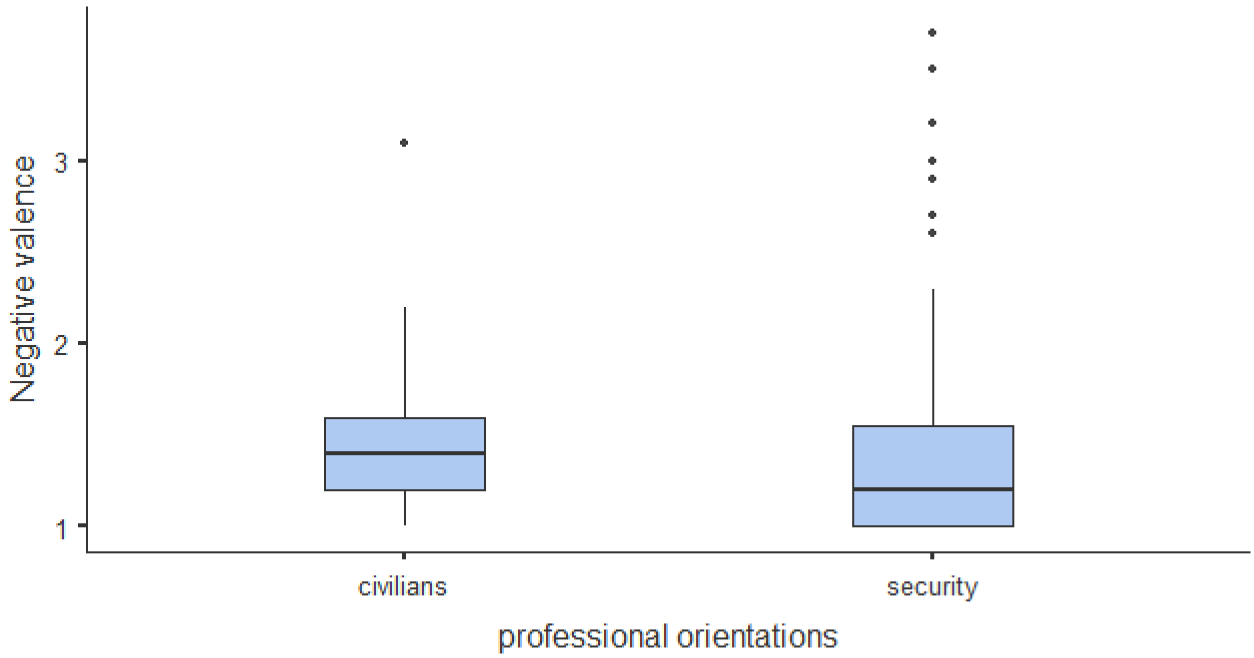
Graph 16. Box plot of differences in aggressiveness according to professional orientation



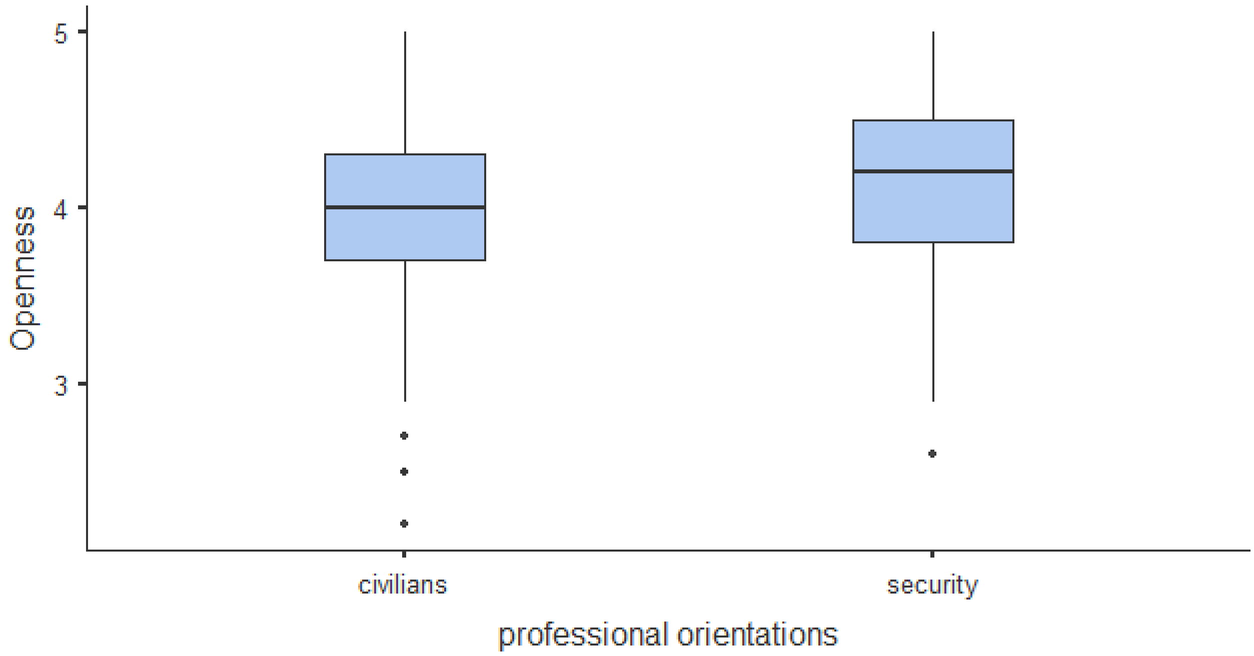
Graph 17. Box plot of differences in extraversion according to professional orientation



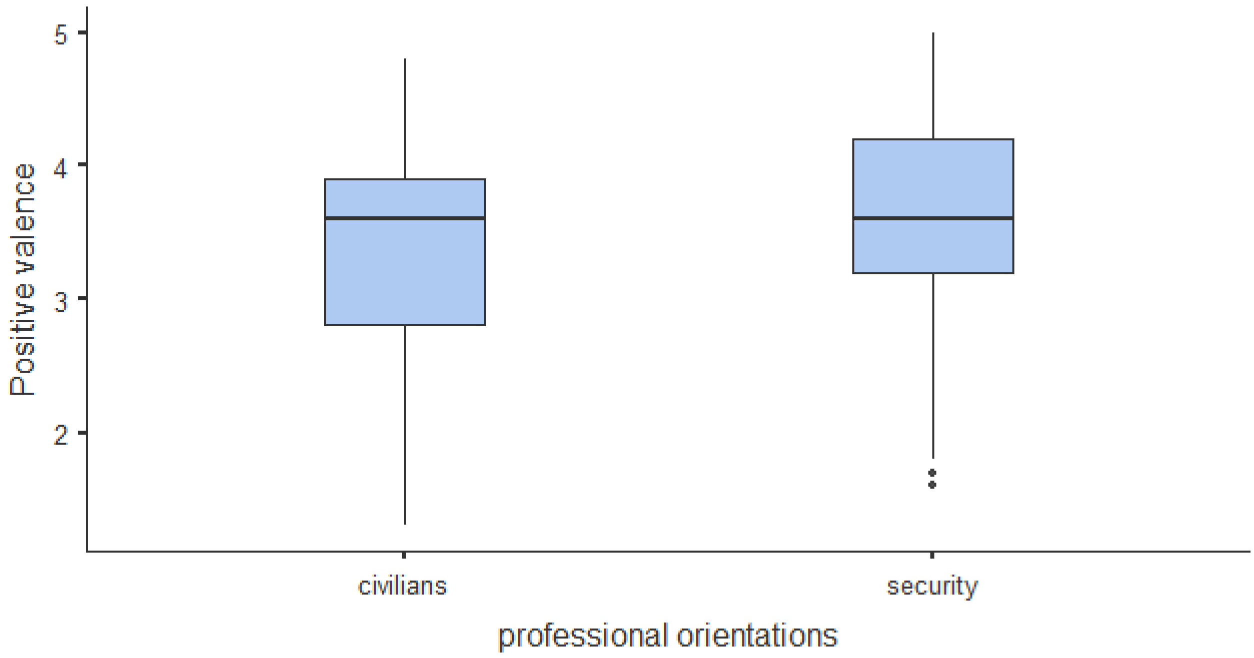
Graph 18. Box plot of differences in neuroticism according to professional orientation



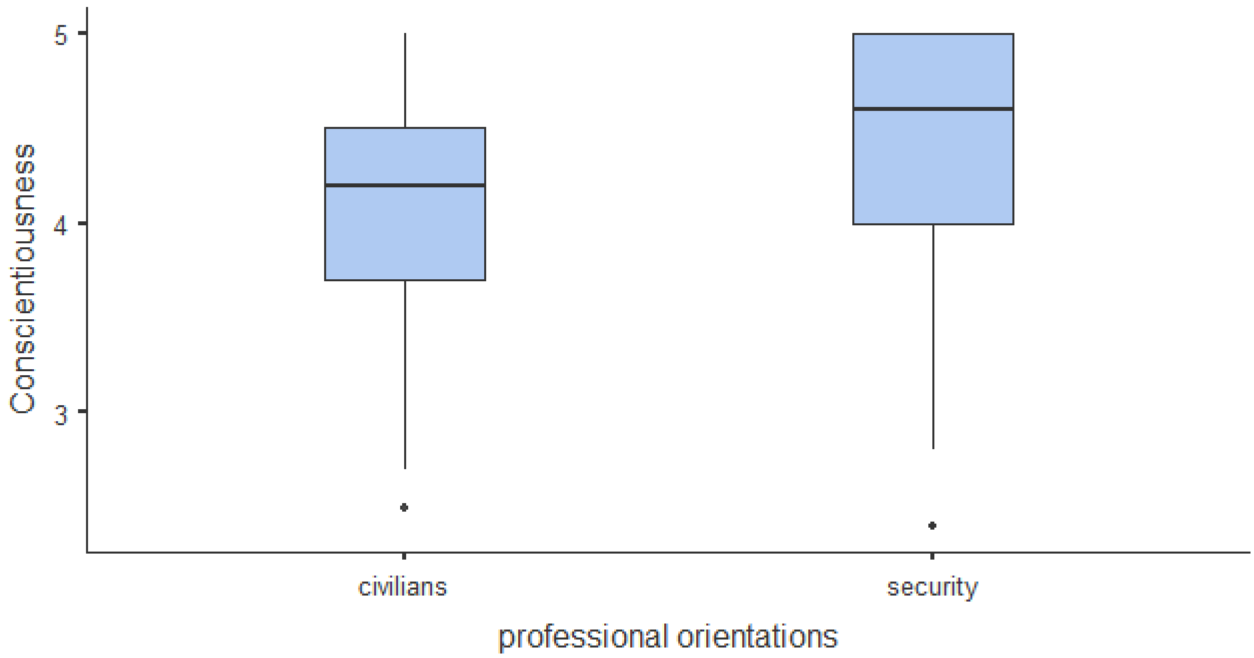
Graph 19. Box plot of differences in negative valence according to professional orientation



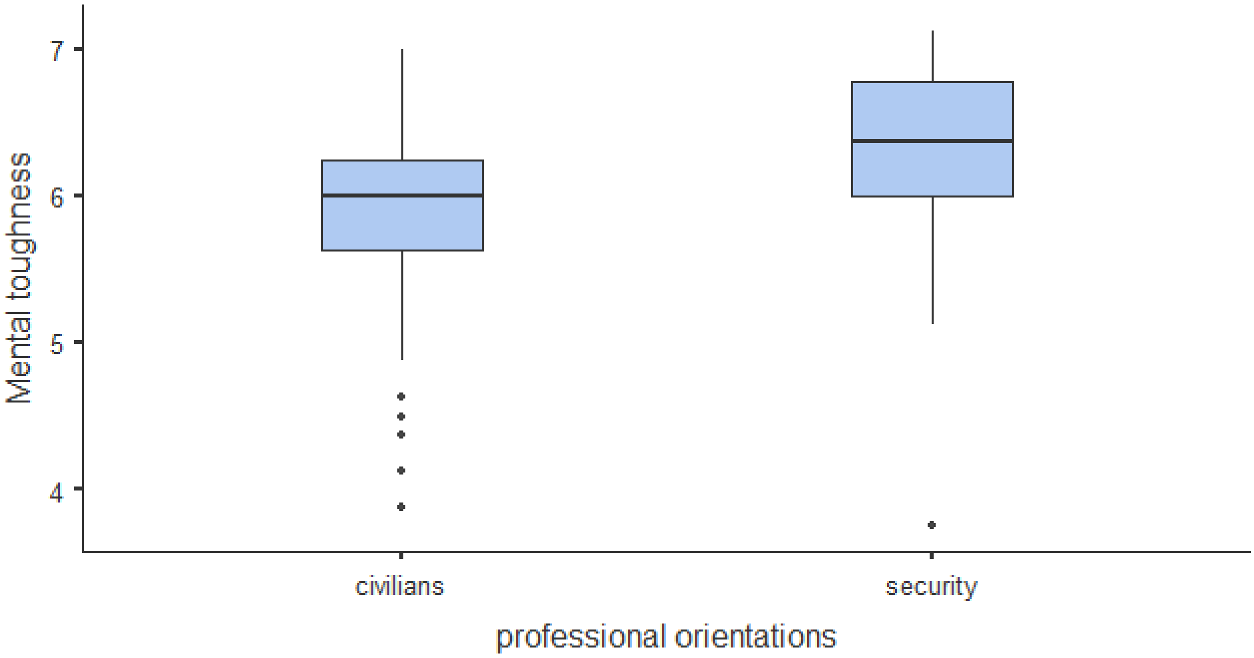
Graph 20. Box plot of differences in openness according to professional orientation



Graph 21. Box plot of differences in positive valence according to professional orientation



Graph 22. Box plot of differences in conscientiousness according to professional orientation



Graph 23. Box plot of differences in mental toughness according to professional orientation

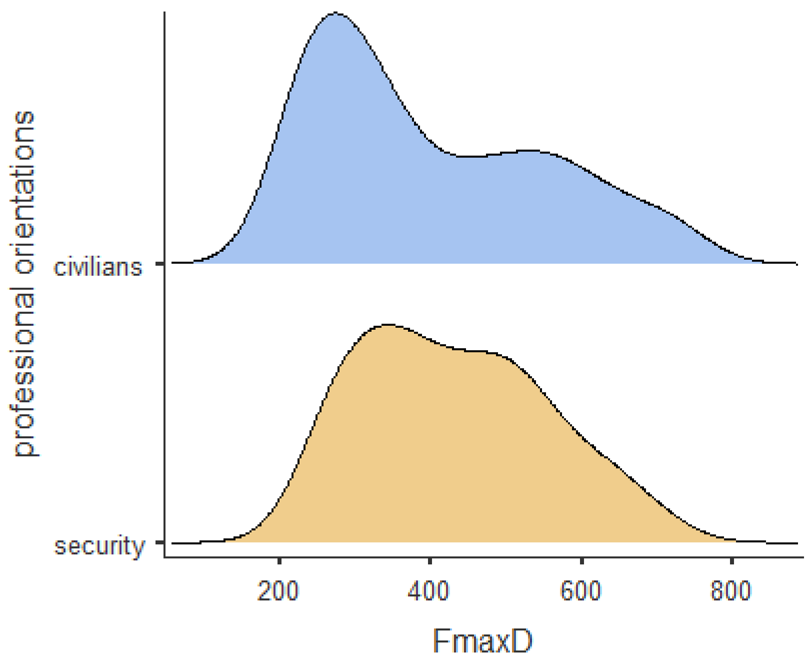
Descriptive statistical analysis of mechanical characteristics of the handgrip according to professional orientations for the whole sample is presented in Table 6.

Table 6. Descriptive statistical analysis of mechanical characteristics of the handgrip according to professional orientations

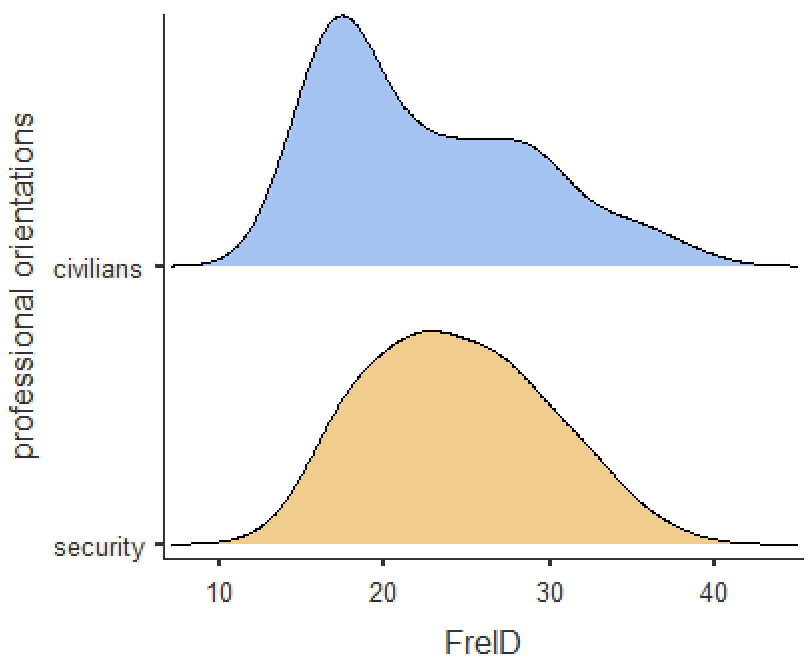
	Civilians (n=69)				Security (n=136)			
	M	SD	Min	Max	M	SD	Min	Max
F_{max}ND**	364.75	140.23	180	689	409.25	125.21	188	721
RFD_{max}ND*	2393.17	1017.14	950	4789	2699.57	860.16	1283	4819
tF_{max}ND	0.81	0.39	0.24	1.99	0.92	0.44	0.24	2.42
$tRFD_{max}$ND	0.12	0.02	0.09	0.19	0.12	0.02	0.09	0.24
F_{max}D*	397.43	153.57	206	735	430.32	121.1	242	706
RFD_{max}D	2657.38	1166.77	964	5215	2744.76	842.97	957	5107
tF_{max}D***	0.78	0.36	0.25	1.72	1.02	0.52	0.22	3.59
$tRFD_{max}$D	0.12	0.02	0.09	0.18	0.12	0.03	0.09	0.33
F_{max}S*	762.19	290.63	392	1409	839.57	242.11	456	1427
RFD_{max}S	5050.55	2148.52	2277	9779	5444.33	1656.38	2390	9507
tF_{max}S**	1.6	0.6	0.58	2.97	1.94	0.81	0.62	5.66
$tRFD_{max}$S	0.24	0.03	0.19	0.36	0.24	0.04	0.19	0.46
DIF	1.1	0.12	0.88	1.43	1.07	0.13	0.75	1.8
DIRFD**	1.12	0.18	0.7	1.59	1.03	0.16	0.65	1.56
EIND	0.16	0.02	0.11	0.21	0.15	0.02	0.12	0.25
EID*	0.15	0.02	0.13	0.24	0.16	0.03	0.11	0.31
EIS	0.31	0.04	0.24	0.41	0.31	0.04	0.24	0.5
F_{rel}ND**	20.65	5.85	11.63	33.61	23.04	5.59	12.26	36.67
RFD_{rel}ND**	135.09	44.23	68.45	220.48	152.05	39.4	78.38	248.86
F_{rel}D**	22.46	6.32	13.5	38.67	24.37	5.29	13.42	37.71
RFD_{rel}D	149.42	50.16	61.79	274.07	155.25	39.45	65.45	279.34
F_{rel}S**	43.11	11.95	26.6	72.28	47.41	10.58	26.46	73.02
RFD_{rel}S*	284.51	91.84	149.31	458.33	307.3	75.72	163.45	520.02
DIF_{rel}	1.1	0.12	0.88	1.43	1.07	0.13	0.75	1.8
$DIRFD_{rel}$**	1.12	0.18	0.7	1.59	1.03	0.16	0.65	1.56
$EIND_{rel}$	0.16	0.02	0.11	0.21	0.15	0.02	0.12	0.25
EID_{rel}*	0.15	0.02	0.13	0.24	0.16	0.03	0.11	0.31
EIS_{rel}	0.31	0.04	0.24	0.41	0.31	0.04	0.24	0.5

Note: *p<0.05, **p<0.01, ***p<0.001

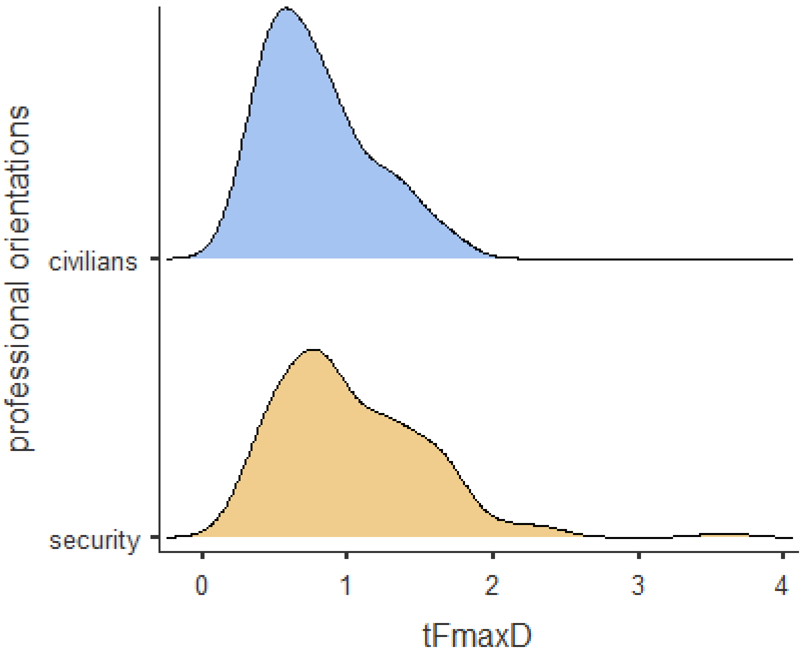
The non-parametric Mann-Whitney U test reveals significant differences between the civilians and security population of participants in: F_{max}ND (U=3634.5, z=-2.6, p<0.01), RFD_{max}ND (U=3678.5, z=-2.5, p<0.05), F_{max}D (U=3786, z=-2.2, p<0.05), tF_{max}D (U=3352, z=-3.3, p<0.001), F_{max}S (U=3690.5, z=-2.4, p<0.05), tF_{max}S (U=3514, z=-2.9, p<0.01), DIRFD (U=3463, z=-3, p<0.01), EID (U=3877, z=-2, p<0.05), F_{rel}ND (U=3508, z=-2.9, p<0.01), RFD_{rel}ND (U=3542, z=-2.8, p<0.01), F_{rel}D (U=3630, z=-2.6, p<0.01), F_{rel}S (U=3552, z=-2.8, p<0.01), RFD_{rel}S (U=3797, z=-2.2, p<0.05), $DIRFD_{rel}$ (U=3498.5, z=-2.9, p<0.01), and EID_{rel} (U=3877, z=-2 p<0.05) which are illustrated in the Graphs 24, 25, 26, 27, 28.



