UNIVERSITY OF NIŠ
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LATERAL DOMINANCY, FORCE VARIABILITY AND ACTIVATION OF MOTOR UNITS IN UNILATERAL AND BILATERAL SPORTS

DOCTORAL DISSERTATION

Niš, 2022

УНИВЕРЗИТЕТ У НИШУ

ФАКУЛТЕТ СПОРТА И ФИЗИЧКОГ ВАСПИТАЊА

Ивана Д. Петровић

ЛАТЕРАЛНА ДОМИНАНТНОСТ, ПРОМЕНЉИВОСТ МИШИЋНЕ СИЛЕ И АКТИВАЦИЈА МОТОРНИХ ЈЕДИНИЦА КОД УНИЛАТЕРАЛНИХ И БИЛАТЕРАЛНИХ СПОРТОВА

ДОКТОРСКА ДИСЕРТАЦИЈА

Ниш, 2022.

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Data on Doctoral Dissertation

Mentor:	Daniel Stanković, PhD, Full Professor aт University of Niš, Faculty of Sports and Physical Education
Title:	LATERAL DOMINANCE, FORCE VARIABILITY AND ACTIVATION OF MOTOR UNITS IN UNILATERAL AND BILATERAL SPORTS

Summary:

Aim: The aim of this study was to determine the differences in muscle force control and motor unit activation between the dominant and non-dominant lower extremity within and between groups of unilateral and bilateral sports, as well as to determine the differences in muscle force control and motor unit activation depending on the characteristics of unilateral and bilateral sports.

Methods: Thirty-six young adults performed low to moderate isometric contractions (2.5, 5, 10, 20, 30, 40, 50 and 60% of maximal voluntary contraction, MVC) in the dominant and non-dominant lower limb, at three different ankle angles (75°, 90°: anatomical position and 105°), which corresponds to the short, medium and long length of the anterior part of the tibialis muscle. At the same time, the discharge characteristics of several motor units in the *tibialis anterior* were recorded.

Results: There are no statistically significant differences in muscle control and motor unit activation between the dominant and non-dominant extremities in the unilateral group of athletes. In the bilateral group of athletes, there is no statistically significant difference in muscle force control between the extremities, but there is one in the variables that defined the activation of motor units. The mean value of motor unit discharge was discharged at lower values in the non-dominant leg compared to the dominant one, except at the force level of 30% MVC. In muscle force control, there is a statistically significant difference between the unilateral and bilateral group of athletes, where the bilateral group of athletes exhibits greater force variability at 2.5% MVC, while the unilateral group of athletes exhibits greater force variability at 60% MVC and greater effective force at all levels of force in relation to the bilateral group. In the activation of motor units, the bilateral group of athletes show higher values of relative and absolute amplitude of variability of the interspike interval of the motor unit in both extremities at all levels of force and at all muscle lengths compered to the unilateral one, while the average value of motor unit discharge in the dominant leg was inconstant at force levels of 2.5% to 30% MVC. Finally, runners exhibit greater absolute variability of force and mean discharge rate of motor units in both extremities compared to cyclists, while volleyball players exhibit greater relative and absolute variability of force in both extremities compared to weightlifters and rowers, as well as higher values of mean discharge rate of motor units in the dominant leg.

Conclusion: There is no difference in the control of muscle force between the lower extremities in healthy athletes. There is a tendency that the training process may influence different effects of neural control of the CNS between the extremities in sports with excessive use of one side of the body. Finally, the results showed that the requirements of sport specificity affect the change in muscle force control and CNS neurocontrol. Additional research is needed to confirm these results and expand the knowledge about the impact of the training process on muscle force control and motor unit behavior in other sports.

Scientific field:	Physical Education and Sports
Scientific discipline:	Sport
Key words:	Dominance; Force Variability; High-density EMG; Motor Unit; Tibialis Anterior
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Наслов: ЛАТЕРАЛНА ДОМИНАНТНОСТ, ПРОМЕНЉИВОСТ МИШИЋНЕ СИЛЕ И АКТИВАЦИЈА МОТОРНИХ ЈЕДИНИЦА КОД УНИЛАТЕРАЛНИХ И БИЛАТЕРАЛНИХ СПОРТОВА

Резиме:

Циљ: Циљ овог истраживања био је да се утврде разлике у контроли мишићне силе и активацији моторних јединица између доминантног и недоминантног доњег екстремитета унутар и између група унилатералних и билатералних спортова, као и да се утврде разлике у контроли мишићне силе и активацији моторних јединица у зависности од карактеристика унилатералних и билатералних спортова.

Методе: Тридесет шест младих одраслих особа, спортиста, извело је ниске до умерене изометријске контракције (2.5, 5, 10, 20, 30, 40, 50 и 60% максималне добровољне контракције, MVC), доминантним и недоминантним доњим екстремитетом, под три различита угла скочног зглоба (75°, 90°: анатомски положај и 105°), што одговара краткој, средњој и дугој дужини предњег дела тибијалног мишића. Истовремено су забележене карактеристике пражњења једног дела моторних јединица у тибијалном мишићу.

Резултати: Не постоје статистички значајне разлике у контроли мишићене силе и активацији моторних јединица између доминантног и недоминантног екстремитета код унилатералне групе спортиста. Код билатералне групе спортиста, не постоји статистички значајна разлика у контроли мишићне силе између екстремитета, али постоји у једној варијабли која дефинише активацију моторних јединица. Средња вредност пражњења моторне јединице се празнила на нижим вредностима у недоминантној нози у односу на доминантну, осим на нивоу силе 30% MVC. У контроли мишићне силе постоји статистички значајна разлика између унилатералне и билатералне групе спортиста, где билатерална група спортиортиста испољава већу променљивост силе на нивоу силе од 2.5%, док унилатерална група спортиста испољава већу промењивост силе на нивоу силе од 60%, као и већу ефикасну силу на свим нивоима силе у односу на билатералну групу. У активацији моторних јединица билатерална група спортиста испољава више вредности релативне и апсолутне амплитуде промењивости међуимпулсног интервала моторне јединице у оба екстремитета на свим нивоима силе и при свим дужинама мишића у односу на унилатералну, док је средња вредност пражњења моторне јединице у доминантној нози код билатералне групе спортиста била нестална на нивоима силе од 2.5 до 30% MVC. На крају, тркачи испољавају већу апсолутну промењивост силе и средњу брзину пражњења моторних јединица код оба екстремитета у односу на бициклисте, док одбојкаши испољавају већу релативну и апсолутну промењивост силе у оба екстремитета у односу на дизаче тегова и веслаче, као и веће вредности средње брзине пражњења моторне јединице у доминантној нози.

Закључак: Разлика у контроли мишићне силе између доњих екстремитета код здравих спортиста не постоји. Постоји тенденција да се тренажним процесом може утицати на другачије деловање неуралне контроле CNS-а између екстремитета у спортовима са наглашеним коришћењем једне стране тела. И на крају, резултати су показали да захтеви специфичности спорта утичу на промену у контроли мишћне силе и неуроконтроли CNS-а. Потребно је спровести додатна истраживања која би потврдила ове резултате и проширила сазнање о утицају тренажног процеса на контролу мишићне силе и понашање моторних јединица у другим спортовима.

Научна област:	Физичко васпитање и спорт
Научна дисциплина:	Спорт

Кључне речи:	доминантност, промењивост силе, EMG високе густине; моторнс јединица; предњи тибијални мишић
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CONTENT

List of published research

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2. **Petrović, I.**, Stanković, D., & Petrović, I. (2018). Relationship of Aerobic Abilities and Agility with Military Physical Tasks in the Serbian Armed Forces. In Pantelić, S. (Ed.), *XXI International Scientific Conference „FIS COMMUNICATIONS 2018"in physical education, sport and recreation",* Book of proceedings (pp. 215-220). Niš: Faculty of Sport and Physical Education.
3. Stanković, D., **Petrović, I.**, & Petrović, I. (2018). Influence of Muscular Strength on Military Physical Tasks in the Serbian Armed Forces. In Pantelić, S. (Ed.), *XXI International Scientific Conference „FIS COMMUNICATIONS 2018"in physical education, sport and recreation",* Book of proceedings (pp. 184-190). Niš: Faculty of Sport and Physical Education.
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5. **Petrović, I.**, & Marinković, M. (2018). Effects of Different Types of Exercise Programs on Arterial Blood Pressure of the Elderly. *Facta Universitatis, Series: Physical Education and Sport, 16*(4), 725-737.
6. Stanković, D., Raković, A., Petković, E., **Petrović, I.** & Savanović, V. (2019). Analysis of Somatotype of Top Young Race Walkers by Means of the Health-carter Method. *Facta Universitatis, Series: Physical Education and Sport, 17*(3), 609-618.
7. **Petrović, I.** (2020). Does the female athlete triad really exist? *Facta Universitatis, Series: Physical Education and Sport, 18*(1), 037-048.
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10. **Petrović, I.**, Amiridis, A.G., Holobar, A., Trypidakis, G., Kellis, E., & Enoka, RM (2022). Leg Dominance Does Not Influence Maximal Force, Force Steadiness, or Motor Unit Discharge Characteristics [in print]. *Medicine & Science in Sports & Exercise.* **IF=5.411**

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1. **Petrović, I.**, Amiridis, Trypidakis, G., A.G., Holobar, A., & Enoka, RM (2022). Type of Training does not Influence Maximal Force, Force Steadiness and Neural Deive During Dorsiflexion [in preparation]. *Journal of Sport and Health Science.*

Manuscript in preparation

2. **Petrović, I.**, Amiridis, A.G., Stanković, D., Holobar, A., & Enoka, RM (2021). Force Fluctuations and Motor Unit Activity in Left-dominant Humans During Dorsiflexion [in preparation]. *Archives of Physical Medicine and Rehabilitation.*
3. **Petrović, I.**, Amiridis, A.G., Holobar, A., & Enoka, RM (2021). Effest of Leg Dominance and Muscle Lenght on Maximal Force, Force Steadiness, Off-direction Forces and Motor Units Discharge Characteristics [in preparation].

LIST OF ABBREVIATIONS

CNS	Central neurvous system
LD	Lateral dominance
fMRI	Functional magnetic resonance imaging
M1	Primry motor cortex
SMA	Supplementary motor area
MU	Motor unit
TA	Musculus tibialis anterior
EMG	Electromyography
HDsEMG	High density surface electromyography

1. INTRODUCTION

It is in the nature of the human body to contain paired organs whose role is to function in a similar way, either through cooperation or separately. Through the evolution of humans, it has been noticed that in the human population there is a more pronounced use of one side of the body (one arm, foot, eye, ear, leg) (Corballis, 2009). A large number of scientists have tried to discover the reason for this natural, and at the same time spontaneous, preference for one side of the body. The reasons for that are of a different nature, they refer to the desire to understand the work of the human system, its proper development, as well as the possibility of correction. Seen through the path of research, much of the research has been based on monitoring the work of the central nervous system (CNS). Two theoretical aspects have emerged: one group of authors believes that the cerebral cortex of both hemispheres affects the control of most voluntary movements on the opposite side of the body where the so-called dominant hemisphere is the one that controls a given function. For example, a spontaneous use of the right hand is an expression of the dominance of the motor function of the left hemisphere (Kagerer, Summers, & Semjen, 2003; Maki, Wong, Sugiura, Ozaki, & Sadato, 2008; Pool, Rehme, Fink, Eickhoff, & Grefkes, 2014; Serrien, Ivry, & Swinnen, 2006; Toga, & Thompson, 2003; Volz, Eickhoff, Pool, Fink, & Grefkes, 2015). Viewed from another aspect, giving preference to one side of the body is considered to result from the frequent use of one side of the body where the necessary motor skills have been developed to perform a particular task (Maupas, Datie, Martinet, & André, 2002; Serrien et al., 2006).

People whose dominance is more pronounced with the right hand are called right-handed, while people who are more skilled with the left hand are called left-handed people. Previous studies have shown that 96% of the population is right-handed and that in these individuals the dominance of the left hemisphere is pronounced, while in left-handed people in the largest part of the population the left hemisphere is also dominant, and in a smaller part of the population it is the right hemisphere (Debbarma, & Mehta, 2018; Toga, & Thompson, 2003). Considering the dominance of the lower extremities, this percentage where the right side is dominant is smaller, and the dominance of the right leg is manifested by 60% to 82% of the population, where 80% have a dominant arm and leg on the same side (Taylor, Strike, & Dabnichki, 2007; Zouhal et al., 2018). On the other hand, the research Čuk, Leben-Seljak, and Štefančič (2001) points to the fact that only 25% to 45% exhibit the dominance of the right side in the lower limb movements and that the dominance is much more dominant in the upper extremities than in the lower ones (Volz et al., 2015). The authors believe that the non-dominant leg is responsible for maintaining balance when landing or maintaining a stable upright posture, as well as the supporting leg in dominant activities which is as a leader in jumping, dribblongs and performing other tasks (Gabbard, & Hart, 1996; Peters, 1988).

The explanation for limb dominance on the same side of the body is explained as a consequence of brain efficiency to reduce duplication of simultaneous neural hemisphere activation (Corballis, 2009; Ghirlanda, Frasnelli, & Vallortigara, 2009), which supports the previous research where at maximum contraction of both extremities at the same time, bilaterally, produced less force and activation of motor units caused by an uneven organization of the neuromotor system when both cerebral hemispheres are activated simultaneously in relation to the performance of individual, unilateral tasks (Howard, & Enoka, 1991).

The demands of professional work or sports require the use of one side of the body more than the other. One of the requirements is to achieve better success in sports where athletes are often expected to neutralize the existence of dominance of one side of the body, and give preference to the non-dominant side that will allow athletes to move more efficiently than the rival, such as football, basketball and volleyball (Fort-Vanmeerhaeghe, Montalvo, Sitjà-Rabert, Kiefer, & Myer, 2015; Sinsurin, Srisangboriboon, & Vachalathiti, 2017; Zouhal et al., 2018). On the other hand, where the requirements of professional work require overemphasized use of one side of the body, there may also be a violation of muscular balance in strength between the two halves of the body (Croisier, 2004), which can further affect the achievement of professionals and sports results where the possibility of increasing the risk of injury is created (Croisier, 2004) and postural defects possibly earned (Jaszczak, 2008).

In previous studies, monitoring muscle variability has been shown to be a successful method for identifying asymmetry in muscle force between two limbs (Adam, De Luca, & Erim, 1998; Oshita, & Yano, 2010, 2011; Perry, Carville, Smith, Rutherford, & Newham, 2007; Skelton, Kennedy, & Rutherford, 2002). Performing static and precise movements depends on good muscle stability, and monitoring the variability of muscle force during isometric contractions has proven to be a good indicator of muscle ability (Missenard, Mottet, & Perrey, 2009; Tracy, 2007; Tracy, Dinenno, Jorgensen, & Welsh, 2007). When performing a voluntary isometric contraction, it is not possible to produce a stable force completely where the intensity of the contraction influences a certain amplitude of force variation in a muscle, known also as tremor (Elble, & Randall, 1978; Galganski, Fuglevand, & Enoka, 1993; Vaillancourt, & Russell, 2002), and in this way muscle fatigue can be successfully identified (Hunter, & Enoka, 2003; Maluf, & Enoka, 2005).

More precisely, many authors followed the activation of motor units in the muscle to identify variability in muscle force and thus tried to explain the impact of neurocontrol on external parts of the body (Barry, Pascoe, Jesunathadas, & Enoka, 2007; Galganski et al., 1993; Jones, Hamilton, & Wolpert, 2002; Laidlaw, Bilodeau, & Enoka, 2000; Moritz, Barry, Pascoe, & Enoka, 2005; Negro, Holobar, & Farina, 2009; Patten & Kamen, 2000; Taylor, Christou, & Enoka, 2003; Tracy, Maluf, Stephenson, Hunter, & Enoka, 2005; Vaillancourt, Larsson, & Newell, 2003). Research has shown that the variability of the force that occurs during muscle contraction is the consequence of recruiting new motor units (McAuley, Rothwell, & Marsden, 1997) and how fast they activate (Christakos, Papadimitriou, & Erimaki, 2006). Some of the authors that studied dominancy have found the difference in the motor units' discharge rate between extremities when performing isometric contractions (Adam et al., 1998), as well as the difference in the number of activated motor units among trained and untrained participants (Semmler, & Nordstrom, 1998a). For example, a four-week strength training is known to influence specific adaptations in motor unit behavior that include a significant increase in motor unit discharge rate, a decrease in limit force during motor units activation, and a similar input-output increase in motor neurons (Del Vecchio et al., 2019).

From previous research, it can be seen that most of the research was concerned with monitoring differences in the maximum force or dynamic movements such as kicking the ball (King, & Wang, 2017), getting up from a chair (Bond, Cook, Swartz, & Laroche, 2017) or quiet standing on one leg (Wang, & Newell, 2014). There is little research to monitor force variability in muscles, a variable known as force stability that has been shown to be good at explaining force variability in movements in clinical tests of motor function (Enoka, & Farina, 2021). Also, most of the research so far has dealt with the study of neural control of the upper extremities (Dai, Liu, Saghal, Brown, & Yue, 2001; Van Duinen, Renken, Maurits, & Zijdewind, 2008; Thickbroom, Phillips, Morris, Byrnes, & Mastaglia, 1998; Vaillancourt, Mayka, Thulborn, & Corcos, 2004). As the muscles of the lower extremities have a higher ratio of muscle mass, and thus a larger number of motor units (Bertram, Bengt, Nyman

Eberhard, & Gunnar Wohlfart, 1955), a smaller number of direct corticospinal connections (Brouwer, & Ashby, 1990), but also a possibly stronger influence of the spinal cord circles on the movements of the lower extremities (Volz et al., 2015) in relation to the upper extremities, so the muscle control of the lower extremities during static contractions is different from the control of the muscles of the upper extremities (Jesunathadas, Klass, Duchateau, & Enoka, 2012).

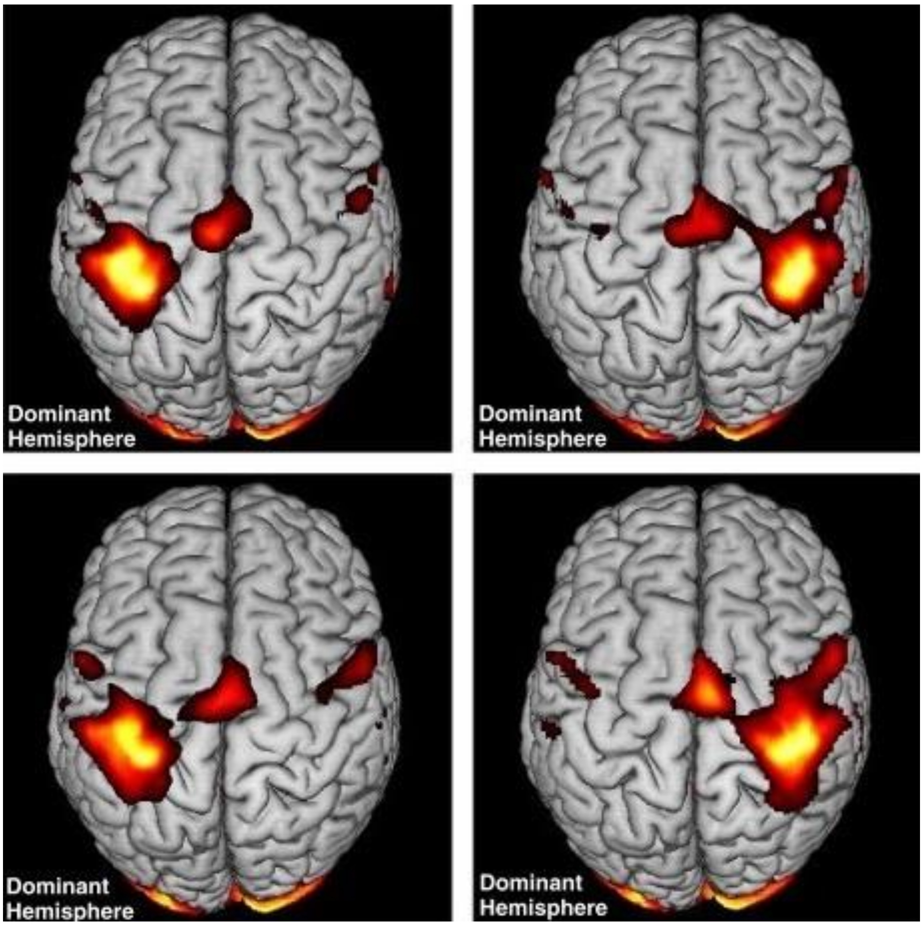
To my knowledge, there are no studies that have monitored the variability of force in the muscle and the characteristics of neural control in the lower extremities in athletes. In regard to it, this study will examine lateral dominance between the lower extremities, their muscle variability and motor unit activation in athletes.

1.1 Definitions of basic terms

1.1.1 Lateral dominance

Dominance is explained in the literature as a phenomenon of CNS where one hemisphere plays a major role in precisely determined movements (Kagerer et al., 2003; Maki et al., 2008; Pool et al., 2014; Volz et al., 2015), and lateral dominance (LD) is defined as preferred use of one side of the body which is more superior when performing most volountery movements compared to the other side of the body (Hebbal, & Mysorekar, 2003). Laterality occurs in all organisms with double body parts (hands, ears, feet, eyes), where one side is better at performing certain tasks (Croisier, 2004).

Data suggesting the existence of greater activation of one side of the cerebral hemispheres was observed using Functional Magnetic Resonance Imaging (fMRI), a technique for measuring localized changes in cerebral blood flow, or the percentage of oxygen in the blood during increased brain activity. In this way, visual images of parts of the brain that were activated during individual movements were made (Wennerfeldt, 2013). Thus, it was observed that the left cerebral hemisphere is dominant in movements responsible for skills and is associated with anatomical and functional asymmetries of the primary motor cortex. (M1), descending pathways of the cerebral cortex, as well as other secondary motor and connecting parts that are more pronounced in right-handed persons, while on the other hand, the right hemisphere, which is not sufficiently explained regarding motor organization, shows less M1 in right-handed subjects (Serrien et al., 2006). Motor maps of the cerebral hemispheres indicate increased opposite (dominant) activation of the bilateral complementary motor area (SMA), motor putamen[1] and M1, where greater preference for the dominant hand corresponds to a stronger neural connection of the opposite SMA when performing movements with the dominant hand. Left-handed subjects compared to the right-handed ones show less asymmetry in the connection of the motor network, which is expressed by different mechanisms of the hemispheres in motor control of the hands (Pool et al., 2014). This attitude was confirmed by other authors, explaining that the right hemisphere is responsible for controlling movement stabilization, while the left is responsible for performing motor actions (Bagesteiro, & Sainburg, 2003; Sainburg, & Wang, 2002). The asymmetry that occurs between the upper extremities is associated with the organization of the nervous system, which is manifested in early prenatal development (Hepper, 2013).



Picture 1. Functional Magnetic Resonance of activated brain parts when performing movements with the dominant (left row) and non-dominant (right row) hand in right-handed (upper row) and left-handed (bottom row) subjects (Pool et al., 2014)

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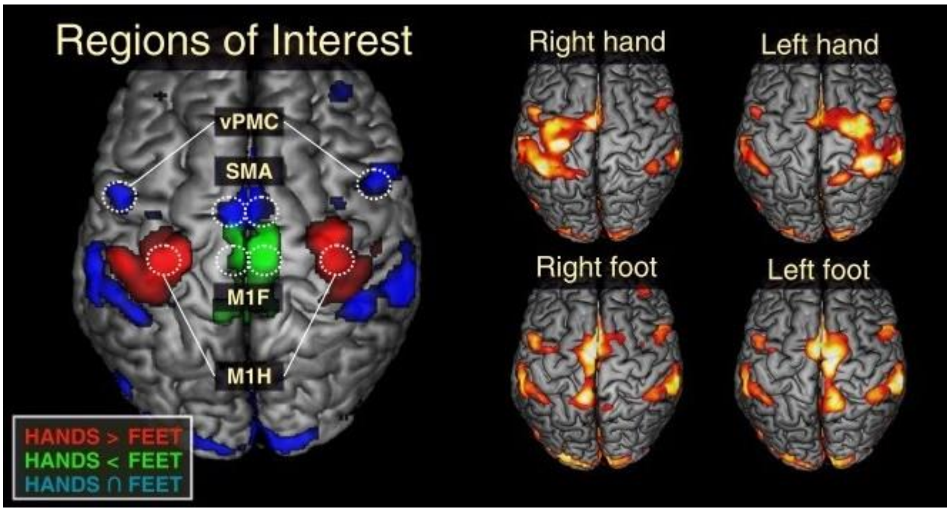
[1] Almost all motor and sensory fibers connect the cerebral cortex with the spinal cord, pass between the main masses of the basal ganglia (nucleus caudatus and putamen) and are called the capsule of the internal brain.

The dominance of the lower extremities is not sufficiently explained. There is a contradiction between the authors defining this term. Some authors state that the dominance of one side of the body is controlled by the brain hemispheres' domination, which leads to giving preference to one side of the body (Maupas et al., 2002; Serrien et al., 2006), and in that way reduces the corticospinal demand of the CNS to avoid double-acting (Clark, Kautz, Bauer, Chen, & Christou, 2013). Other authors consider that dominance is formed by lifestyle habits that give preference to one side (Maupas et al., 2002; Serrien et al., 2006), and that the difference in extremities can be reduced by specific training (Carpes, Bini, & Mota, 2008; McGough, Paterson, Bradshaw, Bryant, & Clark, 2012). Motor maps of the cerebral hemispheres differ significantly in unilateral movements in the upper and lower extremities, where unilateral movements of the upper extremities show greater laterlization in the contralateral M1 compared to the lower extremities (Volz et al., 2015). These authors find the explanation for the reduced interhemispheric inhibition in the lower extremities in the possible stronger influence of the spinal cord circles on the movements of the lower extremities.



Picture 2. Functional Magnetic Resonance of activated brain parts when performing movements with the dominant and non-dominant upper (upper row) and lower limb (lower row): vPMC – ventral premotor cortex; SMA - supplementary motor area; M1F - primary motor cortex during foot movement; M1H - primary motor cortex during hand movement (Volz et al., 2015)

In previous research, on the basis of different kinds of questionnaires and by observing the participants, to determine the laterality in the lower extremities, the researchers monitored the choice of the subject's foot while shooting, jumping rope, jumping, playing Hopscotch, establishing forward/backward movement, after a sudden loss of balance, climbing/descending, descending to one knee, foot tapping, drawing a geometric figure on the sand (Gabbard, & Hart, 1996; Hebbal, & Mysorekar, 2003; Maupas et al., 2002; van Melick, Meddeler, Hoogeboom, Nijhuis-van der Sanden, & van Cingel, 2017; Steenhuis, & Bryden, 1989; Vanden-Abeele, 1980). In the opinion of Smak, Neptune, and Hull (1999), it is a highly individual and variable measure because people react differently to the most demands that depend on musculoskeletal composition, and in some studies tests to determine LD did not predict a good side of limb preference (Maupas et al., 2002). It is necessary to conduct additional research by monitoring neural activation as a parameter for determining LD.

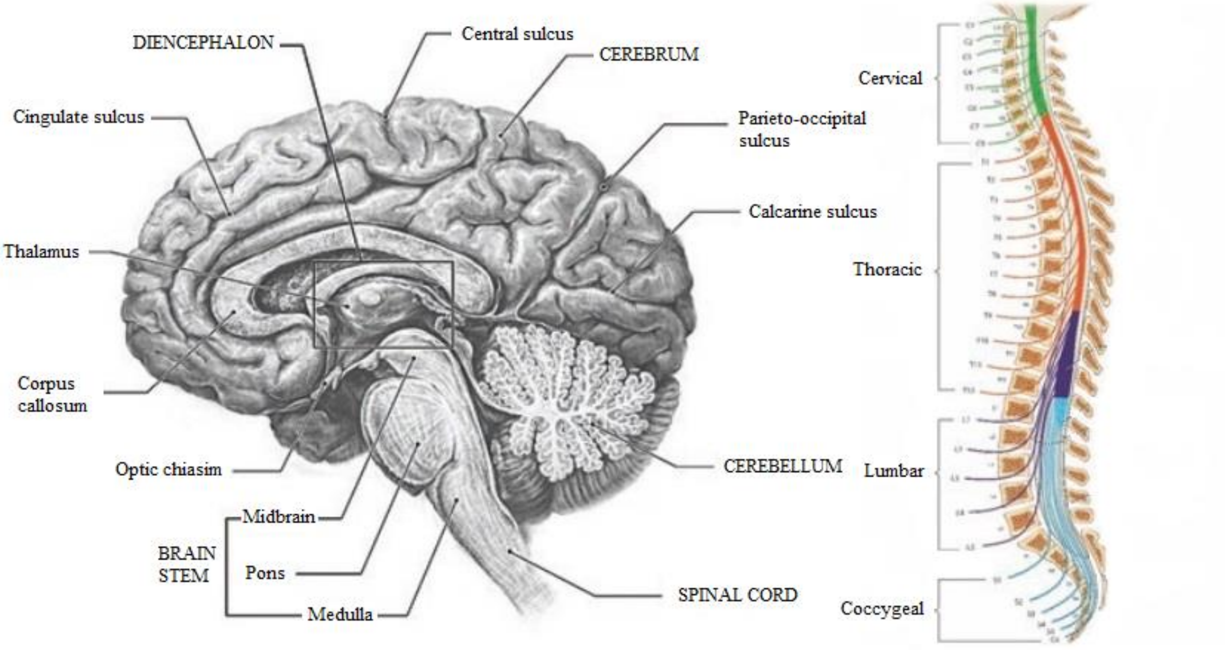
1.1.2 Force muscle variability

The ability to produce a precise and stable force over a longer period of time is called force control in the literature (Chow, & Stokić, 2011). The variability in muscle force during isometric contractions is often influenced by several factors, including the amount of force (Kouzaki, Shinohara, Masani, & Fukunaga, 2004; Shinohara, Yoshitake, Kouzaki, Fukuoka, & Fukunaga, 2003), fatigue (Hunter, & Enoka, 2003; Maluf, & Enoka, 2005), and inactivity (Shinohara et al., 2003), among young normal people. When a muscle contracts, it produces a force that is not completely stable, and varies around the average force (Enoka, 1997).