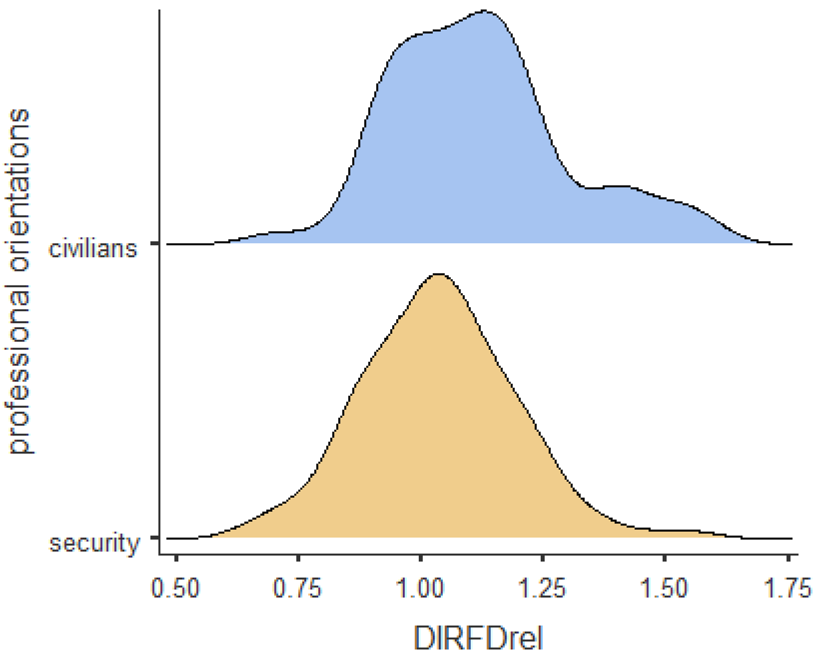
Graph 24. Density histogram of differences in maximal force of the dominant hand according to professional orientation



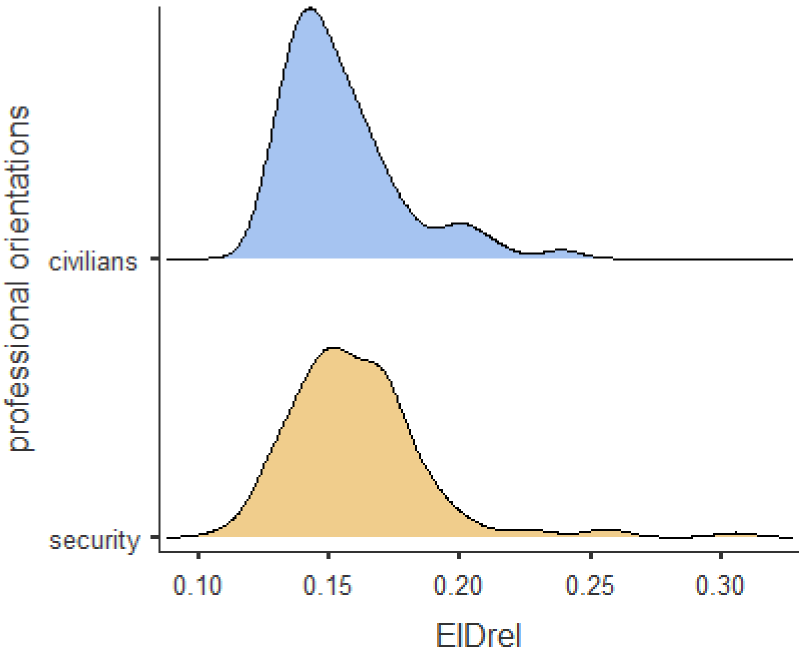
Graph 25. Density histogram of differences in maximal force normalized for body weight of the dominant hand according to professional orientation



Graph 26. Density histogram of differences in time required to reach the maximal force of the dominant hand according to professional orientation



Graph 27. Density histogram of differences in dimorphism index of maximal rate of force development normalized for body weight according to professional orientation



Graph 28. Density histogram of excitation index of the dominant hand normalized for body weight according to professional orientation

Results of the non-parametric Spearman's rank correlation analysis of mechanical characteristics of the handgrip with psychological characteristics for whole sample are presented in Tables 7 and 8.

Table 7. Correlation analysis of absolute values of mechanical characteristics of the handgrip with psychological characteristics

	Agr	Ext	Nrt	NV	Opn	PV	Cns	MT	Mch	Psc	Nrc	DT
F_{max}ND	-0.12	0.01	-0.09	0.11	0.04	0.10	0.09	0.20**	0.05	0.14*	0.12	0.15*
RFD_{max}ND	-0.08	-0.06	-0.03	0.14	0.05	0.10	0.08	0.17*	0.08	0.20**	0.13	0.19**
tF_{max}ND	-0.02	0.07	-0.09	0.03	0.09	0.07	0.08	0.11	-0.03	-0.03	-0.02	-0.01
$tRFD_{max}$ND	0.03	0.03	-0.04	-0.07	-0.07	-0.05	-0.06	0.01	-0.14*	-0.15*	-0.09	-0.17*
FmaxD	-0.10	0.01	-0.08	0.12	0.07	0.14*	0.11	0.22**	0.05	0.18**	0.11	0.15*
RFD_{max}D	-0.07	-0.05	-0.02	0.13	0.03	0.11	0.07	0.15*	0.11	0.23**	0.15*	0.21**
tF_{max}D	-0.11	0.12	-0.06	0.00	0.18*	0.00	0.05	0.14*	-0.04	-0.08	-0.13	-0.08
$tRFD_{max}$D	-0.02	0.05	-0.04	-0.13	0.05	0.03	0.02	0.04	-0.25**	-0.16*	-0.15*	-0.21**
F_{max}S	-0.11	0.00	-0.08	0.12	0.06	0.12	0.10	0.21**	0.05	0.16*	0.11	0.15*
RFD_{max}S	-0.07	-0.06	-0.03	0.13	0.04	0.11	0.08	0.17*	0.09	0.22**	0.14*	0.21**
tF_{max}S	-0.08	0.13	-0.09	0.02	0.15*	0.03	0.07	0.15*	-0.03	-0.05	-0.10	-0.05
$tRFD_{max}$S	-0.01	0.05	-0.06	-0.12	0.00	-0.01	-0.02	0.05	-0.21**	-0.18**	-0.14*	-0.22**
DIF	0.07	-0.05	0.04	0.03	0.01	0.07	0.00	-0.02	0.00	0.04	-0.01	-0.02
DIRFD	0.04	0.02	0.06	0.01	-0.06	0.00	-0.05	-0.09	0.10	0.03	0.06	0.03
EIND	-0.07	0.18**	-0.09	-0.08	-0.04	-0.02	-0.06	0.03	-0.08	-0.19**	-0.07	-0.17*
EID	-0.06	0.13	-0.14*	-0.07	0.08	0.04	0.03	0.16*	-0.16*	-0.15*	-0.15*	-0.19**
EIS	-0.08	0.19**	-0.15*	-0.09	0.04	0.02	0.01	0.12	-0.16*	-0.20**	-0.15*	-0.23**

Note: *p<0.05, **p<0.01, ***p<0.001

Numerous although statistically significant ($p<0.05$) correlations with very weak effect ($\rho<0.2$) were obtained. Also weak negative correlation of Mch with $tRFD_{max}$D and $tRFD_{max}$S; Psc with EIS; DT with $tRFD_{max}$D, $tRFD_{max}$S and EIS; as well as weak positive correlation of MT with F_{max}ND and F_{max}D; Psc with RFD_{max}ND, RFD_{max}D and RFD_{max}S; and DT with RFD_{max}S; were obtained when it comes to absolute values of mechanical characteristics of handgrip.

Something similar happened when it comes to the correlation analysis of allometricly partialized values of mechanical characteristics of the handgrip with psychological characteristics. Also numerous although statistically significant ($p<0.05$) correlations with very weak effect ($\rho<0.2$) were obtained. In addition, weak negative correlation of Psc with $EIND_{rel}$ and EIS_{rel}; and DT with EIS_{rel}; as well as weak positive correlation of MT with F_{rel}ND, and F_{rel}D; Psc with RFD_{rel}ND, RFD_{rel}D, and RFD_{rel}S; and DT with RFD_{rel}ND, RFD_{rel}D, and RFD_{rel}S; were obtained.

Table 8. Correlation analysis of allometricly partialized values of mechanical characteristics of the handgrip with psychological characteristics

	Agr	Ext	Nrt	NV	Opn	PV	Cns	MT	Mch	Psc	Nrc	DT
$F_{rel}ND$	-0.14^{*}	0.01	-0.08	0.08	0.08	0.07	0.07	0.20^{**}	0.03	0.12	0.11	0.14^{*}
$RFD_{rel}ND$	-0.08	-0.08	0.00	0.13	0.09	0.07	0.07	0.16^{*}	0.08	0.20^{**}	0.14^{*}	0.21^{**}
$F_{rel}D$	-0.13	0.01	-0.06	0.11	0.10	0.10	0.08	0.22^{**}	0.04	0.16^{*}	0.11	0.15^{*}
$RFD_{rel}D$	-0.08	-0.06	0.02	0.13	0.05	0.07	0.06	0.12	0.11	0.21^{**}	0.16^{*}	0.22^{**}
$F_{rel}S$	-0.14	0.00	-0.07	0.10	0.09	0.09	0.08	0.21^{**}	0.03	0.14^{*}	0.11	0.14^{*}
$RFD_{rel}S$	-0.08	-0.08	0.00	0.13	0.07	0.07	0.07	0.15^{*}	0.10	0.22^{**}	0.16^{*}	0.22^{**}
DIF_{rel}	0.06	-0.05	0.04	0.03	0.01	0.07	0.01	-0.02	0.00	0.03	-0.01	-0.02
$DIRFD_{rel}$	0.03	0.02	0.06	0.01	-0.06	0.00	-0.05	-0.09	0.09	0.02	0.05	0.03
$EIND_{rel}$	-0.08	0.18^{**}	-0.09	-0.08	-0.04	-0.02	-0.06	0.03	-0.09	-0.20^{**}	-0.08	-0.18^{*}
EID_{rel}	-0.06	0.13	-0.14^{*}	-0.07	0.08	0.04	0.03	0.16^{*}	-0.16^{*}	-0.15^{*}	-0.15^{*}	-0.19^{**}
EIS_{rel}	-0.08	0.19^{**}	-0.15^{*}	-0.10	0.04	0.02	0.01	0.12	-0.16^{*}	-0.20^{**}	-0.15^{*}	-0.23^{**}

Note: *p<0.05, **p<0.01, ***p<0.001

6.2 General Adult Population Subsample

Descriptive statistical analysis of psychological characteristics for the general adult population subsample (n=25) is presented in Table 9. The nonparametric Kolmogorov–Smirnov test didn't showed significant deviations from the normal distribution for any variable.

Table 9. Descriptive statistical analysis of psychological characteristics

	Agr	Ext	Nrt	NV	Opn	PV	Cns	MT	Mch	Psc	Nrc	DT
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	0.7	0.61	0.63	0.76	0.88	1.51	0.72
Min	1.6	3.1	1	1	3.4	2.2	2.5	4.13	1	1	1	1
Max	3.9	4.6	3.2	2.2	5	4.8	5	6.88	3.33	3.75	6	3.42

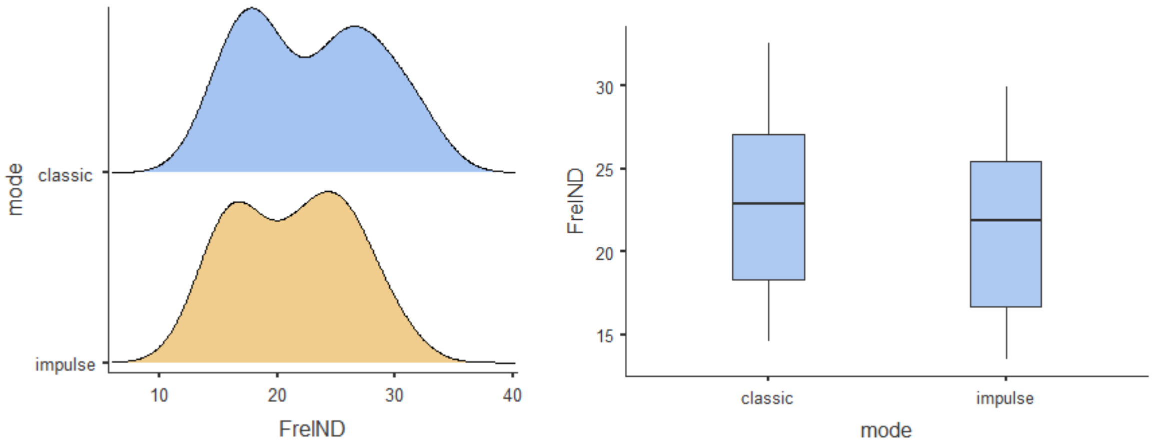
Results of descriptive statistical analysis of mechanical characteristics of the handgrip expressed in classic and impulse mode of isometric contraction for the general adult population subsample are presented in Table 10. The nonparametric Kolmogorov–Smirnov test didn't showed significant deviations 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 ($tRFD_{max}ND$=0.19) but didn't significantly skew the distribution.

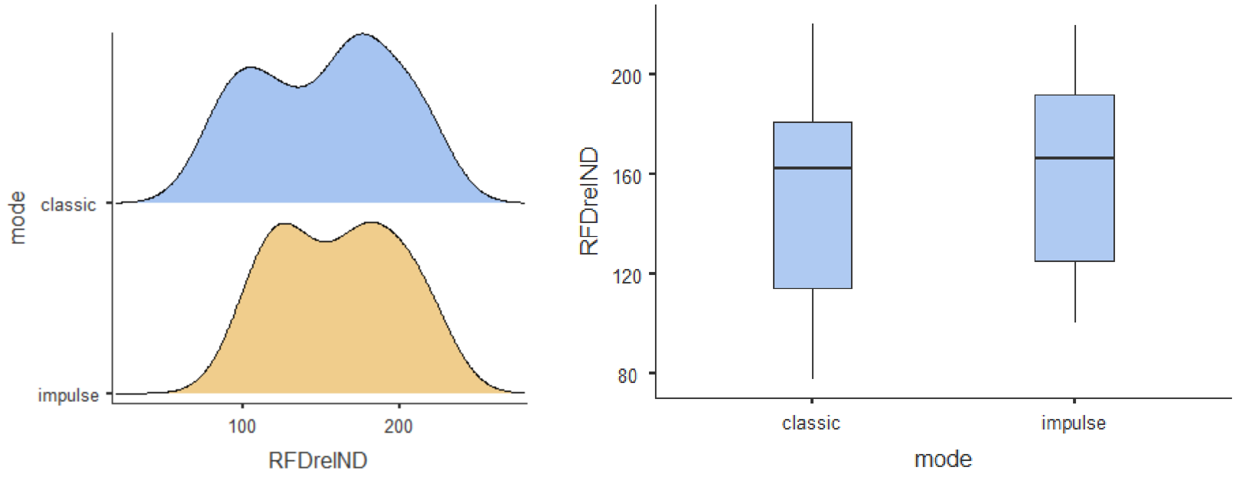
Table 10. Descriptive statistical analysis of mechanical characteristics of the handgrip expressed in classic and impulse mode of isometric contraction

	$F_{rel}ND$	$RFD_{rel}ND$	$tF_{max}ND$	$tRFD_{max}ND$	$F_{rel}D$	RFD_{rel}	$tF_{max}D$	$tRFD_{max}D$	NRID
M	22.86	152.02	0.85	0.12	24.71	163.09	0.77	0.12	0.95
SD	5.62	44.81	0.4	0.02	6.29	48.07	0.27	0.02	0.08
Min	14.6	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	1.1
	$IF_{rel}ND$	$IRFD_{rel}ND$	$ItF_{max}ND$	$ItRFD_{max}ND$	$IF_{rel}D$	$IRFD_{rel}D$	$ItF_{max}D$	$ItRFD_{max}D$	NRIND
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	43.88	0.08	0.01	0.1
Min	13.5	100.11	0.2	0.09	11.45	94.89	0.15	0.1	0.71
Max	29.91	219.68	0.41	0.13	31.54	241.57	0.43	0.14	1.14

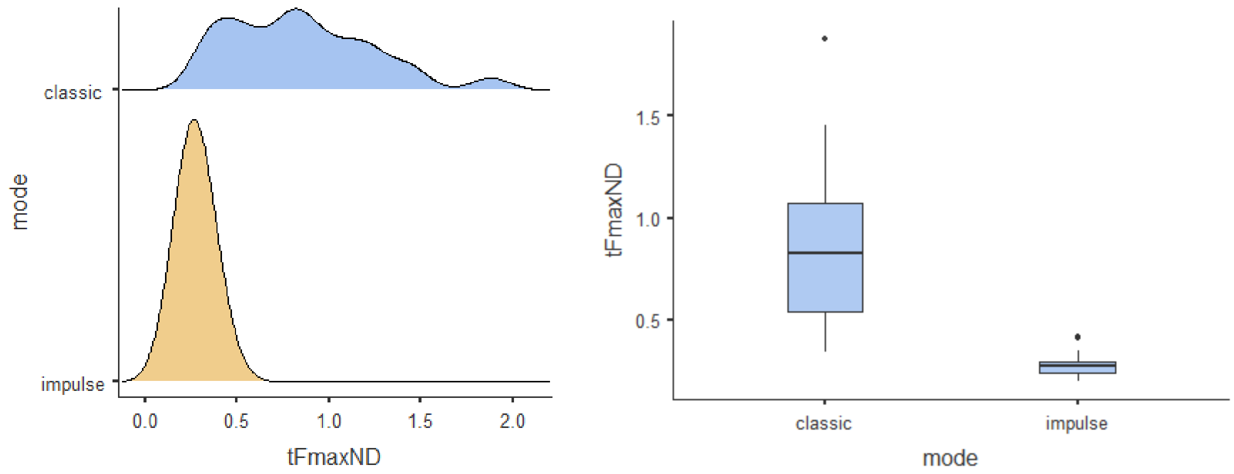
Analysis of variance revealed significant differences with large effect size between classic and impulse mode of isometric contraction for $F_{rel}ND$ ($F=22.3$, $p<0.001$, $\eta_p^2=0.48$), $RFD_{rel}ND$ ($F=10.1$, $p<0.01$, $\eta_p^2=0.30$), $tF_{max}ND$ ($F=52.8$, $p<0.001$, $\eta_p^2=0.69$), $F_{rel}D$ ($F=20.6$, $p<0.001$, $\eta_p^2=0.46$), $RFD_{rel}ND$ ($F=10.3$, $p<0.01$, $\eta_p^2=0.30$), $tF_{max}ND$ ($F=74.5$, $p<0.001$, $\eta_p^2=0.76$) which are illustrated in the Graphs 29, 30, 31, 32, 33, and 34.



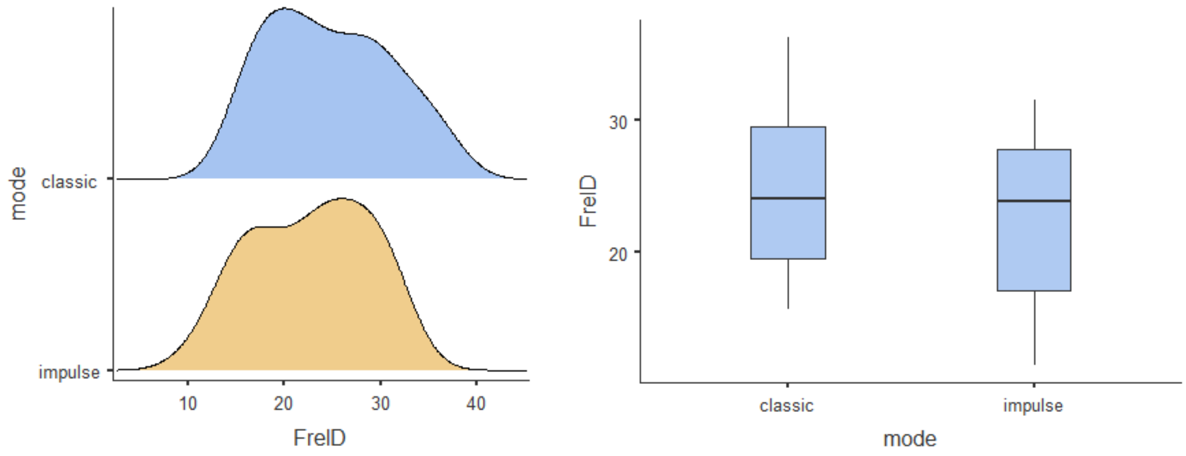
Graph 29. Density histogram and box plot of differences in maximal force normalized for body weight of the non-dominant hand according to mode of isometric contraction



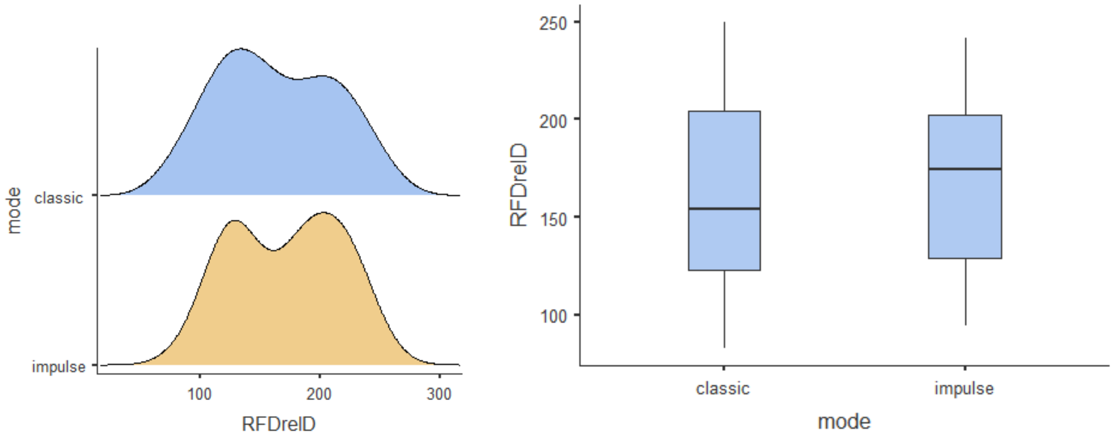
Graph 30. Density histogram and box plot of differences in maximal rate of force development normalized for body weight of the non-dominant hand according to mode of isometric contraction



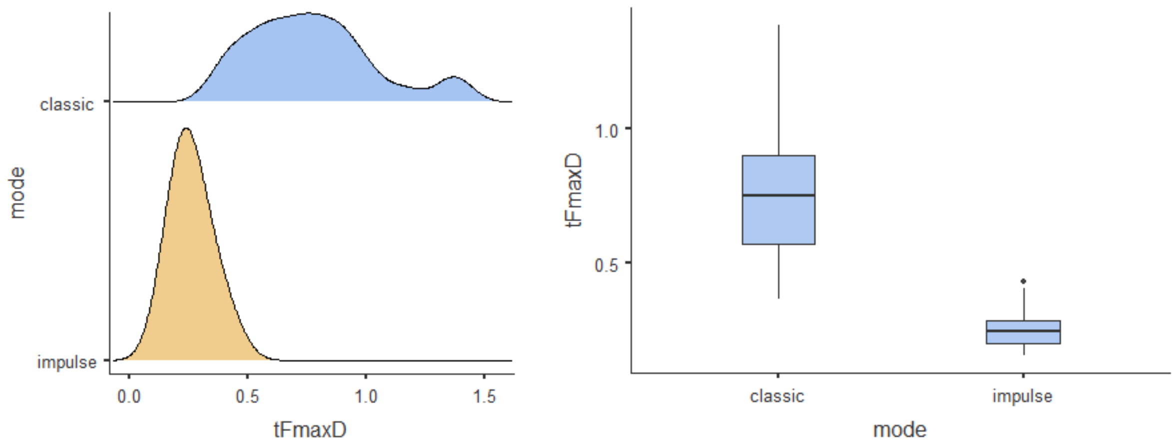
Graph 31. Density histogram and box plot of differences in time required to reach the maximal force of the non-dominant hand according to mode of isometric contraction



Graph 32. Density histogram and box plot of differences in maximal force normalized for body weight of the dominant hand according to mode of isometric contraction



Graph 33. Density histogram and box plot of differences in maximal rate of force development normalized for body weight of the dominant hand according to mode of isometric contraction



Graph 34. Density histogram and box plot of differences in time required to reach the maximal force of the dominant hand according to mode of isometric contraction

Results of the parametric Pearson correlation analyses of mechanical characteristics of handgrip with psychological characteristics for classical mode of isometric contraction is presented in table 11; while for impulse of isometric contraction is presented in table 12.

Table 11. Correlation analysis of mechanical characteristics of the handgrip with psychological characteristics for classical mode of isometric contraction

	Agr	Ext	Nrt	NV	Opn	PV	Cns	MT	Mch	Psc	Nrc	DT
F_{rel}ND	-0.42*	-0.36	0.11	0.47*	-0.01	-0.29	-0.03	0.20	0.33	0.45*	0.26	0.39
RFD_{rel}ND	-0.48*	-0.40*	0.12	0.43*	-0.01	-0.26	0.05	0.22	0.23	0.44*	0.21	0.32
tF_{max}ND	-0.10	0.13	-0.33	-0.10	0.20	0.04	0.14	0.19	-0.14	-0.16	-0.28	-0.25
$tRFD_{max}$ND	0.19	0.20	-0.22	-0.19	-0.16	-0.01	-0.13	0.12	0.03	-0.15	-0.14	-0.10
F_{rel}D	-0.36	-0.42*	0.14	0.50*	-0.05	-0.23	0.01	0.15	0.15	0.49*	0.14	0.31
RFD_{rel}D	-0.36	-0.35	0.12	0.41*	-0.06	-0.24	0.05	0.12	0.12	0.54**	0.19	0.32
tF_{max}D	-0.09	-0.13	0.07	0.08	0.20	-0.13	-0.01	-0.24	-0.08	-0.05	0.00	-0.04
$tRFD_{max}$D	0.14	0.36	-0.06	-0.18	0.10	0.23	-0.20	0.07	-0.14	-0.33	-0.07	-0.12

Note: *p<0.05, **p<0.01

The correlation analysis (Tables 11 and 12) revealed a weak positive association of NV with F_{rel}ND, RFD_{rel}ND, and RFD_{rel}D; Psc with F_{rel}ND, RFD_{rel}ND, FrelD, and IF_{rel}D and DT with IF_{rel}ND, and NRID; as well as weak negative association of Agr with F_{rel}ND RFD_{rel}ND, IFrelND, $IRFD_{rel}$ND, NRIND; Ext with RFD_{rel}ND, F_{rel}D, IF_{rel}ND, and IF_{rel}D. The correlation analysis also revealed strong positive association of NV with F_{rel}D, IF_{rel}ND, $IRFD_{rel}$ND; and Psc with RFD_{rel}D, IF_{rel}ND, $IRFD_{rel}$ND, and $IRFD_{rel}$D.

Table 12. Correlation analysis of mechanical characteristics of the handgrip with psychological characteristics for impulse mode of isometric contraction

	Agr	Ext	Nrt	NV	Opn	PV	Cns	MT	Mch	Psc	Nrc	DT
$IF_{rel}ND$	-0.42*	-0.42*	0.18	0.53**	-0.02	-0.26	-0.07	0.19	0.25	0.52**	0.26	0.40*
$IRFD_{rel}ND$	-0.41*	-0.38	0.18	0.50*	-0.01	-0.20	0.00	0.20	0.26	0.50*	0.26	0.39
$ItF_{max}ND$	0.20	0.25	0.18	0.20	0.10	0.13	-0.09	0.09	0.07	-0.08	-0.03	-0.01
$ItRFD_{max}ND$	0.10	0.36	-0.15	-0.24	0.05	0.13	0.01	-0.12	-0.22	-0.19	-0.09	-0.17
$IF_{rel}D$	-0.36	-0.41*	0.14	0.39	-0.09	-0.29	0.02	0.18	0.14	0.47*	0.12	0.25
$IRFD_{rel}D$	-0.40*	-0.36	0.12	0.39	-0.15	-0.28	0.03	0.15	0.10	0.50*	0.10	0.25
$ItF_{max}D$	-0.12	-0.06	0.15	0.07	0.10	-0.06	0.01	0.22	-0.09	-0.01	-0.07	-0.10
$ItRFD_{max}D$	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: *p<0.05, **p<0.01

Table 13. The starting models of multiple linear regression analysis of mechanical characteristics of the handgrip as predictors of psychological characteristics

	R^2	Adjusted R^2	F
Agr	0.95	0.80	6.28*
Ext	0.74	-0.34	0.57
Nrt	0.82	0.29	1.54
NV	0.76	0.20	1.03
Opn	0.62	-0.53	0.86
PV	0.62	-0.51	0.55
Cns	0.66	-0.35	0.65
MT	0.75	0.01	1.01
Mch	0.56	-0.78	0.42
Psc	0.56	-0.76	0.43
Nrc	0.78	0.14	1.21
DT	0.69	-0.24	0.74

Note: *p<0.05, **p<0.01, ***p<0.001

The multiple linear regression analysis (Table 13) 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 with more efficient models (Table 14, 15 and 16).

Table 14. The resulting models of multiple linear regression analysis of mechanical characteristics of the handgrip as predictors of psychological characteristics

	R^2	Adjusted R^2	F
Agr	0.94	0.90	23.10***
Ext	0.18	0.14	5.01*
Nrt	0.74	0.58	4.48*
NV	0.71	0.47	2.96*
Opn	0.46	0.19	1.71
PV	0.46	0.32	0.28
Cns	0.14	0.06	1.78
MT	0.46	0.35	4.24*
Mch	0.44	0.21	1.9
Psc	0.29	0.26	9.34*
Nrc	0.7	0.55	4.63*
DT	0.55	0.40	3.64*

Note: *p<0.05, **p<0.01, ***p<0.001

Resulting models of regression analyses had significant predictors both for Big Five (Table 15) psychological characteristics.

Table 15. Standardized coefficients for the resulting models of multiple linear regression analysis of mechanical characteristics of the handgrip as predictors of Big Five psychological characteristics

	Agr	Eks	Nrt	NV	Opn	PV	Cns
$F_{rel}ND$	1.4***	-	-	-	-0.9	-1.5**	-
$RFD_{rel}ND$	-4.1***	-	-2.3**	-	5.8	-	-
$tF_{max}ND$	-0.3**	-	-5 0.8***	-0.4*	0.3	-	-
$tRFD_{max}ND$	-	-	-0.4	0.3	-	-	1.1
$F_{rel}D$	-	-	-	3.0**	-	-	-
$RFD_{rel}D$	0.7**	-	-	-7.2*	-1.1*	1.3	-
$tF_{max}D$	0.3*	-	0.9**	0.6	-	-	-
$tRFD_{max}D$	-0.6***	-	-	-	-	-	-
$IF_{rel}ND$	-	-0.4*	2.1**	-	-	-	-1.1
IRFDRELND	0.7*	-	-	-	-3.1	1.7*	-
$ItF_{max}ND$	0.1	-	0.4*	0.4*	-	-	-
$ItRFD_{max}ND$	-1.4***	-	-0.7*	-	-	-	-
$IF_{rel}D$	_	-	-	-2.4*	-	-1.4*	-
$IRFD_{rel}D$	_	-	-	4.5*	-	-	-
$ItF_{max}D$	_	-	-	0.5	0.3	-	-
$ItRFD_{max}D$	0.8***	-	0.5**	-0.3	-	0.8**	-
NRIND	_	-	-	-	-1.9	-	-
NRID	_	-	-0.3	1.1*	0.9**	-	-

Note: *p<0.05, **p<0.01, ***p<0.001

Similar, resulting models of regression analyses had significant predictors both for MT as well as DT (Table 16) psychological characteristics.

Table 16. Standardized coefficients for the resulting models of multiple linear regression analysis of mechanical characteristics of the handgrip as predictors of MT and DT psychological characteristics

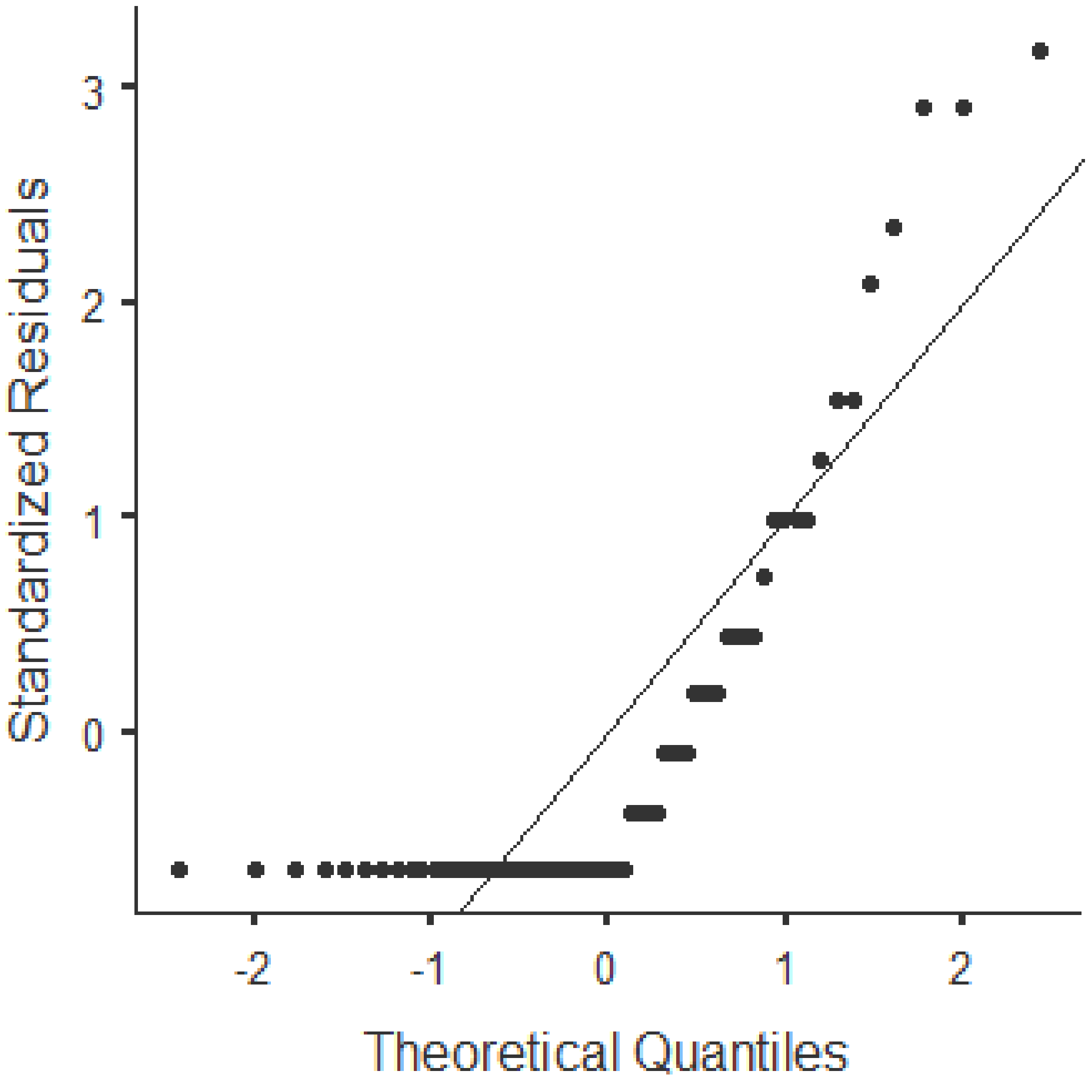
	MT	Mch	Psc	Nrc	DT
$F_{rel}ND$	-	0.7	-	-	-
$RFD_{rel}ND$	-	-	-	-1.5*	-1.3
$tF_{max}ND$	0.4*	-	-	-	-
$tRFD_{max}ND$	0.5*	0.6	-	-	-
$F_{rel}D$	-	-	-	-2.7**	-1.4*
$RFD_{rel}D$	-	-4.6	0.53**	8.1**	2.8**
$tF_{max}D$	-0.6**	-	-	-	-
$tRFD_{max}D$	-	-	-	-	-
$IF_{rel}ND$	-	-	-	-	-
IRFDRELND	-	-	-	3.5***	2.5**
$ItF_{max}ND$	-	0.2	-	-0.3	-
$ItRFD_{max}ND$	-	-0.5	-	-	-
$IF_{rel}D$	-	-	-	-	-
$IRFD_{rel}D$	-	3.5	-	-6.2*	-1.9*
$ItF_{max}D$	-	-	-	-	-
$ItRFD_{max}D$	-	-	-	0.7**	0.5*
NRIND	0.7**	-	-	-	
NRID	-	1.4	-	-1.2	-

Note: *p<0.05, **p<0.01, ***p<0.001

Cross-validation on 75% of randomly selected respondents revealed the following models Agr (R2=0.96), Ext (R2=0.41), Nrt (R2=0.79), NV (R2=0.76), MT (R2=0.45), Psc (R2=0.37), Nrc (R2=0.78), DT (R2=0.70), where Agr, Ext, Nrt, Psc, Nrc, and DT models were significant (p<0.05).

6.3 Police Students Subsample

Descriptive statistical analysis of mechanical characteristics of handgrip as well as MT and DT psychological characteristics for the police students subsample is presented in in Table 17. The Kolmogorov–Smirnov test showed that there were no significant deviations from the normal distribution of any of the variables except Mch. Analyses of Histogram and QQ plot of Mch (Graph 35) lead to similar conclusion.



Graph 35. Q-Q plot of Machiavellianism for the police students subsample

More than 50% of subjects have a minimal score of 1 on Mch. After applying statistical methods for scores distribution normalization, normality of Mch was not improved. That is why it was not included in further analyses.

Table 17. Descriptive statistical analysis of mechanical characteristics of the handgrip with MT and DT psychological characteristics

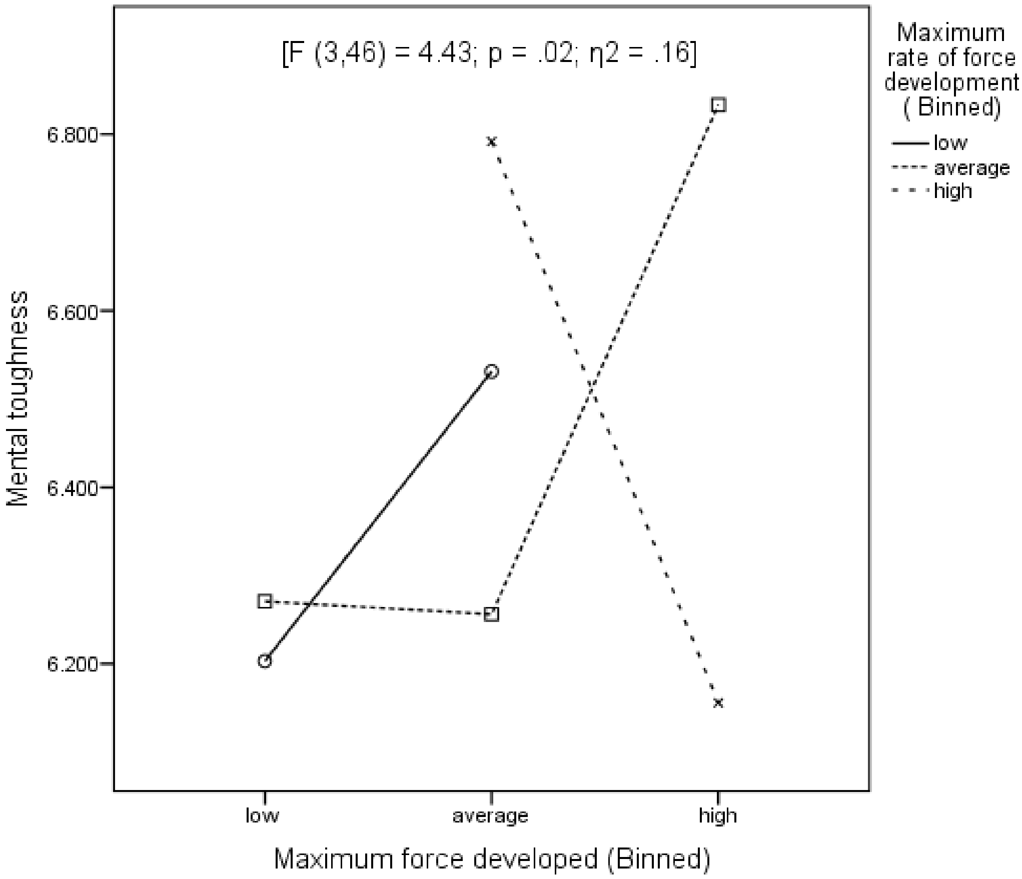
Variables	M	SD	CV	Min	Max	Skewness	Kurtosis
$F_{rel}S$	47.2	10.49	0.22	31.37	73.02	0.53	-0.51
$RFD_{rel}S$	302.36	80.19	0.27	163.45	520.02	0.55	-0.21
$F_{imp}50\%S_{rel}$	1766.,	488.56	0.28	697.06	2937.72	-0.02	-0.25
MT	6.27	0.49	0.08	5.13	7	-0.24	-0.97
Mch	1.59	0.91	0.57	1	4.5	1.73	2.32
Psc	2.03	1	0.49	1	4.75	0.76	-0.2
Nrc	3.16	1.45	0.46	1	6.25	0.32	-0.65
DT	2.26	0.89	0.39	1	4.5	0.81	0.02

Results of the parametric Pearson correlation analysis revealed a weak positive association of FrelS with Psc and moderate positive association of $RFD_{rel}S$ with Psc and DT (Table 18). The Fimp50%S_{rel} was not significantly associated with investigated behaviour al determinants.

Table 18. Correlation analysis of mechanical characteristics of the handgrip with MT and DT psychological characteristics

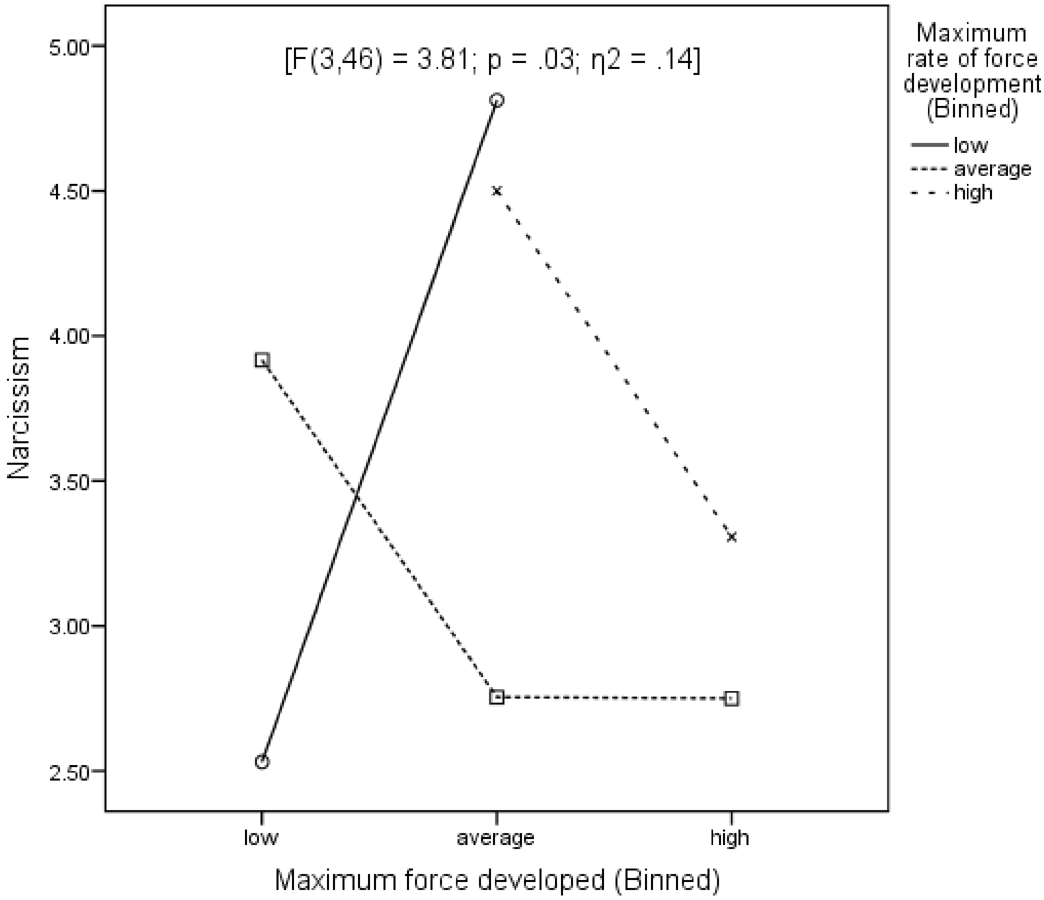
	MT	Psc	Nrc	DT
$F_{rel}S$	0.09	0.26*	0.09	0.16
$RFD_{rel}S$	0.02	0.38**	0.2	0.30*
$F_{imp}50\%S_{rel}$	-0.21	0.03	-0.04	0.03

For the purpose of performing MANOVA, participants were allocated to three equal groups using the 33rd ($F_{rel}S$ = 40.97, $RFD_{rel}S$ = 258.21, $F_{imp}50\%S_{rel}$ = 1605.62) and 66th ($F_{rel}S$ = 52.25, $RFD_{rel}S$ = 333.77, $F_{imp}50\%S_{rel}$ = 1970.89) percentiles as cut-off points. Accordingly, participants were allocated to High, Average, and Low FrelS; High, Average, and Low $RFD_{rel}S$; and High, Average, and Low $F_{imp}50\%S_{rel}$ groups. This allowed investigation the interactions of mechanical characteristics of handgrip on psychological characteristics. The MANOVA for neuromuscular characteristics factors revealed significant ($p < 0.05$) differences with large effect sizes in Psc [F (2,46) = 3.86; p = 0.03 $\eta 2$ = .14] on factor $RFD_{rel}S$. The Bonferroni post-hoc test revealed significant differences in Psc between high and low $RFD_{rel}S$ group (MD = .84; p = .01) as well as high and average $RFD_{rel}S$ group (MD = 0.81; p = 0.01). The MANOVA also revealed following significant ($p < 0.05$) interactions of FrelS and $RFD_{rel}S$ with MT (Graph 36) and Nrc (Graph 37) as well as interactions of $F_{rel}S$ and $F_{imp}50\%S_{rel}$ with Psc (Graph 38), whereby the effect of $F_{rel}S$ on MT and Nrc depended on the level of $RFD_{rel}S$ and $F_{imp}50\%S_{rel}$, respectively.



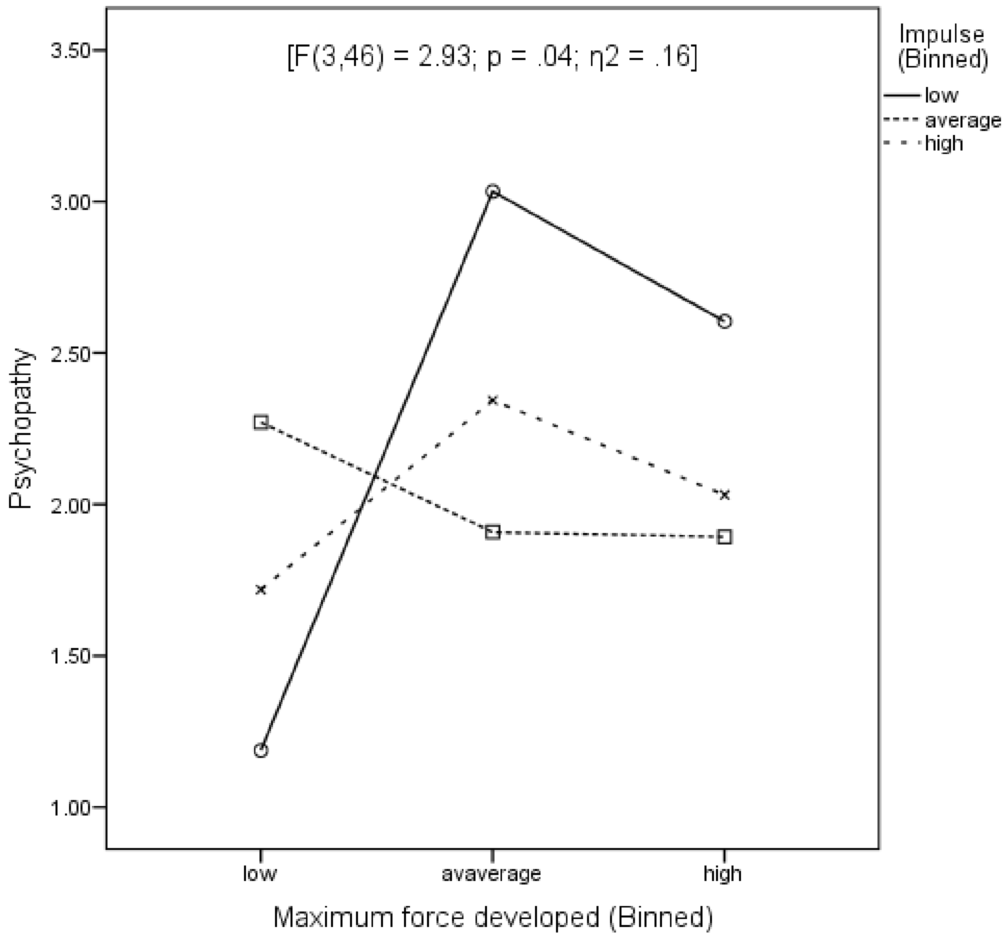
Graph 36. Interactions of FrelS, $RFD_{rel}S$ on MT

Considering the interactions of mechanical characteristics with MT (Graph 36), in the low RFD_{rel} group, those with average F_{rel} had also had higher MT. In the average RFD_{rel} group, those with low and average F_{rel} showed similar MT, while those with high F_{rel} showed the highest MT. In contrast, lower MT occurred in group that had high RFD_{rel} and high F_{rel}.