The authors dealt with the problem of muscle variability and concluded that the ability to maintain force during prolonged submaximal contractions usually requires an increase in the central drive to recruite additional necessary motor units, or by increasing the firing rate of currently actived motor units in order to compensate the mechanisms associated with fatigue that may occur in the CNS, neuromuscular connection, or within the contractile mechanism itself (Kenway, 2015). That activation of a bigger number of motor units will produce force variability, which depends on the contractile characteristics and speed of the discharging of recently recruited motor units (Allum, Dietz, & Freund, 1978; Christakos, 1982). Force variability is best seen in some pathological conditions, where, for example, in a study in patients with subacute stroke, greater variability of force was observed in the manifestation of isometric force bilaterally in the lower extremities compared to the control group, with higher values of variability in the more affected leg, which further implies the possibility of motor damage (Chow, & Stokić, 2011).

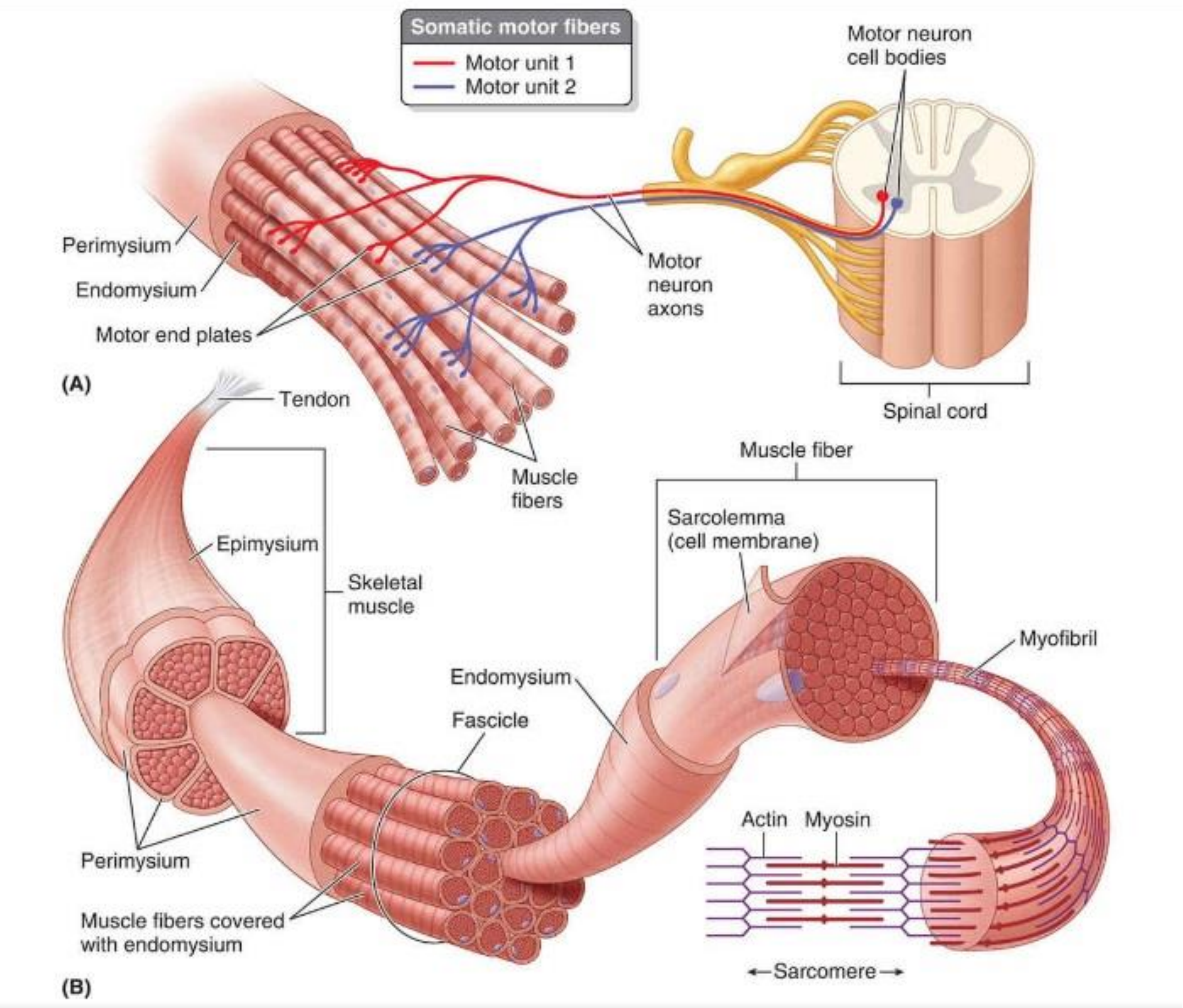
1.1.3 Nervous system

The nervous system consists of the brain and spinal cord that form the CNS, and the sensory and motor nerves that form the peripheral nervous system (Nieuwenhuys, Voogd, & van Hujizen, 2008). The basic unit of the neuromuscular system is the motor unit (MU). When any muscle is activated, the force produced is equal to the number of total forces produced by all the motor units that were activated (Kenway, 2015). The motor unit has two components: a motoneuron and muscle fibers innervated by a motoneuron axon, called a muscle unit.



Picture 3. Two parts of the central nervous system. One part (left), the brain located in the skull, is composed by cerebrum; diencephalon; brain stem consisting of the midbrain, pons and medulla oblongata; and cerebellum. The second part (right), the spinal cord located in the vertebral foramen, is divided into cervical, thoracic, lumbar, sacral, and coccygeal portion (Lee, 2019)

Each individual muscle is made up of a population of motor units that control the force exerted by the muscle during contraction. The population of motoneurons is located in the vertebral foramen of the spinal cord or in the brain stem. Muscle-innervating motoneurons are arranged in a longitudinal cluster known as the motor nucleus or pool of motoneurons (Heckman, & Enoka, 2012). Each muscle fiber is wrapped by a cellular membrane called the sarcolemme. There are wrinkles on the sarcolemme, the so-called T-tubules that coduct a nerve signal along the entire muscle fiber. The so-called alpha-motoneurons, composed of the body (some) located in the corresponding parts of the spinal cord and the efferent nerve fiber (axon) that stretches to the muscles, generate nerve signals for the work of skeletal muscles (Nedeljković, 2016).



Picture 4. Structure of skeletal muscle and motor unit. A. A motor unit consists of a single motor neuron and muscle fibers that innervate it. B. Actin (thin) and myosin (thick) filaments are contractile elements in muscle fibers (Moore, Dalley, & Agur, 2018)

The intensity and speed of muscle contractions depend on the number of activated motor units and the discharge frequency of their alpha-motoneurons. A large number of muscle fibers simultaneously inject one alpha-motoneuron. Together they form a motor unit (Nedeljković, 2016). There is a higher number of MUs in one muscle. These MUs are alternately active and inactive depending on their load, and discharge frequencies, thus the force generation is not constant (Heckman, & Enoka, 2012). One nerve signal always generates the same level of force. If a muscle fiber recruits a new nerve signal before the previous one has returned to its initial value, the muscle fiber creates a new level of force added to the existing one. With a higher frequency of nerve signals, a more complex contraction will be created (Nedeljković, 2016). The number of repetitions of nerve signals needed to create the maximum force within various muscles ranges from 50 Hz to 200 Hz (Enoka, 1995). Therefore, it can be added that the muscle force and the contraction rate influence the time of the activation of the MU, as well as the sequence time of their action potentials (Nedeljković, 2016). The same MU can have a different discharge frequency while maintaining the same muscle contraction force when contracting and relaxing, where with lower loads slower MUs are first activated (Henneman, 1957), and fast MUs during higher loads (Allum et al., 1978). All the MUs in one muscle are activated only if the load is maximal (Nedeljković, 2016).

The amplitude of force variability is consistent with the intensity of the contraction, whereby an increase in voluntary muscle activation also leads to an increase in the amplitude of force variability (Galganski et al., 1993). After recruiting all the MUs, a further increase in power is achieved only by increasing the firing rate of the already activated MUs. The dynamics of the variability in muscular strength is influenced by the patterns of MU recruitment (Allum et al., 1978; McAuley et al., 1997) and the firing levels of the MU (Christakos et al., 2006; Elble, & Randall, 1976; Freund, 1983; Hömberg, Reiners, Hefter, & Freund, 1986). The basic unit of the neuromuscular system, the MU, begins to fire at ~ 6-10 Hz, and unused firings of these recruited MUs strongly affect the physiological tremor (Allum et al., 1978; Elble, & Randall, 1976).

It has been recently demonstrated that it is possible to identify large populations of the MU (Farina, Negro, Muceli, & Enoka, 2016; Holobar, & Zazula, 2007; Negro, Muceli, Castronovo, Holobar, & Farina, 2016; Del Vecchio, Negro, Felici, & Farina, 2018) (Farina et al., 2016; Aleš Holobar & Zazula, 2007; Negro et al., 2016; A. Del Vecchio, Negro, Felici, et al., 2018) and to monitor them through several separate measurements (Martinez-Valdes et al., 2017), as well as during very strong voluntary contractions, 70% MVC (Holobar, Minetto, & Farina, 2014; Del Vecchio, Negro, Falla, et al., 2018; Del Vecchio, Negro, Felici, & Farina, 2017).

1.1.4 Bilateral and unilateral sports

In many sports, patterns of movements consist of bilateral movements of the lower limbs, whose group includes sports such as weightlifting, volleyball, rowing or unilateral movements of the lower limbs, whose group includes sports such as running, cycling, long and high jumping, basketball, football and others (Luk, Winter, O'Neill, & Thompson, 2014).

Bilateral movements are viewed as the collaboration of both extremities when realizing certain tasks, whereas unilateral movements imply partial use of only one extremity (Luk et al., 2014; Valdez, 2003).

1.1.5 Lower limb muscles

The muscles *gastrocnemius medialis*, *gastrocnemius lateralis* and *soleus* together form a muscle group, the so-called *triceps surae*. This group of muscles merges and forms the Achilles tendon and it is responsible for performing the plantar flexion in the ankle. The muscle tibialis anterior acts as an antagonist to the muscles from the triceps surae group, and it is responsible for the dorsal flexion in the ankle. The muscles tibialis anterior and *gastrocnemius medialis* interact reciprocally and maintain stabilization in the ankle during a normal upright stance (Perry, & Burnfiled 1992). While one is in contraction, the other is relaxed and vice versa (Wolf, & Kim, 1997). The muscle *tibialis anterior* (TA) is important because it controls the connection of feet with the ground (Chleboun, Busic, Graham, & Stuckey, 2007), and it is considered responsible for maintaining balance and a normal quiet stance (Vieira, Bisi, Stagni, & Botter, 2017).

Monitoring the behaviour of the MU in TA during voluntary contractions is of significant interest because it is directly involved in the coordination and movement frequency during a walk (Van Cutsem, Feiereisen, Duchateau, & Hainaut, 1997). Also, a certain number of studies researched the neural control of TA as one of the most affected after CNS traumas (Chae, Sheffler, & Knutson, 2008; Merletti, Zelaschi, Latella, Galli, & Angeli, 1978). In previous research it has been found that TA has a greater range of MU recruitment (Van Cutsem et al., 1997; Moritz et al., 2005), as well as a smaller number of synaptic entrances in motoneurons (Brouwer, & Ashby 1990) which reduces the synaptic noise in the system, thus allows better monitoring of the MU. Interestingly, older women with a history of falls were not significantly weaker in any of the strength tests, except in the muscles responsible for dorsiflexion in the ankle (Skelton et al., 2002), which was also confirmed by Perry et al. (2007), who found the dorsal ankle muscles weaker in the elderly with a history of falls compared to healthy individuals of the same age.

2. RESEARCH REVIEW

Due to the lack of basic research that studied neurocontrol and variability of muscle strength between the lower extremities, but to establish a theoretical framework, the research included papers based on aspects related to lateral dominance. In order to be able to answer the research tasks, a review of the research was performed through three connected units that will enable the understanding of the research subject. These are studies of lateral dominance in the upper and lower extremities in the general population of subjects and studies of lateral dominance in athletes. In addition, a critical review of previous research with the problem of this research will be given.

2.1 Research strategy

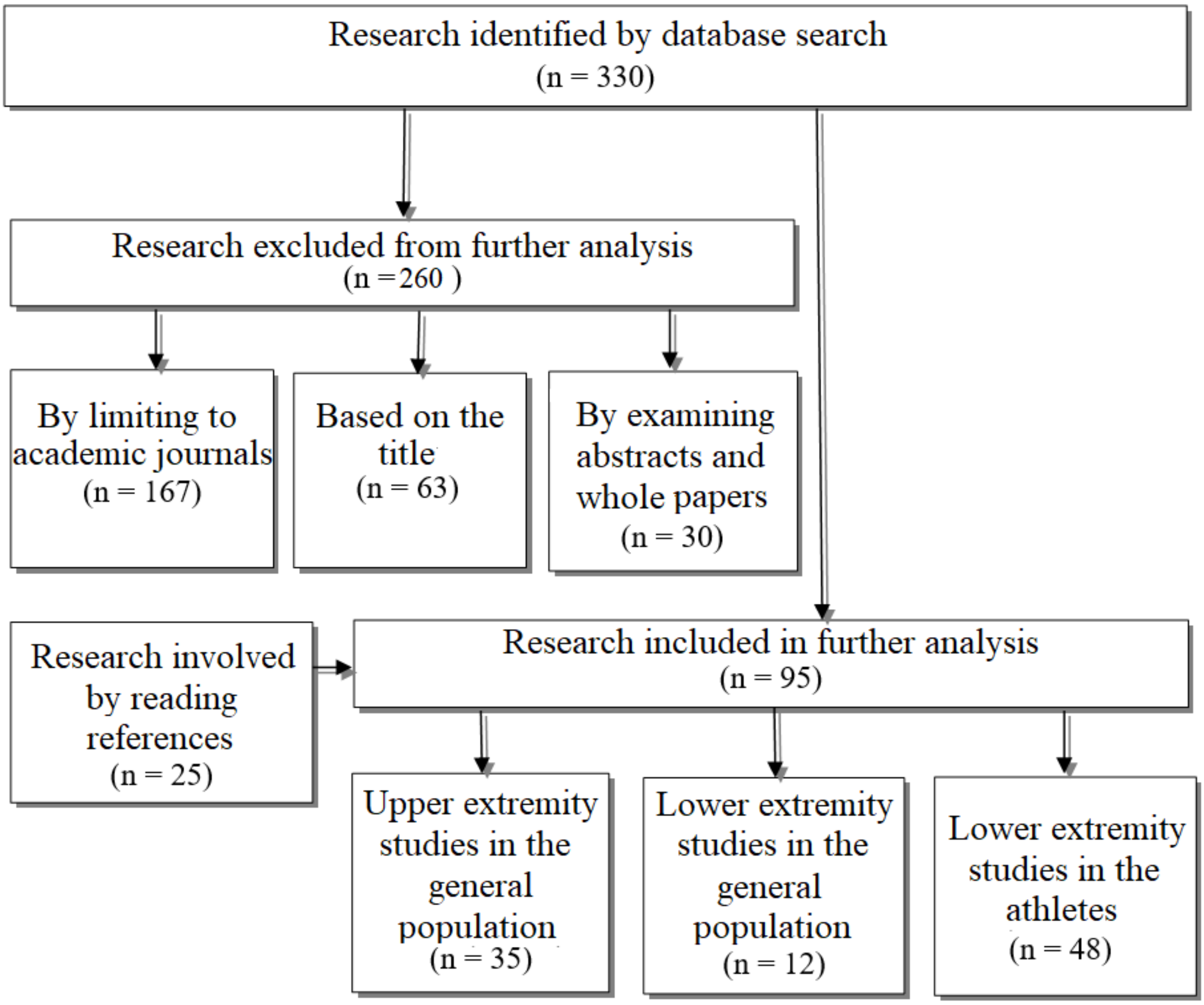
For the collection of relevant research papers, the following electronic databases were used: Google Scholar, DOAJ, PEDro, and PubMed. For the purpose of closer search and the selection of research papers, the search was limited using key words that are related to the problem of this research: Dominance; Force Variability; High-density EMG; Motor Unit; Tibialis Anterior. The database was not limited by the year of publication so that it could include more research related to the topic. In addition, the references of each article included were also scanned to indentify additional relevant studies.

2.2 Selection strategy

The final selection of papers for analysis included all the available studies published in the period from 1983 to 2021 which dealt with the differences between the lower limbs of athletes.

2.3 Process of research paper collection

Database searches returned 330 articles. By limiting the database to the selection of academic journals, 163 articles were identified. Based on the title, 100 research papers were selected for further analysis. By examining the abstracts and whole papers, 30 research articles were excluded from further analysis. In addition, a review of identified research references was performed and 25 new research articles were included in further analysis. The process of collecting relevant research papers is shown in Figure 5.



Picture 5. Process of the research papers collection

2.4 Data analysis

Tables 1, 2, and 3 provide an overview of 95 scientific research papers that met the set criteria. The tables show the following data: the reference, subject of research, sample of participants (sport, number, sex, dominance and age), description of the applied instruments and protocol, and results.

2.4.1 Research articles determining the difference between the upper extremities in neurocontrol and muscle variability in the general population of subjects

Table 1. Review of research characteristics determining the difference between the upper extremites in neurocontrol and muscle variability in the general population of subjects

Reference	Subject of research	Participants' sample (sport, number, sex, dominance and age)	Instruments and protocol	Results
(Kamen, Greenstein, & De Luca, 1992)	Influence of the nervous system on the firing behavior of motor units, as well as the relationship between LD and the degree of variability of the firing speed of motor units	N: 12 G: - LD: RH (8)/LH (4) Y: 18-30	Performing a constant submaximal isometric contraction (trapezoid 3, 12, 3 s) at the force level of 30% MVC. Imaging was performed in the first dorsal interosseous muscle of the left and right arms.	The mean firinig value of MU, by cross - correlation, was higher in pairs of motor units of the dominant arm compared to the non-dominant in both groups of subjects.
(Kim et al., 1993)	Determining asymmetry in left and right motor cortex activation and association with LD	N: 15 G: M (9)/F (6) LD: RH (10)/LH (5) Y: -	Hemisphere imaging by nuclear magnetic resonance before, during and after the task. Participants made repetitive movements with the thumb, which touched the tip of the other four fingers.	There was asymmetry in the hemispheres in the functional activation of the motor cortex during contralateral and ipsilateral movements, especially pronounced in right - handed participants. The right motor cortex was activated during time for contralateral movements, while the left was activated during ipsilateral movements in both groups of subjects.
(Schmied, Vedel, & Pagni, 1994)(Schmied et al., 1994)	Study of motor unit synchronization in wrist extensors	N: 20 G: M LD: RH (6)/LH (14) Y: 18-30	Subjects performed isometric force contractions by pushing the force transducer as to maintain two motor units tonic firing in a time of 3-5 minutes, to produce up to 3000 pulses for each unit. The signals were monitored by EMG.	Pairs of motor units were discharging with a higher degree of synchronization in the dominant hand compared to the non-dominant one. No statistical significant differences were found in the variability of motor unit discharges, nor in their recruitment threshold.
(Semmler, & Nordstrom, 1995)	Influence of dominance on the discharge properties of the motor unit in the first dorsal interosseous muscle of the left and right arm.	N: 12 G: M LD: RH (6)/LH (6) Y: 21–47	Subjects performed a movement of the index finger while maintaining a steady position for 60s at a target force level of 1% to 7% MVC.	The results showed that the strength of MU synchronization and the number of synchronized pairs was much lower in the dominant hand of right-handed subjects (51% of pairs) compared to the non-dominant hand (80% of pairs). In left-handed subjects, the strength and number of synchronized MU pairs were similar in value. This synchronization of MU did not have a significant greater effect on physiological tremor in the muscles between the extremities.

Table 1. *(extension 1-7)*

(Dassonville et al., 1997)	Functional activation in cortical motor parts during dominant and non-dominant arm movement in right-handed and left-handed subjects	N: 13 G: M (7)/F (6) LD: RH (7)/LH (6) Y: 25.5	During magnetic resonance imaging of the brain, the task of the subjects was to maintain a steady position of the finger for 60 s.	The dominant arm showed higher activation in the colateral motor cortex compared to the non-dominant arm in both groups of subjects.
(Adam et al., 1998)	Difference in the recruitment of motor units and the way of their firing in the muscle first dorsal interosseous of the left and right hand	N: 8 G: M LD: RH (3)/LH (4)/ No (1) Y: 27.5 ± 7.5	Subjects performed isometric contractions by performing abduction of the index finger of the left and right hand at a force level of 30% MVC. An invasive method was used to monitor the behavior of motor units.	The mean value of the MU recruitment threshold in the dominant index finger was 20.7% lower than in the non-dominant side. Also, the force trajectory and the mean value of the firing speed of the MU in the non-dominant index finger were less stable than in the dominant one. This further led to less force variability during contractions in the dominant arm.
(Semmler, & Nordstrom, 1998b)	Monitoring of motor unit discharge properties and force variability in the muscle first dorsal interosseous in both arms	Musicians, weightlifters, untrained N: 16 G: M (13)/F (3) LD: RH Y: 19 ± 25/18 ± 20/23 ± 47	Subjects performed low abduction isometric contractions of the left and right index finger for 40 s at the force level of 2% and 11% MVC.	The results showed a small but statistically significant difference in ISI among musicians and untrained subjects. The strength of the MU synchronization was weaker and of the same strength in both hands in musicians and in the dominant hand in untrained subjects. Synchronizations of MU peaks were significant wider in the dominant hand of untrained subjects. The mean common drive coefficient for pairs of MU was significantly lower among musicians in terms of bodybuilders and untrained subjects. RMS tremor amplitude and peak strength were significantly higher in bodybuilders compared to musicians and untrained subjects. The MVC of untrained subjects was significantly higher than that of musicians and bodybuilders.
(Triggs, Subramanium, & Rossi, 1999)	Relationship of asymmetry in cortical motor imaging using TMS	N: 9 G: M (6)/F (3) LD: RH (6)/LH (3) Y: 33 ± 7	Using TMS, the left and right muscles of the *abductor pollicis brevis* and *flexor carpi radialis* were stimulated. Activation was monitored by a magnetic simulator.	The results showed that the number of sites for stimulation of motor-induced potentials was statistically significant in the dominant limb for abductor *pollicis brevis* and *flexor carpi radialis*. A statistically significant difference was found between the left-handed and right-handed subjects where the right-handed subjects had higher activation of abductor *pollicis brevis* in the dominant hand, while the left-handed abductor *pollicis brevis* had higher activation in the non-dominant hand.

Table 1. *(extension 2-7)*

(Beuter, 2000)	Determining the characteristics of physiological tremor in the dominant and non-dominant arm in right-handed subjects	N: 22 G: F LD: RH Y: 20 - 40	Maintaining static contraction of 40 s was preceded by pressure of the index fingers on the joystick for 30 s and periodic pressures of the index fingers. In the first task, subjects could see the LED only during the produced force of 1.6 and 2.2 N. In the second task, the movement was measured with a metronome (50 times in 60 s, or 0.83 Hz) for 60 s. Physiological tremor was observed with neon lasers.	The dominant side exhibited greater force variability, higher power in the range of 7 - 12 Hz and a higher mean frequency.
(Civardi, Cavalli, Naldi, Varrasi, & Cantello, 2000)	Determination of functional asymmetries of the motor cortex in the dominant and non-dominant hemispheres	N: 15 G: - LD: RH (9)/LH (6) Y: 28.8 ± 5.6/27.7 ± 2.8	Relaxed (10% MVC) and active motor threshold were measured using TMS, as well as ipsilateral corticocortical inhibition for the motor parts of the hands.	In right - handed corticocortical inhibition and curve release showed an increased level of release in the dominant versus non - dominant hemisphere. In right - handed subjects, both limbs had greater inhibition and less release in corticocortical inhibition and curve release than in the corresponding area in left - handed subjects. Left-handed people did not show lateralization.
(Sainburg, & Kalakanis, 2000)	Determining the coordination of the movement pattern in the upper extremities	N: 6 G: M (4)/F (2) LD: RH Y: 24–36	Subjects moved their arms in the direction of the target after the signal with an angle in the elbow joint of 20° but different angles in the shoulder joint (5°, 10° and 15°). Kinematic analysis of movement was performed.	Changes in the direction of the trajectory of the right arm did not depend on the impulse of the torque of the elbow interaction, which indicated a more skilful coordination of muscle movements in the dominant side.
(Brouwer, Sale, & Nordstrom, 2001)	Assessment with TMS relative involvement of the corticospinal pathway in first dorsal interosseous muscle activation	N: 32 G: M (16)/F (16) LD: RH (16)/LH (16) Y: 28 ±7	Subjects performed isometric contraction by abduction of the index finger at the level of force 0.5 N, 1 N and 2 N while TMS was applied during the resting threshold intensity, 0.9 or 0.8.	Facilitation of the muscle-evoked potential was greater on the left side in the first dorsal interosseous muscle in both the left and right hand, but the asymmetry was related to the strength of arm dominance. This asymmetry was not associated with finger tapping or task performance, but was positively associated with muscle strength.
(Solodkin, Hlustik, Noll, & Small, 2001)	Identify regions associated with the differences in finger movements in left-handed and right-handed subjects	N: 13 G: - LD: RH (7)/LH (6) Y: 31	Magnetic resonance imaging of the brain. Subjects performed one-time thumb / finger movements at 2 s^{-1}, rest, repeating the thumb / each opposite finger task at 2 s^{-1}, rest.	Left-handed people showed more volume and a larger number of activated parts of the brain than right-handed people, as well as less lateralization. The repetitive task required more intense brain activation in several bilateral regions, while the one-time task required less brain activation but subjects exhibited greater lateralization.

Table 1. *(extension 3-7)*

(Farina, Kallenberg, Merletti, & Hermens, 2003)	Determining the differences in the peripheral and control properties of the neuromuscular system between the left and right trapezius muscles.	N: 14 G: M (10)/F (4) LD: RH (9)/LH (5) Y: 33.0 ± 12.1/22.0 ± 3.7	Subjects performed a static constant contraction with an angle in the elbow at 90º and a load mass of 0 kg, 0.5 kg, and 1 kg.	The results showed a statistically significant difference between the sides, with the dominant side more resistant to fatigue than the non-dominant one.
(De Gennaro et al., 2004)	Comparison of transcranial inhibition and corticospinal activation in left-handed and right-handed subjects	N: 32 G: M (16)/ F (16) LD: RH (16)/LH (16) Y: 25.9 ± 0.8	TMS, pulse intensity 120% motor threshold. The impulses between the intervals were 2, 4, 6, 8, 10, 12, 14, 16, 18, and 20 ms for both cerebral cortices, the motor evoked potential was recorded from the muscle *abductor digiti minimi*.	Corticospinal activation differed in groups of subjects. In the dominant hemisphere, the motor threshold was lower than in the non-dominant one in the left-handed subjects, while in the right-handed ones, the motor evoked potential in the dominant arm was higher.
(Yamauchi, Imanaka, Nakayama, & Nishizawa, 2004)	Determining differences in lateralization and interhemispheric transfer in maintaining movements in left- and right-handed subjects	N: 30 G: M LD: RH (15)/LH (15) Y: 18–22	The task consisted of criterion linear plate moving, holding, and testing.	In right-handed subjects, a constant error in performing the movement with a non-dominant hand was manifested. In left-handed subjects, both extremities manifested a similar error.
(Mottram, Jakobi, Semmler, & Enoka, 2005)	Comparison of discharge characteristics of the same motor unit in the bicep brachii muscle during the performance of two types of fatigue contractions	N: 15 G: M LD: RH Y: 25.6 ± 5.8	Subjects performed the task of maintaining position (elbow angle 90º) and performing submaximal contraction at 3.5 ± 2.1% MVC above the recruitment threshold of an isolated motor unit, apropos the mean force value of 22.2 ± 13.4% MVC for 161 ± 96 s.	The results showed that arm dominance did not affect the adjustment of motor unit activity during submaximal force contractions, nor in the position maintenance test.
(Klöppel et al., 2006)	Influence of dominance on neural activation of the primary sensorimotor cortex, complementary motor area and dorsal premotor cortex	N: 32 G: M (18)/ F (14) LD: RH (16)/LH (16) Y: 25–55	During brain magnetic resonance imaging, the subjects performed the choice reaction tasks, to determine coordination and speed, with their left and right index fingers. There were four symbolic signs, each requiring different movements (pressing the button, left, right or with both index fingers as fast as possible).	The results showed that left-handers show greater activity in the complemetnary motor area and in the right anterior opercular cortex during button pressing with the dominant hand.
(Diederichsen et al., 2007)	Comparison of differences in muscle activation between the shoulder muscles of the dominant and non-dominant side during movement	N: 20 G: M (17)/ F (3) LD: RH (17)/ LH (3) Y: 23–57	Subjects performed 3 to 5 repetitions of *scapula* abduction and external shoulder rotation at a load of 10% MVC. During the execution of the tasks, the activation of the eight muscles was followed by EMG signals.	During abduction, the normalized EMG value was significantly lower on the dominant side compared to the non-dominant side in all muscles except the *infraspinatus* and lower *trapezius*. In contrast, during external rotations, greater activation of EMG was observed in the muscles *supraspinatus, infraspinatus*, lower and upper part of the *trapezius* and *latissimus* on the dominant side.

Table 1. *(extension 4-7)*

(Gupta, Sanyal, & Babbar, 2008)	Determining the relationship between dominance and motor and sensory signal conduction velocity in the right and medial nerve	N: 84 G: M (63)/ F (21) LD: RH (72)/LH (12) Y: 17–21	Monitoring of nerve activation performed by stimulation Motor: 2–5 µv / mm, frequencies: 2–5 Hz, 10 KHz, speed: 2–5 ms / mm. Sensory: sensitivity: 10–20 µv / mm, frequencies: 5–10 Hz, 2–3 KHz, speed: 1–2 ms / mm.	The sensory speed of impulse in the right and left medial nerve was significantly higher in left-handed subjects. The motor speed of the impulse did not differ between the groups of subjects.
(Bilodeau, Bisson, DeGrâce, Després, & Johnson, 2009)	Determining the differences between the upper extremities in the amplitude of muscle tremor in right-handed subjects	N: 17 G: M (9)/ F (8) LD: RH Y: 22–28	The protocol included maintaining a steady horizontal position of the hand (neutral position of the wrist) for 10 s with holding loads of different weights, 0, 114, 425, 1014, 3614 and 5614 g. Muscle activation was monitored by EMG signals from the extensor and flexor muscles of the wrist.	The results showed that the ~ 30% higher amplitude of acceleration of force variability was in the non-dominant hand compared to the dominant one. Statistically significant correlation between RMS acceleration amplitude and EMG power at 5–15 Hz, 20–30 Hz and 40–50 Hz frequencies specific for dominance and load height, as well as between RMS acceleration amplitude and RMS EMG flexor muscle activation at low loads and RMS EMG extensors at high loads for the non-dominant arm but not for the dominant one.
(Goble, Noble, & Brown, 2009)	Determining the influence of proprioceptive tasks on arm / hemisphere symmetry in left-handed subjects	N: 10 G: M (4)/ F (6) LD: LH Y: 23.2 ± 4.6	Performing proprioceptive precision tasks that require memory and interhemispheric transfer and target amplitude (20, 40°).	Left-handed people made a minor mistake when performing precision tasks with the non-dominant hand.
(Gordon, Rudroff, Enoka, & Enoka, 2012)	Comparison of endurance time and neuromuscular adjustment in right- and left-handed subjects during the performance of continuous isometric contractions with the left and right hand	N: 20 G: M LD: RH (10)/LH (10) Y: 21 ± 5	The protocol consisted of maintaining continuous submaximal contractions during a force intensity of 20% MVC. Activation of the *brachialis* muscle was monitored by an EMG device.	The results showed that left-handed subjects showed greater variability of force than right-handed subjects in both position tasks, but also that there was no statistically significant difference between the extremities during the control of position and force tasks.
(Pereira, Freire, Cavalcanti, Luz, & Neto, 2012)	Force variability and sensorimotor strategy of dominant and non-dominant arm during submaximal isometric contractions	N: 24 G: M (13)/F (11) LD: RH (12)/LH (12) Y: 23 ± 3/24 ± 3	Subjects performed continuous isometric contractions at the force level of 30% and 50% MVC for 10 s. Activation of the flexor *digitorum superficialis* forearm and extensor *digitorum muscles* was monitored with EMG. The range of the following frequencies was monitored, 5–13 Hz, 13–30 Hz, 30–60 Hz and 60–100 Hz.	The results showed that MVC and force variability were without statistically significant differences in both, left- and right-handed subjects, while in right-handed subjects at the frequency of 30–60 Hz, neuromuscular activation was higher. The force spectrum was influenced by dominance, with higher oscillations in left-handers at the frequency level of 1–3 Hz.

Table 1. *(extension 5-7)*

(Przybyla, Good, & Sainburg, 2012)	Asymmetry between extremities in movement coordination in left-handed subjects	N: 40 G: M (16)/F (24) LD: RH (20)/LH (20) Y: 18–33	Each subject performed 180 rapid unilateral reach by changing arms after 18 repetitions. Each set of 18 repetitions contained 6 movements on each of the three targets in a different order.	The results showed that the dominant arm of both groups of participants was well coordinated. The non-dominant arm in right-handed subjects showed significantly greater trajectory curvature as well as greater error. Unlike right-handed subjects, left-handed subjects had better developed coordination of their non-dominant arm.
(Aune, Aune, Ettema, & Vereijken, 2013)	Comparison of bilateral deficit between proximal and distal muscles in joints of upper extremities	N: 10 G: M (5)/F (5) LD: RH Y: 23 ± 1.3	Performing voluntary fast isometric contractions by flexing the shoulders and index finger unilaterally and bilaterally.	The results showed a significant absolute bilateral force deficit for the proximal and distal muscles. The relative bilateral force deficit for shoulder flexion was significantly higher than for index finger flexion.
(Daligadu, Murphy, Brown, Rae, & Yielder, 2013)	Differences in hemisphere excitability and unilateral emphasis in right- and left-handed participants	N: 24 G: M LD: RH (12)/LH (12) Y: 24.5/22.0	The activity of the left and right first dorsal interosseous muscles was monitored with EMG. TMS was applied to the arm using the dominant M1. Magnetic stimuli of 10% increment between 90 and 150% RTh were applied. At each stimulus intensity, 16 stimuli were delivered, and the order of the different stimulation intensities was pseudo-randomized.	The results showed that the MU recruitment curve increased activation in the non-dominant arm compared to the dominant one, in both groups of subjects. Left-handed people showed greater activation in their non-dominant (right) hemisphere, while in right-handed people it was vice versa.
(Pool et al., 2014)	Determining the relationship between hand dominance and the motor system	N: 36 G: M/F LD: RH (18)/LH (18) Y: 25.7 ± 3.0	The research protocol included brain imaging with functional magnetic resonance imaging and dynamic causal modeling during the closure of the left and right hands at three frequencies 0.75 Hz, 1.5 Hz and 3.0 Hz.	The results showed that during the movement of the dominant hand, the motor putamen and M1 were significantly higher in the right-handed than in the left-handed. Strong lateralization in the dominant arm-hemisphere system during the execution of movements with the dominant arm. Left-handed subjects showed less asymmetry.
(K. Li et al., 2015)	Determining the influence of finger coordination dominance on force variability with and without visual information during the performance of the precision task	N: 24 G: M LD: RH Y: 24.9 ± 1.6	The subjects kept a joystick with their thumb and forefinger and maintained the level of the given force for 1 minute. In the first 30 s, the visual information was given, while to maintain the last 30 s, the visual information was removed.	The results showed that the right arm was significantly stronger in MVC. No statistically significant differences were obtained between the extremities in submaximal force contractions with and without visual information. In the dominant hand, the thumb produced a more variable force than the index finger. By removing the visual information, a significant increase in the variability of the index finger force of both hands was observed. The values of force variability were statistically higher in the dominant hand compared to the non-dominant one.

Table 1. *(extension 6-7)*

(X. Li et al., 2015)	Determining the influence of dominance on motor unit size index in the first dorsal interosseous and thenar muscles and the relationship with strength measures	N: 26 G: M (17)/F (9) LD: RH (24)/LH (2) Y: 33 ± 12	The protocol required a gradual increase in force from minimum effort to maximum power for 20 s. A dynamometer and a pressure apparatus were used to obtain the data, while electrical stimuli were applied to the ular and medial nerves at the same time.	The muscular strength of the dominant arm was greater than of the non-dominant one. The size index of motor units did not differ statistically between the extremities.
(Gould, Cleland, Mani, Amiridis, & Enoka, 2016)	Comparison of discharge characteristics of one motor unit during continuous isometric contractions during force and position control in the upper extremities	N: 21 G: M (13)/F (8) LD: LH Y: 21.9 ±1.9	The research protocol consisted of performing a gradual increase in force up to 60% MVC over 10 s. Subjects then performed two submaximal contractions of 3% MVC with visual signal and maintenaning a position task.	Arm dominance does not affect the adjustment of motor unit activity during submaximal force contractions, nor in the position test.
(Mitchell, Martin, & Adamo, 2017)	Differences in the arm-hemisphere during the performance of isometric force contractions of 20% and 70% MVC between both arms of the subjects	N: 11 G: M LD: RH Y: 24.9 ± 4.9	Visual tracking of the force on the screen with the help of a joystick, where the visual signal was removed during the tracking of the force with the opposite hand.	MVC was significantly higher in the right hand compared to the left. The error when performing the isometric force at 70% MVC was significantly lower in the right hand, whereas in contrast when performing the isometric force at 20% MVC it was significantly lower in the left hand. The variability of the force was significantly higher in the right hand compared to the left at 70% MVC, where the performance of the isometric force at 20% MVC was significantly more stable than 70% MVC.
(Pinto, Gazzoni, Botter, & Vieira, 2018)	Examination of peripheral properties of dominant and non-dominant *biceps brachii* muscle by analysis of M-wave response to incremental electrical stimulation	N: 20 G: M (14)/F (6) LD: RH (16)/ LH (4) Y: 2 –35/19–25	With increasing stimulation, induction of current pulses in the *biceps brachii*, from 2 mA to the maximum tolerance intensity for each subject, 3.4 min longest.	The amplitude of the M-wave increases more gradually in the dominant arm.
(Debbarma, & Mehta, 2018)	Determining differences in motor and sensory nerve conduction velocity (NCV) between left-handed and right-handed subjects using the ulnar, medial, and radial nerves	N: 100 G: M/F LD: RH (50)/ LH (50) Y: 18–40	Nerve conduction was performed on RMS EMG machine for electrophysiology.	The results showed that the NCV in all nerves was higher in the left-handed than in the right-handed subjects, and that the NCV in the right median nerve was higher in the right-handed. NCV did not differ between extremities in the ulnar and radial nerves, except in the medial one.

Table 1. *(extension 7-7)*

(Burdukiewicz, Pietraszewska, Andrzejewska, Chromik, & Stachoń, 2020)	Influence of applied martial arts techniques and targeted physical activity on asymmetry in muscle mass and isometric force in bodybuilders and martial arts competitors	Bodybuilding, martial arts, non-athletes N: 120 G: M LD: LL (12%) Y: 21.6 ± 2.6	In addition to the body composition of the subjects, the measurement protocol included the measurement of the maximum voluntary contraction during handgrip with the left and right hand.	There are statistically significant differences in grip strength between bodybuilders and non-athletes, which indicate functional dominance of the right limb. Among judokas and jiu-jitsu athletes, this difference was small and statistically insignificant.

Legend: N - number of participants; G - sex; M - male; F - female; LD - lateral dominance; RH - right-handed; RL - left-handed; Y - age; EMG - electromyogram; MVC - maximum voluntary contraction; MU - motor unit; RMS - mean square amplitude.

This group of studies included 35 studies determining the differences between the lower extremities in neurocontrol and muscle variability in the upper extremities in the general population of subjects. The first study from this group was published in 1992 (Kamen et al., 1992), while the last one was published in 2020 (Burdukiewicz et al., 2020). The total number of subjects in all studies was 923. In most studies, 21, the sample included both male and female subjects, in three studies the sex of the subjects was unknown, in one the subjects were female, while in the other studies the sample was male.

A critical review of previous research on the differences between the upper extremities in the general population of participants

The concept of lateral dominance in many studies is based on the study of the influence of motor control on the movements of the upper extremities. Brain magnetic resonance imaging studies have shown that there is functional hemispherical lateralization. In research Kim et al. (1993), Dassonville et al. (1997), Pool et al. (2014) have shown that there is strong lateralization in the dominant arm-hemisphere system during the execution of movements by the dominant arm. Also, during the movement of the dominant hand, the motor putamen and the primary motor cortex were more activated in the right-handed than in the left-handed subjects, and the left-handed subjects showed less asymmetry than the right-handed ones. Using transcranial magnetic stimulation, Triggs, Subramanium, and Rossi (1999) found that the number of sites for stimulation of motor-induced potentials in brain examination was statistically significant in the dominant limb for the muscle's *abductor pollicis brevis* and *flexor carpi radialis*. Specifically, in right-handed people the activation for the *abductor pollicis brevis* was higher in the dominant hand, while in left-handed people the same activation was higher in the non-dominant hand.

Based on the above, where the dominance of one limb has better performance in the dominant arm, the research on finding the connection between motor control and dominance has become a challenge for many researchers. It is believed that the organization of the neuromuscular system may also contribute to the dominance of the upper extremities. However, the results of the research are mixed. Several studies have shown that performing movements with the dominant hand was no better than performing movements with the non-dominant one in isometric contractions, while on the other hand, other studies have shown statistically significant asymmetry.

In the part of the studies where the stability of the force was studied, larger force oscillations were observed in the weaker limb than in the stronger one at the force level of 30% MVC when performing abduction with the index finger (Adam et al., 1998), while on the other hand these differences were not observed at the level of force of 10% MVC (Semmler, & Nordstrom, 1995). In performing isometric contractions at a high force intensity, 70% MVC, the variability of the force was statistically significantly higher in the dominant arm compared to the non-dominant one (Mitchell et al., 2017). These differences in the results of Adam et al. (1998), Semmler and, Nordstrom (1995), and Mitchell, Martin, and Adamo (2017) were due to the influence of different levels of contraction. In Beuter (2000), the dominant side exhibited greater force variability, higher power in the range of 7 - 12 Hz and a higher mean frequency, while Sainburg, and Kalakani (2000), and Yamauchi (2004) observed a more coordinated performance of the movement with the dominant hand. In addition, by monitoring the behavior of motor units, Adam et al. (1998) found differences in the recruitment and firing rate of motor units between the muscles of the first dorsal interosseous dominant and non-dominant arms. The motor units in the dominant hand showed a lower average of firing rates and lower recruitment thresholds than those in the non-dominant hand (Adam et al., 1998). Furthermore, during isometric contractions, pairs of motor units were discharged with a higher degree of synchronization in the dominant hand compared to the non-dominant one, yet statistically non-significant differences were found in the variability of motor units’ discharge as well as in their activation threshold (Schmied et al., 1994). In Kamen, Greenstein, and De Luca (1992), the MU mean firing rate, by cross-correlation, was higher in pairs of motor units of the dominant hand than the non-dominant one. Also, the power of short-term motor unit synchronization was weaker in the dominant than the non-dominant limb in right-handed subjects, but this difference did not exist in left-handed subjects, indicating a more limited distribution of direct projections from motor cortical neurons within the muscular motoneuron pool or reduced cortical excitability during task execution (Semmler, & Nordstrom, 1995). However, arm dominance does not affect the adjustment of discharge rate and variability in the discharge time of motor unit activity in the *biceps brachii* muscle during continuous submaximal contractions requiring force or position control, either in left-handed (Gould et al., 2016) or right-handed participants (Mottram et al., 2005). Together, these data suggest that there may be differences in the organization of motor units between limbs. In addition, there are results that indicate a difference in the activation of motor units in trained subjects compared to the untrained ones. The results on musicians (trained subjects) compared to untrained subjects showed weaker synchronization strength and the same power of MU in both hands in musicians and only in the dominant one in untrained subjects. Furthermore, the mean value of the drive coefficient for MU pairs and force variability were statistically significantly lower in musicians compared to bodybuilders and the untrained, while neural control was not influenced by the manifested maximum voluntary force (Semmler, & Nordstrom, 1998b). Although it is well established that the activation of motor units is a key mechanism by which muscle force is controlled (Clamman, 1993; Kernell, 2003), results on the systematic association of motor unit activation and dominance are rare.

2.4.2 Research determining the differences between the lower extremities in neurocontrol and muscle variability in the general population of subjects

Table 2. A review of research characteristics determining the differences between the lower extremities in neurocontrol and muscle variability in the general population of subjects

Reference	Subject of research	Participants' sample (sport, number, sex, dominance and age)	Instruments and protocol	Results
(Jakobi, & Cafarelli, 1998)	Determining the differences between knee extensors when performing bilateral and unilateral movements	N: 20 G: M (7)/F (6) LD: RH (7)/LH (6) Y: 25.5	Performing unilateral and bilateral isometric contractions at force levels of 25, 50, 75 and 100% MVC. Activation of the quadriceps muscle was monitored by an EMG apparatus.	There was no statistically significant difference in strength between unilateral and bilateral movements, as well as in the activation of agonist and antagonist muscles and the level of MU firing rate.
(Oshita, & Yano, 2010)	Determination of asymmetry in force variability in leg muscles during isometric contractions	N: 20 G: M LD: - Y: 21 ± 2	MVC in knee extensors and flexors. Performing continuous isometric contractions at the force level of 10%, 20% and 30% MVC for 15 s.	In 13 subjects, the knee extensor was stronger in the right leg, while in 17 subjects the knee flexor was stronger in the right leg. Significantly higher force variability in the stronger limb at the force level of 30% MVC while, no differences in force variability were obtained at force levels of 10% and 20% MVC. Thewe was a statistically significant positive correlation between target force values and force variability at each contraction intensity.
(Burnett, Campbell-Kyureghyan, Cerrito, & Quesada, 2011)	Determining the symmetry index at the reaction force of the surface and muscle activity between the lower extremities during walking, getting up and sitting tasks	N: 35 G: M (19)/ F (16) LD: RL (34)/ LL (1) Y: 23.0	For data collection, a multi-camera motion monitoring system and EMG were used to monitor muscle activation of the *erector spinae, rectus abdominis, rectus femoris* and *hamstring* during six cycles of walking 10 - 12 m, getting up and sitting on a chair on one leg (as many times as possible during 30 s)	The results showed that muscle activity was symmetrical for all muscle pairs in all tasks except for the hamstring muscle during the performance of the sitting task.
(Oshita, & Yano, 2011)	Asymmetry in force variability during isometric contractions of low and medium intensity	N: 11 G: M LD: RL Y: 21 ± 1	MVC in knee extensors. Performing continuous isometric contractions at the force level of 10%, 20% and 30% MVC for 15 s. Mechano myogram on the *vastus lateralis* muscle.	Significantly higher force variability in the weaker (left) vastus lateralis at the 30% MVC force level. No differences in force variability were found at force levels of 10% and 20% MVC. A statistically significantly difterent mean power frequency was observed in the mechanomyograpic signal for the two legs only on the moderate-intensity (30% MVC) task.

Table 2. *(extension 1-3)*

(Sarabon, Markovic, Mikulic, & Latash, 2013)	Influence of performing bilateral precision force on symmetry	N: 22 G: M (11)/ F (11) LD: RL (18)/ LL (3) Y: 26.0 ± 0.9	Subjects were producing a stable force with a sudden change in the force pulse velocity. The movements of the ankle joint were symmetrical (both feet performed plantar or dorsal flexion) and asymmetrical (in different directions).	The index of common action was higher while performing asymmetric tasks. Bilateral deficit has no or little impact on bilateral synergy.
(Noble, Eng, & Boyd, 2014)	Determining which parts of the brain coordinate movements in the lower extremities when performing unilateral and bilateral movements	N: 11 G: M (4)/ F (7) LD: RL Y: 19–34	Isometric movements of plantar flexion in the ankle joint were performed at a force level of 15% MVC on the right (dominant), left and with both feet together. The activation of brain regions was followed by magnetic resonance imaging.	Several regions were activated during the performance of bilateral movements: the cerebellar region, the cortical and subcortical regions which, on the other hand, were not activated in unilateral movements. Also, the activation of regions in bilateral movements was greater than the cumulative overview of the unilateral ones.
(Volz et al., 2015)	Differences in the interaction of the cortical motor network in unilateral movements of the upper and lower extremities	N: 16 G: M (4)/ F (12) LD: RH Y: 26 ± 4	The protocol consisted of performing isometric contractions of the wrist and ankle for 22 repetitions of 11 s, while magnetic resonance imaging of the brain and dynamic causal modeling were performed at the same time.	The dynamics of the motor network differed significantly between the unilateral movements of arms and legs. Unilateral arm movements are associated with increased laterlization, stronger excitatory drive on the active contralateral arm in M1 performed by premotor areas, and more pronounced inhibition of M1 inactive ipsilateral arm compared to foot movements. In contrast, during unilateral foot movements, the M1 of the inactive foot was not inhibited by its homologous or premotor regions, but M1 had a significant excitatory effect on the active foot.
(Smith, Stinear, Alan Barber, & Stinear, 2017)(M. C. Smith et al., 2017)	Effects of voluntary contraction of a non-target leg in combination with TMS on corticomotor neurotransmission	N: 22 G: M (11)/ F (11) LD: RH/RL (14)/LH/LL (3)/RH/LL (3)/ LH/RL (2) Y: 19–47	The protocol involved lifting the non-target leg from the ground, followed by activation of the *tibialis anterior* muscles of the target leg with EMG. The target leg referred to the opposite leg from the stimulated M1. TMS was positioned to induce posterior-anterior and medial-lateral cortical currents.	The results showed that lateral dominance did not affect the resting motor threshold (RMT), as well as that there was no greater corticomotor neurotransmission, but also that lateral dominance of the legs and hemispheres were positively correlated with the degree of RMT asymmetry.

Table 2. *(extension 2-3)*

(Bond et al., 2017)	Asymmetry in knee extensor force during unilateral movements and differences in the neural activity of the stronger and weaker legs in order to compensate for the symmetry of strength	N: 24 G: M/F LD: RL (18)/ LL (6) Y: 44.4 ± 7.8/41.5 ± 4.8	Based on the testing, the subjects were categorized into symmetrical and asymmetrical. The protocol included isometric (4 x 3 s, knee angle 120º) and isokinetic knee extensions (4 x 90-180º) on a dynamometer followed by MVC. Tests, getting up from a chair and vertical jumps on force ground were used to determine the asymmetry between the extremities. Activation of the *vastus lateralis* and *biceps femoris* muscles was accompanied by EMG.	The results showed a statistically significant difference between the groups in the isokinetic knee extension, where in the asymmetric group of subjects the asymmetry in the extensions was 4 times higher than in the symmetric group, in getting up from the chair and in activating the *vastus lateralis* muscle during the isokinetic extension where the symmetric group of subjects had higher activation in the stronger leg, while the asymmetric group had higher activation in the weaker leg.
(Yen et al., 2018)	Existence of asymmetry in the maintenance of stable force in the lower extremities	N: 20 G: M (7)/F (13) LD: RL (10)/LL (10) Y: 24 ± 4.4/22.2 ± 0.4	Subjects were required to follow the force on a screen to hit 24 targets by adjusting the direction and magnitude of the isometric force with movements from the ankles at a force level of 70% MVC determined for dorsal and plantar flexion, inversion and eversion movements for each limb.	No differences were observed for any of the movements at MVC. After practicing the movement, the subjects showed improvement in isometric force control without a statistically significant difference in extremities.
(Yamaguchi, Milosevic, Sasaki, & Nakazawa, 2019)	Influence of unilateral and bilateral movements of dorsal ankle flexion on lateral dominance	N: 15 G: M (9)/F (6) LD: RL Y: 26.8 ± 4.1	The measurement protocol included performing tasks with the dominant and non-dominant limb, as well as united control of both extremities with the requirement to monitor the force on the screen, ballistic - a wave in the shape of a square with 1 s width, randomly 3 - 5 s and tonic - a wave in the shape of a square with 5 s width, randomly 5 - 8 s with a load of 10% MVC, where the position of the ankle joint was set at an angle of 0°. Muscle strength was monitored by EMG.	The results showed that there was no statistically significant difference in total muscle activity between unilateral and bilateral limb muscle control. In bilateral movements, during tonic contraction, greater variability of force in muscles was observed than in unilateral movements.

Table 2. *(extension 3-3)*

(Petrović et al., 2022)	Differences between the lower extremities in maximum force, force stability and discharge characteristics of motor units in the *tibialis anterior* muscle during submaximal contractions	N: 20 G: M LD: RL Y: 24.0 ± 5.2	The measurement protocol included performing submaximal isometric contractions with the dominant and non-dominant limb. High-density EMG was used to monitor force variability and motor unit activation in the tibialis anterior muscle at force levels of 5, 10, 20, 40, and 60% MVC and ankle angles 75, 90, and 105°	Maximum force and force stability were similar between the two extremities for all three angles in the ankle. The mean discharge rate, discharge variability, and neural activation variability for motor units in the *tibialis anterior* muscle were similar between the two extremities.

Legend: N - number of participants; G - sex; M - male; F - female; LD - lateral dominance; RL - right-footed, LL - left-footed; Y - age; EMG - electromyogram; MVC - maximum voluntary contraction; MU - motor unit; RMS - mean square amplitude.

This group of studies included 12 studies engaged in determining the differences between the lower extremities in neurocontrol and muscle variability in the lower extremities in the general population of subjects. The first study from this group was published in 1998 (Jakobi, & Cafarelli, 1998), while the last one was published in 2022 (Petrović et al., 2022). The total number of subjects in all studies was 236. In most studies, nine, the sample included both male and female subjects. In other studies the sample was male.

A critical review of previous research on the differences between the lower extremities in the general population of participants

As with the research on the upper extremities, scientists have tried to find a connection between neurosystem control and the lower extremities. During magnetic resonance imaging of the brain, Volz et al. (2015) monitored the activation of parts of the hemispheres when performing unilateral tasks with hands and feet. They came to the conclusion that there were statistically significant differences in the dynamics of the motor network between the unilateral movements of arms and legs. Unilateral arm movements were associated with pronounced lateralization, stronger excitatory drive on the active contralateral arm in the primary motor cortex by premotor areas, and more pronounced inhibition of the M1 inactive ipsilateral arm compared with foot movements. In contrast, during unilateral foot movements, the M1 of the inactive foot was not inhibited by its homologous or premotor regions, but M1 had a significant excitatory effect on the active foot. The explanation for the reduced interhemispheric inhibition in the lower extremities was found by these authors in the possibly stronger influence of the spinal cord circles on the movements of the lower extremity. Noble, Eng, and Boyd (2014) compared the activation of brain regions during the performance of bilateral and unilateral movements and came to the result that more regions were activated during the performance of bilateral movements than the unilateral ones. The authors attribute the greater activation of the cerebral hemispheres during the performance of bilateral movements to interhemispheric inhibition caused by the greater need for motor coordination of both feet at the same time.

Very few studies have measured force variability during submaximal isometric contractions, a variable known as force stability that has been shown to explain significant amounts of variance in performing clinical tests of motor function (Enoka, & Farina, 2020). In line with upper extremity research, Adam et al. (1998), Semmler, and Nordstrom (1995), and Oshito, and Yano (2011) came to the data that higher force oscillations during submaximal contractions were more present in the dominant leg in the *vastus lateralis* muscle than in the non-dominant one at the force level of 30% MVC, while the differences were not manifested at the force levels of 10% and 20% MVC. In an earlier study where quadriceps muscle activation was monitored when performing isometric force at 25%, 50%, 75%, and 100% MVC, no asymmetry between the extremities was also observed (Jakobi, & Cafarelli, 1998), while in Burnett et al. (2011), out of five monitored muscles in the lower extremities, asymmetry was found only in the hamstring muscle when performing the sitting task. On the other hand, recent research has shown a statistically significant difference between asymmetric and symmetric groups of subjects in isokinetic knee extension, where in the asymmetric group of subjects the asymmetry in extensions was four times higher than in the symmetric group. A statistically significant difference was then also found in getting up from a chair and in *vastus lateralis* muscle activation during isokinetic extension where the symmetrical group of subjects had greater activation in the stronger leg, while the asymmetrical had greater activation in the weaker leg (Bond et al., 2017).

In the studies that followed asymmetry in ankle movements, it was recently reported that there were no significant differences between the legs during the performance of the dorsal-plantar flexion task and inversion-aversion movements. Shorter movement time and accuracy of hitting all targets with a defined task during the test indicated better isometric control of the ankle between the extremities (Yen et al., 2018). Since the ability to control and adopt the skill of controlling isometric force was similar between the legs, the authors conclude that their results do not support lateralization for controlling isometric force in the ankle. However, the direction of the muscle torque vector is rarely aligned with a single plane of action, and anatomical differences result in the engagement of synergistic muscles that require special synaptic input to the involved groups of motor neurons (Desmedt, & Godaux, 1981; Nozaki, Nakazawa, & Akai, 2005; Vieira, Minetto, Hodson-Tole, & Botter, 2013), as well as modulation of reflex pathways to counteract the side effects of activated muscle in other directions (Barry et al., 2009; Pérot, & Goubel, 1982). For example, it has recently been shown that force stability is worse during foot adduction than dorsiflexion in the ankle due to greater variability of the nerve drive to the *tibialis anterior* muscle at the same target forces (Panagiota et al., 2021). Moreover, it has been reported that the coefficient of force variation at 10% MVC during the performance of the target isometric dorsal flexion task in the ankle is similar between the left and right extremities, suggesting that limb dominance may not have affected the static task (Yamaguchi et al., 2019). Petrović et al. (2022) confirmed no difference between the limbs in force control or MVC force during submaximal isometric contractions with dorsiflexor muscles, as well as in the modulation of MU discharge characteristics in the *tibialis anterior* muscle during stable submaximal contractions. Unfortunately, this is the only study that has studied the neurocontrol and activation of motor units in the lower extremities, and it requires additional research to confirm these results.

2.4.3 Research determining the difference between the lower extremities in neurocontrol and muscle variability in athletes

Table 3. A review of research characteristics determining the difference between lower extremities in athletes

Reference	**Subject of research**	**Participants' sample (sport, number, sex, dominance and age)**	**Instruments and protocol**	**Results**
(Bauer, 1983)	Determining the differences in rugby shot biomechanics between the lower extremities	Rugby N: 6 G: M LD: - Y: -	Kinematic analysis, EMG A rugby shot from the maximum distance with the dominant and non-dominant leg.	There is a reduction in muscle contraction coordination and muscle activation in the non-dominant leg.
(Secher, Rube, & Elers, 1988)	Determining the differences between bilateral and unilateral movements in a group of athletes and patients with the problem of the examined muscle group	Untrained, athletes (cyclists, weightlifters), patients with polio N: 155 G: M/F LD: - Y: 20–30	Maximum voluntary contraction of the hip and knee extensors individually of one arm / leg or both extremities.	The total manifested strength during bilateral movements is less than the sum of the manifested forces of the left and right extremities during unilateral movements, which did not differ statistically significantly in the untrained subjects and athletes. In subjects with polio, bilateral strength was less than the maximum strength of the stronger leg.
(Howard, & Enoka, 1991)	Determining the correlation between the bilateral deficit and neurosystem	Control group; cycling; weightlifting N: 22 G: M LD: - Y: 29.0±3.2; 33.1±6.6; 22.7±3.0	EMG, electro stimulation Experiment 1: 9 x submax, preparation 21 x max, (agonists: extensors in the left/right knee and flexor in the elbow joint) 3 x 3 submax (25%, 50% and 90%, MVC), for each limb (left/right leg, left arm), 6 x max (unilateral/left arm) and (bilateral/left arm, right leg) 9 x limb-limb test (unilateral/leg-foot) and (bilaterally/both legs), 6 x max EMG (antagonists: flexors in the knee joint) Experiment 2: 3 x preparation 3 x MVC right extensor in the knee joint 6 x MVC left extensor in the knee joint with and without electro stimulation	Statistically significant difference in the performance of bilateral tasks in all groups of subjects and EMG activation in weightlifters compared to cyclists. No differences were observed in hand-foot tasks
(Schot, Bates, & Dufek, 1994)	Determining bilateral symmetry in the lower extremites during landing.	Recreational sport N: 10 G: M (5)/F (5) LD: - Y: 26.5 ± 4.3/26.2 ± 4.4	Kinetic analysis 25 voluntary jumps from a 60 cm height, during three days	Bilateral asymmetry is manifested in a vertical jump on the force platform.