Graph 37. Interactions of $F_{rel}S$, RFDrelS on Nrc

Considering the interactions of mechanical characteristics and Nrc (Graph 37), the Nrc was higher among those with average than in those with low F_{rel}, in low RFD_{rel} group. In average RFD_{rel} group, the highest Nrc could be observed in low F_{rel} group, while it remained the same among those with average and high F_{rel}. Among those with high RFD_{rel}, the Nrc was high in group who had average F_{rel} compared to group who had high F_{rel}.



Graph 38. Interactions of F_{rel}S and Fimp50%S_{rel} on Psc

Considering the interaction of F_{rel} and $F_{imp}50\%_{rel}$ with Psc (Graph 38), participants with low $F_{imp}50\%_{rel}$ showed the lowest Psc if their Fmax was low and the highest Psc if their F_{rel} was average. Among groups with average $F_{imp}50\%_{rel}$, those with low F_{rel} showed somewhat higher Psc compared to those with average and high F_{rel}. Among those with high $F_{imp}50\%_{rel}$, the lowest Psc was shown in group with low F_{rel}, the highest Psc was in average F_{rel} group, while those with high F_{rel} showed somewhat lower Psc. Note that, the Psc was relatively low for average and high $F_{Imp}50\%_{rel}$ groups, regardless of their F_{rel}.

6.4 Security Population Subsample

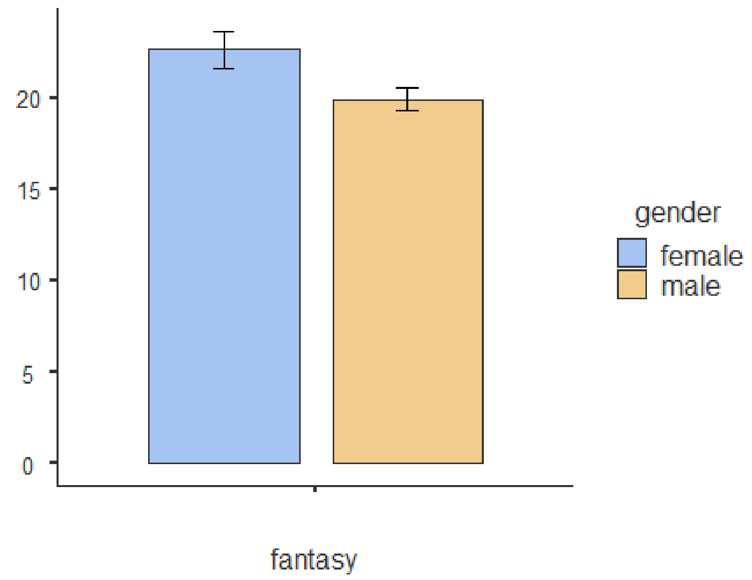
Descriptive statistical analysis of psychological, morphological and mechanical characteristics for male and female groups of security population subsample is presented in Table 19. The Kolmogorov–Smirnov test showed that there was significant deviations from the normal distribution for Nrt, NV, Mch in females as well as Nrt, NV, Cns, PD, MT, Mch, DT, $tRFD_{max}S$ in males. According to CV both subsamples shoved high variability on the Fnt, PD, Agr, Nrt, NV, Mch, Psc, Nrc, DT and tFmaxS.

Table 19. Descriptive statistical analysis for male and female group of security subsample

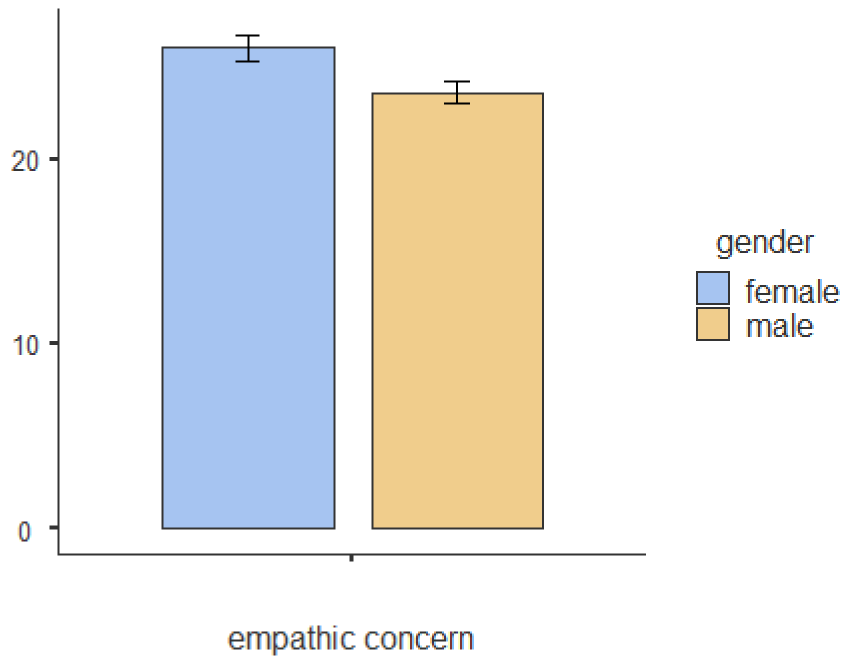
	Female (n=54)						Male (n=82)					
	M	SD	CV	Min	Max	KS Z	M	SD	CV	Min	Max	KS Z
Fnt*	3.23	1.05	0.33	1	5	0.62	2.84	0.84	0.3	1	5	1.04
PT	3.89	0.66	0.17	2	5	0.62	3.8	0.66	0.17	2	5	0.83
EC**	3.71	0.75	0.2	1.57	5	0.77	3.37	0.71	0.21	1.57	5	0.57
PD*	1.76	0.67	0.38	1	4.57	0.97	1.5	0.53	0.35	1	3.57	1.75**
Agr*	2.28	0.77	0.34	1	4.1	0.79	1.99	0.79	0.4	1	4.3	1.16
Ext	4.13	0.6	0.15	2.5	5	1.08	4.17	0.69	0.17	1.4	5	1.21
Nrt	1.59	0.74	0.47	1	4.3	1.56*	1.51	0.68	0.45	1	3.4	2.13***
NV	1.32	0.36	0.27	1	2.3	1.54*	1.48	0.62	0.42	1	3.7	1.97**
Opn	4.1	0.53	0.13	3	4.9	0.79	4.15	0.55	0.13	2.6	5	1.14
PV	3.69	0.74	0.2	1.8	5	0.77	3.64	0.74	0.2	1.6	5	0.81
Cns	4.39	0.61	0.14	2.4	5	1.15	4.35	0.73	0.17	2.4	5	1.78**
MT*	6.21	0.6	0.1	3.75	7	0.69	6.46	0.49	0.08	5.38	7.13	1.68**
Mch	1.75	0.99	0.57	1	4.75	1.64*	2.18	1.31	0.6	1	6.17	1.67**
Psc*	1.86	0.96	0.52	1	4.5	1.37	2.4	1.32	0.55	1	7	1.29
Nrc	3.07	1.41	0.46	1	6	0.85	3.18	1.55	0.49	1	6.25	0.87
DT	2.21	0.85	0.38	1	4.33	1	2.55	1.17	0.46	1	6.17	1.38*
BH***	1.71	0.06	0.04	1.62	1.85	0.68	1.81	0.06	0.03	1.65	1.94	0.77
BW***	65.05	8.68	0.13	51	104	0.97	78.91	10.46	0.13	54.6	136.7	0.88
BMI***	22.3	2.89	0.13	18.96	36.85	1.22	24	2.41	0.1	18.89	37.08	1.13
$F_{max}S$***	605.31	81.9	0.14	456	791	0.92	993.83	180.65	0.18	602	1427	0.49
$RFD_{max}S$***	3811	653.26	0.17	2390	5674	0.32	6519.94	1159.18	0.18	3870	9507	0.57
$tF_{max}S$	1.88	0.67	0.36	0.75	4.75	0.68	1.98	0.9	0.45	0.62	5.66	1.08
$tRFD_{max}S$***	0.25	0.04	0.16	0.19	0.43	1.28	0.24	0.04	0.17	0.2	0.46	2.16***

Note: *p<0.05, **p<0.01, ***p<0.001

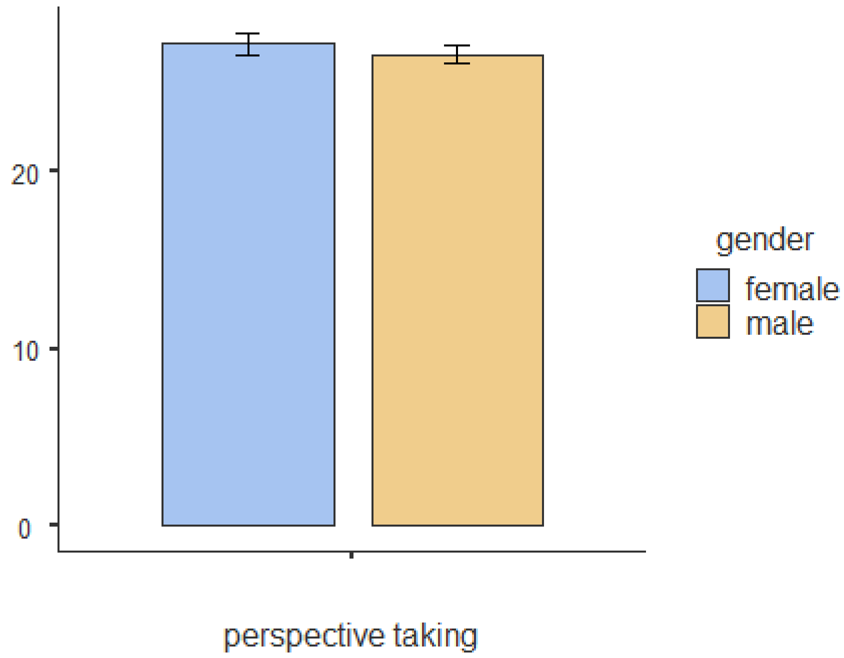
The non-parametric Mann-Whitney U test reveals significant differences between the female and male subsample with medium effect size in Fnt (U=1756.50, Z=-2.03, p<0.05, r=0.27), EC (U=1692.50, Z=-2.60, p<0.01, r=0.35), PD (U=1649.50, Z=-2.53, p<0.05, r=0.22), which are illustrated in the graphs 39, 40 and 41, Agr (U=1705.50, Z=-2.26, p<0.05, r=0.30), MT (U=1655.50, Z=-2.50, p<0.05, r=0.33), Psc (U=1649.50, Z=-2.54 p<0.05, r=0.33), BMI (U=1080.00, Z=-5.04, p<0.001, r=-.71) and $tRFD_{max}S$ (U=1388.00, Z=-3.67, p<0.001, r=0.51), as well as with large effect size in BH (U=514.00, Z=-7.57, p<0.001, r=1.03), BW (U=504.50, Z=-7.60, p<0.001, r=1.03), $F_{max}S$ (U=93.50, Z=-9.43, p<0.001, r=1.30), $RFD_{max}S$ (U=72.00, Z=-9.53, p<0.001, r=1.29). Significant differences with medium effect size was revealed between the police and security students in Mch (U=918.50, Z=-5.82, p<0.001, r=0.64), BW (U=1689.50, Z=-2.21, p<0.05, r=0.24), and $tRFD_{max}S$ (U=1080.50, Z=-4.94, p<0.001, r=0.54), illustrated in Graphs 39, 40, and 41.



Graph 39. Differences in fantasy according to gender



Graph 40. Differences in empathic concern according to gender



Graph 41. Differences in perspective taking according to gender

Table 20. Correlation analysis of IRI subscales with morphological and mechanical characteristics for male and female group of security subsample

	Female (n=54)				Male (n=82)			
	Fnt	PT	EC	PD	Fnt	PT	EC	PD
BH	-0.05	-0.04	-0.15	-0.08	-0.01	-0.11	0.00	-0.17
BW	-0.20	-0.08	-0.36**	-0.06	-0.11	-0.25*	-0.11	-0.12
BMI	-0.24	-0.06	-0.35*	-0.03	-0.18	-0.19	-0.13	-0.07
$F_{max}S$	-0.25	-0.13	-0.34*	-0.09	0.05	-0.10	-0.14	-0.05
$RFD_{max}S$	-0.28*	-0.31*	-0.45**	-0.03	0.09	-0.13	-0.11	-0.05
$tF_{max}S$	-0.08	0.08	0.04	-0.08	0.02	0.07	0.03	-0.22
$tRFD_{max}S$	0.20	0.34*	0.18	-0.09	-0.02	0.10	-0.08	-0.03

Note: *p<0.05, **p<0.01

Results of the non-parametric Spearman's rank correlation (Tables 20 and 21) revealed a weak positive association of PT with Ext, Opn, MT, and $tRFD_{max}S$; and EC with Opn among females, as well as Fnt with Agr, Nrt, and NV; PT with Ext, Opn, Cns, and MT; EC with Ext; and PD with NV, Mch, Nrc and DT; among males. Weak negative association of Fnt with $RFD_{max}S$; PT with Agr, and $RFD_{max}S$; EC with Psc, DT, BW, BMI, $F_{max}S$ and $RFD_{max}S$; and PD with Ext, Opn, PV; among females, as well as Fnt with Cns; PT with NV, Psc, DT, and BW; EC with Mch, Psc, and DT; and PD with Opn, PV, Cns, and MT; among males were also revealed. In the end, strong positive correlations were revealed in PD with Nrt among females and males, as well as strong negative correlations in PD with Cns, and MT among females, and PD with MT among males.

Table 21. Correlation analysis of IRI subscales with psychological characteristics for male and female group of security subsample

	Female (n=54)				Male (n=82)			
	Fnt	PT	EC	PD	Fnt	PT	EC	PD
Agr	0.03	-0.37**	-0.25	0.04	0.33**	-0.21	-0.14	0.12
Ext	0.17	0.31*	0.26	-0.33*	-0.04	0.29**	0.29**	-0.12
Nrt	0.25	-0.26	0.06	0.62**	0.38**	-0.10	0.08	0.50**
NV	0.12	-0.17	-0.23	0.26	0.30**	-0.22*	-0.18	0.33**
Opn	0.41**	0.40**	0.34*	-0.37**	0.19	0.31**	0.11	-0.32**
PV	0.16	0.19	-0.03	-0.43**	0.21	0.08	0.01	-0.23*
Cns	-0.22	0.29*	0.01	-0.66**	-0.24*	0.24*	0.11	-0.46**
MT	-0.06	0.42**	0.02	-0.59**	0.01	0.25*	0.02	-0.55**
Mch	-0.02	-0.11	-0.25	0.20	0.11	-0.17	-0.32**	0.25*
Psc	-0.07	-0.20	-0.36**	-0.06	-0.01	-0.37**	-0.32**	0.13
Nrc	-0.14	-0.08	-0.23	-0.07	0.19	-0.14	-0.10	0.29**
DT	-0.12	-0.13	-0.37*	-0.03	0.16	-0.24*	-0.26*	0.26*

Note: *p<0.05, **p<0.01

6.5 Athletic Subsample

Descriptive statistical analysis for the female group of athletic subsample is presented in Tables 22 and 23.

Table 22. Descriptive statistical analysis morphological and psychological characteristics for female group of athletic subsample

	Well-trained (n=47)						Elite (n=13)					
	M	SD	CV	Min	Max	KSZ	M	SD	CV	Min	Max	KSZ
Agr	2.24	0.75	33.71	1	4.1	0.78	2.58	0.77	29.75	1.6	3.8	0.43
Ext	4.1	0.62	15.2	2.5	5	0.95	3.92	0.54	13.65	2.9	4.5	0.85
Nrt	1.76	0.85	48.12	1	4.3	1.41*	1.49	0.59	39.31	1	2.9	0.83
NV	1.35	0.37	27.39	1	2.3	1.60*	1.33	0.36	27.16	1	2.1	1
Opn	4.17	0.53	12.71	3	4.9	0.75	4.02	0.58	14.32	2.7	5	0.67
PV	3.61	0.78	21.54	1.8	5	0.68	3.97	0.49	12.23	3.1	5	0.59
Cns	4.31	0.62	14.36	2.4	5	0.92	4.55	0.4	8.72	3.7	5	0.78
BH*	1.71	0.07	4.16	1.58	2	0.94	1.74	0.05	3.16	1.65	1.85	0.62
BW*	63.65	8.78	13.79	44	104	0.96	68.9	8.69	12.61	53	82	0.49
BMI	22.03	2.89	13.11	17.63	36.85	1.21	22.7	2.19	9.65	19.32	25.83	0.46

Note: *p<0.05, **p<0.01

Table 23. Descriptive statistical analysis of mechanical characteristics of handgrip for female group of athletic subsample

	Well-trained (n=47)						Elite (n=13)					
	M	SD	CV	Min	Max	KSZ	M	SD	CV	Min	Max	KSZ
F_{max}ND	291.74	44.92	15.4	188	387	0.57	313.92	60.52	19.28	220	460	0.74
RFD_{max}ND	1910.85	352.3	18.44	1283	2654	0.6	2073	429.24	20.71	1374	2938	0.61
tF_{max}ND	0.83	0.32	38.73	0.31	1.75	0.75	1.06	0.59	55.78	0.4	2.42	0.87
$tRFD_{max}$ND	0.12	0.01	12.04	0.09	0.16	0.85	0.11	0.01	10.83	0.1	0.14	0.59
F_{max}D**	312.51	44.12	14.12	231	427	0.52	359.69	61.03	16.97	274	503	0.51
RFD_{max}D*	1970.43	364.19	18.48	1203	3118	0.54	2298.46	526	22.88	1468	3483	0.68
tF_{max}D	0.99	0.37	37.49	0.25	1.79	0.57	1.05	0.51	48.38	0.4	2.33	0.55
$tRFD_{max}$D	0.13	0.03	24.06	0.09	0.28	1.68**	0.12	0.01	7.67	0.11	0.14	0.51
DIF*	1.08	0.13	11.85	0.86	1.43	1.02	1.15	0.08	6.86	1.03	1.31	0.59
DIRFD	1.04	0.16	15.02	0.65	1.5	0.35	1.11	0.08	7.62	1	1.24	0.9
EIND	0.15	0.02	12.99	0.12	0.2	0.47	0.15	0.02	10.11	0.13	0.17	0.59
EID	0.16	0.03	18.87	0.11	0.31	1.39*	0.16	0.01	9.44	0.14	0.19	0.49
EIS	0.32	0.04	13.9	0.24	0.5	0.63	0.31	0.03	8.89	0.26	0.35	0.54

Note: *p<0.05, **p<0.01

The nonparametric Kolmogorov–Smirnov test showed significant deviations from the normal distribution for the variables Nrt, NV, $tRFD_{max}D$ and EID in the well-trained athletes subsample. According to CV both subsamples shoved high variability on the Agr, Nrt, $tF_{max}ND$ and $tF_{max}D$.

Results of descriptive statistical analysis for the male sample are presented in Table 24 and 25.

Table 24. Descriptive statistical analysis morphological and psychological characteristics for male group of athletic subsample

	Well-trained (n=72)						Elite (n=23)					
	M	SD	CV	Min	Max	KSZ	M	SD	CV	Min	Max	KSZ
Agr*	2.02	0.72	35.8	1	4.1	1.16	2.46	0.9	36.51	1.1	4.3	1.28
Ext	4.05	0.7	17.37	1.4	5	0.85	4.22	0.44	10.47	3.3	5	0.64
Nrt	1.61	0.69	42.83	1	3.4	1.96***	1.77	0.81	45.71	1	3.3	0.9
NV	1.47	0.54	37.03	1	3.5	1.66**	1.73	0.74	42.72	1	3.7	1.1
Opn	4.02	0.55	13.79	2.6	5	0.84	4.26	0.53	12.49	2.9	5	0.95
PV	3.56	0.74	20.67	1.6	5	0.66	3.83	0.7	18.28	2.2	4.9	0.93
Cns	4.28	0.75	17.58	2.4	5	1.55*	4.18	0.66	15.77	2.9	5	0.93
BH	1.82	0.08	4.17	1.65	2	1.01	1.85	0.06	3.18	1.75	2	0.59
BW	78.49	7.83	9.98	60.4	97	0.39	82.55	8.74	10.59	68	101	0.49
BMI	23.96	1.85	7.72	19.99	28	0.55	24.34	2.25	9.26	19.86	27.16	0.75

Note: *p<0.05, **p<0.01, *** p<0.001

Table 25. Descriptive statistical analysis of mechanical characteristics of handgrip for male group of athletic subsample

	Well-trained (n=72)						Elite (n=23)					
	M	SD	CV	Min	Max	KSZ	M	SD	CV	Min	Max	KSZ
$F_{max}ND$	492.86	91.66	18.6	284	702	0.5	505.61	92.53	18.3	283	704	0.74
$RFD_{max}ND$	3285.22	628.76	19.14	1782	4734	0.62	3379.96	668.83	19.79	1767	4789	0.8
$tF_{max}ND$	0.92	0.46	49.66	0.27	2.13	1.24	0.83	0.49	59.1	0.24	2.39	0.71
$tRFD_{max}ND$	0.12	0.02	16.31	0.1	0.24	1.47*	0.12	0.02	14.92	0.09	0.18	1.16
$F_{max}D$	520.65	96.95	18.62	294	735	0.52	517.09	88.28	17.07	349	720	0.57
$RFD_{max}D$	3432.26	775.14	22.58	2011	5215	0.72	3395.65	632.78	18.64	1990	4990	0.44
$tF_{max}D$	0.99	0.61	61.49	0.22	3.59	1.34*	0.81	0.36	44.35	0.34	1.48	0.66
$tRFD_{max}D$	0.12	0.03	26.94	0.1	0.33	2.28***	0.11	0.01	11.75	0.09	0.15	0.7
DIF	1.07	0.11	10.56	0.83	1.42	0.68	1.03	0.11	10.99	0.75	1.29	0.56
DIRFD	1.06	0.16	14.88	0.73	1.49	0.39	1.02	0.16	15.35	0.83	1.56	1.04
EIND	0.15	0.02	10.54	0.12	0.21	0.92	0.15	0.03	18.11	0.12	0.25	0.99
EID	0.15	0.02	15.7	0.12	0.25	1.19	0.15	0.01	9.52	0.13	0.18	0.61
EIS	0.31	0.04	11.62	0.25	0.42	0.83	0.31	0.03	11.03	0.26	0.4	0.91

Note: *p<0.05, **p<0.01, *** p<0.001

The nonparametric Kolmogorov–Smirnov test showed significant deviations from the normal distribution for the variables Nrt, NV, $tRFD_{max}ND$, $tF_{max}D$, $tRFD_{max}D$ and EIND in the well-trained athletes subsample. Similarly to women, according to CV both the well-trained and elite male athletes shoved high variability on the Agr, Nrt, $tF_{max}ND$ and $tF_{max}D$.

Results of the non-parametric Spearman's rank correlation analyses are presented in tables 26 and 27.

Table 26. Correlation analysis of mechanical characteristics of handgrip and psychological characteristics for female group

	Well-trained (n=47)							Elite (n=13)						
	Agr	Ext	Nrt	NV	Opn	PV	Cns	Agr	Ext	Nrt	NV	Opn	PV	Cns
$F_{max}ND$	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*
$RFD_{max}ND$	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*
$tF_{max}ND$	-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
$tRFD_{max}ND$	-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
$F_{max}D$	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
$RFD_{max}D$	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*
$tF_{max}D$	-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
$tRFD_{max}D$	-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

The correlation analysis (Table 26) revealed a weak positive association of Ext with EIND and Cns with DIRFD as well as weak negative association of Ext with RFDMAXND; Nrt with EIS and NV with DIRF; among the well-trained female athletes. When it comes to the elite female athletes, positive strong correlation of PV with F_{max}ND, as well as positive moderate correlations of Agr with tF_{max}D; Ext with BMI and tF_{max}ND; Opn with F_{max}ND, RFD_{max}ND and F_{max}D; PV with F_{max}ND, RFD_{max}ND and F_{max}D; F_{max}ND and RFD_{max}ND, are also revealed.

Table 27. Correlation analysis of mechanical characteristics of handgrip and psychological characteristics for male group

	Well-trained (n=72)							Elite (n=22)						
	Agr	Ext	Nrt	NV	Opn	PV	Cns	Agr	Ext	Nrt	NV	Opn	PV	Cns
F_{max}ND	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
RFD_{max}ND	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*
tF_{max}ND	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
tRFD_{max}ND	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
F_{max}D	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
RFD_{max}D	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
tF_{max}D	-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
tRFD_{max}D	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

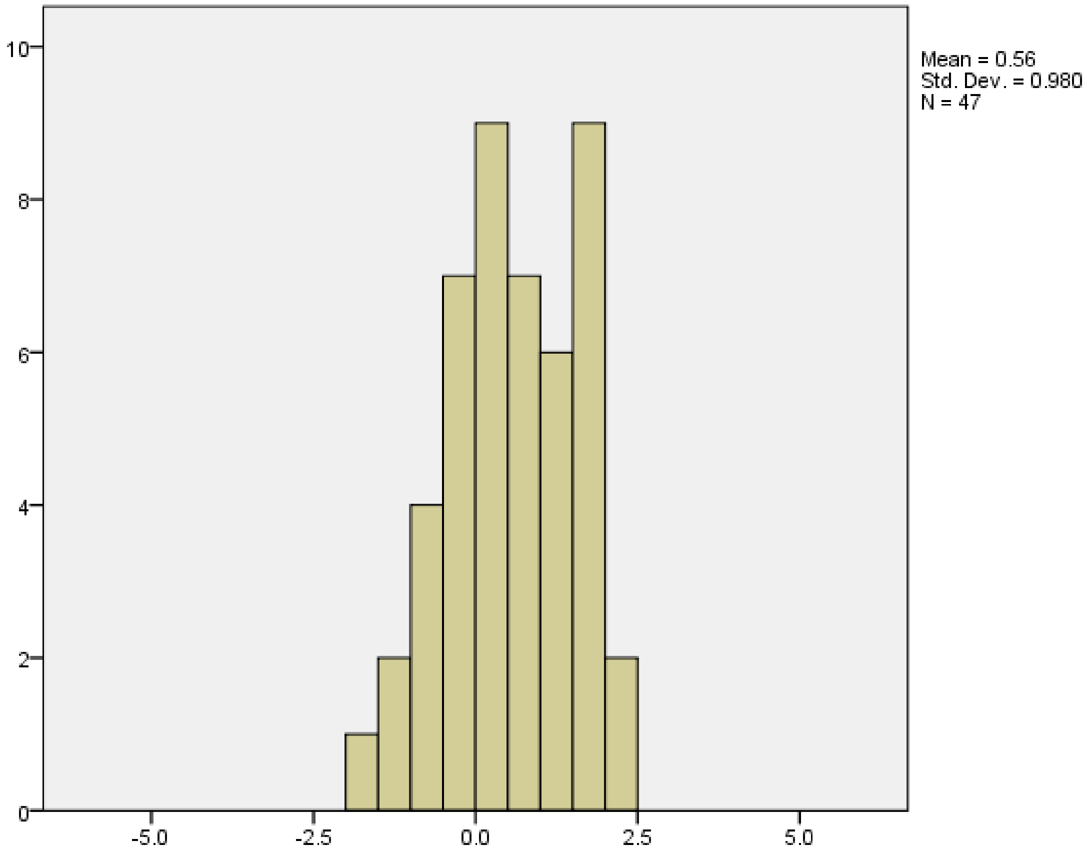
The results of correlation analysis (Table 27) revealed a weak positive association of Agr with F_{max}ND, RFD_{max}ND, F_{max}D and RFD_{max}D; as well as weak negative association of Agr with tF_{max}D; Ext F_{max}ND, RFD_{max}ND, F_{max}D and RFD_{max}D; among the well-trained male athletes. When it comes to the elite male athletes, positive moderate correlations of Nrt with RFD_{max}ND and F_{max}D; NV with RFD_{max}ND and Opn with tF_{max}D, as well as, negative moderate correlations of Ext with RFD_{max}ND; NV with $tRFD_{max}$ND; and Cns with RFD_{max}ND, are also revealed.

The non-parametric Mann-Whitney U test reveals 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), F_{max}D (U=160.5, z=-2.6, p=0.009), RFD_{max}D (U=178.5, z=-2.3, p=0.023) and DIF (U=169, z=-2.4, p=0.014). In male sample the non-parametric Mann-Whitney U test reveals significant differences between the well-trained and elite athletes only in Agr (U=562.0, z=-2.3, p=0.021). When it comes to gender differences, the non-parametric Mann-Whitney U test didn’t revile significant differences between the male and female well-trained, the male and female elite athletes when it comes to psychological characteristics.

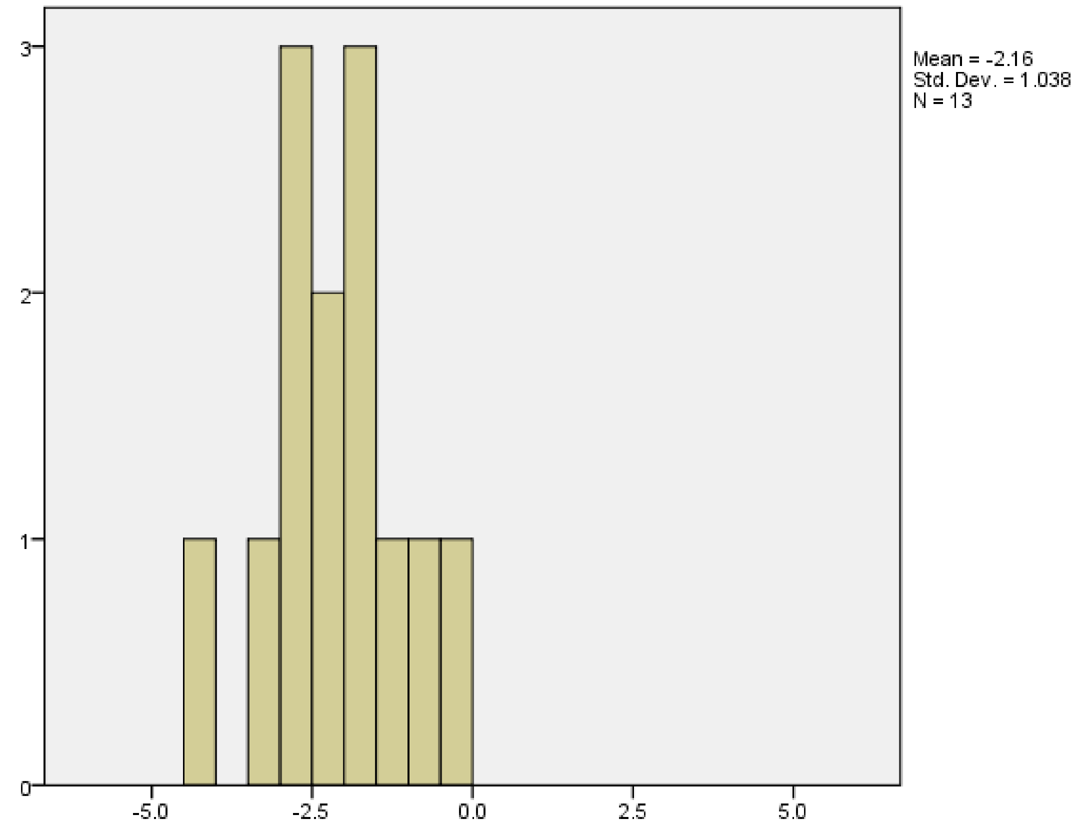
After applying statistical methods for scores distribution normalization, normality of Nrc and $tRFD_{max}$D in female as well as NV in male sample was not improved. That is why they were not included in further analyses. The results of the canonical discriminant analysis shows the existence of a statistically significant discriminant functions both in female (Wilks’s Λ=0.44, $\chi^2_{(22)}$=37.67, p=0.020) and male sample (Wilks’s Λ=0.59, $\chi^2_{(20)}$=41.18, p=0.004). Canonical correlations are 0.75 for female and 0.64 for male sample. The resulting models with 90% accuracy for female and 80% accuracy for male recognized participants as well-trained or elite athletes. Discriminant function for female sample has the largest relationship with F_{max}D, RFD_{max}D, BW and DIF, while discriminant function for male sample has the largest relationship with Agr, BW, NV, Opn and PV (Table 28, Graphs 42, 43, 44, and 45).

Table 28. The structure matrix of the discriminant functions for female and male group of athletic subsample

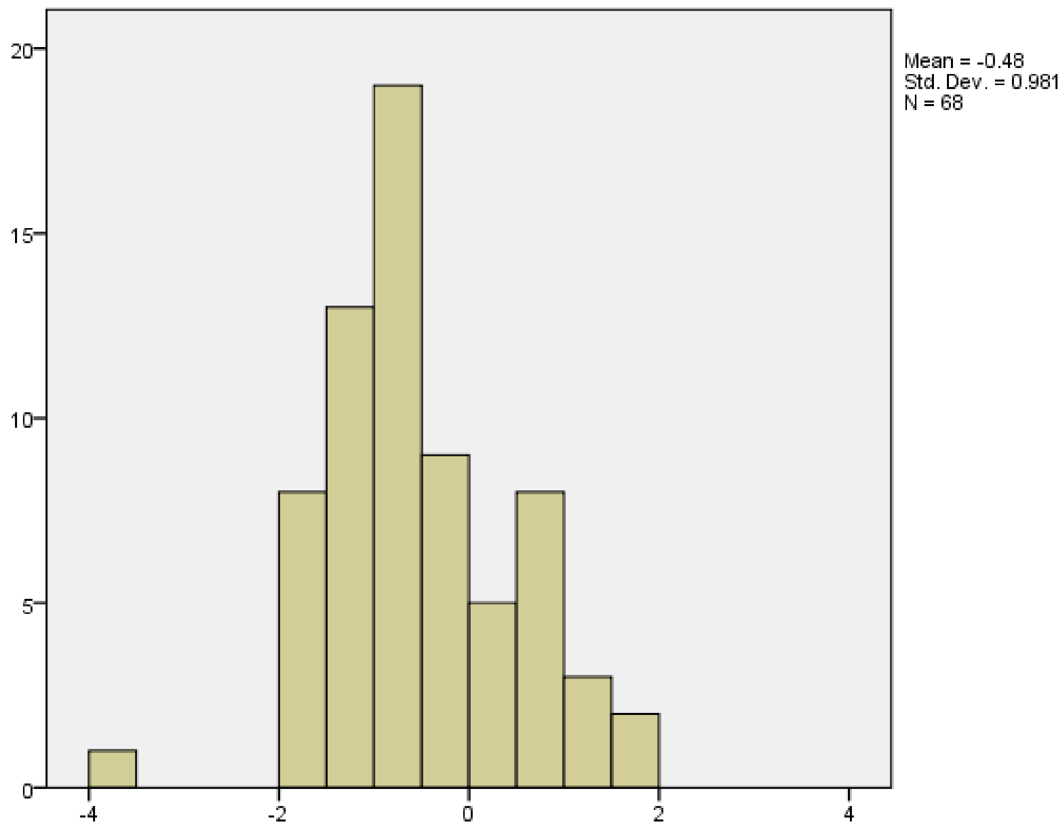
Female	Function	Male	Function
$F_{max}D$	-0.34	Agr	0.35
$RFD_{max}D$	-0.28	BW	0.27
BW	-0.22	NV	-0.24
DIF	-0.22	Opn	0.21
$tRFD_{max}ND$	0.19	PV	0.2
BH	-0.17	BH	0.19
PV	-0.17	Cns	-0.17
DIRFD	-0.17	DIF	-0.17
Agr	-0.16	$tF_{max}D$	-0.14
$tRFD_{max}D$	-0.16	Ext	0.11
Opn	0.16	DIRFD	-0.11
$tF_{max}ND$	-0.16	BMI	0.11
$F_{max}ND$	-0.15	$tF_{max}ND$	-0.1
$RFD_{max}ND$	-0.14	$RFD_{max}ND$	0.09
Cns	-0.14	$tRFD_{max}ND$	0.08
Nrt	0.11	$F_{max}ND$	0.08
Ext	0.1	EIND	-0.03
BMI	-0.09	EIND	0.03
$tF_{max}D$	-0.06	$RFD_{max}D$	-0.01
EINS	0.04	EIS	0
EIND	0.03	$F_{max}D$	0
EIND	0.02		



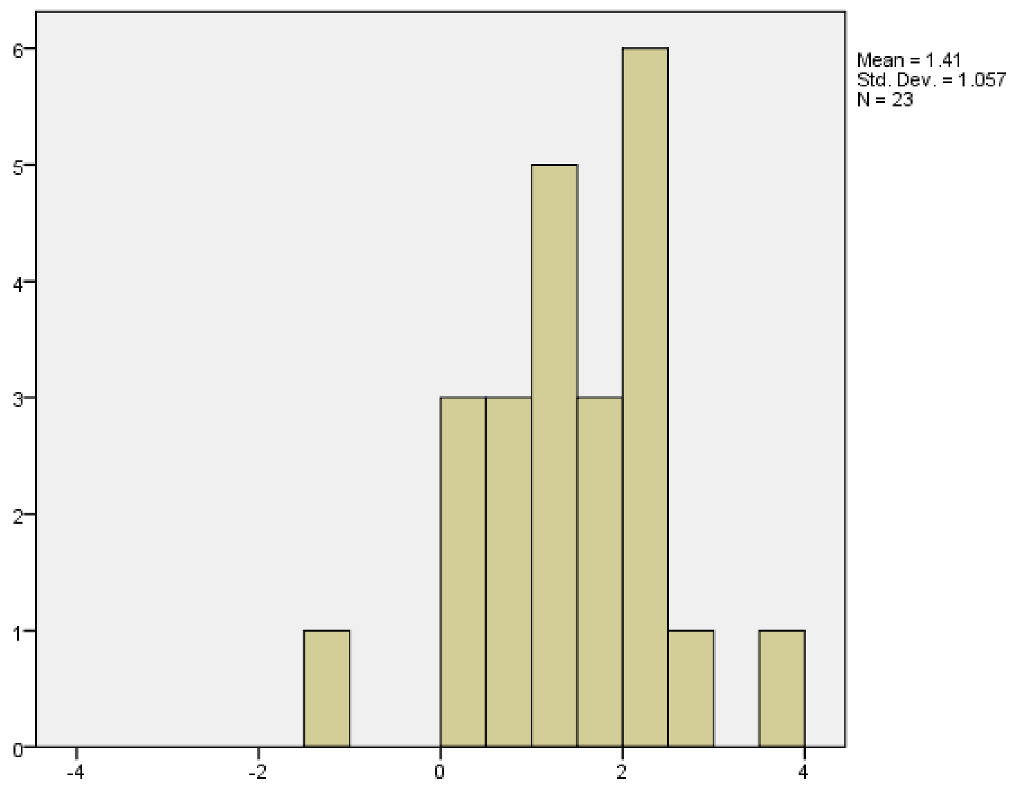
Graph 42. Canonical discriminant function female well-trained athletes



Graph 43. Canonical discriminant function female elite athletes



Graph 44. Canonical discriminant function male well-trained athletes



Graph 45. Canonical discriminant function male elite athletes

7 DISCUSSION

This study primarily aimed to explore the quantitative characteristics of the association of maximal force, rate of force development, endurance in the manifestation of force, time parameters of manifestation of given force characteristics, as well as index parameters of handgrip measured in isometric contraction, with the Big Five personality traits, mental toughness, dark triad, and empathy in adults. This study also aimed to determine the specificity of these relationships in different populations and the metrological characteristics of the newly formed index variables.

Our findings have revealed numerous significant associations between the mechanical characteristics of handgrip strength and all the psychological characteristics assessed, thereby supporting our first, second, and third auxiliary hypotheses. The patterns of relationships are broadly similar across all investigated subgroups, with a few notable exceptions related to the specific characteristics of the groups studied. This fact also applies to the anticipated intensity of correlations, meaning that the interpretation of the results in relation to auxiliary hypothesis 4 is not unanimous.

Additionally, we documented several effective regression models in which the mechanical characteristics of the handgrip serve as predictors. These models can explain a significant percentage of the variance in psychological characteristics, thus supporting our fifth auxiliary hypothesis. However, it is important to note the limitation of this part of the study, which pertains to the sample size, and caution should be exercised when interpreting these findings.

Furthermore, we observed moderating effects of various factors related to the manifestation of mechanical handgrip characteristics, as well as interactions with these factors, on the psychological characteristics of the participants, which supports our sixth auxiliary hypothesis. Overall, our research supports the central hypothesis: there are associations between the mechanical characteristics of handgrip strength and psychological characteristics that are specific to different adult populations. As for the second aim, the newly derived index parameters have good metric characteristics and can be recommended for further research.

However, not all results are unanimous when confirming the research hypotheses, so their deeper contextualization is necessary. As with the presentation, the results will first be discussed partially, with the entire sample and sub-samples, and then the discussion of all presented results will follow. Study limitations will be listed and discussed in closing on the overall findings.

7.1 Total Sample

In this section, we will analyze and interpret the findings of the total sample of respondents.

For a valid interpretation of the results obtained from the total sample of participants, it is crucial to take a close look at the characteristics of the sample shown through descriptive statistics (Tables 1 and 2). Comparing the morphological characteristics with the general population (Dopsaj et al., 2018; 2021; Rakić et al., 2019), as well as mechanical characteristics of handgrip (Dopsaj et al., 2018; 2019a; 2019b; Ivanović & Dopsaj, 2012) it is visible that our sample represents above average healthy and physically prepared group. Comparing the psychological characteristics of the sample to the general population (Dinić et al., 2018b; Tasic et al., 2020; Vukmirovic et al., 2020), even to the athletes (Milošević et al., 2024; Zarić et al.,2021) our sample also represent above average stress resilient group, which should be primarily attributed to the large number of young active and tactical athletes in the sample, which can be seen in the tables 6 and 7. If we add to this the fact that there is a large number of sports students and elite athletes in the civil group, a clear picture of the sample structure can be obtained. The mentioned specificities will be further analyzed in more detail through analyses of sub-samples, which will be presented in the following subsections.

When analyzing the characteristics of the total sample, one should also note the significant heterogeneity (Tables 1 and 2) in terms of numerous characteristics. Such heterogeneity will have implications for understanding the relationships that are obtained. First of all, this resulted in a deviation from the normal distribution of some psychological variables (Table 1), which demonstrated good discriminativeness through numerous previous validation studies (Čolović et al., 2014; Dinić et al., 2018; Gucciardi et al., 2015; Jonason & Webster, 2010; Stamatis et al., 2021a; Milošević et al., 2022). Deviation from the normal distribution of handgrip mechanical characteristics when considering the total sample (Table 2) is expected because it is highly dimorphic according to gender (Gallup et al., 2007a; Kamarul et al., 2006). When it comes to the force parameters, at the level of the total sample, we have two relatively normal distributions (male and female) that overlap to some extent in male minimum and female maximum values (Table 4, Graphs 9, 10, 11, 12, 13, 14) resulting in normality deviated total distribution. With this in mind, it is observable that applied allometric partialisation improved the metric characteristics of these indicators. Its use when observing gender heterogeneous samples can be recommended for further research.

Analysis of the variance of the total sample revealed differences in the manifestation of all groups of variables between the genders as well as the security population and civilians (Tables 3, 4, 5 and 6 as well as Graphs 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, and 28).

Comparing women and men reveals expected differences in both the morphological and mechanical characteristics of handgrip strength (Dopsaj et al., 2018; 2019a; 2019b; 2021; Gallup et al., 2007a; Ivanović & Dopsaj, 2012; Kamarul et al., 2006; Rakić et al., 2019). Women tend to be smaller and, consequently, exhibit less force than men. Notably, allometric partialization did not eliminate these differences, suggesting its effectiveness for future research. This finding indicates that men's advantage in producing force is not solely due to greater muscle mass but also involves differences in muscle structure and composition. While a comprehensive discussion of this finding is beyond the scope of this dissertation, it highlights the potential for further investigation.

Interestingly, there are areas where gender does not affect the expression of handgrip mechanics. For instance, the time required to generate maximum force and the dimorphism indexes show no differences based on gender. It can be posited that, although male muscles may generate more force per unit of time, the nervous systems of both men and women require the same duration to achieve maximum contraction force. Additionally, the way force is manifested, as indicated by the relationship between the dominant and non-dominant hands, appears to be a universal human characteristic that is independent of gender. Similarities in the manifestation of psychological characteristics are also in line with expectations (Čolović et al., 2014; Dinić et al., 2018; Gucciardi et al., 2015; Jonason & Webster, 2010; Milošević et al., 2022; Stamatis et al., 2021a, b), except that the greater aggressiveness of women is surprising. This finding could be explained as a peculiarity of the security subsample, about which more will be said soon.

The differences observed between the security and civilian groups can be understood, in part, as a result of the selection process that members of the security population undergo (Koropanovski et al., 2022; Milošević & Milošević, 2014; Papadakis et al., 2021). However, the intensity of these differences also suggests that the civilian sample demonstrates good physical fitness.

It is particularly interesting to analyze areas where no differences exist between the two groups. Notably, the absence of variation in the dark triad personality traits and their dimensions is quite surprising. This finding highlights the need to enhance the current system for selecting members of the security population.

A similar conclusion can be drawn regarding the mechanical characteristics of the handgrip (see Table 6). The security population exhibits superior mechanical characteristics of the handgrip, which are more dependent on muscle strength. In contrast, the differences are minimal or nonexistent in characteristics that rely more on neural components.

When we consider the job profiles and challenges faced by future workers in the security sector (Amanović & Milošević, 2022; Milošević & Milošević, 2014), it becomes apparent that there is a need to improve the current selection and training systems to address these issues. Finally, when it comes to the relationship of mechanical characteristics of the handgrip with Big Five personality traits (Tables 7 and 8), obtained relationship is according to expectation (Atkinson et al., 2012; Crust & Clough, 2005; Fink et al., 2016; Gallup et al., 2010; Goldberg et al., 2017; Hegerstad et al., 2019; Kerry & Murray, 2018; Mueller et al., 2016, 2018; Stephan et al., 2022), but they are weaker than assumed. Namely, although the magnitude of the recorded correlation is in line with previous studies, we expected more pronounced correlations since we introduced a more pronounced nervous part of the handgrip's mechanical characteristics in our research. This finding can be interpreted as a peculiarity of the sample and the influence of categorical and grouping variables that interfere with the investigated relationships between the mechanical characteristics of the handgrip and psychological characteristics. Even the application of allometric partialization (Table 8) did not improve much. This influence of gender, personal history, physical fitness and professional orientations as interfering variables is expected (Cronin et al., 2017; Gallup et al., 2007; Kamarul et al., 2006; Innes, 1999; Liu et al., 2005); the division of the sample into more homogeneous sub-samples seems justified and will give a clearer picture of the investigated relationships of the mechanical characteristics of the handgrip and psychological characteristics.

On the other hand, this research revealed new relationships with the psychological variables of MT and DT, which have not been examined in previous research. With these variables, a positive correlation with force parameters can be observed, while with time parameters, we have a positive correlation with MT and a negative connection with DT. This finding is in line with the findings of studies dealing with the relationship between MT and DT (Milošević et al., 2022; Papageorgiou et al., 2019; Sabouri et al., 2016), which show the existence of common variance in the expression of two groups of characteristics. Similarly, the maximal force to the maximal rate of force development ratio positively correlates with MT and negatively with DT. This finding is also in accordance with the findings of previous studies (Milošević et al., 2022; Papageorgiou et al., 2019; Sabouri et al., 2016), which also show the diametrically opposite manifestation in behaviour. All these findings could be interpreted as the muscular component being crucial for correlation with MT and the neural component playing a more significant role concerning DT. Namely, the tendency to engage in physical exercise and training accompanies the subjects with higher MT. In contrast, a greater tendency towards antisocial behaviour accompanies the innate speed of generating nerve impulses. These theses also support previous research about the nature of the relationship between MT and DT and physical exercise (Beitia et al., 2022; Brito et al., 2023; Cooper et al., 2020; Coswig et al., 2023; Crust& Clough, 2005; Hegerstad et al., 2019; Milošević al., 2024; Papageorgiou al., 2019; Sabouri et al., 2016; Stamatis et al., 2016 a; Van Cutsem et al., 2017). This finding could also fit into the neurocognitive model of sensitivity to reward and punishment (Bell, 2012; Hardy et al., 2014), which is assumed to underlie primarily MT but could also be extended for DT. Furthermore, this finding could be interpreted as a validation of theoretical assumptions about MT as a characteristic that can develop (Gucciardi et al., 2015; Stamatis et al., 2016 a; Weinberg et al., 2011) more than it is an innate personality trait. However, an experimental design is needed to prove such a claim, which was not the case in our research.