Table 3. *(extension 1-6)*

(Smak, Neptune, & Hull, 1999)	The impact of the level of pedalling on the bilateral asymmetry among cyclists	Cycling N: 11 G: M LD: - Y: 22.2 ± 2.7	Bicycle, 10 min warming up (120W/90 rpm) 5 x 3 min (120/60-75-90-105-120 rpm) Visual tracking	As the pedal rotation rate increased, the asymmetry decreased. Although the dominant leg showed statistically significant higher lever strength, the non-dominant leg showed significantly higher average positive and negative strength.
(Parkin, Nowicky, Rutherford, & McGregor, 2001)	Determining the asymmetry in force between the lower limbs and trunk muscles among rowers	Rowing, Controls N: 38 G: M LD: - Y: 21.7 ± 2.7/21.0 ± 4.6	Isokinetics dynamometer 2 x concentric contraction for flex and ext, rad◦s-2, 60 s pauses, 1.75 rad◦s-2 2 x excentric, 1.75 rad◦s-2 3 x isometric contraction, 90° in the knee joint, 3 s steady	The results showed no asymmetry in the knee extensors and flexors. EMG activation was significantly higher in rowers in the *erector spinae* muscle during extension and was associated with the rowing side.
(Dörge, Andersen, SØrensen, & Simonsen, 2002)	Determining the differences between the lower extremities in shot biomechanics	Football N: 7 G: M LD: RL (6)/LL (1) Y: -	Kinematic analysis, camera 3 max quick shots on goal, 11 m away, dominant and non-dominant leg	A higher kick speed with the dominant foot was displayed. There was no difference in muscle moment or force development rate.
(Orchard, Walt, McIntosh, & Garlick, 2002)	Determining the differences in the muscle activation between the lower extremities	Football N: 4 G: M LD: RL Y: -	Kinematic analysis, EMG 6 x drop punt shot with dominant and non-limping leg	There is a small difference between the EMG profile in dominant and non-dominant foot kicks.
(Siqueira, Pelegrini, Fontana, & Greve, 2002)	Determining the differences in dominancy between the lower extremities and the balance between agonist and antagonist.	Running; Jumping; Controls N: 54 G: M LD: - Y: 29.0 ± 3.2/33.1 ± 6.6/22.7 ± 3.0	Isokinetic dynamometer Concentric and excentric activation in the knee joint 60º/240º/s	Statistically significant higher torque and total work in the extensor of the dominant leg in non-athletes. In runners, there was a statistically significant difference in extensor strength in favor of the dominant leg.
(Karamanidis, Arampatzis, & Brüggemann, 2003)	Determining the symmetry in kinematics in different running techniques	Running N: 12 G: F LD: - Y: 23.4 ± 3.8	Kinematic analysis Treadmil running, speed 2.5, 3.0 and 3.5 m/s, step rate +/- 10%	The symmetry of the left and right leg is lower for the parameters of angular velocity and higher for the parameters of linear and angular displacement
(Valdez, 2003)	Determining the asymmetry in flexibility, stability, power, strength and muscular endurance between the lower extremities	Controls; Unilateral; Bilateral N: 24 G: M (12)/ F (12) LD: RL (21)/LL (3) Y: 21.0 ± 1.2/20.8 ± 1.3/20.3 ± 1.4	Inclinometer, one-leg jump, force platform, isokinetic dynamometer (*m. quadriceps* and *m. hamstring* strength at 60°/s and muscular endurance 180°/s)	There is no asymmetry in flexibility, stability, strength, power and muscular endurance between the lower extremities.
(Daly, Saxon, Turner, Robling, & Bass, 2004)	Determining the relationship between muscle size and bone geometry and their response to physical exercise	Tennis N: 47 G: F LD: - Y: 8-17	Magnetic resonance imaging, osteodensiometry.	In the inactive arm in tennis players, the results showed that muscle circumference is linearly related to bone development. In the active arm, the results showed a significant change in bone size, mass, and strength. As only 12-16% of muscle mass is increased in a trained arm compared to an untrained one, it is believed that the change in bone structure is influenced by other factors in addition to muscle.
(Rahnama, Lees, & Bambaecichi, 2005)	Determining the correlation in muscular strength and flexibility between the lower extremities	Football N: 17 G: M LD: - Y: 23.4 ± 3.8	Isokinetic dynamometer, goniometer Warm up 1. 3 x MVC for angular speeds of 1.05, 2.09, 5.23 rad/s (concentric contraction) and 2.09 rad/s (excentric contraction) in knee joint with both legs separately 2. Max flexion in the hip joint	There is a reduced strength in the knee flexion in the dominant leg. Its correlation with flexibility was not observed.

Table 3. *(extension 2-6)*

(Bobbert, De Graaf, Jonk, & Casius, 2006)	Determining the activation impact on the bilateral deficit in jumping	Volleyball/gymnastics N: 8 G: M LD: - Y: 20 ± 4	Force platform, Kinematic analysis, EMG Both legs jump, one leg jump (right) with arms crossed on the back; 30 rebounds, 1min break	Participants showed a statistically significant shortcoming in performing jumps on both legs compared to jumping on one leg. 75% of the bilateral deficit is a consequence of the higher speed of muscle contraction in the jump with both legs, and due to the ratio of force and speed, less force is produced.
(Nunome, Ikegami, Kozakai, Apriantono, & Sano, 2006)	Determining the differences between kinematics in the lower extremities in instep shot	Football N: 5 G: M LD: RL Y:16.8±0.4	Kinematic analysis 5 x max quick kicks on goal, 11 m away, one and other leg	There is a statistically significant difference in the extremities at multiple kinematic parameters. Faster swing when shooting with the right foot, researchers associate with greater muscle momentum in the dominant leg.
(Smith, Ball, & MacMahon, 2009)(J. Smith et al., 2009)	Determining the differences in the leg and ball interaction between the lower extremities	Football N: 18 G: M LD: Y: 22.8±4.2	Kinematic analysis Kick's maximal speed, left/right foot from 40 m distance	In five of the seven examined kinematic parameters, the dominant leg produced significantly higher values with a large effect size.
(Hides et al., 2010)	Determining the asymmetry in muscle *psoas* and muscle *quadratus lumborum* among football players	Football N: 54 G: M LD: RL (43)\LL (19) Y: 22.4 ± 3.9	MRI L4-L5 for muscle *psoas* L3-L4 for muscle *quadratus lumborum*	Asymmetry in muscle *psoas* was significantly higher in the dominant leg, while in muscle *quadratus lumborum* the value was higher in the non-dominant leg.
(Kobayashi et al., 2010)	Determining the bilateral difference in ankles torque during squats in long jumpers	Long jump N: 18 G: M LD: Y: 21.6 ± 1.7	Kinematic analysis, force platform 3 x squats (50%, 70% and 90% 3RM)	The maximum flexion in the hip joint and the highest torque showed a statistically significant difference between the extremities during the performance of squats with long jumpers at all load levels.
(De Ruiter, De Korte, Schreven, & De Haan, 2010)	The relationship of dominancy in lower extremities with the rate of production of isometric moment and jump height	Different kinds N: 8 G: M LD: RL (6)\LL (2) Y: 21.5 ± 2.2	Dinmometer, EMG, Electro stimulation, camera 1. 3 x max one leg jump, knee angle 120°, pause 30 sec 2. 5 x unilateral maximal isometric contraction, knee angle 120° 3. Triple electro stimulation during MVC and relaxed muscle Visual tracking	Knee extensor torque production rate, neural activation, and jump height are very similar in the dominant and non-dominant limb.
(Ball, 2011)	Determining the differences between lower extremity kinematics in punt kick	Football N: 17 G: M LD: - Y: 23.5 ± 1.6	Kinematics 3 x shot from 5 m run Shot from 45 m with the dominant and non-dominant leg.	Statistically significant higher activation of the pelvis, knees and abdomen on the dominant side, whereas the non-dominant side showed greater activation in the hips and thighs.
(Buckeridge, Hislop, Bull, & McGregor, 2012)	Determining the differences in asymmetries of the lower extremities kinematics in rowers	Rowing (elite; club; beginner) N: 22 G: M LD: - Y: 24.6 ± 4.5/21.3 ± 1.5/20.8 ± 3.1	Kinematic analysis, Rowing ergometer Set 1: 4 min rowing 18 strokes/min Set 2: 4 min rowing 20 strokes/min Set 3: 500 m rowing pace/best score at 2000 m race Set 4: 30 strokes at the maximum speed and power	All groups of subjects showed asymmetry of the lower extremities, with hip asymmetry significantly greater than knee asymmetry.

Table 3. *(extension 3-6)*

(Willems, & Ponte, 2013)	Determining the difference in fatigue in muscle *quadriceps femoris* between the dominant and non-dominant leg during unilateral isometric contractions	Sportsmen N: 18 G: M LD: - Y: 20 ± 2	EMG Seating position (in all angles 90°), arms crossed on the chest, 1. 3 x SubMax 4-6 s 2. 3 x MVC 3. 20% MVC to failure 4. 20 s MVC Visual tracking	MVC m. quadriceps femoris was higher on the dominant side by 4.6%. Duration during submaximal contraction, force variability, and RMS did not differ significantly between the extremities. After 20% MVC, in early recovery, dominant muscle *quadriceps femoris* had a statistically significant force loss.
(Kobayashi et al., 2013)	Determining the bilateral difference between one leg jumping and knee isokinetic force	Long jump N: 11 G: M LD: - Y: 23 ± 1	Dynamometer Isokinetic flexion and extension in the knee joint 60° and 180°/s-1 3 x ext/flex, 2 min break Verbal guidance Force platform, Kinematic analyses One leg jumps without the arm swing (left/right)	The bilateral asymmetry in the knee strength is associated with the bilateral asymmetry in kinematics and knee kinetics during one leg jumps.
(Bini, & Hume, 2014)	Assessment of bilateral asymmetry in cycling	Cycling, triathlon N: 10 G: M (7)/ F (3) LD: RL Y: 30 ± 7	Bicycle ergometer, 3 min warm-up (100W/90rpm) 150W with power increase of 25 W/min to exhaustion Visual tracking	As the level of the torque power increases, the asymmetry of lower extremities increases in favor of the dominant leg.
(Luk et al., 2014)	Determining the force differences in unilateral and bilateral sports between the lower extremities among weightlifters and long jumpers	Weight lifting, long jump N: 19 G: M Y: 25 ± 3.3/19.4 ± 1.4	Force platform; 3 x 5 jumps with no arm swing 1 - double jump; 2/3 - double jump on the dominant/non-dominant leg; 4/5 - single jump on the dominant/non-dominant leg	Weightlifters showed statistically significant less asymmetry than long jumpers. In both groups, dominant leg produced a higher force and velocity than the non-dominant leg during any type of double-leg jump, but not in one-leg jumps. Both extremities in the subjects showed significantly higher force and strength and significantly lower speed in single jumps on one leg compared to double jumps.
(Rumpf et al., 2014)	Determining the kinetic asymmetries during runing among young runners	Running: Pre-/Mid-/Post-puberty N: 122 G: M LD: - Y: 10.5 ± 1.37/14.5 ± 0.93/15.4 ± 0.74	Treadmill, kinematics Warm up 10 min Sprints 3 x 5 sec, 4 min break	The asymmetry in the horizontal force for pre- / mid- / post- was 15.4/14.8/14.7%, in the vertical force 18.1/20.2/20.8%, in force 14.9/15.8/15.5%. Strength asymmetry was statistically significantly more present in the prepubertal age group compared to the other two.
(Trivers et al., 2014)	Influence of lower extremity symmetry on racing performance in elite athletes from Jamaica	Runners (100 m and 800 m), controls N: 189 G: - LD: - Y: 23.0 ± 23.2/23.0 ± 23.6	Anthropometric parameters.	Athletes had statistically significantly more symmetrical lower extremities. Runners in the 800 m had more symmetrical limbs than sprinters. Also, the results showed that runners in the 100 m with greater symmetry in the extremities achieve better top results.
(Fort-Vanmeerhaeghe et al., 2015)	Determining the neuromusculature asymmetry among basketball players	Basketball N: 29 G: F LD: RL (27)/LL (2) Y: 15.7 ± 1.3	Force platform One leg repeating jumps (vertical, horizontal and lateral) Balance test (three directions) Sprint test with a change of direction	The results showed a greater difference between skilled and unskilled legs, compared to the test-assessed dominance. There was a statistically significant difference in all measured parameters between skilled and unskilled foot. Differences between right and left or dominant and non-dominant legs existed in balance-postlaterally and repetitive jumps-laterally.

Table 3. *(extension 4-6)*

(Furlong, & Harrison, 2015)	Assessment of the muscular asymmetry of the lower leg	Sportsmen N: 21 G: M (11)/F (10) LD: RL Y: 23.8 ± 2.3	Adapted force slider, kinematic analysis; Plantar flexion 90 times; Angle in hip 135°, angle in knee140° and 160°; Max 70% 11RM	There is a statistically significant difference between lower limb muscles (plantar flexors) during dynamic, rapid contractile cycles.
(Pappas, Paradisis, & Vagenas, 2015)	Determining the level of presence of the (a)symmetry in lower extremities among runners	Running N: 22 G: M LD: RL (12)/ LL(10) Y: 22.5 ± 1.1	Video camera, Kinematic analysis Treadmill running 30 s (4.44 m/s)	Statistically significant asymmetry was expressed in flight time and maximum ground force response of the seven monitored variables.
(Fort-Vanmeerhaeghe, Gual, Romero-Rodriguez, & Unnitha, 2016)	Determination of neuromuscular asymmetry in basketball and volleyball players	Basketball, volleyball N: 79 G: M (41)/F (38) LD: RL (70)/LL (9) Y: 23.7 ± 4.5	Force platform 3 repetitive jumps on one leg	A statistically significant difference in limb interaction was observed in both groups of subjects in the dominant and non-dominant leg, as well as in the stronger and weaker leg. In female subjects, there was a statistically significantly higher asymmetry compared to male subjects.
(McPherson, Dowling, Tubbs, & Paci, 2016)	Determining the difference between the dominancy of lower extremities in unilateral and bilateral tasks	Baseball, basketball, football, tennis, running N: 148 G: M LD: - Y: 21.7 ± 3.6	Kinematic analysis Unilateral task: single leg landing (left-right) from 14 cm height and vertical jump Bilateral task: both legs landing from 44.5 cm height and vertical jumpup	No statistically significant asymmetry was observed in the lower extremities at unilateral landing. Flexion in the knee joint and hip was significantly different between the extremities in bilateral landing.
(Škarabot, Cronin, Strojnik, & Avela, 2016)	Comparison of the degree of bilateral deficiency and maintenance of interhemispheric interaction during unilateral and bilateral contractions	Weightlifting (bilateral), jump (unilateral), controls N: 20 G: M LD: - Y: 23.6 ± 3.9	Electrical stimulation and trancranial magnetic stimulation. Performing maximal unilateral and bilateral isometric contractions in the knee extensor.	Bilateral deficit was statistically significant for the entire sample of participants, but not for groups individually. The level of voluntary activation and amplitude of motor-induced potential was significantly higher in bilateral contractions compared to unilateral, without differences between groups.
(Bini, Jacques, Carpes, & Vaz, 2017)	Assessing the possibility of reducing the asymmetry by a specific training	Cycling/triathlon N: 20 G: M LD: RL (16)/ LL (4) Y: 30 ± 7	Bike connected to a trainer, 1. 3 x 1 min 70% max (360 ± 43W), 1 min pause, cadence monitoring 252 ± 43W / 90 rpm 2. Participants with asymmetry> 20% → 12 series, 1min / 1min, visual feedback Visual tracking	Statistically significant asymmetry was observed in asymmetric subjects. By applying specific training, the asymmetry was neutralized
(Girard, Brocherie, Morin, & Millet, 2017)	Determining the differences in the symmetry between lower extremities during repeated sprints	Running N: 13 G: M LD: RL Y: 31.2 ± 4.8	Treadmill, kinematic analysis 3 x RSA, 2 min break RSA - 5 sprints with 25 sec passive rest	Repeated running on tridmill shows asymmetry in the extremities in many kinematic parameters.
(Ludwig, Simon, Piret, Becker, & Marschall, 2017)	Determining the differences in the dominant and non-dominant limb in younger elite and amateur football players after a one-sided landing	Futball N: 114 G: M LD: RL Y: 14.6 ± 1.1	The task of the participants was to make a landing on one leg from the box. Valgus angles in the knee joint were compared.	Statistically significant differences were identified for valgus angles between the dominant and non-dominant leg in both groups of subjects, showing a larger angle in the dominant leg.

Table 3. *(extension 5-6)*

(Marchini, Pereira, Pedroso, Christou, & Neto, 2017)	Determining the influence of age differences in motor variability during the performance of dorsal flexion coordination tasks in the ankle and the possibility of reducing asymmetry with training	Young and older non-athletes, older in the training process 1 year N: 32 G: M (10)/F (22) LD: - Y: 30–60	The protocol included successive repetitions of the task of maintaining a constant force (5 N, trapezoid 3-20-3 s) and targeting the achievement of force levels (10 N in 250ms), with and without visual monitoring.	Older participants had statistically significant higher variability of force, regardless of physical fitness status, compared to younger respondents. The removal of visual monitoring statistically significantly increased the variability of force and decreased synergy in all groups of subjects.
(Sinsurin et al., 2017)	Determining the influence of lower limb dominance and landing direction in volleyball players	Volleyball N: 19 G: F LD: RL Y: 19.7 ± 0.01	Force platform and kinamotogram; One-leg jumps from 30 cm height no arm swing (forward 0°, diagonal 30° and 60° and lateral 90°)	Statistically significant difference in limbs in landing strategies in different directions. Statistically significant increase in force in dorsal flexion of the joint in the lateral direction in relation to other directions.
(Boccia et al., 2018)	Determination of asymmetry between extremities at the rate of torque development in ballistic contraction at submaximal moment	Football N: 20 G: M LD: - Y: 17 ± 1	Subjects performed three concentric isokinetic contractions at 240◦ / s and a series of isometric contractions at a force level of 20 to 100% MVC.	The observed asymmetry in the subjects was > 15%. 40% (quadriceps) and 60% (hamstring) of the subjects showed asymmetry in the isometry of the rate of torque development at the force level of 50% MVC.
(Zouhal et al., 2018)	The impact of the laterality on agility among elite football players	Football: elite, amateur N: 80 G: M LD: Y: 18.2 ± 2.2/19.6 ± 2.1	Accelerometer and cameras; Agility Test: Visual motorized task with 180-degree and 5 m sprints; 9 reps (3 x 3 rotations: left, right, central) Visual signal	The dominant leg correlated with the contralateral eye. The reaction time in the right eye was statistically significantly higher in elite football players. A statistically significant difference was observed between the extremities and the time of rotation movement in elite football players. Lateral dominance was similar between elite football players and amateurs.
(Mo et al., 2020)	Influence of running speed and training experience on bilateral symmetry during running.	Running: elite, recreational, amateurs N: 31 G: M (18)/F (13) LD: - Y: 31.7 ± 4.1/35.2 ± 7.4/29.1 ± 4.3	Temporal and kinematic parameters Tridmil 3 min / 5 speed (8, 9, 10, 11 and 12 km / h)	A statistically significant effect of speed was observed on the symmetry index in flight time, which was significantly higher at a speed of 8 km/h. Elite runners exhibited a linear reduction in the symmetry index with increasing speed. Recreational runners exhibited the most symmetrical behavior in high-speed running
(Tucker, & Hanley, 2020)	Analysis of increasing walk variability and symmetry at different speeds in world-class fast walkers	Fast walking: eliteN: 18 G: M (11)/F (7) LD: - Y: 25.7 ± 4.1/25.9 ± 4.1	Tridmil 3 min/4 speeds (11, 12, 13 and 14 km/h)	Each athlete showed asymmetry in at least one parameter, but none in more than half of the monitored parameters. Variability and asymmetry did not change with increasing speed.

Table 3. *(extension 6-6)*

(Satas, Jurgelaitiene, Brazaitis, Eimantas, & Skurvydas, 2020)	Determining the influence of knee extensor fatigue on bilateral force, variability and coordination with and without visual monitoring	Fast walking: recreational N: 22 G: M (18)/F (4) LD: RL Y: 22.6 ± 2.0/22.2 ± 1.3	EMG, muscle stimulation 210 submaximal continuous isometric contractions of the knee extensor with and without visual monitoring Group 1: symmetrical task (both legs at the knee angle below 60º); Group 2: asymmetric task (60º and 30º)	Performing bilateral isometric contractions reduced voluntary and electrically induced force without changes in the variability and accuracy of bilateral force control. The stability and accuracy of bilateral force generation were higher in both visual feedback tasks. Greater bilateral accuracy of force control was observed during the performance of the asymmetric task, with and without visual feedback.
(DeAdder, 2020)	Determination of asymmetry between extremities in subjects with> 10%, athletes	Top athletes: pre/post puberty N: 122 G: M (57)/F (65) LD: - Y: 8 - 11/17+	EMG with eight muscles of the lower extremities Walking on a 5 m force platform at natural speed Running on a 10 m force platform at 66.6% of top speed A changeable task. Running 66.6% with change of direction (left-right) and transition to fast running.	27% of the total population showed asymmetry in the extremities > 10%. In all cases, prepubertal athletes exhibited greater asymmetry than athletes after puberty. Male subjects exhibited greater asymmetry in knee joint flexion at initial contact and highest knee extension moment. Subjects with asymmetry > 10% showed asymmetry in the greatest flexion of the knee joint.
(Elkins, 2020)	Determination of asymmetry in production is greatest during isometric contractions	Football N: 21 G: M (10)/F (11) LD: - Y: 20.5 ± 1.7/ 19.5 ± 1.4	Participants performed maximal isometric mid-thigh pull over dual force plates with and without the assistance of lifting straps.	Both groups of participants (men and women) showed asymmetry in performing the task.
(Bishop, Brashill, et al., 2021)	Determining asymmetry between limbs in different age groups of subjects	Football: over 23, 18 and 16 years N: 51 G: M LD: - Y: 19.8 ± 6 1.1/17.5 ± 6 0.5/ 15.1 ± 6 0.7	Repetitive jumps on one and both legs; 5, 10 and 20 m sprint; 505 speed change test.	Differences between extremities were manifested in the repeated jump on one leg. There were several statistically significant correlations between asymmetry and physical test performance.
(Bishop, Berney, et al., 2021)	Determining the bilateral deficit and the relationship in linear velocity and change of direction	Students, physically active N: 18 G: M LD: - Y: 19.8 ± 6 1.1/17.5 ± 6 0.5/ 15.1 ± 6 0.7	Repetitive jumps on one and both legs, drop jumps and standing long jumps; 10 and 30 m sprint; 505 speed change test.	Bilateral deficit was manifested in repetitive jumps, drop jumps, and long jumps and correlated with the 505 velocity test. The results showed that a larger deficit correlates with a faster change of direction.
(Kons et al., 2021)	Determining the influence of consecutive judo matches on the asymmetry between the extremities and the bilateral deficit	Judo N: 14 G: M LD: - Y: -	Four simulated matches of 4 min each. Before the first match and after each subsequent one, the subjects were tested: repetitive jumps, long jump, hand grip with a dominant and non-dominant limb	Participants showed statistically significant asymmetry only in the test of repeated jumps, which increased after the second match. Hand grip decreased significantly after the first and second match, with no observed asymmetry.

Legend: N - number of participants; G - sex; M - male; F - female; LD - lateral dominance; RL - right-footed, LL - left-footed; Y - age; EMG - electromyogram; MVC - maximum voluntary contraction; MU - motor unit; RMS - mean square amplitude.

This group of studies included 48 studies engaged in determining the differences between the lower extremities in neurocontrol and muscle variability in the lower extremities in athletes. The first study from this group was published in 1983 (Bauer, 1983), while the last one was published in 2021 (Kons et al., 2021). The total number of subjects in all studies was 1840. In 12 studies the sample included both male and female subjects. In four studies the sample was female, in one the gender was unknown and in the rest the participants belonged to the male group.

A critical review of previous research on the differences between the lower extremities in athletes

Previous research examining lower extremity dominance in athletes has mostly focused on maximal contractions or dynamic performance of movements in tasks such as kicking a ball (Ball, 2011; Bauer, 1983; Dörge et al., 2002; Nunome et al., 2006; Orchard et al., 2002; Smith et al., 2009), different types of jumps (Bishop, Berney, et al., 2021; Bishop, Brashill, et al., 2021; Bobbert et al., 2006; Fort-Vanmeerhaeghe et al., 2016, 2015; Kobayashi et al., 2010; Kons et al., 2021; Luk et al., 2014; McPherson et al., 2016; De Ruiter et al., 2010; Schot et al., 1994; Sinsurin et al., 2017; Siqueira et al., 2002; Valdez, 2003), cycling, rowing and running (Bini, & Hume, 2014; Bini et al., 2017; Buckeridge et al., 2012; DeAdder, 2020; Girard et al., 2017; Karamanidis et al., 2003; Mo et al., 2020; Pappas et al., 2015; Rumpf et al., 2014; Smak et al., 1999; Tucker, & Hanley, 2020). The results of the research are various. In the kinematic parameters in a large number of studies, the dominant leg showed statistically higher values in the measured parameters in relation to the non-dominant leg (Bini, & Hume, 2014; Dörge et al., 2002; Fort-Vanmeerhaeghe et al., 2015; Kobayashi et al., 2010; Nunome et al., 2006; Pappas et al., 2015; Sinsurin et al., 2017; Siqueira et al., 2002; Smak et al., 1999; Smith et al., 2009; Tucker, & Hanley, 2020). For example, the results showed that the dominant foot in football players is faster and stronger in kicks (Rahnama et al., 2005), the technique of performing the kick is better in the dominant leg (Smith et al., 2009), but also that these differences did not have a great influence on its performance. In runners, research showed differences in favor of the dominant leg in vertical force (Pappas et al., 2015; Rumpf et al., 2014), and the flight time and foot contact time with the ground (Karamanidis et al., 2003). These results indicate that the dominant leg produces a statistically significantly higher maximum force and speed during flight than the contralateral leg. They explain this difference as a consequence of greater strength and better ability to coordinate the dominant leg (Niu, Wang, He, Fan, & Zhao, 2011; Sadeghi, Allard, Prince, & Labelle, 2000).

In contrast, in the second part of the study, the results showed that in some parameters the non-dominant leg is superior to the dominant one. For example, in a study by Ludwig et al. (2017) the dominant foot showed less stability than the non-dominant one during a kick in football players. Similarly, in research Ball (2011), greater activation was observed in the hips and thighs in football players in the non-dominant leg compared to the dominant one, which provides better stabilization of the leg, due to the coupling of movements between the extremities, shifting efforts from the target muscle group to another muscle group (Salem, Salinas, & Harding, 2003). These results may be the reason for the adaptation of the movement to the specific requirements of the sport during the training process. On the other hand, it was noticed that the asymmetry between the extremities is more pronounced at a higher intensity of tasks, where with the increase in torque power when cycling, the asymmetry in the extremities also increased (Bini, & Hume, 2014), and that the asymmetry can be corrected by properly guided training (Bini et al., 2017; Girard et al., 2017). Different to this, Luk et al. (2014) compared asymmetry in the lower extremities in weightlifters and jumpers. As expected, the jumpers exhibited greater asymmetry between extremities than the weightlifters. These results indicate the contribution of the training process to the even development of abilities in both extremities in weightlifters, while jumpers, due to the nature of the sport and repeated movements of predominantly one side of the body, developed asymmetry in the monitored parameters. Furthermore, in a study by Siqueira et al. (2002) runners did not show asymmetry in strength between legs, but in non-athletes this difference was statistically significant. In a recent study by De Adder (2020), carried out on a large population of participants which included top athletes of different age and gender, the author came to the data that in athletes in prepubertal age there was a statistically significant asymmetry in the lower extremities, while this difference was not observed in the top athletes at a later age, which again indicates the possibility of correction during the training process. The possibility of correcting asymmetry through the training process has been confirmed in previous research in which the term *plasticity* was used, and explained as functional dominance (Wennerfeldt, 2013). For example, in the research of Fort-Vanmeerhaeghe et al. (2015) the dominant leg was not a more skilled leg in performing tasks with basketball players. This shows that with the training process we can influence the adaptation of the musculoskeletal system to specific tasks by repetitive performing. Other authors are of the opinion that the repeated performance of one limb, as in sports with greater activation of one limb, can cause neuromuscular adaptations such as neural innervations and muscle activation (Challis, 1998). This view is confirmed by Fort-Vanmeerhaeghe et al. (2015) who claim that there are differences in neuromuscular asymmetry between the extremities. Unfortunately, no research has followed the activation of motor units and their behavior in the lower extremities in athletes in order to verify these attitudes.

Similar to the measurement of kinematic parameters, in studies where the difference in strength between the extremities was monitored, a difference in muscle strength in favor of the dominant leg was observed (Furlong, & Harrison, 2015; Siqueira et al., 2002; Willems & Ponte, 2013). In the study by Rahnam, Lees, and Bambaecichi (2005) similarly to previous research, the authors noticed a difference in the development of knee flexor muscle strength, which was weaker in the dominant leg than the non-dominant one, which the authors explain as a consequence of the training process. In addition, Hides et al. (2010) using magnetic resonance imaging, came to the data that there is a possibility that due to the specific nature of performing tasks with the dominant and non-dominant leg individually, there may be a difference in the dominance of individual muscles. For example, in their research on football players, it was found that the *iliopsoas* muscle of the dominant leg was more developed than in the non-dominant one, while the dominance of the *quadratus lumborum* muscle exhibited the opposite, which the authors associate with the adaptation of the muscular system to performing specific movements in sports.

In Bauer (1983), in addition to movement kinematics, the author monitored the activation of electromyographic (EMG) signals between the lower extremities in rugby players and concluded that the differences in shoot performance were due to poor intersegmental movement of the non-dominant leg, and not muscle activity. Similar data were obtained by Orchard et al. (2002), where the results of EMG activation showed similar muscle activity in both legs, but the dominant leg showed higher foot speed, higher angular velocity in the knee joint and greater pelvic range, while the non-dominant leg showed higher angular velocity in the hip joint as well as higher range of motion of the hip. Such results can be explained by an influence of mutual compensations between extremities by multiple movements of the joints, where the effort is transferred from the target muscle group to another muscle group (Salem et al., 2003).

Based on these analyses, it can be concluded that a large number of studies have studied the differences in strength and kinematic parameters between extremities, and a small number by activating motor units in muscles and neurocontrol of the CNS. Also, asymmetries were observed between the upper extremities in a large number of subjects and in the lower limbs in all sport groups. In the general population of subjects, this asymmetry in the lower extremities was less pronounced. Research has shown that the difference is noticeable in the parameters of kinematics and power. A very small number of studies have studied neural control, and only in the upper extremities, whose results showed a statistically significant difference in the behavior of motor units in the monitored muscles. As it is known that the rate of activation of motor neurons and the maximum rate of discharge of motor units largely depends on the individual's ability to exhibit rapid force contractions (Del Vecchio, Negro, et al., 2019) and that training can influence specific adaptations in the behavior of motor units (Semmler, & Nordstrom, 1998b; Del Vecchio, Casolo, et al., 2019), the results of this research will provide new insight into differences in muscle strength and motor unit activation between the lower extremities in athletes, a topic that has not been explored in previous studies.

3. SUBJECT AND PROBLEM

The subject of the research is lateral dominance, force muscle variability and motor units' activation in unilateral and bilateral sport groups.

Based on the set subject of the research, the basic problem of this research was defined, leading to the following questions related to lateral dominance, force muscle variability and motor units' activation in unilateral and bilateral sport groups.

This research answers the following questions:

1. Are there any statistically significant differences in the control of the muscle force between the dominant and non-dominant lower extremities within the groups of unilateral and bilateral sports?
2. Are there any statistically significant differences in the motor units' activation between the dominant and non-dominant lower extremities within the groups of unilateral and bilateral sports?
3. Are there any statistically significant differences in the control of muscle force and the motor units' activation between the dominant and non-dominant lower extremities between unilateral and bilateral sports groups?
4. Are there any statistically significant differences in the control of muscle force between the dominant and non-dominant lower extremities depending on the characteristics of unilateral and bilateral sports?
5. Are there any statistically significant differences in the motor units' activation between the dominant and non-dominant lower extremities depending on the characteristics of unilateral and bilateral sports?

4. AIM AND TASKS

On the basis of the subject and problem set, five aims of the research can be defined:

1. The first aim is to determine the differences in the control of muscle force between the dominant and non-dominant lower extremities within the groups of unilateral and bilateral sports.
2. The second aim is to determine the differences in the motor units' activation between the dominant and non-dominant lower extremities within the groups of unilateral and bilateral sports.
3. The third aim is to determine the differences in the control of muscle force and the motor units' activation between the dominant and non-dominant lower extremities between unilateral and bilateral sports groups.
4. The fourth aim is to determine the differences in the control of muscle force between the dominant and non-dominant lower extremities, depending on the characteristics of unilateral and bilateral sports groups.
5. The fifth aim is to determine the differences in the motor units' activation between the dominant and non-dominant lower extremities depending on the characteristics of unilateral and bilateral sports groups.

4.1 Tasks of the research

On the basis of the set aims, concrete research tasks have been formulated:

1. Assess general sample indicators;
2. Assess lateral dominancy among the participants;
3. Assess muscle force variability among the participants;
4. Assess motor units' activation among the participants;
5. Using statistical data processing, determine the differences in the control of muscle force and the motor units' activation between the lower extremities in unilateral and bilateral sports groups, both within and between groups of sports;

6. Using statistical data processing, determine the differences in the control of muscle force and motor units’ activation between the lower extremities depending on the characteristics of unilateral and bilateral sports.

5. HYPOTHESIS

Based on the defined problem, subject and aim of the research, the following hypotheses were set:

1. H_1 – There is a statistically significant difference in muscle force control between the dominant and non-dominant lower extremities in the group of unilateral athletes.
2. H_2 – There is a statistically significant difference in muscle force control between the dominant and non-dominant lower extremities in the group of bilateral athletes.
3. H_3 – There is a statistically significant difference in motor units' activation between the dominant and non-dominant lower extremities in the group of unilateral athletes.
4. H_4 – There is a statistically significant difference in motor units' activation between the dominant and non-dominant lower extremities in the group of bilateral athletes.
5. H_5 – There is a statistically significant difference in muscle force control between the dominant and non-dominant lower extremities between the unilateral and bilateral groups of athletes.
6. H_6 – There is a statistically significant difference in motor units' activation between the dominant and non-dominant lower extremities between the unilateral and bilateral groups of athletes.
7. H_7 – There is a statistically significant difference in muscle force control between the dominant and non-dominant lower extremities depending on the characteristics of unilateral sports.
8. H_8 – There is a statistically significant difference in muscle force control between the dominant and non-dominant lower extremities depending on the characteristics of bilateral sports.
9. H_9 – There is a statistically significant difference in motor units' activation between the dominant and non-dominant lower extremities depending on the characteristics of unilateral sports.

10. H_{10} – There is a statistically significant difference in motor units' activation between the dominant and non-dominant lower extremities depending on the characteristics of bilateral sports.

6. METHOD OF THE RESEARCH

6.1 Sample

The sample of participants included 20 active unilaterals, 15 long-distance runners and 5 cyclists (30.7 ± 8.8 years, 177.3 ± 7.0 cm, 73.0 ± 6.4 kg, 3 left-leg dominant) and 16 active bilaterals, 8 volleyball players, 7 weightlifters and 1 rower (24.3 ± 9.3 years, 181.1 ± 8.4 cm, 85.1 ± 8.8 kg, 4 left-leg dominant), male. Prior to participation, each candidate was interviewed in detail to determine if they were healthy and free of injuries, neurological disorders, and if they were not taking any medications that could affect their ability to perform experimental tasks. Subjects with health problems, lower extremity injuries in the previous two years, or restrictions on physical activity were excluded from the study. The selected candidates were then introduced to the experimental protocol and before the start of participation signed an informative consent describing possible negative effects. The research was approved by the Laboratory of Neuromechanics, the Department of Physical Education and Sport Science in Serres, Aristotle University of Thessaloniki, Greece, and approval for the implementation of experimental procedures was obtained from the Ethics Committee for Human Research of Aristotle University, in accordance with the Declaration of Helsinki (ERC - 003/2021). Religious affiliation, as well as skin color (race) did not limit the choice of participants.

6.2 Measuring instruments sample

6.2.1 General indicators of the sample

A set of measures that define a general indicator of the sample:

1. Age (YEAR);
2. Body height (HEIGHT);
3. Body weight (MASS);
4. Body Mass Index (BMI);
5. Questionnaire for determining lower limb dominance (QLD).

Based on the obtained body height and body weight results, the BMI, expressed in kg/m², was calculated. This set of measures that define the general indicator of the sample are contained in the International Biological Program (National Heart Lung and Blood Institute - United States, http://www.nhlbisupport.com/bmi/bmi-m.htm).

Determining the dominance of the lower extremities was done using the questionnaire by Van Melick et al. (2017).

6.2.2 Measuring instruments for assessing muscle force and activation of motor units

The measuring instruments for assessing muscle force and motor units' activation will be extracted from the Matlab (Natick, MA: The Math Works, Inc., 2019a) for analysis in a logged-off mode, and were as follows:

1. Coefficient of variation of muscle force ($\mathrm{COV_F}$) defined as the relative amplitude of force variability for the most stable 10 s:

$$\mathrm{CoV_F} = \frac{SD}{Mean} \times 100;$$

2. Standard deviation of muscle force ($\mathrm{SD_F}$) defined as the apsolute amplitude of force variability for the most stable 10 s:

$$\mathrm{SD_F} = \sqrt{\frac{|x-\bar{x}|^2}{n}};$$

3. Root mean square (RMS) defined as the effective value of force variability for the most stable 10 s:

$$\mathrm{X_{RMS}} = \sqrt{\frac{1}{n}\left(x\alpha^2 + x\beta^2 + \cdots + xn^2\right)};$$

4. Coefficient of variation of MUs' interspike intervals ($\mathrm{CoV_{ISI}}$) defined as the relative amplitude of the MUs' interspike intervals variability for the most stable 10 s:

$$\mathrm{CoV_{ISI}} = \frac{SD}{Mean} \times 100;$$

5. Standard deviation of MUs' interspike intervals ($\mathrm{SD_{ISI}}$) defined as the apsolute amplitude of the MUs' interspike intervals variability for the most stable 10 s:

$$\mathrm{SD_{ISI}} = \sqrt{\frac{|x-\bar{x}|^2}{n}};$$

6. Mean discharge rate of MU (MDR) defined as the mean value of released action potentials for each recognized motor unit during the most stable 10 s:

$$\text{MDR} = \frac{1}{n}\sum_{i=1}^{n} x_i.$$

Previous research has shown that the activation of motor units and their discharge rate are greater in the short lent of a muscle than in the long one (Pasquet, Carpentier, & Duchateau, 2005). Regarding this, each of the applied variables was tested for the ankle angles of 75°, 90°, and 105°, so the research was realized with a total of 18 variables.

The selection of variables was performed and adjusted on the basis of the most frequently analyzed variables in previous research.

6.3 Measurement organization

6.3.1 Measurement conditions

The measurements of the general parameters of the sample and anthropometric parameters were carried out under the following conditions:

1. All the measurements were carried out in rooms that are sufficiently illuminated and warm, so that the participants would feel comfortable.
2. During the measurement, the participants were barefoot and minimally dressed.
3. For the assessment of the general indicators of the sample the following instruments were used: an anthropometer, a measuring tape and a standard scale which was calibrated after every 10 participants.
4. Before the start of the measurement, the examiner was well-trained for measuring all the provided anthropometric measures.

The tests for the assessment of muscle force and motor units' activation were carried out under the following conditions:

1. All the measurements were carried out in a specially equipped laboratory.
2. The laboratory was sufficiently illuminated and warmed up so that the participants could feel comfortable.
3. During the measurement, the participants were barefoot and wore shorts (short sports trousers).

4. All the instruments were previously disinfected and during the realization of the measurement hygienic gloves and one-time use materials (shavers, bipolar electrodes, napkins, etc.) were used.
5. All the measurements were carried out by one examiner.

6.4 Measurement technique

6.4.1 Description of the tests for estimating the general indicator of the sample

1. Age (YEAR) – represent the years number of subjects rounded to the integer number of years.
2. Body height (HEIGHT) – it was measured by Martin's anthropometer with an accuracy of 0.1 cm. A participant, barefoot and minimally dressed, stood in an upright position on a stable horizontal surface. The head was in such a position that the frankfurt flat was horizontal, the back maximally straightened up, and the feet together. The examiner came from the left side of the examinee and placed the anthropometer vertically along the back of the body, normally in the relation to the ground, and then descended the slider with the horizontal bar on top of the examinee’s head. After that, the examiner read the result with an accuracy of 0.1 cm.
3. Body mass (MASS) – it was measured by a standardised scale, with an accuracy of 0.5 kg, placed on a horizontal ground. A participant, barefoot and minimally dressed, stood on the scale and remain calm in an upright position until the body weight value was obtained, which was read with an accuracy of 0.5 kg.
4. Body mass index (BMI) – it is an internationally recognized measure of obesity and it will be calculated according to the formula BMI = MASS (kg) / HEIGHT $(m)^2$ (National Heart Lung and Blood Institute - United States, http://www.nhlbisupport.com/bmi/bmi-m.htm).

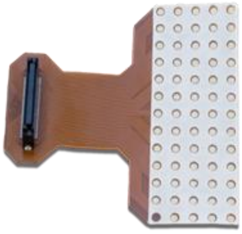
6.4.2 Description of the tests for assessing muscle force and motor units’ activation

The instruments used for the measurements met the standards and they were:

1. Isometric dynamometer (TF022-NEG1, OT Bioelettronica, IT) - the dynamometer measured the expressed muscle force of a participant (Picture 6).

Picture 6. Isometric dynamometer (TF022-NEG1, OT Bioelettronica, IT)

2. Force transducer (200 kg; 2,001 mv/V, S/N 11406; TF022, CCT transducers) – a calibrated cell transducer was used to convert the expressed muscle force into an electrical signal.
3. 64 Multi Array Electrode (IED; OT Bioelettronica, Turin, Italy) – to achieve electrical conductivity with the skin, the semi-resistant adhesive grid consisted of 64 electrodes was used (13 rows x 5 columns, gold plated, 1 mm in diameter, with a distance of 8 mm between the electrodes) and it was placed on the TA (Picture 7).



Picture 7. 64 Multi Array Electrode (IED; OT Bioelettronica, Turin, Italy)

4. *Quattrocento* amplifier (OT Bioelettronica, Torino, Italy, 3 dB, bandwidth 10–500 Hz) – it was used as an amplifier for the acquisition of surface/intramuscular EMG signals (Picture 8). This high-density electromyograph (HDsEMG) has proven to be good for identification an increase in the motor units recruitment or firing rate of currently activated MU during prolonged submaximal muscle contraction (Noven, 2014). Previous research has shown that during the production of force, the synchronization of motor firings increase from 8 Hz to 12 Hz rhythmically (Elble, & Randall, 1976; Noven, 2014), and that muscular variability can be identified by EMG (McAuley, & Marsden, 2000). The study of force variability in an active muscle with the help of appropriate EMG has been shown to be an excellent approach for

monitoring peripheral manifestations of central nerve oscillations. (Kenway, 2015; Noven, 2014). Thus, for example, force variability is more noticeable at low forces (Galganski et al., 1993; Laidlaw et al., 2000; Taylor et al., 2003). In the previous study, it was confirmed that the HDsEMG can record the MU activation and identify their behavior non-invasively (Martinez-Valdes et al., 2017). Some of the benefits of HDsEMG using can be found in monitoring a wider range of force levels (Holobar et al., 2009), peripheral characteristics of MU, the speed of the conductivity of muscle fibers, the MU behavior (Holobar et al., 2009), as well as monitoring the MU characteristics in longitudinal studies (Martinez-Valdes et al., 2017).

Picture 8. *Quattrocento* amplifier (OT Bioelettronica, Torino, Italy, 3 dB, bandwidth 10–500 Hz)

6.1 Experimental setup

The measurement was carried out in the illuminated and spacious Laboratory of Neuromechanics at the Department of Physical Education and Sport Science at Serres, University of Thessaloniki, Greece during two different days to avoid the effect of fatigue, as the protocol tests took about two hours per visit. The protocol of the measurement included only the participants with no history of injuries of lower limb muscles. The participants were asked to be available on three occasions, during three different days. During the first contact, they were given a detailed explanation of the test procedure. During the second and third contact, the participants came to the laboratory where the necessary measurements were carried out. The participants were required to refrain from hard exercises 24 to 48 hours prior to testing. Also, the daily variability of muscle contractility was minimized by performing two measurements at the same time of the day, by monitoring the stability of the muscle of one leg during the first visit to the laboratory and the other one during the second visit (Racinais, Blonc, Jonville, & Hue, 2005). Just before starting the measurement of isometric muscle strength, the body height and weight of the subjects were measured, and the dominant leg was determined using the questionnaire. All the measurements were carried out by experienced and pre-trained persons. All the participants were dressed minimally and barefoot, thus the optimal temperatures were set according to these conditions. After a standardized warming up, the main task was to monitor the muscle force and activation of the motor units in the TA in the dominant and non-dominant legs during an isometric maximal and sub-maximal voluntary contraction. The order of the measurements for legs was rendomized among the participants where the dominant or non-dominant leg was not always the first on the first day of the measurements.

The participants sat comfortably on the specially adapted table with their back supported while a dominant/non-dominant leg was placed in the ledge of the isometric dynamometer (TF022-NEG1, OT Bioelettronica, IT), where a foot was tightened with straps (~ 2 cm wide). The position of the examinee was sitting with an angle in the hip joint ~ 90° (90° = upright sitting position), the knee angle ~ 120° and the ankle angles ~ 75°, 90° and 105° (90° = vertical to the tibia) to avoid quadriceps muscle coactivation. Two digital bipolar goniometers with one degree of freedom (MLTS700, AD Instruments) were used during the measurement to continuously maintain approximately the same angles in the knee joint and ankle joint. The foot was fixed with straps for an adjustable base that was continuously connected to the calibrated cell (CCt transducers, load cell model TF 022., Toronto, Italy). Fixing feet straps were placed over the distal third of the metatarsal bones and immediately in front of the ankle. The non-examined leg was placed comfortably on an auxiliary table. Visual information was displayed on a 50-inch screen placed at a distance of 1.5 m from the eyes of the participants. The recording was performed on the TA. The semi-resistant adhesive grid was placed on the abdomen of the TA (IED; OT Bioelettronica, Turin, Italy) (Rainoldi, Melchiorri, & Caruso, 2004). After preparing the skin (shaving, light skin abrasion, cleaning with the 70% ethanol), the muscle perimeter was identified by palpation by the examiner, and its profile was marked with a surgical pen. The adhesive grid was attached to the surface of the muscle using a single-layer foam pad (ELSCH064, OT Bioelettronica, Turin, Italy). After preparing the skin (shaving, light skin abrasion, cleaning with the 70% ethanol), the muscle perimeter was identified by palpation by the examiner, and its profile was marked with a surgical pen. The contact between the skin and electrode was optimized by filling the cavities of the adhesive layers with a conductive gel (ACCREAM, OT Bioelettronica, Turin, Italy). A moistened electrode was used as a ground electrode and was attached to the wrist, while the other reference electrode was placed around the ankle of the measured leg shown in Figure 1.

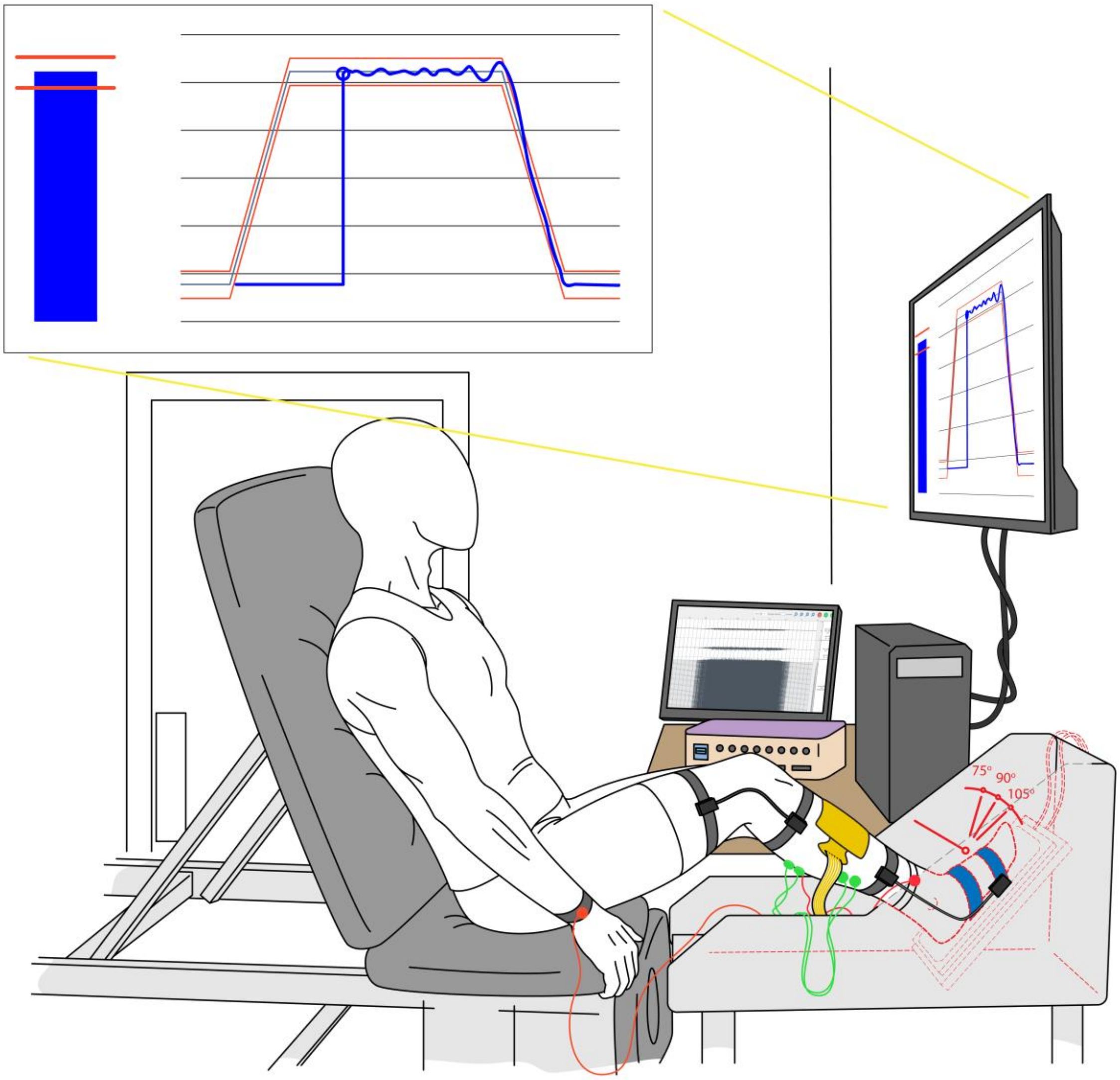


Figure 1. The experimental setup consisted of a customized ankle ergometer (OT Bioelettronica, Turin, Italy). The force exerted by the dorsal muscles in the ankle was measured using a force transducer attached below the foot. High-density electromyograph (HDsEMG) signals were recorded from the anterior tibial muscle of each leg with a semi-resistant adhesive grid (yellow electrode). Reference electrodes were placed on the wrist for bipolar imaging and on the ankle for crosslinking (red wires). One goniometer each was placed on the knee and ankle to measure the angle of the joint. Visual feedback was presented on the screen for the target force (red lines) and the manifested force (blue lines) during the ascent, plateau maintenance and relaxation phases (middle part of the screen) and the current force level (right side of the screen). Visual information covered about 80% of the screen (Petrović et al., 2022)

The warming up consisted of three to five isometric contractions of dorsal flexors with different intensities of free estimation of the maximum force, each separated with a time interval of 30 s. In the process of familiarization with the procedure, the participants were asked to focus on performing the dorsal flexion in the ankle correctly in order to activate the necessary muscles.

After warming up, the participants performed two MVC dorsal flexions with a 30 s break between the measurements. The participants were instructed while performing maximum dorsal flexion in the ankle, to manifest the greatest intensity of force from the muscle of the lower limb, as well as "to pull as hard as possible" for 3 to 5 s. During that time, they received a verbal incentive from the examiner. The highest force produced during the dorsal flexion was used as a reference for determining the target sub-maximal contraction.

After a five-minute break, the participants performed the contractions that consisted of a 3s preparation phase (relaxation phase), the linear force increase of 5s to the target level of force of 2.5%, 5%, 10%, 20%, 30%, 40%, 50% and 60% MVC, with a sustained level of force for 15s in order to maintain muscle stability and avoid possible tremors in the muscle. This was followed by a linear force decrease of 5s, with the same intensity as during the linear increase to the rest period of 3s (relaxation phase). During each assignment, the participants were provided with visual feedback on the achieved level of force, which was displayed on the screen as a trapezoid.

Maximal dorsal flexions, as well as sub-maximal isometric dorsal flexion were performed with a constant angle in the knee joint of 120° (180°, full extension) and the angles in the ankle of 75°, 90° and 105°. Three repetitions were realized for each level of the target force (2.5%, 5%, 10%, 20%, 30%, 40%, 50% and 60% MVC). Sub-maximal trapezoidal contractions were carried out randomly to avoid adjusting to the movement of one force level, with a two-minute break between the repetitions. The most stable repetition for each target force value was taken for further analysis.

6.2 Data analysis

HDsEMG signals were amplified, tuned, band-pass filtered before being accepted for analysis in a logged-out mode (10-500 Hz) and digitized using a 12-bit analog-to-digital (A/D) converter, Quattrocento (EMG-Quattrocento, OT Bioelettronica, Turin, Italy) and the sample frequency was 2048 Hz. The force signal was recorded with the OT Biolab software (version 1.0.3, OT-Bioelettronica, IT) and synchronized with EMG. The feedback of the force signal was obtained using the adjusted LabVIEW program (LabVIEW 8.0, National Instruments, Austin, USA). After removing data from missing and noisy channels, mean square amplitude (RMS) was calculated by summing the band-pass filtered (20-500 Hz) average values from the monopolar signals for each viable signal. Discrimination of motor units was performed in a logged-out mode with a customized MATLAB code that included a semi-automated Convolution Kernel Compensation (CKC) algorithm (Holobar, & Farina, 2014; Holobar, Glaser, Gallego, Dideriksen, & Farina, 2012; Holobar, & Zazula, 2004) based on the blind-source separation technique and extracting the discharge time of MU from the EMG signal curves. Pulse to noise ratio (PNR), presented by Holobar and Farina (2014), was used to assess the quality of MU identification. MUs with PNR > 29 dB (accuracy of firing identification of motor units > 90%) were used for further analysis. The results of the decomposed process were manually reviewed and edited to improve the automatic identification of spikes with the DEMUSE software tool (v5.01; The University of Maribor, Slovenia). MUs with a short (< 20 ms) spike intervals (ISI) or with irregular firing patterns (ISI > 400 ms or coefficient of variation for ISI > 20%) were rejected (Pascoe, Gould, & Enoka, 2013). In this way, only the MUs that were constantly active during the entire duration of continuous isometric contractions were included in the further analysis (Figure 2).

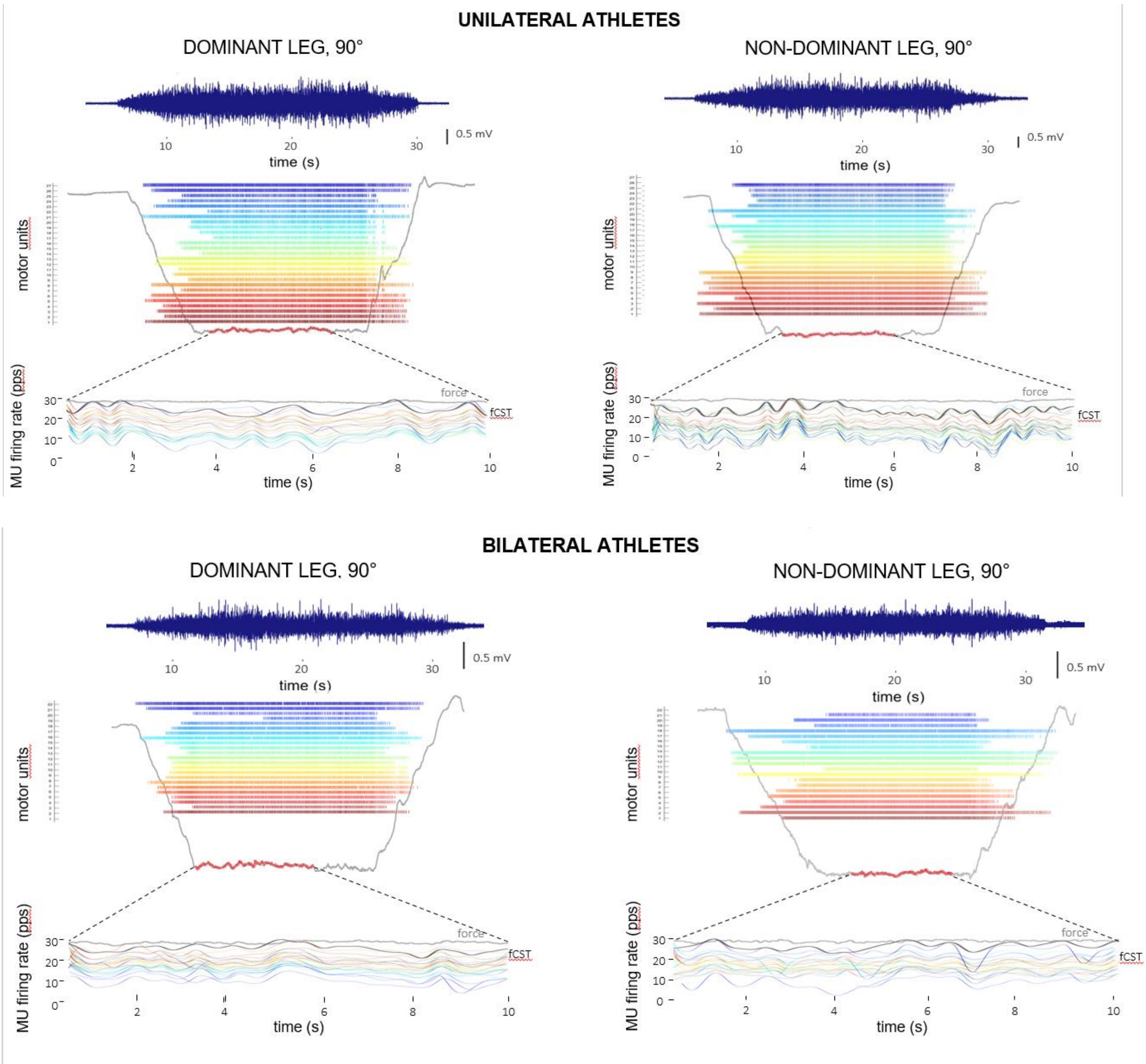


Figure 2. Representative data showing the isometric force of dorsal flexion during a voluntary contraction force of 40% MVC at ankle angles of 75 ° (elongated), 90 ° (mean length) and 105 ° (shortened) for each leg in the unilateral and bilateral group of sports. Each panel shows (top to bottom) EMG signal interference (blue horizontal lines), multiple MU discharge time (differently colored markings) and expressed muscle force (gray line)

6.3 Methods of data processing

Data analysis was performed using the IBM SPSS software (version 26, IBM, Chicago). The normality of data distribution was confirmed by the Shapiro-Wilk test. Mean value ± standard deviation were calculated for all output variables. Differences in muscle force control and motor unit activation were analyzed by the one-factor univariate analysis of variance of repeated measurements with the Bonferroni post hoc test to locate statistical significance. The magnitude of the effect in each dependent variable was quantified by a partial eta square coefficient (ηp^2) and interpreted as: small, ~ 0.1; medium, ~ 0.6 and high, > ~ 0.14 (Wikiversity, 2020, https://en.wikiversity.org/wiki/Eta-squared).