In this part of the research, there was no control for confounding variables, so one should be careful in concluding the nature and intensity of the obtained correlations. The reason for this was the desire to further analyze this external influence by comparing the results obtained on an uncontrolled and controlled sample. The only control was for body mass through allometric partialization, which has proven to be a good methodological choice for future research.

After we have presented the overall results, we can proceed to a further analysis by subsamples in which, on the one hand, there will be fewer respondents, but on the other hand, confounding and grouping variables will be put under a greater degree of control.

7.2 General Adult Population Subsample – Classical and Impulse Mode of Isometric Contraction

In this section, we analyze the findings in the smallest group of subjects, the general adult population subsample, focusing on the role of isometric contraction modalities when it comes to the correlation of mechanical characteristics of handgrip and psychological characteristics.

Before a deeper discussion of relationships, which are the focus of this dissertation, it is necessary to analyze the characteristics of the researched group (Tables 9 and 10). Comparing the morphological characteristics with the general population (Dopsaj et al., 2018, 2021; Rakić et al., 2019), it could be noticed that participants come from average or slightly above-average physically prepared and healthy populations. According to descriptive indicators (Table 9), all handgrip mechanical variables are also near average (Dopsaj et al., 2018, 2019a, 2019b; Ivanović & Dopsaj, 2012). Similar can be concluded by comparing the psychological characteristics of the sample compared to the general population (Dinić et al., 2018b; Tasic et al., 2020; Vukmirovic et al., 2020).

The results of the MANOVA confirm the findings of previous studies (Dopsaj et al., 2021; Sahaly et al., 2001; Suzovic & Nedeljkovic, 2009) about the manifestation of mechanical characteristics in the classic and impulse mode of isometric contraction (Graphs 29, 30, 31, 32, 33, and 34), which supports the assumptions of the difference in physiological mechanisms responsible for their manifestation.

Obtained correlations (Tables 11 and 12) also mainly align with prior research (Fink et al., 2016; Goldberg et al., 2017; Kerry & Murray, 2018; Stephan et al., 2022; Sutin et al., 2018) when it comes to the existence and direction of relationships of mechanical characteristics of handgrip 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. It should be taken into account that the researched subsample is composed of persons of both sexes, but unlike the previous research, allometric partialization enabled, to some degree, the removal of the effect of body mass on the production of muscle force (Jaric et al., 2005; Dulac et al., 2016). Therefore, the obtained correlations are valid descriptions of the researched relationship, not the sampling artefact. However, repeating the findings obtained on only male or female samples is necessary for future research to ensure these claims are valid.

As another novelty to previous findings, this dissertation reveals the absence and existence of the relationships between handgrip mechanical characteristics with MT and DT dimensions.

Namely, while MT, Mch and Nrc (similar to Opn, Nrt, Cns and PV) do not significantly correlate with mechanical characteristics of the handgrip, Psc positively correlates with F_{max} and RFD_{max} (similar to NV). This result is consistent with the findings of previous studies that examined the relationship between MT and DT both among themselves and with the Big Five (Brito et al., 2023; Coswig et al., 2023; Milošević et al., 2022; Papageorgiou et al., 2019; Sabouri et al., 2016). DT positively correlates with F_{rel}ND and 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). NRID can also be described as an indicator of the possibility of creating more nerve impulses when needed and efficiently executing the movements while maintaining neural reserve. This link between the lack of ability to efficiently execute movements and tendencies of antisocial behaviour can be described as a lack of impulse control in both the sense of motor control and behaviour in general. Adding to this negative correlation of Agr and Ext with F_{max} and RFD_{max}, the psychological profile of persons able to generate a large amount of force quickly (and vice versa) can be described as openly non-aggressive introverts with a negative self-image prone to antisocial behaviour, emotional coldness, and impulsive and manipulative behaviour.

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 physical aggression. In line with this conclusion is the finding of the regression analysis, which will be presented in more detail soon, that NRI is the main predictor of MT. According to this, a more remarkable ability to control impulses is also a characteristic of a person with a more developed MT. Such description is in accordance with MT conceptualisation and behavioural expressions (Bell, 2012; Clough et al., 2002; Giles et al., 2012; Gucciardi et al., 2015, 2016 a,b, 2017; Hardy et al., 2014; Horsburgh et al., 2009; Stamatis et al., 2021a).

When it comes to observed correlations, it should also be noted that although there is a similarity in the intensity and direction of the correlations from one psychological variable to another, the difference can be observed when comparing the non-dominant to the dominant hand, RFD_{max} to F_{max}, as well as the impulse mode to the classical mode of isometric contraction. This observation is also a novelty of this dissertation compared to the previous research, which opens new possibilities for explaining the relationships obtained. Although all mentioned variables represent a complex neuromuscular characteristic, because of its dependence on the speed of recruitment of motor units, RFD_{max} 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), this is especially true for non-dominant hand in impulse mode of contraction. The possibility that some relationship between the mechanical characteristics of handgrip and psychological characteristics can be additionally explained by the peculiarities of the functioning of the nervous system and not exclusively with the muscular strength factors is worth additional studies. However, these are only correlations, and care should be taken that our research cannot serve as a basis for concluding causality.

Similar to the total sample, there was no control for confounding variables in this part of the research. The reason for this was the sample size. The only control was allometric partialization, which made it possible to obtain significant relationships by analyzing a very heterogeneous sample.

Obtained regression models (Tables 13, 14, 15, 16), have surprisingly high coefficient of determination. This raises concerns about over fitting. Outlier analysis showed that this can't 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 too tiny 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.

Obtained regression models point out a promising possibility that the results of similar studies in the future will bring numerous opportunities for practical application in addition to the theoretical value. What regression analysis adds to the correlation is primarily a synergistic effect of subtle differences in the manifestation of the handgrip's measured mechanical characteristics when predicting the psychological factors in question. Here, the duration of the excitation has its share in explaining the variance of some psychological factors, not only the intensity of the excitation, as it could be concluded based on correlation analysis. Regression analysis also showed unique connection patterns with the mechanical characteristics of handgrips that were specific to individual psychological characteristics. This further means that, in fact, the relations of different psychological characteristics are linked to other physiological mechanisms responsible for the manifestation of different mechanical characteristics of the handgrip. As if each of these physiological mechanisms, in turn, explains a unique part of the variance in psychological traits. We assume that this is the main reason why high coefficients of determination were obtained. In this way, a more explicit connection of motor behaviour with a broader domain of behaviour government is established. However, it should be noted once again that this is only a pilot attempt to investigate the already insufficiently investigated relationships between mechanical and psychological characteristics in different isometric contraction modalities. The sample size, which did not allow for control of outliers, could have contributed significantly to the magnitude of the coefficients of determination. Therefore, it is reasonable to fear that their magnitude may have been overestimated in this study and that they will be smaller when the analysis is conducted on a larger group of subjects. In any case, these results show that further investigation of this topic is justified and necessary.

When all of the above is taken into account, regardless of methodological limitations and necessary caution, the handgrip test, as used in this study, represents a promising method for screening various personality traits, including mental toughness, aggressiveness, and the dark triad.

7.3 Police Students Subsample – Endurance in Force

In this section, we will analyze the findings of the group of police students who performed the task of handgrip endurance, thereby giving impetus to expanding research on our topic.

Once again, before a deeper discussion of relationships, which are the focus of this dissertation, descriptive indicators of the subsample should be looked at (Table 17). As expected, the participants in this group represent an exceptionally physically and mentally healthy and developed population compared to the results of previous studies (Dopsaj et al., 2018, 2019a, 2019b, 2021; Ivanović & Dopsaj, 2012; Marković et al., 2018; Rakić et al., 2019). Similar results are obtained when it comes to psychological characteristics. The MT of the group can be described as highly developed, even if compared to elite athletes (Milošević et al., 2024: Zarić et al., 2021), while the DT is extremely weak (Mch and Psc) and weakly present (Nrc). This observation is especially true when compared to the results of the general population (Dinić et al., 2018; Jonason & Webster, 2010). It also should be noted that a limited range of manifestations of all researched characteristics impacted the obtained relationships.

Regarding the direction of relationships (Table 18) it should be remembered that the obtained trend is valid only for a group of highly selected individuals. On the other hand, finding a specific correlation between the mechanical characteristics of handgrip and the psychological characteristics of police students contributes to the applied goals of the dissertation. Therefore, it is reasonable to assume that repeating this research on a broader sample of candidates for police schools instead of on a specified sample would show even more pronounced links between the mechanical characteristics of handgrip and psychological characteristics, which could be used to improve the selection process. In support of these assumptions, the results obtained on the extended security and athletic sample (Tables 20, 21, 26 and 17) also speak.

The findings of correlation analysis are in line with the findings of earlier research (Crust & Clough, 2005; Fink et al., 2010, 2016; Goldberg et al., 2017; Stephan et al., 2022) in which the handgrip strength was associated with various psychological characteristics and behavioural indicators. Unlike the previous studies that used strength, i.e. F_{rel}, as the only mechanical characteristic of the handgrip indicator, we found that RFD_{rel} has a more intense relationship with MT and DT. Surprisingly, the direction of correlations between the mechanical characteristics of handgrip measures and DT was opposite to what was hypothesized, as well as to the findings of the previously mentioned studies (Dinić et al., 2018; Fink et al., 2016; Goldberg et al., 2017; Papageorgiou et al., 2019). A similar thing happened with the total sample (Tables 7 and 8), but the relationship was too weak to discuss. The findings could partially explain the positive association with DT variables that the maximal force of handgrip correlates with aggressive, sexual and socially dominant behaviour (Atkinson et al., 2012; Gallup et al., 2007, 2010). The selection bias (i.e., healthy subject bias) (Delgado-Rodriguez, 2004) could further explain the positive association of HGS with DT as all participants are selected from the normal population based on age, their cognitive capabilities, physical abilities, and psychological characteristics and traits (Koropanovski et al., 2022). Considering this, the only thing that can be sure of is that the obtained direction of associations is valid only for this group of specifically selected individuals. Given the specificity of the police job and the selection process to become an officer, this provides practical value to this study as a base ground for further development of profiles of police officers based on mechanical characteristics of handgrip and psychological characteristics. While these correlations exist, caution is necessary as our research does not establish causality.

Contrary to expectations based on studies linking MT to persistence in work and training (Beitia et al., 2022; Cooper, et al., 2020; Crust& Clough, 2005; Giles et al., 2018; Gucciardi et al., 2016 b), no significant relationship with Fimp50% was obtained. A similar thing happened in the study of police college students (Hegerstad et al., 2019). We assume that this finding is primarily an artefact of the selection of candidates for police colleges, as well as the lack of control for the influence of gender, rather than an expression of the absence of studied relationships in the population. Also, contrary to expectations, MT did not show any significant relationship with either Maximal Force or Rate of Force Development. This kind of finding has already been obtained in earlier studies on highly physically fit and selected groups. Namely, no connection between MT and hand grip strength was found among firefighters either (Beitia et al., 2022). We assume that this finding should be interpreted in the same way as the previous one and that greater control of confounding variables is needed, first of all, gender, which was not the case here.

The results of MANOVA (Graphs 36, 37, and 38) demonstrated the complex interplay of the mechanical characteristics of handgrip and psychological characteristics among police students. The results showed that the interplay between F_{rel} as a reflection of neuromuscular strength and RFD_{rel} as a reflection of neuromuscular quickness may reflect in students' MT and Nrc, while F_{rel} and $F_{imp}50\%_{rel}$ as a reflection of neuromuscular strength and stable neuromuscular endurance may reflect in students' Psc. This finding suggests two possible specific mechanical profiles of handgrip variables related to psychological characteristics. The first profile, which consists of high F_{rel} and high RFD_{rel} with low $F_{imp}50\ \%_{rel}$, reflects a low MT, moderate Nrc, and increased Psc. With higher $F_{imp}50\%_{rel}$ and lower RFD_{rel}, such tendencies disappear (Psc is falling) or are controlled to a greater extent with increased MT. The second spotted profile of average F_{rel}, high RFD_{rel} and low $F_{imp}50\%_{rel}$, which are characterized by high MT, high Nrc, and high Psc, have psychological characteristics scores much closer to police work. This observation is especially true because previous studies show that Nrc associated with MT predicts positive outcomes in various domains (Milošević et al., 2024; Papageorgiou et al., 2019; Sabouri et al., 2016). Also, findings that indicate the association of MT with better stress management (Gerber et al., 2013; Mojtahedi et al., 2023; Nabilpour et al., 2018; Papageorgiou et al., 2019) support our assumptions. This assumption also aligns with previous studies that found Nrc to be the bridge between pro and antisocial behaviour (Papageorgiou et al., 2019). The obtained results could provide a higher level of individualization of the training process to improve both the physical and mental characteristics of police students.

Nevertheless, whether the results support the need to improve the selection process of candidates already undergoing psychological testing arises. Do the results show that among the selected candidates are those with the potential for maladaptive responses to stress or malevolent behaviour? While answers to these questions require a longitudinal study, our results suggest that these questions could be worth exploring. The results show that the selection process could be improved to be more sensitive to tendencies for benevolent behaviour and impulse control. Obtained profiles (Graph 35, 36, and 37) show the mechanism of occurrence of undesirable reactions and behaviour even if all descriptive indicators (Table 17) are good. Such an occurrence could be prevented by supplying an already existing selection process with additional data that is easy and convenient to collect, and that could be tracked longitudinally with minimal effort and resources.

In this part of the research, in addition to the influence of body mass on force production, the level of physical fitness and professional orientation were also controlled. On the other hand, members of both sexes were analyzed simultaneously, which certainly had an impact on the final results. This fact should be taken into account when drawing conclusions about the generalizability of the findings.

7.4 Security Population Subsample – Empathy

In this section, we will analyze the findings in the group security subsample, which is composed of students of police, national security, and workers in these fields. As a contribution to previous research and the application of this thesis's results in practice, the interpersonal reactivity questionnaire in this group is highlighted.

Regarding descriptive indicators (Table 20), everything is the same for this group as for the previous one. Comparing it with the general population and previous research (Dinić et al., 2018; Dopsaj et al., 2018, 2019a, 2019b, 2021; Ivanović & Dopsaj, 2012; Jonason & Webster, 2010; Marković et al., 2018; Milošević et al., 2024; Rakić et al., 2019; Zarić et al., 2021) we can define it as above-average physically prepared, and mental and physically healthy as well as stress resilient population. These findings also prove that the researched population is strictly selected based on superior physical abilities, level of physical fitness, and psychological profile (Dopsaj et al., 2019; Koropanovski et al., 2022; Papadakis et al., 2021). Moreover, once again, this fact must be considered when discussing the results obtained and making conclusions. Since the Big Five, MT and DT, have already been discussed in detail, and we expect more discussions about them when the athletic subsample is taken into account to avoid unnecessary repetition of similar findings, this section will emphasize empathy.

When it comes to the level of empathy development and the presence of empathy among police and security students, based on the descriptive indicators (Table 19), one can observe the average presence of EC and PT, slightly below the average presence of Fnt as well as a weak presence of PD. Although this seems like a desirable ratio of empathy dimensions in future police and security officers and agents, comparing the obtained results with the general population (Davis, 1983; De Corte et al., 2007; Hawk et al., 2013), it can be concluded that the subsample does not stand out in this regard, as one might expect from a strictly selected population. A similar conclusion can be drawn when comparing our participants with Swedish police students (Inzunza et al., 2022). Although a large proportion of the sample exhibits exceptional characteristics when it comes to empathy, there is also a considerable proportion of the sample with average or below-average empathy scores. This claim is especially valid for men. In general, the scope for improvement of the existing selection system has been again shown, especially if the shift toward social skills (Bloksgaard & Prieur, 2021) is to be achieved. Nevertheless, the results can be the foundation for setting reference selection standards for police and security students.

When comparing different groups within this subsample, first of all, it can be noticed that police and security students have a reasonably similar selection profile when it comes to psychological, morphological and mechanical characteristics of handgrip. Security students have something more pronounced Mch, BW and something less $tRFD_{max}$. Although there is quite a similarity between the jobs these students prepare for, public and national security represent specific domains. Therefore, a more significant difference in the obtained profiles of the two groups was expected. Again, this result also represents space for more profound research and analysis to improve the two selection systems.

Contrary to the previous one, the obtained differences between women and men both in empathy (Graphs 38, 39, 40) and in other measured characteristics are in complete accordance with the previous results (Davis, 1983; De Corte et al., 2007; Dopsaj et al., 2018, 2019, 2021; Hawk et al., 2013; Ivanović & Dopsaj, 2012; Rakić et al., 2019). Women have smaller bodies than men, so they are physically weaker than men. They are also more empathetic and have less present tendencies towards behaviour; on the other hand, men are physically more potent and have a more developed MT. The only surprise is the greater aggressiveness obtained in women, which is a novelty compared to previous studies. Since it was mentioned in the introduction, when the total sample was discussed, it seems this data is a specific property of the security population. Although it can be interpreted as the specificity of the sample and the selection system of police and security students, further research is needed to understand and explain why this is happening.

The correlation between empathy and other psychological characteristics (Table 21) aligns with expectations. MT represents a certain novelty in this context. Previous studies have shown existing positive correlations between MT and self-compassion (Stamatis et al., 2016 b) among athletes. This result indicates that a relationship between MT levels and empathic potential should be expected. In our study, we obtained MT's positive connection with the cognitive aspects of empathy and its negative connection with the emotional one. When we compare this finding with DT, where the relationship is in the opposite direction, that is, positive with the emotional aspect and negative with the cognitive aspect, we can conclude not only that greater MT is present in members of the security population with more significant empathic potential, but also lower tendencies towards antisocial behaviour due to lack of empathy. Such claims are supported by the findings of studies dealing with the relationship between MT, DT and empathy (Milošević et al., 2022; Papageorgiou et al., 2019; Sabouri et al., 2016), as well as the conceptualisation and expression of these characteristics in behaviour.

On the other hand, when it comes to the relationship between empathy and morphological as well as mechanical characteristics of handgrip (Table 20), based on the results of prior research (Crust & Clough, 2005; Faith et al., 2001; Fink et al., 2010, 2016; Goldberg et al., 2017; Magee et al., 2013; Stefanovic et al., 2021; Stephan et al., 2022; Sutin & Terracciano, 2016) which has established associations between BMI and handgrip strength with various behavioural indicators, similar relationships were expected when it comes to empathy. Nevertheless, expectations came trustworthy above all among women, while for men, the only significant was a negative relationship between BW and PT. In general, physical strength, ability, and fitness indicators were negatively associated with empathy in women. In this regard, the RFD_{max} stood out in particular. Although RFD_{max} is a complex neuromuscular characteristic, as explained a few times earlier, 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). Another possibility worth additional studies is whether this property causes a lack of empathy. Nevertheless, it seems that the described gender specifics speak in favor of women as more suitable for the role of police and security officer when from the position of proclaimed policing by social skills (Bloksgaard & Prieur, 2021). Although these correlations are present, it is important to exercise caution, as our research does not demonstrate causality.

In this group, control was established for gender, level of physical fitness, and professional affiliation. Therefore, allometric partialization was not performed because the groups were already reasonably homogeneous.

7.5 Athletic Subsample – Possibilities for Application

Before synthesizing all the obtained results, in this part, we will deal with the last subgroup characterized by long-term physical exercise and training, regardless of whether it was followed by achieving sports success. Nevertheless, athletic success was the basis for further segmentation of this group so that confounding variables would be put under greater control and the results of this dissertation would have a more significant practical impact on the selection process of elite athletes.

For the last time, before discussing relationships, according to descriptive indicators (Tables 22, 23, 24, and 25), comparing the morphological characteristics, all handgrip mechanical variables, as well as psychological characteristics of the general population (Dopsaj et al., 2018, 2019a, 2019b, 2021; Ivanović & Dopsaj, 2012; Rakić et al., 2019), it could be stated that participants come from above-average or at least in line with average physically prepared, and healthy population. Regarding psychological indicators, all four subsamples are characterized by weakly present Nrc and NV, moderate Agr, moderately high PV, and highly present Ext, Opn, and Cns. Compared to 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.

The observed correlations (Tables 26 and 27) mainly align with prior research (Fink et al., 2016; Goldberg et al., 2017; Kerry & Murray, 2018; Stephan et al., 2022; Sutin et al., 2018) when it comes to the existence and direction as well as gender specificity of relationships of mechanical and psychological characteristics. The only contrary to expectation is the negative correlation of $RFD_{max}ND$ and Cns in male elite athletes. This finding is the first specificity of the male elite athletes subsample compared to the general population and the other subsamples of this research regarding researched relationships. Adding to this numerous positive correlations of handgrip mechanical characteristics 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), testosterone levels and Cns (Crewther et al., 2024) only in males was found in previous studies. How do we interpret the obtained link of high mechanical characteristics with high Agr and insufficiently developed Cns in males? The described relationship points to the possibility that the inheritance of superior mechanical characteristics of handgrip in male elite athletes hinders the development of the Cns because high results can be achieved with less effort. It can be further hypothesized that since women are traditionally not expected to have physical strength, in order to reach the high level of physical fitness demonstrated by our participants, they had to go through more rigorous training and even a lack of understanding of the environment, which contributed to the development of Cns. Moreover, women did not associate their AGR with physical strength since they were weaker than men. However, these are just speculations; our research only provides us with information about correlations, and a new experimental study is needed to draw causal conclusions.

Correlation analyses (Tables 26 and 27) also show that relationships between handgrip mechanical and psychological characteristics are stronger among elite than well-trained athletes. Compared with previous studies results (Fink et al., 2016; Kerry & Murray, 2018; Stephan et al., 2022), a trend can be observed that with the level of physical fitness and abilities as well as sports success, the researched relationships become more vigorous. In other words, physical exercise affects not only the body but also the character. Suppose we add to this the observed superiority of RFD_{max} over F_{max} when describing the relationship of handgrip mechanical with psychological characteristics, by what this dissertation diverges from previous similar research. In that case, some new possibilities can be seen in explaining the relationships that were obtained. As mentioned before, although RFD_{max} is a complex neuromuscular characteristic, it primarily reflects the ability of the nervous system to quickly produce and transport impulses (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 somewhat related to or even responsible for psychological characteristics development is worth additional studies. Again, it should be emphasized that this is primarily about correlations, not causality.

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). A higher BH, BM, $F_{max}D$ and $RFD_{max}D$ characterize female elite athletes. In contrast, male elite athletes are characterized by more Agr counter to the whole sample and security subsample findings. 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 accurate recognition of well-trained and elite athletes among female and male samples. Considering the economy of the performed measurements and assessments and the sample includes athletes from different sports disciplines, compared to similar earlier studies (Robertson et al., 2022), the obtained discriminant models can be marked as very effective. When it comes to gender differences, it can be seen (Table 28, Graphs 41, 42, 23, and 44) that recognition of female athletes relies primarily on mechanical characteristics of handgrip; recognition of male athletes relies mainly on psychological characteristics, while morphological characteristics are equally important in both models. This finding represents this study's most important applied contribution because it paves the way for quick and economical selection of elite athletes.

In this part of the research, in addition to controlling for gender, the level of control for physical fitness was raised to an even higher level than in previous analyses. This was done by distinguishing between well-trained and elite athletes. In this way, a high degree of control over external influences on the relations investigated was established. On the other hand, we also obtained some too-small groups, which do not fully satisfy the criteria for rigorous statistical inference.

7.6 Overall Findings

In the final part of the discussion chapter, all the findings presented so far will be considered and compared to gain more information and deeper insights into our topic.

Taking all the results obtained into account, it can be seen immediately that numerous correlations between all the psychological and mechanical characteristics of the handgrip were found. With this, the expansion of previous research from the relationship of maximal force into the detailed analysis of the force-time curve found its justification, and numerous theoretical and practical implications can be drawn from it.