7. RESULTS

7.1 Basic descriptive parameters and data distribution

Tables 4, 5 and 6 show the basic statistical parameters of general sample indicators. The analysis determine that the subjects from the unilateral group of athletes were on average 38 years old (37.6 ± 10.9), body height 177 cm (177.3 ± 0.1), body mass 73 kg (73.0 ± 6.4) and BMI 23 (23.2 ± 1.9), while subjects from the bilateral group of athletes were on average 24 years old (24.3 ± 9.3), body height 181 cm (181.1 ± 8.4),), body mass 85 kg (85.1 ± 8.8) and BMI 26 (26.0 ± 2.3).

Table 4. Descriptive statistics and normality of distribution of general sample indicators among unilateral and bilateral groups of athletes

Variables	**N**	***Mean* ± *SD***	***Min. – max.***	***Range***	**N**	***Mean* ± *SD***	***Min. – max.***	***Range***
	Unilateral group				**Bilateral group**			
YEAR (год)	*20*	31.5 ± 8.8	17.0 – 55.0	38.0	*16*	24.3 ± 9.3	17.0 – 52.0	35.0
HEIGHT (cm)	*20*	177.3 ± 7.0	163.0 – 188.0	25.0	*16*	181.1 ± 8.4	163.0 – 191.0	28.0
MASS (kg)	*20*	73.0 ± 6.4	64.0 – 88.0	24.0	*16*	85.1 ± 8.8	71.0 – 109.0	38.0
BMI (kg/m^2)	*20*	23.2 ± 1.9	19.2 – 26.2	7.1	*16*	26.0 ± 2.3	22.4 – 31.2	8.7

Legend: N - number of sunjects; Mean - average value, SD - standard deviation; Min. - minimum value; Max. - maximum value; Sig. - significance; YEAR - age; HEIGHT - height; MASS - body weight; - BMI - body mass index.

Table 5. Descriptive statistics and normality of distribution of general sample indicators in the unilateral group of athletes

Variables	**N**	***Mean* ± *SD***	***Min. – max.***	***Range***	**N**	***Mean* ± *SD***	***Min. – max.***	***Range***
	Runners				**Cyclists**			
YEAR (год)	*15*	30.7 ± 9.6	17.0 – 55.0	38.0	*5*	32.2 ± 6.9	26.0 – 44.0	18.0
HEIGHT (cm)	*15*	179.0 ± 6.4	169.0 – 188.0	19.0	*5*	172.2 ± 7.4	163.0 – 180.0	17.0
MASS (kg)	*15*	74.6 ± 6.4	65.0 – 88.0	23.0	*5*	68.0 ± 4.2	64.0 – 73.0	9.0
BMI (kg/m^2)	*15*	23.3 ± 1.9	19.2 – 26.3	7.1	*5*	23.0 ± 1.9	19.5 – 23.0	4.7

Legend: N - number of sunjects; Mean - average value, SD - standard deviation; Min. - minimum value; Max. - maximum value; Sig. - significance; YEAR - age; HEIGHT - height; MASS - body weight; - BMI - body mass index.

Table 6. Descriptive statistics and normality of distribution of general sample indicators in the bilateral group of athletes

Variables	**N**	***Mean* ± *SD***	***Min. – max.***	***Range***	**N**	***Mean* ± *SD***	***Min. – max.***	***Range***	**N**	***Mean***
	Volleyball players				**Weightlifters**				**Rowers**	
YEAR (год)	*8*	26.5 ± 12.5	17.0 – 52.0	35.0	*7*	22.4 ± 4.5	19.0 – 31.0	12.0	*1*	20.0
HEIGHT	*8*	187.4 ±	182.0 –	9.0	*7*	174.4 ±	163.0 –	24.0	*1*	178.0

(cm)		3.4	191.0			7.3	187.0			
MASS (kg)	*8*	86.4 ± 5.9	81.0 – 99.0	18.0	*7*	84.7 ± 11.9	71.0 – 109.0	38.0	*1*	78.0
BMI (kg/m^2)	*8*	24.6 ± 1.5	22.4 – 27.1	4.7	*7*	27.8 ± 2.0	24.6 – 31.2	6.6	*1*	24.6

Legend: N - number of sunjects; Mean - average value, SD - standard deviation; Min. - minimum value; Max. - maximum value; Sig. - significance; YEAR - age; HEIGHT - height; MASS - body weight; - BMI - body mass index.

Table 7 contains the average number of identified MUs in the TA muscle in both extremities for each group of athletes, at the three ankle angles and eight target forces. After visual inspection and manual correction, the total number of identified MUs was [18407 (AVERAGE 16.0) and 18330 (AVERAGE 12.7); for the dominant and non-dominant limb, respectively] in theunilateral group of athletes and [7502 (AVERAGE 6.5) and 9511 (AVERAGE 8,3); for the dominant and non-dominant limb, respectively] in the bilateral group of athletes.

Table 7. Mean value (± SD) of the number of motor units recorded from the tibialis anterior muscles in both extremities for each group of athletes, at three ankle angles and eight target forces

			Target force (%MVC)							
Angle			**2.5**	**5**	**10**	**20**	**30**	**40**	**50**	**60**
75º	**U**	**D**	13.6±7.3	15.7±7.1	17.1±7.8	16.2±8.8	14.7±9.0	14.4±8.2	12.0±7.5	12.2±7.1
		ND	12.3±10.1	14.0±11.2	17.2±8.1	17.0±7.7	15.1±8.0	14.7±8.6	12.5±7.4	11.4±6.2
	B	**D**	7.4±6.4	9.9±7.9	9.3 ± 6.8	10.7±8.2	8.1±5.9	6.8±3.5	7.3±5.7	6.1±4.7
		ND	10.0±8.5	10.8±7.2	10.9±8.2	10.4±5.3	9.0±5.4	8.4±4.3	17.1±3.1	6.5±3.8
90º	**U**	**D**	10.5±8.5	16.2±7.1	17.4±7.4	17.5±8.3	16.0±2.7	13.4±7.1	12.0±6.1	11.6±5.8
		ND	12.1±9.5	14.3±9.6	16.9±8.3	16.9±8.5	16.1±8.2	15.1±7.5	14.1±5.8	12.0±6.4
	B	**D**	5.1±5.0	8.2 ± 7.4	8.7±7.1	7.4±5.3	7.0±5.1	7.7±6.8	5.6±3.4	4.6±3.2
		ND	11.1±7.4	11.5±5.8	12.6±8.3	12.3±6.9	10.9±5.6	8.3±5.2	9.7±4.6	7.6±5.4
105º	**U**	**D**	8.3±5.8	15.0±7.8	17.0±7.3	19.2±9.1	17.7±7.9	12.9±6.8	12.1±7.1	10.8±5.6
		ND	10.3±6.9	14.2±8.8	17.7±8.7	19.0±6.5	17.0±7.3	13.4±7.4	15.7±6.9	12.2±5.8
	B	**D**	4.8±5.1	8.8±6.2	8.3±6.2	7.1±6.8	7.0±6.3	7.5±6.7	4.7±3.7	4.6±2.9
		ND	7.9±5.6	12.0±6.7	12.1±6.0	12.6±6.2	11.7±6.2	9.6±5.0	8.5±4.4	6.4±2.9

Legend: MVC - maximum voluntary contraction; U - unilateral group of athletes; B - bilateral group of athletes; D - dominant leg; ND - non-dominant leg.

7.2 Differences in muscle force control between the dominant and non-dominant lower extremity in the unilateral group of athletes

Tables 8, 9 and 10 show the results in muscle force control between the dominant and non-dominant lower extremity in the unilateral group of athletes.

Table 8. Differences in the coefficient of variation of force (COVF) between the dominant and non-dominant lower extremity in the unilateral group of athletes

Variable	**Source of variation**	**df_{time}, $df_{Error(time)}$**	**F - value**	**Sig.**	**ηp^2**
COVF	*LEG*	1.000, 114.000	0.850	0.359	0.007

	ANGLE	2.000, 114.000	0.186	0.831	0.003
	*LEG*ANGLE*		0.592	0.555	0.010
	FORCE	2.059, 234.675	152.799	**0.000**	0.573
	*FORCE*LEG*		0.217	0.811	0.002
	*FORCE*ANGLE*	4.117, 234.675	0.695	0.600	0.012
	*FORCE*LEG*ANGLE*		1.556	0.185	0.027

Legend: COV_F – coefficient of variation of force; df –degree of freedom; Sig. – degree of statistical significance; ηp^2 – eta square coefficient; LEG – dominant and non-dominant leg; ANGLE – ankle angle (75º, 90º, 105º); FORCE – force level (2.5, 5, 10, 20, 30, 40, 50, 60% MVC)

A two-factor ANOVA showed no statistically significant difference in the process values of the variable COV_F between the dominant and non-dominant lower extremity in the unilateral group of athletes, but did reveal statistical significance in the process differences in expressed force ($F(2.059, 234.675) = 152.799$, $p < 0.0005$, $\eta p^2 = 0.573$). Eta square coefficient showed high value of the effect. The variability of the force decreases linearly as the force level increases, from 2.5% to 60% MVC. There are no statistically significant differences in other process values of the variable COV_F.

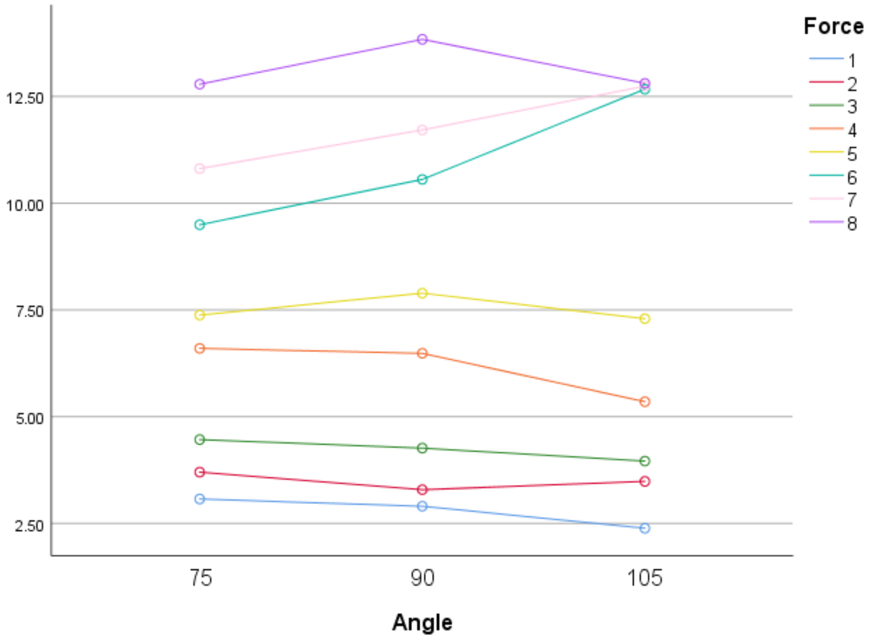
Table 9. Differences in standard deviation of force (SD_F) between the dominant and non-dominant lower extremity in the unilateral group of athletes

Variable	**Source of variation**	**df_{time}, $df_{Error(time)}$**	**F - value**	**Sig.**	**ηp^2**
SD_F	*LEG*	1.000, 114.000	3.851	0.052	0.033
	ANGLE	2.000, 114.000	0.109	0.897	0.002
	*LEG*ANGLE*		0.024	0.976	0.000
	FORCE	3.382, 385.531	182.825	**0.000**	0.616
	*FORCE*LEG*		0.752	0.536	0.007
	*FORCE*ANGLE*	6.764, 385.531	2.415	**0.021**	0.041
	*FORCE*LEG*ANGLE*		0.341	0.931	0.006

Legend: SD_F – standard deviation of force; df –degree of freedom; Sig. – degree of statistical significance; ηp^2 – eta square coefficient; LEG – dominant and non-dominant leg; ANGLE – ankle angle (75º, 90º, 105º); FORCE – force level (2.5, 5, 10, 20, 30, 40, 50, 60% MVC)

A two-factor ANOVA is at the limit of statistical significance in the process values of the variable SD_F between the dominant and non-dominant lower extremity in the unilateral group of athletes ($F(1.000, 114.000) = 3.851$, $p = 0.052$, $\eta p^2 = 0.033$). In addition, there is statistical significance in the process differences of the manifested force ($F(3.382, 385.531) = 182.825$, $p < 0.0005$, $\eta p^2 = 0.616$). Eta square coefficient showed a high value of the effect. Contrary to the variability of force, standard deviation of force increases linearly as the force levels increase, from 2.5% to 60% MVC. Also, there is a statistically significant interaction of the manifested force and angle in the ankle joint ($F(6.764, 385.531) = 2.415$, $p = 0.021$, $\eta p^2 = 0.041$) which is manifested in an emphasized increase in the value of the variable SD_F

in the angle of the ankle 105° compared to the angle of 75° at the force levels of 40% and 50% MVC (Plot 1).



Plot 1. Interaction of manifested force (1 = 2.5%, 2 = 5%, 3 = 10%, 4 = 20%, 5= 30%, 6 = 40%, 7 = 50%, 8 = 60% MVC) and angles in the ankle (75°, 90° and 105°) in the standard deviation of force (SD_F) in the unilateral group of athletes

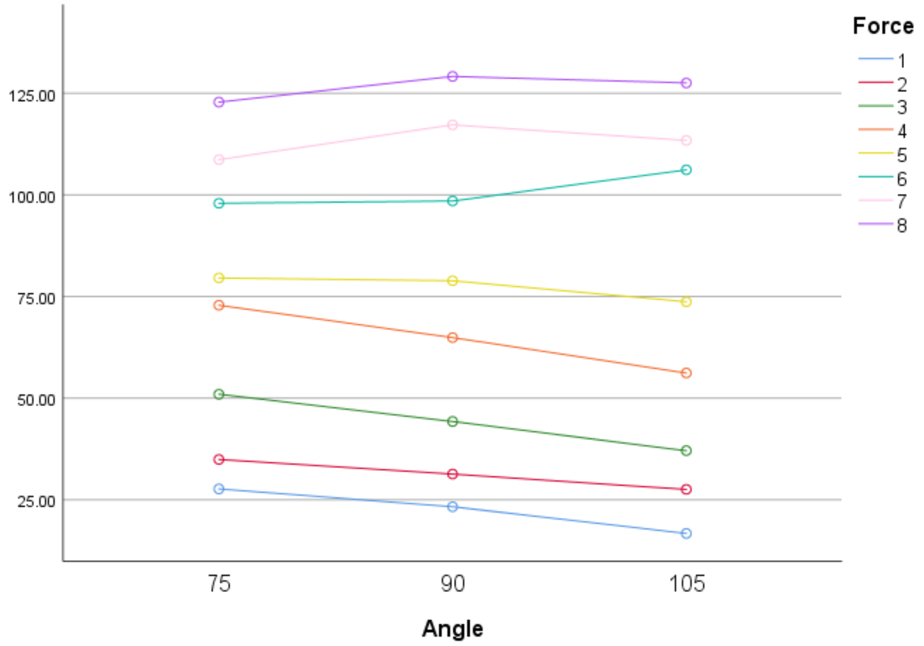
There are no statistically significant differences in other process values of the SD_F variable.

Table 10. Differences in root mean square (RMS) between the dominant and non-dominant lower extremities in the unilateral group of athletes

Variable	**Source of variation**	**df_{time}, $df_{Error(time)}$**	**F – value**	**Sig.**	**ηp^2**
RMS	*LEG*	1.000, 114.000	2.805	0.097	0.032
	ANGLE	2.000, 114.000	0.419	0.658	0.027
	*LEG*ANGLE*		0.178	0.837	0.012
	FORCE	3.737, 384.547	387.384	**0.000**	0.773
	*FORCE*LEG*		1.242	0.294	0.011
	*FORCE*ANGLE*	6.746, 384.547	2.157	**0.039**	0.036
	*FORCE*LEG*ANGLE*		1.040	0.402	0.018

Legend: RMS – root mean square; df –degree of freedom; Sig. – degree of statistical significance; ηp^2 – eta square coefficient; LEG – dominant and non-dominant leg; ANGLE – ankle angle (75º, 90º, 105º); FORCE – force level (2.5, 5, 10, 20, 30, 40, 50, 60% MVC)

A two-factor ANOVA showed a non-statistically significant difference in the process values of the variable RMS between the dominant and non-dominant lower extremity in the unilateral group of athletes, but did show statistical significance in the process differences in expressed force (F(3.737, 384.547) = 387.384, $p < 0.0005$, $\eta p^2 = 0773$). Eta square coefficient showed a high value of the effect. The absolute force increases linearly as the force levels increase, from 2.5% to 60% MVC. There is also a statistically significant interaction between the applied force and the angle in the ankle ($F(6.746, 384.547) = 2.157$, $p = 0.039$, $\eta p^2 = 0.036$) which is manifested by higher values of the variable RMS at the angle of 75 ° compared to the angle of 105 ° at low levels of force, 2.5%, 10% and 20% MVC (Plot 2).



Plot 2. Interaction of manifested force (1 = 2.5%, 2 = 5%, 3 = 10%, 4 = 20%, 5= 30%, 6 = 40%, 7 = 50%, 8 = 60% MVC) and angles in the ankle (75°, 90° and 105°) in the root mean square (RMS) in the unilateral group of athletes

There are no statistically significant differences in other process values of the RMS variable.

7.3 Differences in muscle force control between the dominant and non-dominant lower extremity in the bilateral group of athletes

Tables 11, 12 and 13 show the results in the control of muscle force between the dominant and non-dominant lower extremity in bilateral group of athletes.

Table 11. Differences in the coefficient of variation of force (COVF) between the dominant and non-dominant lower extremity in the bilateral group of athletes

Variable	Source of variation	df_{time}, $df_{Error(time)}$	F - value	Sig.	ηp^2
COVF	*LEG*	1.000, 90.000	0.139	0.710	0.002
	ANGLE	2.000, 90.000	0.954	0.389	0.021

	*LEG*ANGLE*		0.056	0.942	0.001
	FORCE	2.795, 251.510	119.188	**0.000**	0.570
	*FORCE*LEG*		1.307	0.273	0.014
	*FORCE*ANGLE*	5.589, 251.510	2.154	0.052	0.046
	*FORCE*LEG*ANGLE*		1.481	0.233	0.032

Legend: COVF – coefficient of variation of force; df –degree of freedom; Sig. – degree of statistical significance; ηp^2 – eta square coefficient; LEG – dominant and non-dominant leg; ANGLE – ankle angle (75º, 90º, 105º); FORCE – force level (2.5, 5, 10, 20, 30, 40, 50, 60% MVC)

A two-factor ANOVA showed no statistically significant difference in the process values of the variable COVF between the dominant and non-dominant lower extremity in the bilateral group of athletes, but did reveal statistical significance in the process differences in expressed force ($F(2.795, 251.510) = 119.188$, $p < 0.0005$, $\eta p^2 = 0.570$). Eta square coefficient showed a high value of the effect. The variability of the force decreases linearly as the force level increases, from 2.5% to 60% MVC. The interaction between the level of force and ankle angle came close to showing statistical significance ($F(5.589, 251.510) = 2.154$, $p = 0.052$, $\eta p^2 = 0.046$). There are no statistically significant differences in other process values of the variable COVF.

Table 12. Differences in standard deviation of force (SDF) between the dominant and non-dominant lower extremity in the bilateral group of athletes

Variable	**Source of variation**	**df$_{time}$, df$_{Error(time)}$**	**F - value**	**Sig.**	**ηp^2**
SDF	*LEG*	1.000, 90.000	0.015	0.901	0.000
	ANGLE	2.000, 90.000	0.141	0.868	0.003
	*LEG*ANGLE*		0.561	0.573	0.012
	FORCE	2.604, 234.381	102.977	**0.000**	0.534
	*FORCE*LEG*		0.518	0.645	0.006
	*FORCE*ANGLE*	5.208, 234.381	0.919	0.472	0.020
	*FORCE*LEG*ANGLE*		0.766	0.580	0.017

Legend: SDF – standard deviation of force; df –degree of freedom; Sig. – degree of statistical significance; ηp^2 – eta square coefficient; LEG – dominant and non-dominant leg; ANGLE – ankle angle (75º, 90º, 105º); FORCE – force level (2.5, 5, 10, 20, 30, 40, 50, 60% MVC)

A two-factor ANOVA showed no statistically significant difference in the process values of the variable SDF between the dominant and non-dominant lower extremity in the bilateral group of athletes, but did return statistical significance in the process differences in expressed force ($F(2.604, 234.381) = 102.977$, $p < 0.0005$, $\eta p^2 = 0.534$). Eta square coefficient showed high value of the effect. Contrary to the variability of force, the standard deviation of force increases linearly as the force level increases, from 2.5% to 60% MVC. There are no statistically significant differences in other process values of the variable SDF.

Table 13. Differences in root mean square (RMS) between the dominant and non-dominant lower extremities in the bilateral group of athletes

Variable	**Source of variation**	**df_{time}, $df_{Error(time)}$**	**F - value**	**Sig.**	**ηp^2**
RMS	*LEG*	1.000, 90.000	0.733	0.394	0.008
	ANGLE	2.000, 90.000	0.575	0.472	0.017
	*ANGLE*LEG*		0.291	0.748	0.006
	FORCE	3.649, 328.420	232.467	**0.000**	0.721
	*FORCE*LEG*		1.130	0.341	0.012
	*FORCE*ANGLE*	7.298, 328.420	0.965	0.459	0.021
	*FORCE*LEG*ANGLE*		0.509	0.835	0.011

Legend: RMS – root mean square; df –degree of freedom; Sig. – degree of statistical significance; ηp^2 – eta square coefficient; LEG – dominant and non-dominant leg; ANGLE – ankle angle (75º, 90º, 105º); FORCE – force level (2.5, 5, 10, 20, 30, 40, 50, 60% MVC)

A two-factor ANOVA showed a non-statistically significant difference in the process values of the variable RMS between the dominant and non-dominant lower extremity in the bilateral group of athletes, but did show statistical significance in the process differences in expressed force ($F(3.649, 328.420) = 232.467$, $p < 0.0005$, $\eta p^2 = 0.721$). Eta square coefficient showed a high value of the effect. The absolute force increases linearly as the force level increases, from 2.5% to 60% MVC as in the unilateral group of athletes. There are no statistically significant differences in other process values.

7.4 Differences in motor unit activation between the dominant and non-dominant lower extremity in the unilateral group of athletes

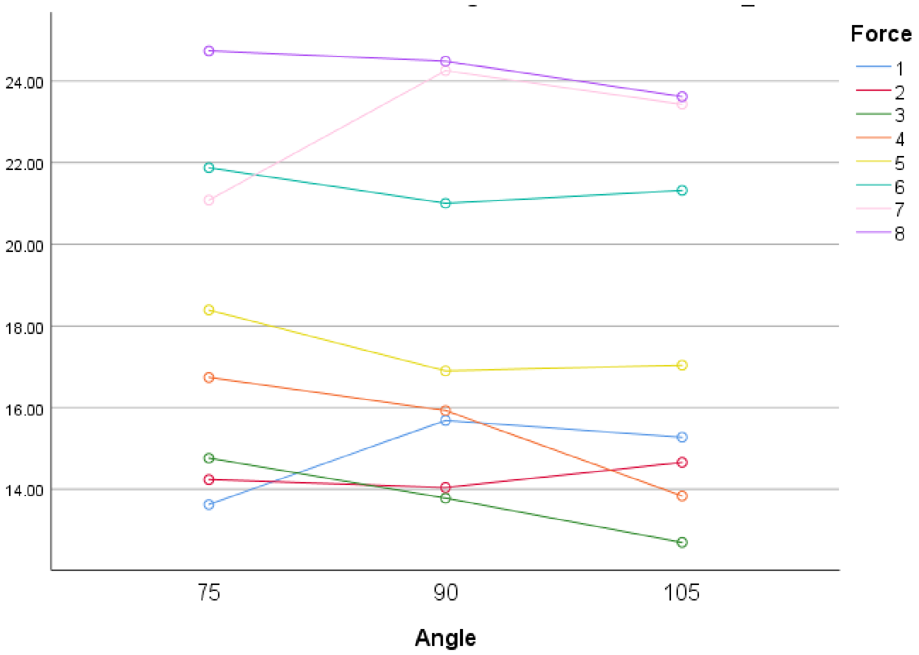
Tables 14, 15 and 16 show the results in motor unit activation between the dominant and non-dominant lower extremity in the unilateral group of athletes.

Table 14. Differences in the coefficient of variation of the interspike interval of a motor unit (COV_{ISI}) between the dominant and non-dominant lower extremity in the unilateral group of athletes

Variable	**Source of variation**	**df_{time}, $df_{Error(time)}$**	**F - value**	**Sig.**	**ηp^2**
COV_{ISI}	*LEG*	1.000, 114.000	0.018	0.893	0.000
	ANGLE	2.000, 114.000	0.247	0.781	0.004
	*LEG*ANGLE*		0.340	0.712	0.006
	FORCE	4.799, 547.128	93.776	**0.000**	0.451
	*FORCE*LEG*		0.451	0.805	0.004
	*FORCE*ANGLE*	9.599, 547.128	1.997	**0.034**	0.034
	*FORCE*LEG*ANGLE*		0.715	0.705	0.012

Legend: COV_{ISI} – coefficient of variation of the interspike interval of a motor unit; df –degree of freedom; Sig. – degree of statistical significance; ηp^2 – eta square coefficient; LEG – dominant and non-dominant leg; ANGLE – ankle angle (75º, 90º, 105º); FORCE – force level (2.5, 5, 10, 20, 30, 40, 50, 60% MVC)

A two-factor ANOVA showed no statistically significant difference in the process values of the variable COV_{ISI} between the dominant and non-dominant lower extremity in the unilateral group of athletes, but did return statistical significance in the process differences in expressed force ($F(4.799, 547.128) = 93.776$, $p < 0.0005$, $\eta p^2 = 0.451$). Eta square coefficient showed a high value of the effect. The variability of the interspike interval of a motor unit increases linearly as the force level increases, from 2.5% to 60% MVC. There is also a statistically significant interaction of force and angle ($F(9.599, 547.128) = 1.997$, $p = 0.034$, $\eta p^2 = 0.034$) which is manifested by a smaller value of the variable COV_{ISI} at an angle of 75 ° compared to other angles at the force level of 2.5% and 50% MVC (Plot 3). There are no statistically significant differences in other process values of the variable COV_{ISI}.



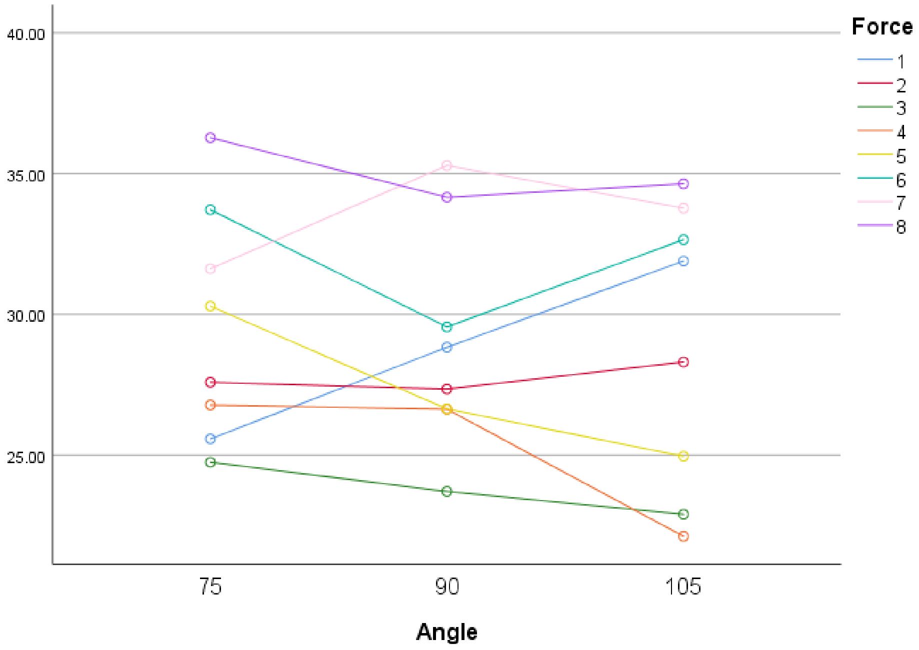
Plot 3. Interaction of manifested force (1 = 2.5%, 2 = 5%, 3 = 10%, 4 = 20%, 5= 30%, 6 = 40%, 7 = 50%, 8 = 60% MVC) and angles in the ankle (75°, 90° and 105°) in coefficient of variation of the interspike interval of a motor unit (COV_{ISI}) in the unilateral group of athletes

Table 15. Differences in the standard deviation of the interspike interval of a motor unit (SD_{ISI}) between the dominant and non-dominant lower extremity in the unilateral group of athletes

Variable	**Source of variation**	**df_{time}, $df_{Error(time)}$**	**F - value**	**Sig.**	**ηp^2**
SD_{ISI}	*LEG*	1.000, 114.000	0.001	0.978	0.000
	ANGLE	1.000, 114.000	0.120	0.887	0.002
	*LEG*ANGLE*		0.137	0.872	0.002
	FORCE	5.482, 624.902	18.640	**0.000**	0.141
	*FORCE*LEG*		1.260	0.277	0.011
	*FORCE*ANGLE*	10.963, 624.902	1.875	**0.040**	0.032
	*FORCE*LEG*ANGLE*		1.288	0.227	0.022

Legend: SD_{ISI} – standard deviation of the interspike interval of a motor unit; df –degree of freedom; Sig. – degree of statistical significance; ηp^2 – eta square coefficient; LEG – dominant and non-dominant leg; ANGLE – ankle angle (75º, 90º, 105º); FORCE – force level (2.5, 5, 10, 20, 30, 40, 50, 60% MVC)

A two-factor ANOVA showed no statistically significant difference in the process values of the variable SD_{ISI} between the dominant and non-dominant lower extremity in the unilateral group of athletes, but did show statistical significance in the process differences in expressed force ($F(5.482, 624.902) = 18.640$, $p < 0.0005$, $\eta p^2 = 0.141$). Eta square coefficient showed a high value of the effect. Standard deviation of the interspike interval of a motor unit increases linearly as the force level increases, from 2.5% to 60% MVC. There is also a statistically significant interaction of force and angle ($F(10.963, 624.902) = 1.875$, $p = 0.040$, $\eta p^2 = 0.032$) which is manifested by a lower value of the variable SD_{ISI} at an angle of 75° compared to other angles at the force level of 2.5% and 50% MVC, higher values of the variable SD_{ISI} at an angle of 75° compared to other angles at the force level of 30% MVC, and lower values of the variable SD_{ISI} at an angle of 105° compared to other angles at the force level of 20% MVC (Plot 4). Eta square coefficient showed a midle value of the effect. There are no statistically significant differences in other process values in the variable SD_{ISI}.



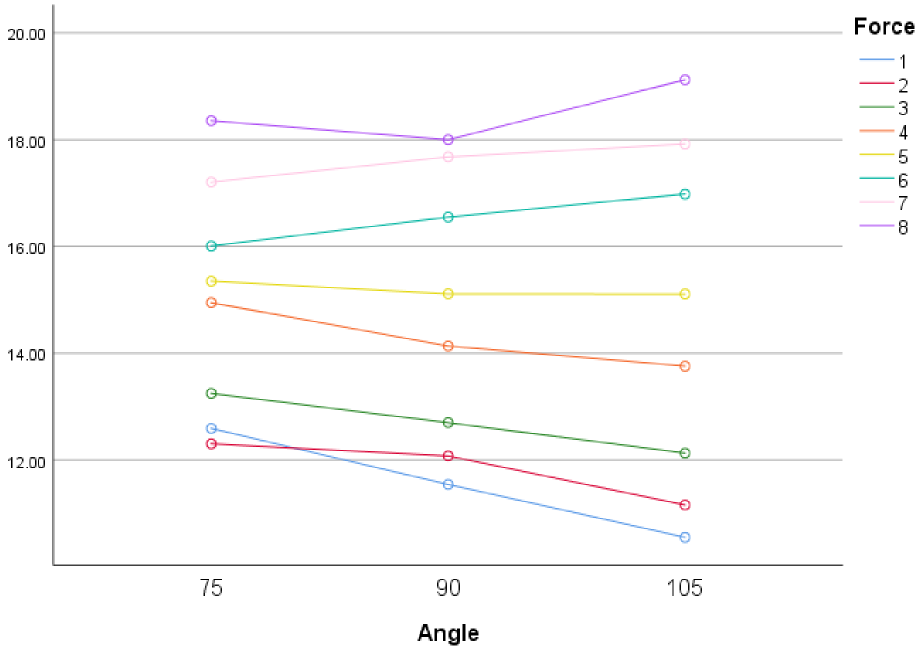
Plot 4. Interaction of manifested force (1 = 2.5%, 2 = 5%, 3 = 10%, 4 = 20%, 5= 30%, 6 = 40%, 7 = 50%, 8 = 60% MVC) and angles in the ankle (75°, 90° and 105°) in standard deviation of the interspike interval of a motor unit (SD_{ISI}) in the unilateral group of athletes

Table 16. Differences in the mean discharge rate of a motor unit (MDR) between the dominant and non-dominant lower extremity in the unilateral group of athletes

Variable	**Source of variation**	**df_{time}, $df_{Error(time)}$**	**F - value**	**Sig.**	**ηp^2**
MDR	*LEG*	1.000, 114.000	1.328	0.252	0.012
	ANGLE	2.000, 114.000	0.591	0.556	0.010
	*LEG*ANGLE*		0.129	0.879	0.010
	FORCE	4.653, 530.491	225.901	**0.000**	0.665
	*FORCE*LEG*		1.095	0.361	0.010
	*FORCE*ANGLE*	9.307, 530.491	3.820	**0.000**	0.063
	*FORCE*LEG*ANGLE*		0.543	0.849	0.009

Legend: MDR – mean discharge rate of a motor unit; df –degree of freedom; Sig. – degree of statistical significance; ηp^2 – eta square coefficient; LEG – dominant and non-dominant leg; ANGLE – ankle angle (75º, 90º, 105º); FORCE – force level (2.5, 5, 10, 20, 30, 40, 50, 60% MVC)

A two-factor ANOVA showed no statistically significant difference in the process values of the variable MDR between the dominant and non-dominant lower extremity in the unilateral group of athletes, but did return statistical significance in the process differences in expressed force ($F(4.653, 530.491) = 225.901$, $p < 0.0005$, $\eta p^2 = 0.665$). Mean discharge rate of a motor unit increases linearly as the force level increases, from 2.5% to 60% MVC. There is also a statistically significant interaction of force and angle ($F(9.307, 530.491) = 3.820$, $p < 0.0005$, $\eta p^2 = 0.063$) which is manifested by a higher value of the variable MDR at an angle of 75 ° compared to the other angles at force levels of 2.5% and 10% MVC (Plot 5). Eta square coefficient showed a high value of the effect.



Plot 5. Interaction of manifested force (1 = 2.5%, 2 = 5%, 3 = 10%, 4 = 20%, 5= 30%, 6 = 40%, 7 = 50%, 8 = 60% MVC) and angles in the ankle (75°, 90° and 105°) in mean discharge rate of a motor unit (MDR) in the unilateral group of athletes

There are no statistically significant differences in other process values in the variable MDR.

7.5 Differences in motor unit activation between the dominant and non-dominant lower extremity in the bilateral group of athletes

Tables 17, 18 and 19 show the results in the activation of motor units between the dominant and non-dominant lower extremity in the bilateral group of athletes.

Table 17. Differences in the coefficient of variation of the interspike interval of a motor unit (COV_{ISI}) between the dominant and non-dominant lower extremity in the bilateral group of athletes

Variable	**Source of variation**	**df_{time}, $df_{Error(time)}$**	**F - value**	**Sig.**	**ηp^2**
CoV_{ISI}	*LEG*	1.000, 90.000	1.199	0.276	0.013
	ANGLE		1.401	0.252	0.030
	*LEG*ANGLE*		0.032	0.969	0.001
	FORCE	5.655, 508.963	68.809	**0.000**	0.433
	*FORCE*LEG*		0.265	0.947	0.003
	*FORCE*ANGLE*	11.310, 508.963	1.568	0.102	0.034
	*FORCE*LEG*ANGLE*		1.139	0.327	0.025

Legend: COV_{ISI} – coefficient of variation of the interspike interval of a motor unit; df –degree of freedom; Sig. – degree of statistical significance; ηp^2 – eta square coefficient; LEG – dominant and non-dominant leg; ANGLE – ankle angle (75°, 90°, 105°); FORCE – force level (2.5, 5, 10, 20, 30, 40, 50, 60% MVC)

A two-factor ANOVA showed no statistically significant difference in the process values of the variable COV_{ISI} between the dominant and non-dominant lower extremity in the bilateral group of athletes, but did show statistical significance in the process differences in expressed force ($F(5.655, 508.963) = 68.809$, $p < 0.0005$, $\eta p^2 = 0.433$). Eta square coefficient showed a high value of the effect. Variability of the interspike interval of a motor unit increases linearly as the force level increases, from 2.5% to 60% MVC. There are no statistically significant differences in other process values of the variable COV_{ISI}.

Table 18. Differences in the standard deviation of the interspike interval of a motor unit (SD_{ISI}) between the dominant and non-dominant lower extremity in the bilateral group of athletes

Variable	**Source of variation**	**df_{time}, $df_{Error(time)}$**	**F - value**	**Sig.**	**ηp^2**
SD_{ISI}	*LEG*	1.000, 90.000	0.314	0.576	0.003
	ANGLE	2.000, 90.000	0.392	0.677	0.009
	*LEG*ANGLE*		0.013	0.987	0.000
	FORCE	5.499, 494.897	24.823	**0.000**	0.216
	*FORCE*LEG*		0.476	0.811	0.005
	*FORCE*ANGLE*	10.998, 494.897	1.465	0.141	0.032
	*FORCE*LEG*ANGLE*		1.603	0.094	0.034

Legend: SD_{ISI} – standard deviation of the interspike interval of a motor unit; df –degree of freedom; Sig. – degree of statistical significance; ηp^2 – eta square coefficient; LEG – dominant and non-dominant leg; ANGLE – ankle angle (75°, 90°, 105°); FORCE – force level (2.5, 5, 10, 20, 30, 40, 50, 60% MVC)

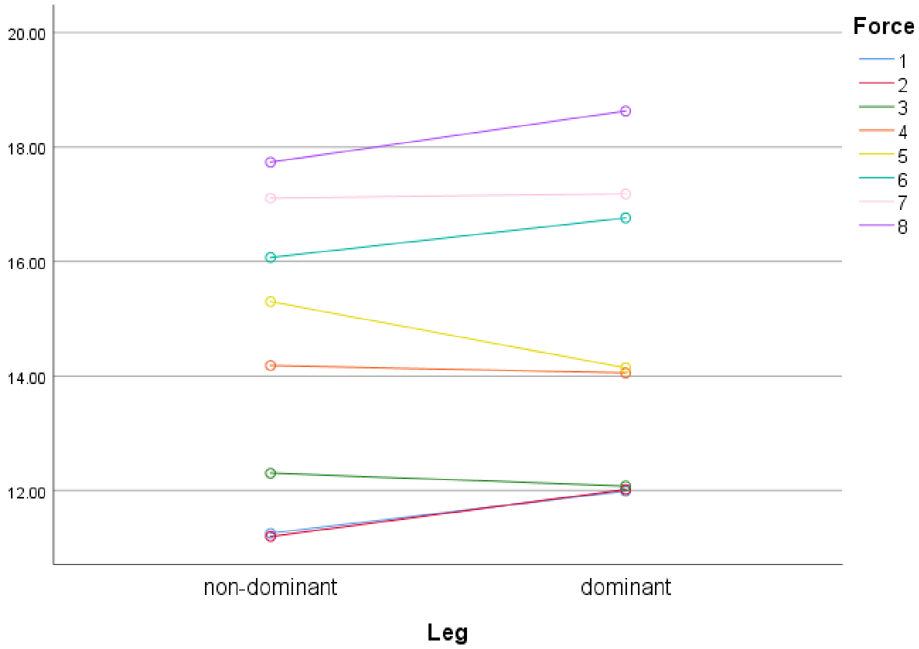
A two-factor ANOVA showed no statistically significant difference in the process values of the variable SD_{ISI} between the dominant and non-dominant lower extremity in the bilateral group of athletes, but but did reveal statistical significance in the process differences in expressed force (($F(5.499, 494.897) = 24.823$, $p < 0.0005$, $\eta p^2 = 0.0216$). Eta square coefficient showed a high value of the effect. Standrad deviation of the interspike interval of a motor unit increases linearly as the force level increases, from 2.5% to 60% MVC. There are no statistically significant differences in other process values of the variable SD_{ISI}.

Table 19. Differences in the mean discharge rate of a motor unit (MDR) between the dominant and non-dominant lower extremity in the bilateral group of athletes

Variable	**Source of variation**	**df_{time}, $df_{Error(time)}$**	**F - value**	**Sig.**	**ηp^2**
MDR	*LEG*	1.000, 90.000	0.585	0.446	0.006
	ANGLE	2.000, 90.000	1.416	0.248	0.031
	*LEG*ANGLE*		1.246	0.293	0.027
	FORCE	4.531, 407.756	181.216	**0.000**	0.668
	*FORCE*LEG*		3.454	**0.006**	0.037
	*FORCE*ANGLE*	9.061, 407.756	0.886	0.538	0.019
	*FORCE*LEG*ANGLE*		1.523	0.137	0.033

Legend: MDR – mean discharge rate of a motor unit; df –degree of freedom; Sig. – degree of statistical significance; ηp^2 – eta square coefficient; LEG – dominant and non-dominant leg; ANGLE – ankle angle (75º, 90º, 105º); FORCE – force level (2.5, 5, 10, 20, 30, 40, 50, 60% MVC)

A two-factor ANOVA showed no statistically significant difference in the process values of the variable MDR between the dominant and non-dominant lower extremity in the bilateral group of athletes, but did return statistical significance in the process differences in expressed force ($F(4.531, 407.756) = 181.216$, $p < 0.0005$, $\eta p^2 = 0.668$). Eta square coefficient showed a high value of the effect. The mean discharge rate of a motor unit increases linearly as the force level increases, from 2.5% to 60% MVC. There is also a statistically significant interaction of lower extremities and manifested muscle force ($F(4.531, 407.756) = 3.454$, $p = 0.006$, $\eta p^2 = 0.037$) which is manifested by higher values of the variable MDR in the dominant leg compared to the non-dominant at higher force levels (50% to 60% MVC), similar values at low force levels (2.5% to 20% MVC) and much lower values of MDR in the dominant leg at force level 30% MVC (Plot 6).



Plot 6. Interaction of manifested force (1 = 2.5%, 2 = 5%, 3 = 10%, 4 = 20%, 5= 30%, 6 = 40%, 7 = 50%, 8 = 60% MVC) and angles in the ankle (75°, 90° and 105°) in mean discharge rate of a motor unit (MDR) in the unilateral group of athletes

There are no statistically significant differences in other process values in the variable MDR.

7.6 Differences in muscle force control between the dominant and non-dominant lower extremity between unilateral and bilateral groups of athletes

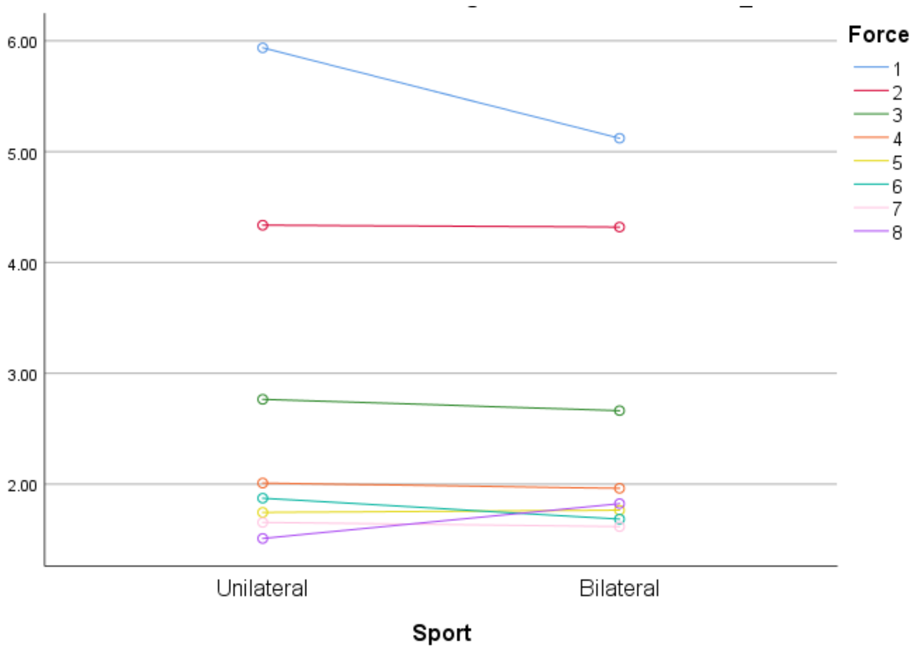
Tables 20, 21 and 22 show the results in the control of muscle force between the dominant and non-dominant lower extremity between unilateral and bilateral groups of athletes.

Table 20. Differences in the coefficient of variation of force (COVF) between the dominant and non-dominant lower extremity between the unilateral and bilateral groups of athletes

Variable	**Source of variation**	**df_{time}, $df_{Error(time)}$**	**F - value**	**Sig.**	**ηp^2**
COVF	*LEG*	1.000, 204.000	0.822	0.366	0.004
	SPORT		0.567	0.452	0.003
	ANGLE	2.000, 204.000	0.468	0.627	0.005
	*LEG*SPORT*	1.000, 204.000	0.155	0.694	0.001
	*LEG*ANGLE*	2.000, 204.000	0.495	0.611	0.005
	*SPORT*ANGLE*		0.615	0.541	0.006
	*LEG*SPORT*ANGLE*		0.148	0.863	0.001
	FORCE	2.346, 478.545	261.037	**0.000**	0.561
	*FORCE*LEG*		1.151	0.322	0.006
	*FORCE*SPORT*		3.108	**0.038**	0.015
	*FORCE*ANGLE*	4.692, 478.545	0.752	0.577	0.007
	*FORCE*LEG*SPORT*	2.346, 478.545	0.282	0.789	0.001
	*FORCE*LEG*ANGLE*	4.692, 478.545	2.129	0.065	0.020
	*FORCE*SPORT*ANGLE*		1.948	0.090	0.019
	*FORCE*LEG*SPORT*ANGLE*		0.810	0.536	0.008

Legend: COVF – coefficient of variation of force; df –degree of freedom; Sig. – degree of statistical significance; ηp^2 – eta square coefficient; LEG – dominant and non-dominant leg; SPORT – unilateral and bilateral group of athletes; ANGLE – ankle angle (75º, 90º, 105º); FORCE – force level (2.5, 5, 10, 20, 30, 40, 50, 60% MVC)

A three-factor ANOVA showed no statistically significant difference in the process values of the variable COV_F between the dominant and non-dominant lower extremity between the unilateral and bilateral groups of athletes. There is a statistically significant difference in the process differences of the manifested force ($F(2.346, 478.545) = 261.037$, $p < 0.0005$, $\eta p^2 = 0.516$). Eta square coefficient showed a high value of the effect. The variability of the force decreases linearly as the force level increases, from 2.5% to 60% MVC. Also, there is a statistically significant interaction between the manifested force and the group of athletes ($F(2.346, 478.545) = 3.108$, $p = 0.038$, $\eta p^2 = 0.036$) which is manifested by a greater variability of force at the force level of 2.5% in the bilateral group of athletes and at the force level of 60% MVC in the unilateral group of athletes (Plot 7).



Plot 7. Interaction of manifested force (1 = 2.5%, 2 = 5%, 3 = 10%, 4 = 20%, 5= 30%, 6 = 40%, 7 = 50%, 8 = 60% MVC) between the unilateral and bilateral groups of athletes in the coefficient of variation of force (COVF)

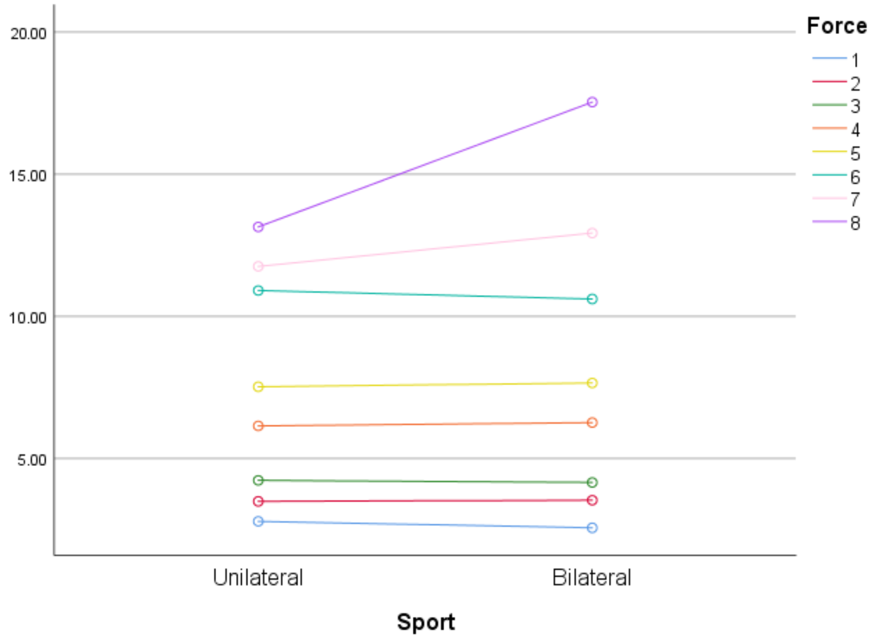
There are no statistically significant differences in other process values of the variable COVF.

Table 21. Differences in standard deviation of force (SDF) between the dominant and non-dominant lower extremity between the unilateral and bilateral groups of athletes

Variable	**Source of variation**	**df$_{time}$, df$_{Error(time)}$**	**F - value**	**Sig.**	**ηp^2**
SDF	*LEG*	1.000, 204.000	1.326	0.251	0.006
	SPORT		1.728	0.190	0.008
	ANGLE	2.000, 204.000	0.066	0.931	0.001
	*LEG*SPORT*	1.000, 204.000	1.814	0.179	0.009
	*LEG*ANGLE*	2.000, 204.000	0.273	0.761	0.003
	*SPORT*ANGLE*		0.197	0.821	0.002
	*LEG*SPORT*ANGLE*		0.439	0.645	0.004
	FORCE	3.263, 665.707	262.460	**0.000**	0.563
	*FORCE*LEG*		0.161	0.992	0.001
	*FORCE*SPORT*		7.781	**0.000**	0.037
	*FORCE*ANGLE*	6.527, 665.707	1.488	0.174	0.014
	*FORCE*LEG*SPORT*	3.263, 665.707	1.106	0.348	0.005
	*FORCE*LEG*ANGLE*	6.527, 665.707	0.889	0.509	0.009
	*FORCE*SPORT*ANGLE*		1.355	0.226	0.013
	*FORCE*LEG*SPORT*ANGLE*		0.561	0.776	0.005

Legend: SDF – standard deviation of force; df –degree of freedom; Sig. – degree of statistical significance; ηp^2 – eta square coefficient; LEG – dominant and non-dominant leg; SPORT – unilateral and bilateral group of athletes; ANGLE – ankle angle (75°, 90°, 105°); FORCE – force level (2.5, 5, 10, 20, 30, 40, 50, 60% MVC)

A three-factor ANOVA showed no statistically significant difference in the process values of the variable SD_F between the dominant and non-dominant lower extremity between the unilateral and bilateral groups of athletes. There is a statistically significant difference in the process differences of the manifested force ($F(3.263, 665.707) = 262.460$, $p < 0.0005$, $\eta p^2 = 0.563$). Eta square coefficient showed a high value of the effect. The variability of the force increases linearly as the force level increases, from 2.5% to 60% MVC. Also, there is a statistically significant interaction between the manifested force and the group of athletes ($F(3.263, 665.707) = 7.781$, $p < 0.0005$, $\eta p^2 = 0.037$) which is manifested by a higher standard deviation of force at the force level of 60% MVC in the bilateral group of athletes (Plot 8). Eta square coefficient showed a middle value of the effect.



Plot 8. Interaction of manifested force (1 = 2.5%, 2 = 5%, 3 = 10%, 4 = 20%, 5= 30%, 6 = 40%, 7 = 50%, 8 = 60% MVC) between the unilateral and bilateral groups of athletes in the standard deviation of force (SD_F)

There are no statistically significant differences in other process values of the variable SD_F.

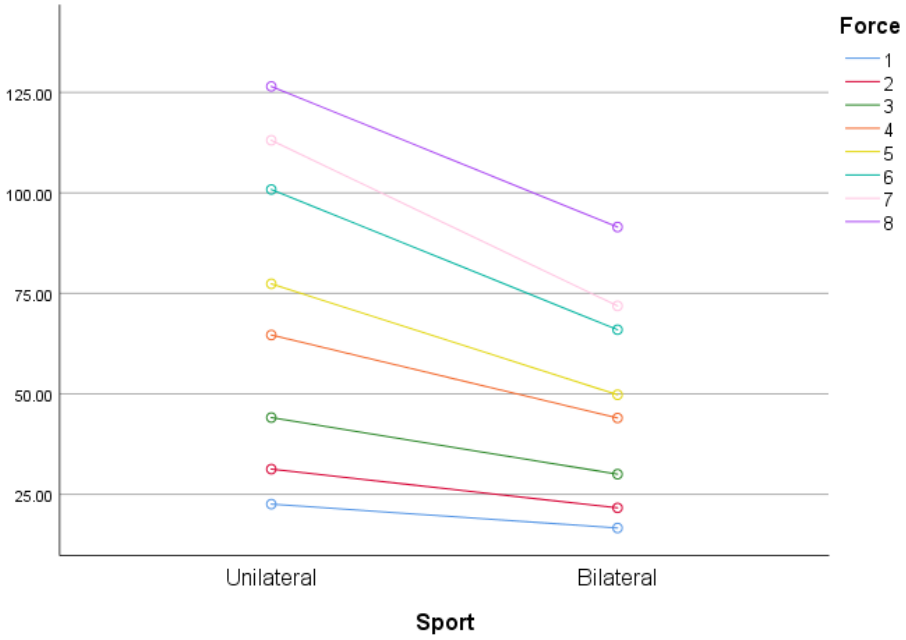
Table 22. Differences in root mean square (RMS) between the dominant and non-dominant lower extremity between the unilateral and bilateral groups of athletes

Variable	**Source of variation**	**df_{time}, $df_{Error(time)}$**	**F - value**	**Sig.**	**ηp^2**
RMS	*LEG*	1.000, 204.000	0.570	0.451	0.003
	SPORT		67.240	**0.000**	0.248
	ANGLE	2.000, 204.000	0.874	0.419	0.008
	*LEG*SPORT*	1.000, 204.000	3.153	0.077	0.015

*LEG*ANGLE*	2.000, 204.000	0.173	0.841	0.002
*SPORT*ANGLE*		0.143	0.867	0.001
*LEG*SPORT*ANGLE*		0.237	0.789	0.002
FORCE	3.539, 722.027	582.537	**0.000**	0.741
*FORCE*LEG*		0.244	0.894	0.001
*FORCE*SPORT*		23.643	**0.000**	0.104
*FORCE*ANGLE*	7.079, 722.027	2.023	**0.049**	0.019
*FORCE*LEG*SPORT*	3.539, 722.027	2.016	0.099	0.010
*FORCE*LEG*ANGLE*	7.079, 722.027	1.004	0.427	0.010
*FORCE*SPORT*ANGLE*		1.082	0.373	0.010
*FORCE*LEG*SPORT*ANGLE*		0.529	0.815	0.005

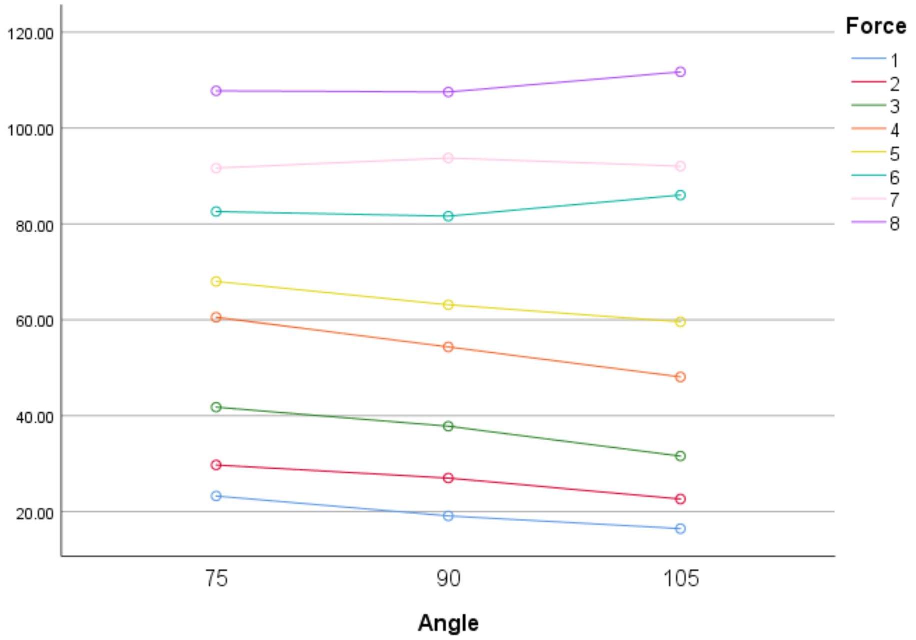
Legend: RMS – root mean square; df –degree of freedom; Sig. – degree of statistical significance; ηp^2 – eta square coefficient; LEG – dominant and non-dominant leg; SPORT – unilateral and bilateral group of athletes; ANGLE – ankle angle (75º, 90º, 105º); FORCE – force level (2.5, 5, 10, 20, 30, 40, 50, 60% MVC)

A three-factor ANOVA showed no statistically significant difference in the process values of the variable RMS between the dominant and non-dominant lower extremity between the unilateral and bilateral groups of athletes, but there is a statistically significant difference between groups of athletes (F(1.000, 204.000) = 67.240, $p < 0.0005$, $\eta p^2 = 0.248$). Further, there is a statistically significant interaction of the manifested force and group of athletes (F(3.539, 722.027) = 23.643, $p < 0.0005$, $\eta p^2 = 0.105$) which is manifested by higher values of absolute force in both extremities in the unilateral group of athletes compared to the bilateral group (Plot 9).



Plot 9. Interaction of manifested force (1 = 2.5%, 2 = 5%, 3 = 10%, 4 = 20%, 5= 30%, 6 = 40%, 7 = 50%, 8 = 60% MVC) between the unilateral and bilateral groups of athletes in the root mean square (RMS)

Besides this, there is a statistically significant difference in the process differences of manifested force (F(3.539, 722.027) = 582.537, $p < 0.0005$, $\eta p^2 = 0.741$) where the value of the variable RMS increases linearly as the force level increases, from 2.5% to 60% MVC, as well as a statistically significant interaction between the manifested force level and the angle in the ankle (F(7.079, 722.027) = 2.023, $p = 0.049$, $\eta p^2 = 0.019$) which is manifested by lower values of absolute force at low force levels (2.5% to 20% MVC) at an angle of 105° compared to 75° and 90° in both groups of athletes (Plot 10).



Plot 10. Interaction of manifested force (1 = 2.5%, 2 = 5%, 3 = 10%, 4 = 20%, 5= 30%, 6 = 40%, 7 = 50%, 8 = 60% MVC) and angles in the ankle (75°, 90° and 105°) in root mean square (RMS) between the unilateral and bilateral groups of athletes

There are no statistically significant differences in other process values of the variable RMS.