When it comes to correlations, only $F_{Imp}50\%$ did not reveal the existence of a statistically significant correlation. In this regard, a small number of respondents performed this test. The correlation with MT was on the edge of statistical significance. This finding was contrary to expectations based on studies linking MT to persistence in work and training (Beitia et al., 2022; Cooper et al., 2020; Crust& Clough, 2005; Giles et al., 2018; Gucciardi et al., 2016 b), jet already happened in the study of police college students (Hegerstad et al., 2019). With the increase of the sample size and its differentiation into men and women, as well as with the expansion of the sample of psychological characteristics, the emergence of statistically significant relationships should be expected. Also, $F_{Imp}50\%$ demonstrated through the analysis of variance the existence of specific relationships with psychological characteristics. With this, further research in the context of a relationship with psychological characteristics is justified.

Since the correlation of psychological characteristics with F_{max} is already known (Fink et al., 2016; Goldberg et al., 2017; Kerry & Murray, 2018; Stephan et al., 2022; Sutin et al., 2018), obtained relationships with RFD_{max} should be highlighted as an exciting novelty brought by this dissertation. Everything presented so far speaks in favor of accepting the first three auxiliary hypotheses that there is an association between the characteristics of the maximum handgrip force (H1), maximum rate of force development (H2) and endurance in the manifestation of handgrip force (H3) with the psychological characteristics of the participants.

The intensity of relationships is smaller in the total sample than in subsamples. When the interfering variables of gender, body dimensions, personal, professional, training as well as sports history are brought under control to a greater extent, the observed relationships are strengthened (Tables 7, 8, 11, 12, 18, 20, 26, and 27). When it comes to comparing more and less physically fit populations, results of previous studies on genera population (Fink et al., 2016; Goldberg et al., 2017; Kerry & Murray, 2018; Stephan et al., 2022; Sutin et al., 2018), police students, well-trained and elite athletes it is possible to determine the trend of strengthening relationships with increasing levels of physical fitness, which confirms auxiliary hypothesis (H4) that the association between the mechanical characteristics of the handgrip and the psychological characteristics of the participants follow the same trend in different subsamples, but are more intense in physically more fit population (Tables 26, and 27). Exceptions, to a certain extent, are some robust correlations in our general population subsample; however, given its size, this should not affect the conclusion of the hypothesis. Another exception is the positive relationship with Agr only in elite male athletes, but most relationships have similar direction in different subsamples.

Investigating relationships in the impulse mode of isometric contraction proved to be the most significant innovation. It resulted in the most substantial obtained relationships between the mechanical characteristics of the handgrip and the psychological characteristics, thus confirming the auxiliary hypothesis (H5) that mechanical characteristics of the handgrip are predictors of psychological characteristics.

Research in the police students subsample revealed the existence of numerous profiles of students related to the psychological and mechanical characteristics of handgrip. This finding confirmed the last auxiliary hypothesis (H6) that there are moderating effects of belonging to a specific subpopulation and the factor of the manifestation of the mechanical characteristics of the handgrip as well as the interaction of these factors on the psychological characteristics of the participants. Also, this finding in an obvious way shows that the results of this research could be applied for improving the existing system of selection of future police students.

All said so far justifies accepting the central hypothesis (H) of this research that there are associations between the mechanical characteristics of the handgrip and psychological characteristics, which are specific to the different populations of adults. In detail, most findings agree with the assumption that more pronounced mechanical characteristics have a positive relationship with desired or preferred psychological characteristics. The most apparent counter-example is the positive relationship with Agr in elite male athletes. Positive links with Psc among police students and the general adult population show similar things. On the one hand, this shows that it is not possible to include all the obtained connections of mechanical and psychological characteristics with one explanation, as in the conclusions of previous studies, but it also confirms previous criticisms of the Big Five model that it is too narrow when it comes to assessing numerous outcomes (Boyle et al., 2008; Papageorgiou et al., 2019; Saucier & Srivastava, 2015).

In addition to the emergence and direction, the question of the intensity of the obtained connections also arises. Namely, the vast majority of the correlations found, although statistically significant, could be described as moderate or weak. However, it should be borne in mind that in the research on this topic so far, the highest obtained correlations ranged from 0.30 to 0.32 (Fink et al., 2016; Goldberg et al., 2017; Kerry & Murray, 2018; Stephan et al., 2022; Sutin et al., 2018), so that our study brings a previously unrecorded high intensity of connections. Also, in the area of individual differences, only 25% of the highest correlation coefficients exceed 0.3 (Gignac & Szodorai, 2016), which places the results of our study at the very top regarding the intensity of the obtained connections in the whole research field. This finding is primarily a consequence of the complexity of the observation and research methodology of this topic that was applied in this study.

In this way, the primary goal of this research to explore the quantitative characteristics of the association of maximal force (F_{max}), maximal rate of force development (RFD_{max}), endurance in the manifestation of force ($F_{imp}50\%$), time parameters of manifestation of given force characteristics, as well as index parameters of handgrip expressed in different modes of isometric contraction, with the Big Five personality traits, mental toughness, dark triad, and empathy in adults, then determining the specificity of these relationships in different populations is fulfilled. When it comes to the metrological characteristics of the newly formed index variables (DIF, DIRFD, EIS and NRIS), it should be pointed out that they performed pretty well (Tables 2, 4, 6, 10, 23, 25, 26), that they brought much new information about the investigated relationships (Tables 7, 8, 12, 15, 16, 27, 28 and Graphs 14, 27, 28), and that their further research in connection with the topic of this work is justified.

Before we proceed with further analyses, we must pay closer attention to potential biases or external influences on the findings. The variables whose potential influence were investigated or controlled were gender, professional orientation, level of physical activity, and body dimensions. The primary method of controlling the impact of body dimensions on force production was allometric partialization. This method proved to be effective, as it did not change the subsample's relationships to force parameters but contributed to metric characteristics (Tables 2, 4, 6, 10, 17 and Graphs 9, 10, 11, 12, 24, 25). When it comes to the relationship between the mechanical characteristics of the handgrip and psychological factors, this method contributed to a more precise insight and understanding of these relationships (Tables 8, 11, 12, 15, 16, 18 and Graphs 36, 37, 38). Gender, professional orientation, and level of physical fitness were controlled primarily by division into sub-samples. In this way, it was observed that in heterogeneous groups, the relations between mechanical and psychological characteristics are mainly obscured by external influences. On the other hand, in homogeneous groups, when confounding variables are controlled to a greater extent, these relations gain strength. In addition to the above, a detailed descriptive analysis of all indicators by all subgroups was also performed (Tables 1, 2, 3, 4, 5, 6, 9, 10, 17, 19, 22, 23, 24, 25, and Graphs 3, 4, 5 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 39, 40, 41). These indicators were also analyzed in detail and linked to indicators from various previous studies on different populations. In this way, each specificity of the sample and subsamples are described in detail, which provides information about any limitations that exist when it comes to generalizing the findings.

As far as future research is concerned, it should also be noted that researching the dominant versus non-dominant hand as opposed to investigating the sum of the dominant and non-dominant hand has advantages and disadvantages. The effectiveness of laying sums should take precedence while showing the results of the dominant and non-dominant hands is more informative. There will be more to say about this soon. As far as allometric partialization is concerned, it proved to be superior to raw force measures because it has more excellent discrimination and does not change the obtained patterns of relationships. Its further use in the research on this topic is recommended. Also, when it comes to impulse or classical mode of isometric contraction, although the subsample size is far too small to draw definite conclusions, it is a promising method of exploring our topic. Differences in mechanisms responsible for obtaining relationships in classic and impulse modes were observed. In future research, both modalities of isometric contraction should be the subject of study.

The nature of the researched mechanical characteristics should also be considered for a deeper theoretical interpretation of the results. As mentioned earlier, handgrip strength (expressed through F_{max}) has relatively high heritability; a significant part of its manifestation also depends on environmental factors (Frederiksen et al., 2002). Training adaptations which contribute the most to the increase in F_{max} relate primarily to muscle hypertrophy (Coffey & Hawley, 2007), while RFD_{max} increases mainly through enhancement of the speed of recruitment of motor units (Van Cutsem et al., 1998). Regarding $F_{imp}50\%$, the important role of supraspinal factors is recorded (Gandevia, 2001). These findings could be roughly summarized as follows: Although all three mechanical characteristics represent complex neuromuscular features, F_{max} is the component which the most reflects training adaptations of muscles; RFD_{max} primarily reflects the inherent ability of the nervous system to quickly produce and transport impulses, while $F_{imp}50\%$ reflects the centrally governed ability of perseverance in effort. As results show, all three mechanical characteristics have their unique relationship with the psychological characteristics. Our research implies that the specificities of the nervous system are one of the possible mechanisms by which research relationships can be explained. However, this is only an implication because our research is correlative, and experimental studies are needed for causal inference.

In order to be able to claim with certainty that the obtained relationships are, to a greater extent, a consequence of the nervous about the muscular component of mechanical characteristics of the handgrip, as suggested by the comparison of F_{max}, RFD_{max} and time for obtaining forces, impulse and classical modalities of muscle contraction as well as the comparison of the dominant and non-dominant hand, it is necessary to conduct new research in which the RFD would be measured in different time intervals from the beginning of the contraction, since RFD obtained from the early phase of force development predominantly depend upon the level of neural excitation (Knezevic et al., 2014). Until then, one could further assume that the relationships between the obtained mechanical and psychological characteristics can be direct and indirect and that there can be three mechanisms to explain them. The ability to move in a certain way can lead to choosing and consolidating different styles and behaviour patterns. On the other hand, the common physiological, first of all, neural basis enables the ability to move in a certain way, as well as the choices and consolidation of styles and patterns of behaviour. The return influence of behaviour tendencies on the development of mechanical characteristics can also be assumed, thus closing the circle of mutual interdependence. In this sense, the interdependence of physical fitness and MT is the most obvious. Indeed, a higher MT accompanies individuals who engage in physical training more often and last longer in it (Beitia et al., 2022; Cooper, et al., 2020; Crust& Clough, 2005; Giles et al., 2018; Gucciardi et al., 2016 b). Also, the results of our study and previous ones (Papadakis et al., 2021; Stamatis 2020, 2021 a,b) show the possibility of a feedback loop and the building of MT through physical training (Gucciardi et al., 2015; Stamatis 2020, 2021b; Weinberg et al., 2011). This reciprocal causality between the system components is a well-known phenomenon in psychological literature, for example, short-term memory and the development of cognitive strategies (Siegler & Alibali, 2005) or language and cognition (Pinker, 1994). However, this research is only a small step towards establishing and validating such a model.

Related to what was previously said, the results of this research can be interpreted from the perspective of the nature vs nurture debate. Since it was concluded that the relationships between mechanical and psychological characteristics are more substantial in a more physically active population, such as athletes or police students, this finding could be interpreted as the influence of personal activity and the environment on the development of the investigated relationships. However, the correlations are weak when the trained and untrained populations are mixed. This finding can be interpreted as the training affects the mechanical characteristics and less the psychological ones, whereby the training history masks the existence of relationships. Also, the connection patterns are similar in all investigated subsamples, and the size of the correlations in general population is an argument supporting the nature (heredity) thesis. Moreover, in this sense, RFD is interesting for further research.

Along with all just presented is the interpretation of the overall findings as a validation of the assumption that MT is a psychological characteristic that can be built through personal development, in our case, primarily physical exercise and training (Gucciardi et al., 2015; Stamatis et al., 2016 a, 2021b; Weinberg et al., 2011). Namely, in our research, a higher level of MT was a characteristic of more physically fit groups, and its connection was more substantial with muscular than with neural components. At this point, we should also mention the results of studies in which no correlation between MT and physical fitness was found in strictly selected groups known for their high level of physical fitness (Beitia et al., 2022; Cooper, et al., 2020; Crust& Clough, 2005; Giles et al., 2018; Gucciardi et al., 2016 b). Considering all our results, the absence of these relations in such groups, similar to the findings we obtained comparing the total sample and the selected sub-samples, is an artefact of the selection process. Namely, only highly developed individuals in both domains are selected for tactical athlete groups. This finding further affects the blurring of the existing relationships if the total population is observed.

In our study, it has also been shown that MT can be one of the corrective factors in the behaviour and control of aggressive impulses in populations that use physical force in their work, such as police officers, national security and the like, which is similar to results of prior studies (Bell, 2012; Clough et al., 2002; Giles et al., 2012; Gucciardi et al., 2015, 2016 a,b, 2017; Hardy et al., 2014; Horsburgh et al., 2009; Stamatis et al., 2021a). These findings lead us to the practical implications of the results of this dissertation.

The question arises of how coaches and trainers can apply this research in athletic training. Weather conditions and strength exercises can help athletes to build their personality, character, and mental toughness. What kind of specific exercise program should they use for particular personality changes? Or, vice versa, can psychological intervention help athletes build mechanical properties of skeletal muscles? Being cross-sectional and correlation, our research cannot specifically answer these questions. We examined correlation but no causalities. What we know from previous research is that a physical training-only approach is not effective (Stamatis et al., 2016 a) and that building MT requires a carefully planned psychological intervention (Ajilchi et al., 2019). Also, the development of MT is a long-term process (Stamatis et al., 2016 a) that should be taken into account in the planning of interventions; that is, it should be understood that the expectation of significant results in this field in a short period is doubtful. Furthermore, the coaching style should be adapted to the needs and characteristics of each athlete because what can be tolerable or even motivate athletes with high MT can act as a disincentive or even be harmful to others (Gucciardi et al., 2017). Insisting on MT and neglecting self-compassion in this sense can lead to impairment of mental health (Stamatis et al., 2016 b). Unfortunately, this is a frequent case, especially in sports and physically demanding occupations. Because of all the possible risks that this approach can bring, an interdisciplinary approach to sports training is needed, as is the education of coaches process (Stamatis et al., 2018).

Regarding the results of our study, both approaches, physically and psychologically, seem plausible and justified. Our research shows that physical exercise and personality development are positively correlated. However, taking a unilateral approach to this problem would not be effective. Our study shows that an interdisciplinary approach makes sense when it comes to training. Personality, character, and mental toughness are not built only through hard work or physical exercise but also through the adoption of cognitive strategies and habits, possibly reshaping the entire mindset, which allows for healthy reactions to stressful situations and their management. Having such a mindset helps us endure hard work and training, not fear it and eventually more easily engage in it. Therefore, the first step is a detailed assessment of the current state, not only of physical but also of mental characteristics—analysis of potential threats, strengths and weaknesses, as well as opportunities for improvement. Then, design an individual program for both physical exercise and counseling, as well as therapeutic work, with the aim of achieving progress in both fields - mechanical and psychological characteristics. To make this possible, further research is needed.

The results have many other implications for practical application. First of all, the implication for the individualization of training programs to enhance both the physical and mental attributes of police and security students, which could, with additional research, be extended to adults engaged in physically demanding and stressful occupations (police officers, firefighters, soldiers, national security, and similar) as well as to athletes. Our research also prompts questions regarding the refinement of candidate selection processes. Findings suggest the potential value of exploring candidates' proclivity for maladaptive stress responses or malevolent behaviours. This exploration could be facilitated by augmenting the existing selection process with additional easily obtainable data, allowing for longitudinal tracking with minimal resources.

Since personality assessments are often based on self-assessment inventories, this practice relies heavily on two assumptions. The first refers to the ability of the respondents to provide valid self-assessments, and the second refers to the motivation of the respondents to provide honest answers about their insights. In competitive situations like entrance exams or job interviews, this is questionable. Police work, one of the most stressful occupations (Kukić et al., 2021), is a vivid example of this problem. Having in mind the circumstances of prolonged chronic stress and the potential of harming themselves, citizens, and even the whole society, a rigorous system of selection and monitoring of the work and health of current and future police officers has been established (Dopsaj et al., 2019b; Koropanovski et al., 2022; Milosevic & Milosevic, 2014; Papadakis et al., 2021). Despite that, we frequently witness maladaptive and malevolent behaviour of police officers (Alang et al., 2020; Grassi et al., 2019). As a possible solution, with the aim of better understanding and predicting prolonged stress reactions, broadening the domain of personality assessment with the most widespread personality models, such as the Big Five with the mental toughness and the Dark triad, was proposed (Papageorgiou et al., 2019; Weinberg et al., 2011). However, it is even less likely that honesty will be obtained in answering these questionnaires, which are pronounced by which and what kind of answers recommend or disqualify a candidate for police or similar work. So, mechanical and physiological characteristics correlations can be used to improve the selection procedure. Also, it is reasonable to expect even stronger correlations between researched variables to be found in future research with a broader population participating in entrance exams. Furthermore, this research shows potential for widening this investigation with various protocols for measuring and calculating different mechanical characteristics of handgrip until the "golden standard" is established when applying handgrip tests for the mentioned purposes.

Although our results do not support the idea that personality traits and characteristics can be accurately assessed with a handgrip strength test, the potential for using such parameters for screening purposes is obvious. Handgrip strength tests have often been used to assess physical fitness levels and overall body strength and health in athletes and the general population. With a few additional adjustments, the handgrip strength test can mark individuals with high, moderate and low expressions of numerous psychological characteristics. Such characteristics are, for example, aggression, mental toughness, or dimensions of the dark triad. Also, our study showed that the adjustments mentioned were not expensive or difficult to make.

Conversely, the obtained results also hold implications for further research on empathy in police and security populations. It further prompts an already raised question regarding the refinement of candidate selection processes. While conclusive answers necessitate longitudinal investigations, our findings suggest the potential value of exploring candidates' empathy, job performance, and responses to stress to raise the level of police and security work and the health of those who performed it.

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 generalizing findings. 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. This claim is significant to remember when it comes to regression analysis results. The deliberate selection of specific cohorts in this study also introduces limitations related to the generalizability of findings. The findings may not readily apply to other police, security or athletic cohorts or broader populations due to the focused nature of the sample. This fact restricts the ability to make sweeping conclusions about behaviours in the broader context, mainly when influenced by socio-demographic factors. At this point, most of our sample is from the athletic and physically fit population, so the obtained differences in genders do not reflect general differences but rather differences of these selected groups. 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. The influence of confounding variables of training and sports history, as well as the level of physical fitness, should also be taken into account. In some segments of this dissertation, it has been brought under control to a certain extent. However, this fact should be taken into account when interpreting the obtained results and when thinking about their generability. Also, in order to get a more accurate picture of the researched relationships, their greater control is needed.

Furthermore, psychological surveys open the door to response bias, as participants may not always provide accurate or candid responses. 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. Lastly, 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. These considerations are important for contextualizing the findings and understanding the scope of their applicability beyond the specific cohort studied. For this purpose, new experimental longitudinal studies are required. The good news is that the obtained results justify the investment of additional funds to repeat this research on a larger and more population-representative sample, even as experimental longitudinal studies.

8 CONCLUSION

This dissertation was conducted to explore the quantitative characteristics of the association of maximal force, rate of force development, endurance in the manifestation of force, time parameters of manifestation of given force characteristics, as well as index parameters of handgrip measured in isometric contraction, with the Big Five personality traits, mental toughness, dark triad, and empathy in adults, then determining the specificity of these relationships in different populations, as well as the metrological characteristics of the newly formed index variables.

In relation to the first auxiliary hypothesis which reads: there is an association between the characteristics of the maximum handgrip force and the psychological characteristics of the participants, based on the results of this dissertation, it can be concluded that it is fully confirmed because the existence of a statistically significant correlation ($p<0.05$) with Agr ($\rho=-0.14$), PV ($\rho=0.14$), MT ($\rho=0.22$), Psc ($\rho=0.18$), DT ($\rho=0.15$) in total sample (Table 7 and 8), Agr ($r=-0.42$), NV ($r=0.50$), Psc ($r=0.49$) in classic mode of isometric contraction in general population subsample (Table 11), Agr ($r=-0.42$), Ext ($r=-0.42$), NV ($r=0.53$), Psc ($r=0.52$), DT ($r=-0.40$) in impulse mode of isometric contraction in general population subsample (Table 12), Psc ($r=0.26$) in police students subsample (Table 18), EC ($\rho=-0.34$) in security population subsample (Table 20), Opn ($\rho=0.67$), PV ($\rho=0.82$), CNS ($\rho=0.58$) in female athletic sub sample (Table 26), Agr ($\rho=0.32$), Ext ($\rho=-0.26$), Nrt ($\rho=0.47$) in male athletic subsample (Table 27).

In relation to the second auxiliary hypothesis which reads: there is an association between the characteristics of maximum rate of force development and the psychological characteristics of the participants, based on the results of this dissertation, it can be concluded that it is fully confirmed because the existence of a statistically significant correlation ($p<0.05$) with MT ($\rho=0.17$), Psc ($\rho=0.23$), Nrc ($\rho=0.15$), DT ($\rho=0.22$) in total sample (Table 7 and 8), Agr ($r=-0.48$), Ext ($r=-0.40$), NV ($r=0.43$), Psc ($r=0.54$) in classic mode of isometric contraction in general population subsample (Table 11), Agr ($r=-0.41$), NV ($r=0.50$), Psc ($r=0.50$) in impulse mode of isometric contraction in general population subsample (Table 12), Psc ($r=0.38$), DT ($r=0.30$) in police students subsample (Table 18), Fnt ($\rho=-0.28$) , PT ($\rho=-0.31$) , EC ($\rho=-0.45$) in security population subsample (Table 20), Ext ($\rho=-0.37$), Opn ($\rho=0.57$), PV ($\rho=0.63$), Cns ($\rho=0.67$) in female athletic sub sample (Table 26), Agr ($\rho=0.31$), Ext ($\rho=-0.42$), Nrt ($\rho=0.56$), NV ($\rho=0.46$), Cns ($\rho=-0.42$) in male athletic subsample (Table 27).

About the third auxiliary hypothesis, which reads: there is an association between the characteristics of endurance in the manifestation of handgrip force and the psychological characteristics of the participants, based on the results of this dissertation, it can be concluded that it is mainly confirmed because lack of significant correlation but (Table 18) but at the same time existence of a statistically significant ($p<0.05$) interactions of $F_{rel}S$ and $F_{imp}50\%S_{rel}$ with Psc (Graph 38).

Concerning the fourth auxiliary hypothesis, which reads: the association between the mechanical characteristics of the handgrip and the psychological characteristics of the participants follow the same trend in different subsamples but are more intense in the athletic and police-security group compared to the general population based on the results of this dissertation, it can be concluded that it is mainly confirmed because the direct comparison of correlation intensity in trained and elite athletes (Table 26, table 27) but also a few exceptions when correlations in different subsamples are indirectly compared (Tables 7, 8, 11, 12, 18, 20, 26, and 27).

About the fifth auxiliary hypothesis which reads: mechanical characteristics of handgrip are predictors of psychological characteristics, based on the results of this dissertation, it can be concluded that it is fully confirmed because the existence of a statistically significant ($p<0.05$) regression models of Agr ($R^2=0.94$), Eks ($R^2=0.18$), Nrt ($R^2=0.74$), NV ($R^2=0.71$), MT ($R^2=0.46$), Psc ($R^2=0.29$), Nrc ($R^2=0.70$), and DT ($R^2=0.55$), in general population subsample (Tables 13, 14, 15, 16).

In relation to the sixth auxiliary hypothesis which reads: there are moderating effects of belonging to a specific subpopulation and the factor of the manifestation of the mechanical characteristics of the handgrip as well as the interaction of these factors on the psychological characteristics of the participants, based on the results of this dissertation, it can be concluded that it is fully confirmed because the existence of significant ($p < 0.05$) differences with large effect sizes in Psc [$F(2,46) = 3.86$; $p = 0.03$ $\eta2 = .14$] on factor $RFD_{rel}S$, interactions of $F_{rel}S$ and $RFD_{rel}S$ with MT and Nrc as well as interactions of FrelS and $F_{imp}50\%Srel$ with Psc in police students subsample (Graphs 36, 37, 38), differences in in the intensity and even direction of correlations between members of different groups within the subsample (Tables 7, 8, 11, 12, 18, 20, 26, and 27), as well as the manifestation of mechanical and psychological characteristics of members of different groups within the subsample (Tables 1, 2, 3, 4, 5, 6, 9, 10, 17, 19, 22, 23, 24, 25, and Graphs 3, 4, 5 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18 , 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 39, 40, 41).

Concerning the central hypothesis, which reads: there are associations between the mechanical characteristics of the handgrip and psychological characteristics, which are specific to the different populations of adults, it can be concluded that it is confirmed because the existence of statistically significant correlations (Tables 7, 8, 11, 12, 18, 20, 26, and 27), regression models (Tables 13, 14, 15, 16), differences (Tables 1, 2, 3, 4, 5, 6, 9, 10, 17, 19, 22, 23, 24, 25, and Graphs 3, 4, 5 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 39, 40, 41) and interactions (Graphs 36, 37, 38).

This dissertation confirmed the existence of so far known but also numerous unknown correlations (Tables 7, 8, 11, 12, 18, 20, 26, and 27) between handgrip mechanical with psychological characteristics, both in the total sample and numerous subsamples. Occupational and gender-specific patterns were also revealed (Tables 1, 2, 3, 4, 5, 6, 9, 10, 11, 12, 17, 18, 19, 20, 22, 23, 24, 25, 26, and 27 as well as Graphs 3, 4, 5 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 36, 37, 38, 39, 40, 41). Analyzing force-time curve parameters in handgrip tasks and different modes of isometric contraction, a novelty compared to previous similar research, proved to be a promising method, bringing numerous new insights about the researched relationships.

The results confirm the previous research and provide additional possibilities and explanations of the observed relationships. Attention was drawn to the potential peculiarities of the nervous system as a possible explanation for the obtained correlations. The potential of interpreting the obtained results was also shown in the light of the nature vs. nurture debate regarding the relationship between mechanical and psychological characteristics. In this way, the connection of motor behaviour and control with the broader context of behaviour was additionally established and illuminated.

The dissertation highlights the complex interplay between the mechanical and psychological characteristics of handgrips among different populations of adults. This investigation identifies intricate relationships that lead to distinct profiles of handgrip mechanical characteristics associated with behavioural determinants. These findings underscore the need for a critical reevaluation and refinement of candidate selection processes in police, national security, and similar professions. They also emphasize the importance of adopting a more nuanced approach considering physical and psychological factors in recruitment. Furthermore, our study brings to light a unique and noteworthy observation – a positive correlation between desirable physical attributes, represented by mechanical characteristics of the handgrip, and undesirable behavioural determinants in some populations, which is particularly important for future police and security students and workers. This intriguing relationship warrants in-depth exploration and careful examination within the broader context of occupational health and well-being. It poses important questions about the intricacies of human behaviour and the potential implications for training and professional development strategies in physically demanding and stressful occupations (law enforcement, firefighting, military, national security, and similar) and sports.

Regarding instant practical application, the obtained discrimination models (Table 28 and Graphs 42, 43, 44, 45) represent an effective tool for selection in sports.

Also, the results of this dissertation have relevant theoretical implications in understanding the nature of mental toughness, which further suggests the need to improve the recruitment process of tactical athletes and the possibility of training to improve the mental toughness of already selected candidates and workers in this field.

This dissertation has provided additional evidence for a link between skeletal muscles' mechanical and psychological characteristics. However, it also extends existing knowledge in several ways. We have uncovered new insights into the relationships stemming from an expanded understanding of these characteristics, which have not been previously explored. Specifically, we have identified the nuances of these connections within distinct populations. Our findings indicate that, under conditions that control for interfering variables, the relationships observed so far appear with significantly greater intensity. Therefore, this study has achieved its objectives and provides a strong foundation for future research.

We have outlined the directions and approaches for further investigation of this topic. The experiences gained from this study will help in the effective design of upcoming studies, as numerous methodological solutions have been tested, compared, and evaluated. This will ease the work for future researchers. In addition to its theoretical and research implications, this study demonstrates clear avenues for practical application of the results, some of which can be implemented immediately. At the same time, most still require additional research in order to be able to implement them in practice.

This research highlights, once again, the essential connection between movement and psychological well-being. A modern lifestyle that restricts physical activity poses significant risks not only to individual development but also to society as a whole. It is imperative for all professionals in the field of physical culture to engage in further research, prevention efforts, and to combat these concerning trends.

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10.1 Figures and Graphs

1. Figure 1. left: Front of Sensory Homunculus. Mpj29. Creative Commons Attribution-Share Alike 4.0 International. https://commons.wikimedia.org/wiki/File:Front_of_Sensory_Homunculus.gif. Retrived 01.03.2023.
2. Figure 1. right: BA312 - Primary Somatosensory Cortex - lateral view - with homunculus. Polygon data were generated by Database Center for Life Science(DBCLS). SC-BY-SA-2.1-jp. https://commons.wikimedia.org/wiki/File:BA312_-_Primary_Somatosensory_Cortex_-_lateral_view_-_with_homunculus.png. Retrived 01.03.2023.\

1. Graph 1. Record of the force-time curve in the classical modality of isometric muscle contraction of the hand. Dopsaj, M., Klisarić, D., Kapeleti, M., Ubović,M., Rebić, N., Piper, N., Trikoš. B., Stančić, D., Samardžić, N., Rajković, A., Nikolić, D., Nikolić, M., Vasiljević, M., Božović, B. With author permision.
2. Graph 2. Record of the force-time curve in the impulse modality of isometric muscle contraction of the hand. Dopsaj, M., Klisarić, D., Kapeleti, M., Ubović, M., Rebić, N., Piper, N., Trikoš. B., Stančić, D., Samardžić, N., Rajković, A., Nikolić, D., Nikolić, M., Vasiljević, M., Božović, B. With author permision.
3. Graphs 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 23 and 44. Adapted printouts from software jamvi and spss. Miloš Milošević.

11 APPENDICES

11.1 Ethic committee approval

UNIVERZITET U BEOGRADU
FAKULTET SPORTA I FIZIČKOG VASPITANJA

РЕПУБЛИКА СРБИЈА
Универзитет у Београду
Факултет спорта и физичког васпитања
02 Бр 484-2
24.02. 2011 год
БЕОГРАД, Благоја Паровића 156

Saglasnost Etičke komisije Fakulteta sporta i fizičkog vaspitanja Univerziteta u Beogradu za realizaciju projekta „Efekti primenjene fizičke aktivnosti na lokomotorni, metabolički, psiho-socijalni i vaspitni status populacije R Srbije“ (br. 47015)

Na osnovu uvida u plan projekta „Efekti primenjene fizičke aktivnosti na lokomotorni, metabolički, psiho-socijalni i vaspitni status populacije R Srbije“ (br. 47015, rukovodilac doc. dr Milivoj Dopsaj), a koji je odobren od Ministarstva za nauku i tehnološki razvoj R Srbije u okviru ciklusa nacionalnih naučnih projekata za period 2011-2014. godine, Etička komisija Fakulteta sporta i fizičkog vaspitanja Univerziteta u Beogradu iznosi mišljenje da se, kako u koncipiranju tako i u planiranju realizacije istraživanja i primene dobijenih rezultata, polazilo od principa koji su u skladu sa etičkim standardima, čime se obezbeđuje zaštita ispitanika od mogućih povreda njihove psiho-socijalne i fizičke dobrobiti.

U skladu sa iznetim mišljenjem Etička komisija Fakulteta sporta i fizičkog vaspitanja Univerziteta u Beogradu daje saglasnost za realizaciju istraživanja planiranih projektom „Efekti primenjene fizičke aktivnosti na lokomotorni, metabolički, psiho-socijalni i vaspitni status populacije R Srbije“ (br. 47015, rukovodilac doc. dr Milivoj Dopsaj) a koji je odobren od Ministarstva za nauku i tehnološki razvoj R Srbije u okviru ciklusa nacionalnih naučnih projekata za period 2011-2014. godine.

Za Etičku komisiju

red. prof. dr Đušan Ugarković

van. prof. dr Vladimir Koprivica

РЕПУБЛИКА СРБИЈА
ФАКУЛТЕТ СПОРТА И ФИЗИЧКОГ ВАСПИТАЊА
02 бр. 484-2
07.3. 2011 год.
БЕОГРАД Благоја Паровића 156

CERTIFIED TRANSLATION FROM SERBIAN INTO ENGLISH

GORDANA VEKARIĆ

Stamp: Republic of Serbia, University of Belgrade
Faculty of Sport and Physical Education
02 no. 484-2
24 February 2011
Belgrade, Blagoja Parovica 156

UNIVERSITY OF BELGRADE
FACULTY OF SPORT AND PHYSICAL EDUCATION

APPROVAL OF THE ETHICS COMMITTEE OF THE FACULTY OF SPORT AND PHYSICAL EDUCATION, UNIVERSITY OF BELGRADE FOR EXECUTION OF THE PROJECT "EFFECTS OF THE APPLIED PHYSICAL ACTIVITY ON LOCOMOTOR, METABOLIC, PSYCHO-SOCIAL AND EDUCATIONAL STATUS OF THE POPULATION OF THE REPUBLIC OF SERBIA" (No. 47015)

Based on the inspection of the plan of the project "Effects of the Applied Physical Activity to Locomotor, Metabolic, Psycho-Social and Educational Status of the Population of the Republic of Serbia" (No. 47015, project leader assistant prof. Milivoj Dopsaj, PhD), approved by the Ministry of Science and technological development of the Republic of Serbia within the cycle of national scientific projects for the period from 2011 to 2014, the Ethics Committee of the Faculty of Sport and Physical Education of the University of Belgrade considers that both in research conception and execution planning as well as in the application of the obtained results, from its beginning the project has been undertaken based on the principles which comply with ethical standards, ensuring thus protection for human subjects from possible violation of their psycho-social and physical benefit.

In conformity with the aforesaid opinion, the Ethics Committee of the Faculty of Sport and Physical Education of the University of Belgrade has granted the approval for realization of the research planned by the project "Effects of the Applied Physical Activity to Locomotor, Metabolic, Psycho-Social and Educational Status of the Population of the Republic of Serbia" (No. 47015, project leader Assistant prof. Milivoj Dopsaj, PhD) which is approved by the Ministry of Science and technological development of the Republic of Serbia within the cycle of national scientific projects for the period from 2011 to 2014.

For the Ethics Committee
full prof. Dušan Ugarković, signed
associate prof. Vladimir Koprivica, signed
(Stamp)

END OF TRANSLATION

№ 178/11

I CERTIFY THAT this document which has been given to me in Serbian language, has been correctly translated into English.

IN WITNESS WHEREOF I have hereunto set my hand and seal, this 1st day of March 2011 in Beograd.

My appointment is permanent.

Gordana Vekarić, Sworn to Court
Interpreter for English and Italian language
Milutina Milankovića 130/33, Beograd, Serbia
tel:++381 11 711 03 38
e-mail:gocaa@eunet.rs

Appointed by the Decision of the Republic Minister of Justice,
Belgrade, Serbia № 74-02-46/91-03

11.2 Published papers

ОРИГИНАЛНИ НАУЧНИ ЧЛАНАК

УДК:613.25:572.087
DOI: 10.5937/fizkul%v-32145

АНАЛИЗА ПРОЦЕНТА ТЕЛЕСНИХ МАСТИ, МЕРЕНИХ МЕТОДОМ МУЛТИКАНАЛНЕ БИОИМЕДАНЦЕ, КОД СТАНОВНИКА РЕПУБЛИКЕ СРБИЈЕ

Миливој Допсај[1], Стефан Марковић[2], Анастасија Коцић[2], Александра Домановић[2], Милош Милошевић[2], Александар Пајкић[2], Фарис Ђуркић[2], Александар Вићентијевић[2], Марко Ерак[2], Бранислав Божовић[2]

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[2]Факултет спорта и физичког васпитања, Универзитет у Беогаду, студент ДАС, Србија

Сажетак

Циљ ове студије је дефинисање популационих показатеља процента масти у телу (ПБФ) становништва Републике Србије. Узорак је чинило 8.145 испитаника, од чега 3.051 (37.5%) су биле жене просечне старости 32.0±9.8 година, а преосталих 5.094 (62.5%) су били мушкарци старости 32.9±11.3 година. Просечна вредност ПБФ за субузорак жена била је 28.46 ± 9.19%, а за субузорак мушкараца 18.00± 7.98%. Резултати факторске анализе варијансе показали су да постоји статистички значајна разлика ($p<0.001$) вредности ПБФ у односу на пол ($F=1243.719$) и узраст испитаника ($F=508.469$), као иинтеракција фактора пол и узраст ($F=22.593$). Регресиона анализа је показала да узраст код жена објашњава 82.09, а код мушкараца 85.08 процената варијансе испитиване варијабле у функцији узраста, с тим да је функција која најбоље објашњава варијансу ПБФ код жена имала линеаран, а код мушкараца нелинеаран, тј. полиномски облик. И пол и узраст су означени као фактори који имају утицај за прекомерно повећање ПБФ, док су као посебно ризична група, у којој су прекомерне вредности ПБФ најзаступљеније, издвојене жене старије од 50 година (просечна преваленција предгојазних и гојазних је 37.81 и 23.89%, респективно), као и мушкарци старији од 60 година (просечна преваленција предгојазних и гојазних је 25.48 и 38.36%, респективно).

Кључне речи: ПРЕКОМЕРНА УХРАЊЕНОСТ / ПРЕВАЛЕНЦИЈА ГОЈАЗНОСТИ /ТРЕНД ПРОМЕНЕ / ПРЕВЕНЦИЈА

Спортивная тренировка

DOI: 10.14529/hsm210111

ASSOCIATION OF MENTAL TOUGHNESS WITH COMPETITIVE SUCCESS OF YOUNG FEMALE BASKETBALL PLAYERS

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Aim. The aim of this study was to investigate the association between mental toughness and competitive performance of young female basketball players. **Materials and methods.** The sample of 38 female basketball players who were under 16 years old and played for the four best-ranked basketball clubs in the highest league of Serbia was recruited. Their mental toughness was evaluated via mental toughness questionnaire (MTQ48) and their performance index rating was evaluated by their season statistics obtained from the official web page of the Serbian Basketball Association. **Results.** Correlation analysis revealed a significant association of performance index rating with mental toughness and its constituents such as control and confidence

Int. J. Morphol.,
39(6):1694-1700, 2021.

Profile for Body Fat Percentage of Serbian Working Population, Aged from 18 to 65, Measured by Multichannel Bioimpedance Method

Perfil del Porcentaje de Grasa Corporal de la Población Activa Serbia, de 18 a 65 Años, Medido por el Método de Bioimpedancia Multicanal

Milivoj Dopsaj[1,4]; Zoran Pajic[1]; Anastasija Kocic[1]; Marko Erak[1]; Aleksandar Pajkic[1,2]; Aleksandar Vicentijevic[1]; Milos Milosevic[1,3] & Branislav Bozovic[1]

DOPSAJ, M.; PAJIC, Z.; KOCIC, A.; ERAK, M.; PAJKIC, A.; VICENTIJEVIC, A.; MILOSEVIC, M. & BOZOVIC, B. 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, 2021.

SUMMARY: Obesity prevalence and trends of PBF related to age were defined on a sample of 8100 people among whom, 4955 were male (Age = 31.2 ± 10 yr) and 3145 were female (Age = 32.1 ± 11.3 yr). Body structure measurements were performed using a standardized method of multichannel bioimpedance analysis (BIA), using a body structure analyzer – InBody 720. The total sample was divided into two subsamples according to sex, where every subsample was divided into five different age groups.The mean PBF values of the Male total sample were 18.2 ± 8.0 % and the female total sample was 28.3 ± 9.2 %. Results of Kruskal-Wallis ANOVA with Dwass-Steel-Critchlow-Fligner post-hock showed that there are statistically significant differences ($p < 0.001$) between all age groups among themselves except groups 50 - 60 and 60 - 65 ($p = 0.09$). Analysis of obesity prevalence according to the PBF indicator in different age groups revealed the existence of statistically significant ($p < 0.001$) trends of increasing obesity with age, both in men and women. Based on the result of this study, it can be concluded that most of the Serbian working population are in the range of normal PBF values, excluding the male 30-39.9 yr and female 60-65 yr age categories as groups which are more prone to obesity levels.

KEY WORDS: Obesity; Prevalence; Body Composition; Body Structure.

INTRODUCTION

It is well known that the modern lifestyle is characterized by sedentariness and insufficient physical activity (Rakic *et al.*, 2019). The increasing use of new technologies has been one of the main factors influencing

Developing the system for measuring and controlling the status of body composition has become an increasingly popular tool for monitoring the general health status (Gába *et al.*, 2015), or health status of a specific population, such as

Milos Milosevic

Movement As Personality Trait Indicator - What Can Kinesiology Offer to The Psychology of Individual Differences

Faculty of Physical Education and Sports Management, Singidunum University, Belgrade, Serbia
Faculty of Sport and Physical Education, University of Belgrade, Serbia
Integrated Science Association (ISA), Universal Scientific Education and Research Network (USERN), Belgrade, Serbia

The aim of this presentation is informs the scientific community about research and investigation of the relationship between motor and psychological characteristics, i.e. about examinations of different dimensions of muscle force production as a physiological correlate of personality traits as well as evaluation of the value of measuring movement properties as indicators for objective assessment of personality characteristics. Although the underlying assumption of trait theories is that numerous tendencies for behaving in a certain way can be described through a limited number of personality traits that are largely an expression of the peculiarities of the nervous system functioning, most influential personality inventories assess personality traits based on self-assessment. This practice is especially questionable when the respondents because of subjectivity or lack of ability can't give valid self-assessments themselves or in competitive situations, such are entrance exams or job interviews are not motivated to give honest answers about their insights. That is why numerous dimensions of muscle force such as maximal force, rate of the force development, endurance in force and similar are explored as potential physiological correlates of personality traits such as Aggressiveness, Extraversion, Neuroticism, Negative Valence, Openness, Positive Valence, Conscientiousness, Mental toughness, Machiavellianism, Psychopathy, Narcissism, Empathy and so on. The second line of the research refers to the possibility of estimating the pace of early cognitive development using a battery of motor tests. In this presentation, the

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Original scientific paper

Psychometric Properties of the Serbian Version of Mental Toughness Inventory and Dark Triad Dirty Dozen in Police Students

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Abstract: Police work is a stressful occupation, where officers are exposed to chronic and intense stressors. When it comes to understanding and predicting reaction to prolonged stress, it has been shown that there is more to personality than what can be captured by the most widespread personality models. Adding Mental Toughness as the capacity to tolerate and overcome stress at work, as well as the Dark Triad as a tendency for malevolent behaviour, to the traditional model of assessing the personality of a police officer can improve the prediction of important outcomes. The aim of this paper was to examine the psychometric properties of the Serbian translations for the Mental Toughness Inventory (MTI) and the Dark Triad Dirty Dozen (DTDD) in a population of police students. The research was conducted on a sample of 92 students in their first and second years at the University of Criminal Investigation and Police Studies. Considering the specificity of the sample, both instruments showed good reliability (Cronbach's Alpha Based on Standardized Item $\alpha = 0.81$ for MTI and $\alpha = 0.84$ for DDTD); factor structure was confirmed for the MTI ($\chi^2 = 51.5$, $p < 0.001$, CFI = 0.864) and DTDD ($\chi^2 = 105$, $p < 0.001$, CFI = 0.886) as well as convergent ($r = -.384$, $p < 0.01$ between Mental toughness, and Machiavellianism). Although deviations from the normal distribution were obtained, having in mind the rigor of psychological and physical selection into the Police University, the obtained psychometric properties of the MTI and DTDD were acceptable and we recommend the instruments for further usage.

Keywords: mental toughness, Narcissism, Machiavellianism, psychopathy, validation, police.

Graphical abstract

sciendo

Original Paper

Biomedical Human Kinetics, 16, 131–138, 2024
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Mental toughness and empathy as match performance predictors of high-level female basketball players

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Abstract

Study aim: The aim of this study was to explore empathy and mental toughness as predictors of match performance of young basketball players.
Material and methods: The correlation design was used in order to meet the research goals. The research was conducted on a sample of 40 female basketball players, with average age of 16.15 ± 1.02 years, members of the four best teams of the National First Women's Cadet League. Half of the players in the sample were also national team members. The independent variables empathy and mental toughness were assessed with the Interpersonal Reactivity Index and Sports Mental Toughness Questionnaire. The dependent variable match performance was assessed through match performance analysis based on indicators from official league statistics by calculating the performance index rating (PIR).
Results: The results of the hierarchical multiple regression analysis showed that by adding empathy to the model of mental toughness, the percentage of PIR variance explained increased from 21% to 46%.
Conclusion: Adding empathy to the model of mental toughness increased its predictive value. The model of mental toughness and empathy, as predictors of match performance of young basketball players, was found to be very effective. The results are not unambiguous and indicate the need for further research in this area, as it could have a positive impact on the selection system in sport. Also, the research represents a step towards greater integration of sports and collective creativity studies.

Key words: Match performance – Basketball players – Empathy – Mental toughness – SMTQ – Collective creativity

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Article

Exploring the Interplay of Handgrip Neuromuscular, Morphological, and Psychological Characteristics in Tactical Athletes and General Population: Gender- and Occupation-Based Specific Patterns

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Abstract: Background/Objectives: The correlation of handgrip strength (HGS) and morphological characteristics with Big Five personality traits is well documented. However, it is unclear whether these relationships also exist in highly trained and specialized populations, such as tactical athletes, and whether there are specific differences compared to the general population. This study aimed to explore the interplay of handgrip neuromuscular, morphological, and psychological characteristics in tactical athletes and the general population of both genders. Methods: The research was conducted on a sample of 205 participants. A standardized method, procedure, and equipment (Sports Medical solutions) were used to measure the isometric neuromuscular characteristics of the handgrip. Basic morphological characteristics of body height, body mass, and body mass index were measured with a portable stadiometer and the InBody 720 device. Psychological characteristics were assessed with the Mental Toughness Index and Dark Triad Dirty Dozen questionnaires. Results: Numerous significant correlations were obtained, as well as differences between tactical athletes and the general population of both genders. The most prominent correlations were between the excitation index with Psychopathy and the Dark Triad ($\rho = -0.41, -0.39$) in female tactical athletes, as well as Neuroticism with body height, maximal force, and the maximum rate of force development in the male general population ($\rho = 0.49, 0.43, 0.41$). The obtained results also revealed gender and occupational specific patterns of researched relationships. Conclusions: Although the results of this study indicated the possibility of the existence of correlations between handgrip neuromuscular, morphological, and psychological characteristics in tactical athletes of both genders, nevertheless, at the moment, there is not enough solid evidence for that. That is why new research is needed. An analysis of muscle contractile and time parameters as neuromuscular indicators in the HGS task proved to be a possible promising method, which brought numerous new insights about the researched relationships. For practical application in the field, we propose including Mental Toughness and the Dark Triad traits in the selection process for future police officers and national security personnel based on the obtained results.

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CANDIDATE'S BIOGRAPHY

Miloš Milošević was born in 1980 in Belgrade. Graduated in 2007 at the Faculty of Philosophy, University of Belgrade, majoring in psychology. He received his doctorate in 2019 at the Faculty of Dramatic Arts, University of Arts in Belgrade, Department of Theory of Dramatic Arts, Media and Culture. Since 2020, a student of doctoral studies at the Faculty of Physical Education and Sports, where in 2021 and 2022 he was declared the student of the year for doctoral studies.

Gained work experience as an educator at the Media Education Center (2006-2009); school psychologist at XV Belgrade High School (2009-2017); guest lecturer at the College of Electrical Engineering and Computer Science of Vocational Studies in Belgrade (2015-2016); lecturer at the Faculty of Sports of the University "Union - Nikola Tesla" (2016-2017) and assistant at the Faculty of Physical Culture and Sports Management, University "Singidunum" (2017-2019). In 2019, he was elected to the position of assistant professor at the Faculty of Philology, "Sinergija" University in Bjeljina. In 2020, he was elected to the position of assistant professor at the Faculty of Physical Education and Sports Management, "Singidunum" University in Belgrade. Since 2020, member of the international association of researchers Universal Scientific Education and Research Network. In 2022, he was hired as an external associate for interdisciplinary master's studies at the University of Arts in Belgrade, and master's studies at the Faculty of Dramatic Arts, University of Arts in Belgrade. From 2023, head of the cultural policy and cultural management study program of the UNESCO Department of Cultural Policy and Management, University of Arts in Belgrade.

Collaborator on several scientific research and professional projects, author and co-author of over 90 published scientific research results in the field of social, humanistic and medical sciences.

Изјава о ауторству

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