7.7 Differences in motor unit activation between the dominant and non-dominant lower extremity between unilateral and bilateral groups of athletes

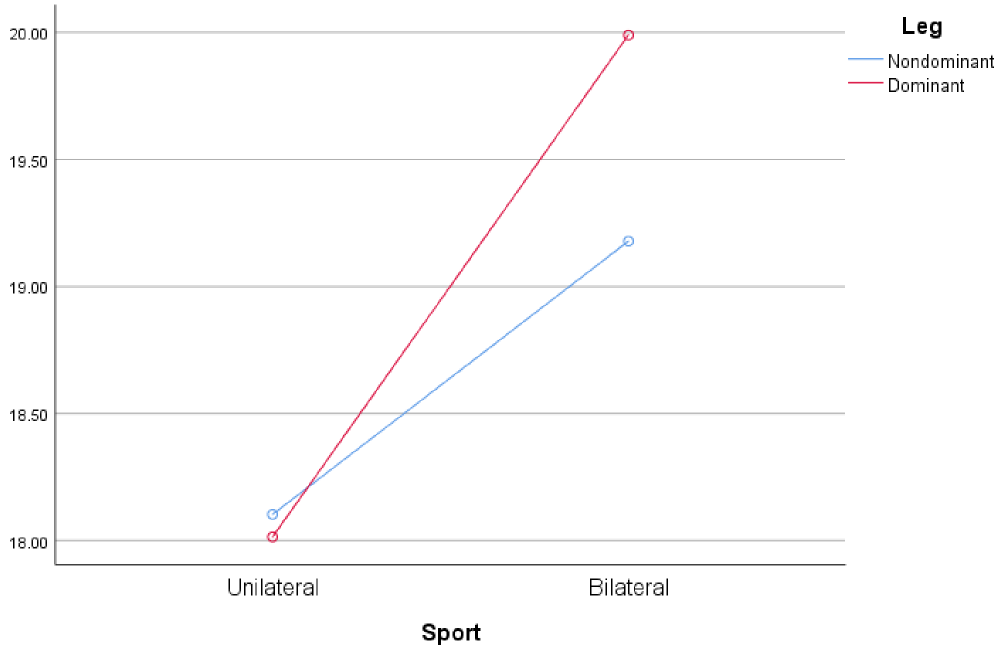
Tables 23, 24 and 25 show the results in motor unit activation between the dominant and non-dominant lower extremity between the unilateral and bilateral groups of athletes.

Table 23. Differences in the coefficient of variation of the interspike interval of a motor unit (COV_{ISI}) between the dominant and non-dominant lower extremity between the unilateral and bilateral groups of athletes

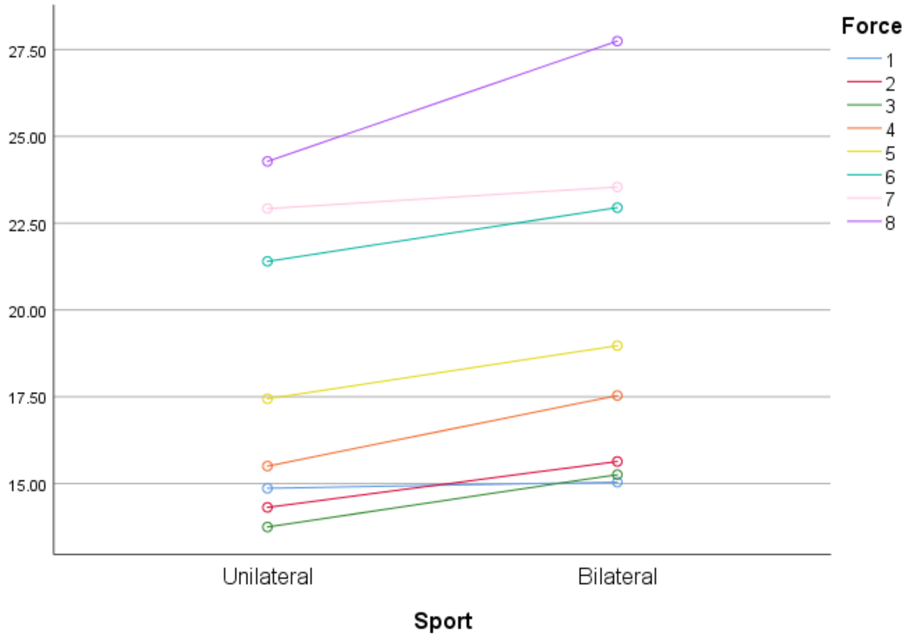
Variable	**Source of variation**	**df_{time}, $df_{Error(time)}$**	**F - value**	**Sig.**	**ηp^2**
COV_{ISI}	*LEG*	1.000, 204.000	0.533	0.466	0.003
	SPORT		9.479	**0.002**	0.044
	ANGLE	2.000, 204.000	1.163	0.314	0.011
	*LEG*SPORT*	1.000, 204.000	0.825	0.365	0.004
	*LEG*ANGLE*	2.000, 204.000	0.270	0.764	0.003
	*SPORT*ANGLE*		0.623	0.537	0.006
	*LEG*SPORT*ANGLE*		0.066	0.936	0.001
	FORCE	5.472, 1116.219	159.678	**0.000**	0.439
	*FORCE*LEG*		0.405	0.861	0.002
	*FORCE*SPORT*		1.958	0.076	0.010
	*FORCE*ANGLE*	10.943, 1116.219	2.365	**0.007**	0.023
	*FORCE*LEG*SPORT*	5.472, 1116.219	0.287	0.932	0.001
	*FORCE*LEG*ANGLE*	10.943, 1116.219	0.495	0.907	0.005
	*FORCE*SPORT*ANGLE*		1.211	0.275	0.012
	*FORCE*LEG*SPORT*ANGLE*		1.537	0.113	0.015

Legend: COV_{ISI} – coefficient of variation of the interspike interval of a motor unit; df –degree of freedom; Sig. – degree of statistical significance; ηp^2 – eta square coefficient; LEG – dominant and non-dominant leg; SPORT – unilateral and bilateral group of athletes; ANGLE – ankle angle (75º, 90º, 105º); FORCE – force level (2.5, 5, 10, 20, 30, 40, 50, 60% MVC)

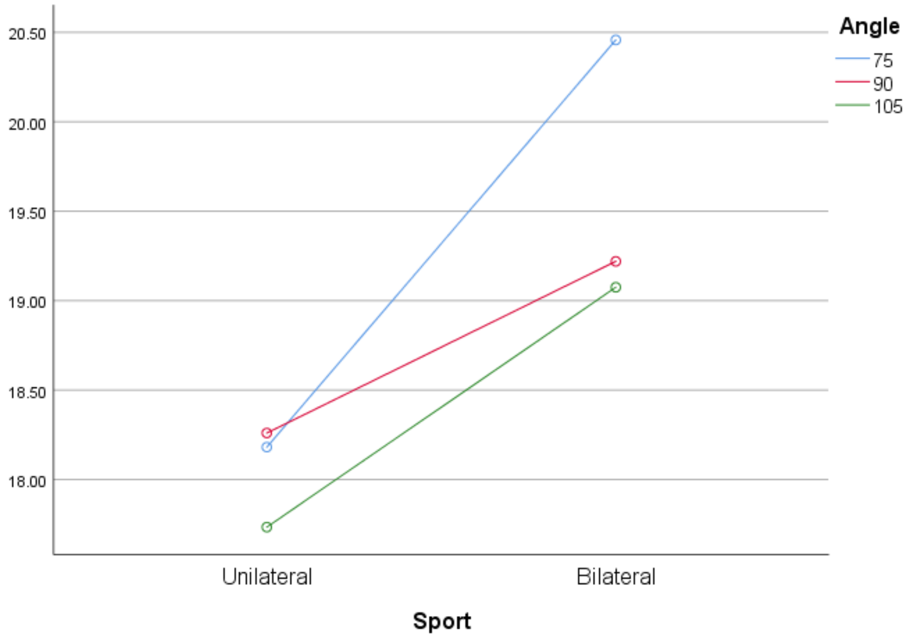
A three-factor ANOVA showed no statistically significant difference in the process values of the variable COV_{ISI} between the dominant and non-dominant lower extremity between the unilateral and bilateral groups of athletes, but there is a statistically significant difference between sport groups ($F(21.000, 204.000) = 9.479$, $p = 0.002$, $\eta p^2 = 0.044$) which is manifested by higher COV_{ISI} values in both extremities in the bilateral group of athletes compared to the unilateral (Plot 11), at force levels, 5%, 10%, 20% and 60% MVC (Plot 12) and at all the ankle angles (Plot 13).



Plot 11. Interaction of the dominant and nondominant lower extremity between the unilateral and bilateral groups of athletes in coefficient of variation of the interspike interval of a motor unit (COV_{ISI})

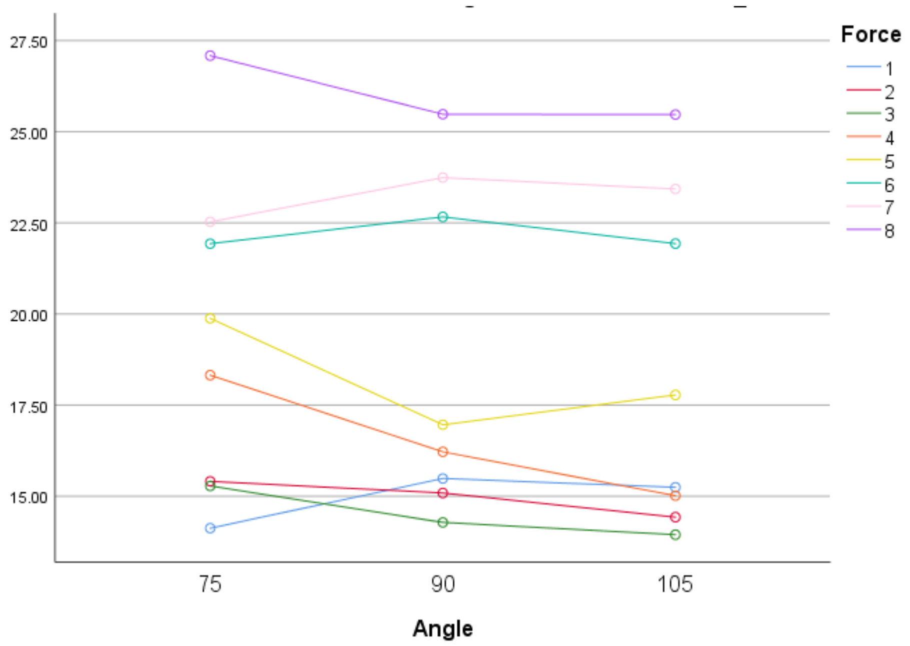


Plot 12. Interaction of manifested force (1 = 2.5%, 2 = 5%, 3 = 10%, 4 = 20%, 5= 30%, 6 = 40%, 7 = 50%, 8 = 60% MVC) between the unilateral and bilateral groups of athletes in coefficient of variation of the interspike interval of a motor unit (COV_{ISI})



Plot 13. Interaction of ankle angles (75°, 90° and 105°) between the unilateral and bilateral groups of athletes in coefficient of variation of the interspike interval of a motor unit (COV_{ISI})

Also, there is a statistically significant difference in the process differences of manifested force ($F(5.472, 1116.219) = 159.678$, $p < 0.0005$, $\eta p^2 = 0.439$) whose value of the variable COV_{ISI} increases linearly as the force level increases, from 10% to 60% MVC and the interaction between the manifested level of force and the ankle angle ($F(10.943, 1116.219) = 2.365$, $p = 0.007$, $\eta p^2 = 0.023$) which is manifested by higher values of COV_{ISI} at the angle of 75° compared to the angles of 90° and 105° at force levels of 20% and 30% MVC (Plot 14).



Plot 14. Interaction of manifested force (1 = 2.5%, 2 = 5%, 3 = 10%, 4 = 20%, 5= 30%, 6 = 40%, 7 = 50%, 8 = 60% MVC) and ankle angles (75°, 90° and 105°) between the unilateral and bilateral groups of athletes in coefficient of variation of the interspike interval of a motor unit (COV_{ISI})

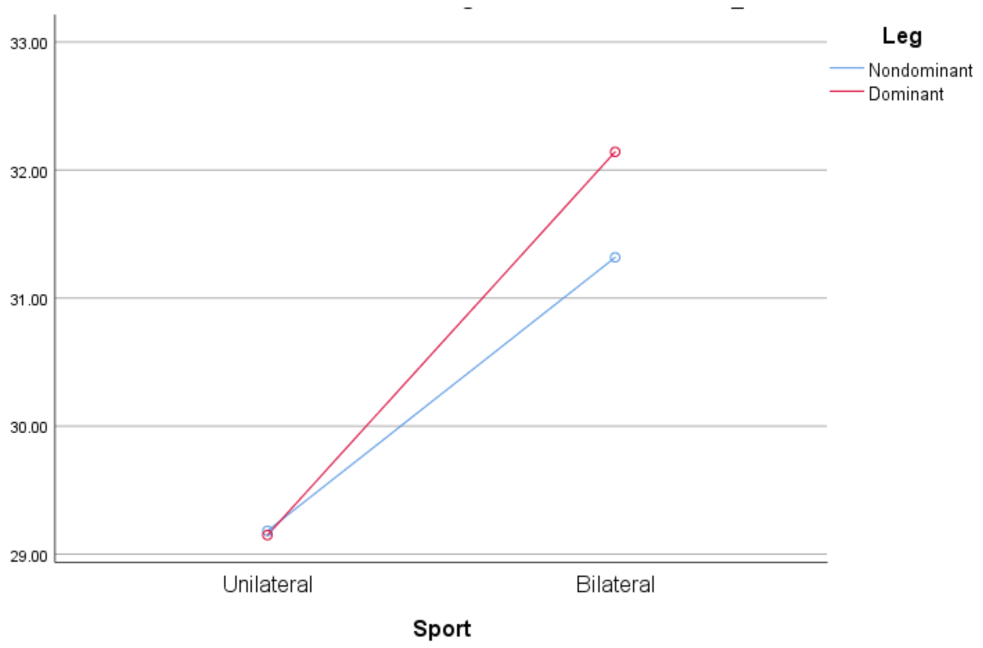
There are no statistically significant differences in other process values of the variable COV_{ISI}.

Table 24. Differences in the standard deviation of the interspike interval of a motor unit (SD_{ISI}) between the dominant and non-dominant lower extremity between the unilateral and bilateral groups of athletes

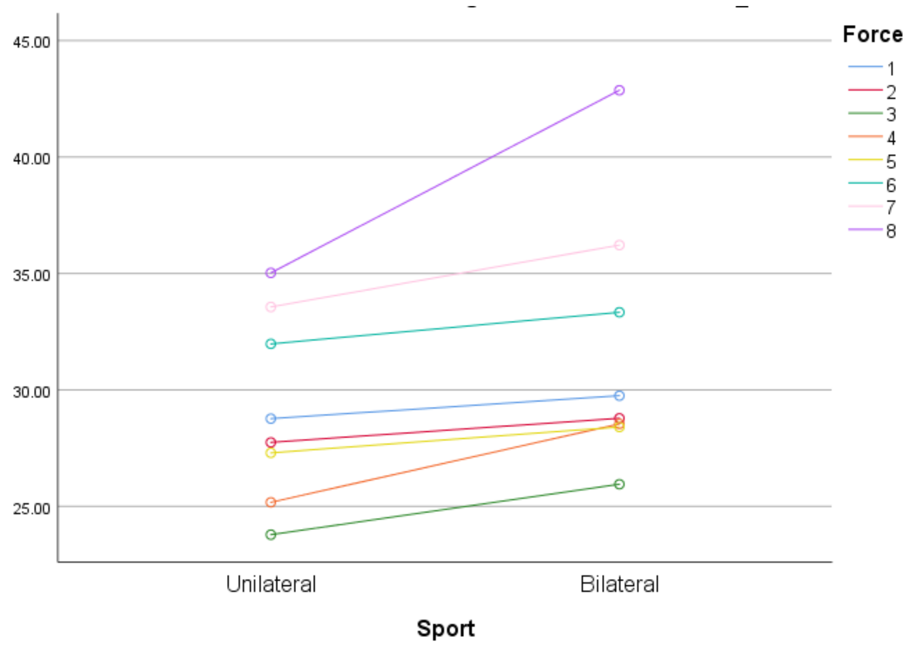
Variable	**Source of variation**	**df_{time}, $df_{Error(time)}$**	**F - value**	**Sig.**	**ηp^2**
SD_{ISI}	*LEG*	1.000, 204.000	0.185	0.668	0.001
	SPORT		7.746	**0.006**	0.037
	ANGLE	2.000, 204.000	0.502	0.606	0.005
	*LEG*SPORT*	1.000, 204.000	0.216	0.643	0.001
	*LEG*ANGLE*	2.000, 204.000	0.025	0.975	0.000
	*SPORT*ANGLE*		0.092	0.912	0.001
	*LEG*SPORT*ANGLE*		0.109	0.897	0.001
	FORCE	5.835, 1190.336	33.103	**0.000**	0.173
	*FORCE*LEG*		1.460	0.190	0.007
	*FORCE*SPORT*		2.572	**0.019**	0.012
	*FORCE*ANGLE*	11.670, 1190.336	1.842	**0.039**	0.018
	*FORCE*LEG*SPORT*	5.835, 1190.336	0.161	0.986	0.001
	*FORCE*LEG*ANGLE*	11.670, 1190.336	1.062	0.389	0.010
	*FORCE*SPORT*ANGLE*		1.450	0.139	0.014
	*FORCE*LEG*SPORT*ANGLE*		1.983	**0.024**	0.019

Legend: SD_{ISI} – standard deviation of the interspike interval of a motor unit; df –degree of freedom; Sig. – degree of statistical significance; ηp^2 – eta square coefficient; LEG – dominant and non-dominant leg; SPORT – unilateral and bilateral group of athletes; ANGLE – ankle angle (75º, 90º, 105º); FORCE – force level (2.5, 5, 10, 20, 30, 40, 50, 60% MVC)

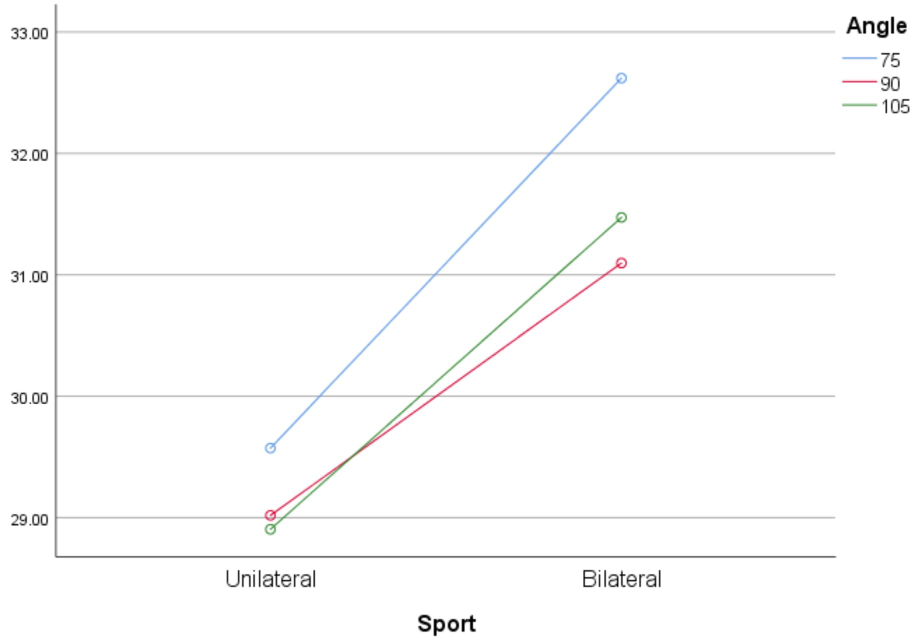
A three-factor ANOVA showed no statistically significant difference in the process values of the variable SD_{ISI} between the dominant and non-dominant lower extremity between the unilateral and bilateral groups of athletes, but there is a statistically significant difference between sport groups ($F(21.000, 204.000) = 7.746$, $p = 0.006$, $\eta p^2 = 0.037$) which is manifested by higher values of SD_{ISI} in both extremities in the bilateral group of athletes compared to the unilateral (Plot 15), at all force levels (Plot 16) and at all the ankle angles (Plot 17).



Plot 15. Interaction of the dominant and nondominant lower extremity between the unilateral and bilateral groups of athletes in standard deviation of the interspike interval of a motor unit (SD_{ISI})

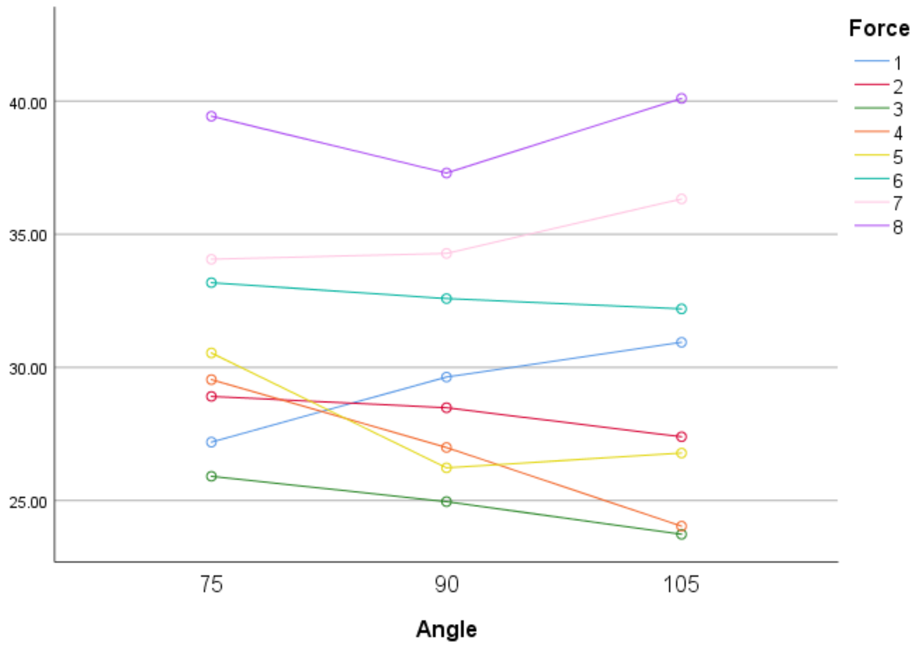


Plot 16. Interaction of manifested force (1 = 2.5%, 2 = 5%, 3 = 10%, 4 = 20%, 5= 30%, 6 = 40%, 7 = 50%, 8 = 60% MVC) between the unilateral and bilateral groups of athletes in standard deviation of the interspike interval of a motor unit (SD_{ISI})



Plot 17. Interaction of ankle angles (75°, 90° and 105°) between the unilateral and bilateral groups of athletes in standard deviation of the interspike interval of a motor unit (SD_{ISI})

Also, there is a statistically significant difference in the process differences of manifested force and group of athletes (F5.835, 1190.336 (5.835, 1190.336) = 2.572, p = 0.019, $\eta p^2 = 0.012$) which is manifested by lower values of the variable SD_{ISI} in the unilateral group of athletes compared to bilateral at force levels 10%, 20% and 60% MVC (Plot 16). Furthermore, there is a statistically significant difference in the process differences of manifested force ($F(5.835, 1190.336) = 33.103$, $p < 0.0005$, $\eta p^2 = 0.173$) whose value of the variable SD_{ISI} increases linearly as the force level increases, from 2.5% to 60% MVC and the interaction between the manifested level of force and the ankle angle ($F(11.670, 1190.336) = 1.842$, $p = 0.039$, $\eta p^2 = 0.018$) which is manifested by higher values of SD_{ISI} at the angle of 75° compared to angles of 90° and 105° at force levels of 20% and 30% MVC (Plot 18).



Plot 18. Interaction of manifested force (1 = 2.5%, 2 = 5%, 3 = 10%, 4 = 20%, 5= 30%, 6 = 40%, 7 = 50%, 8 = 60% MVC) and ankle angles (75°, 90° and 105°) between the unilateral and bilateral groups of athletes in standard deviation of the interspike interval of a motor unit (SD_{ISI})

Finally, there is a statistically significant group interaction of force, legs, groups of sports and angles ($F(11.670, 1190.336) = 1.983$, $p = 0.024$, $\eta p^2 = 0.019$). The unilateral group of athletes showed a lower value of the variable SD_{ISI} in both extremities compared to the bilateral group of athletes with a larger difference in the dominant leg, as well as at all force levels with the largest difference in the 60% MVC force level. Additionally, there were lower values of the variable SD_{ISI} in all angles in the unilateral group of athletes (Plots 15, 16 and 17)

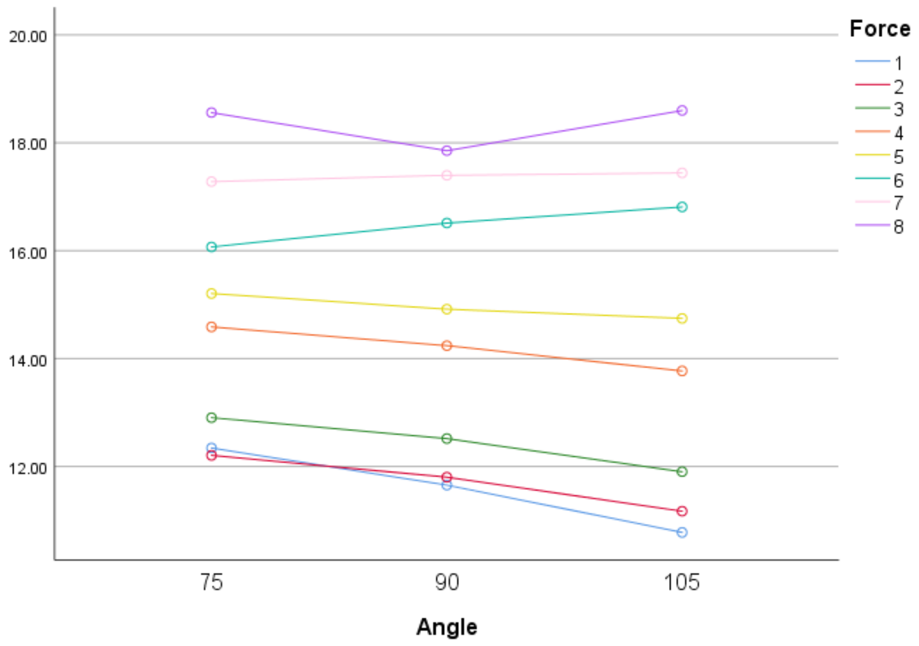
Table 25. Differences in mean discharge rate of a motor unit (MDR) between the dominant and non-dominant lower extremity between the unilateral and bilateral groups of athletes

Variable	**Source of variation**	**df_{time}, $df_{Error(time)}$**	**F - value**	**Sig.**	**ηp^2**

MDR	*LEG*	1.000, 204.000	1.781	0.184	0.009
	SPORT		1.576	0.211	0.008
	ANGLE	2.000, 204.000	1.750	0.176	0.017
	*LEG*SPORT*	1.000, 204.000	0.120	0.730	0.001
	*LEG*ANGLE*	2.000, 204.000	0.373	0.689	0.004
	*SPORT*ANGLE*		0.060	0.942	0.001
	*LEG*SPORT*ANGLE*		0.805	0.449	0.008
	FORCE	4.864, 992.189	400.461	**0.000**	0.663
	*FORCE*LEG*		1.949	0.086	0.009
	*FORCE*SPORT*		0.596	0.699	0.003
	*FORCE*ANGLE*	9.727, 992.189	3.376	**0.000**	0.032
	*FORCE*LEG*SPORT*	4.864, 992.189	2.783	**0.018**	0.013
	*FORCE*LEG*ANGLE*	9.727, 992.189	1.109	0.352	0.011
	*FORCE*SPORT*ANGLE*		1.048	0.402	0.010
	*FORCE*LEG*SPORT*ANGLE*		1.033	0.413	0.010

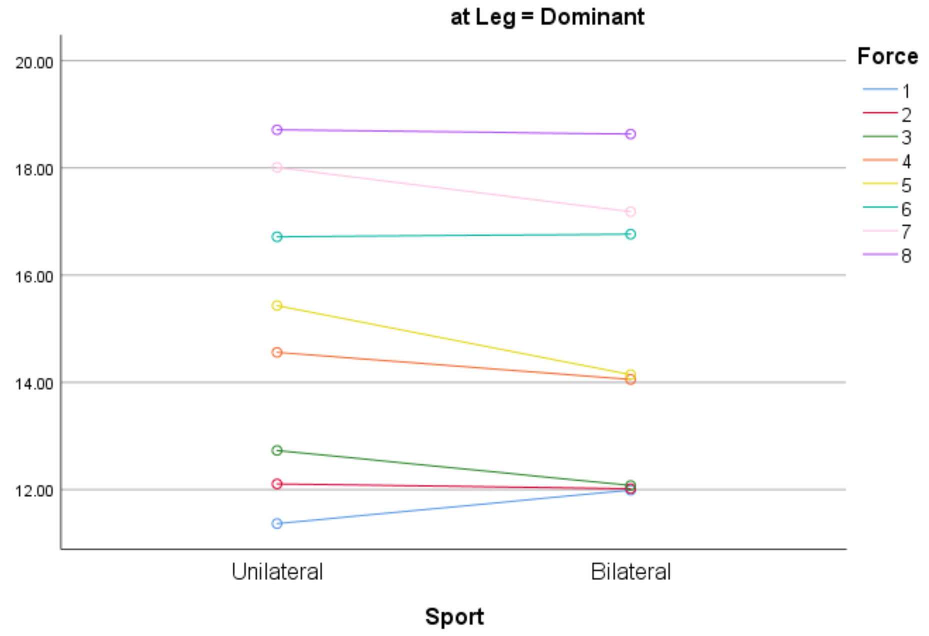
Legend: MDR– mean discharge rate of a motor unit; df –degree of freedom; Sig. – degree of statistical significance; ηp^2 – eta square coefficient; LEG – dominant and non-dominant leg; SPORT – unilateral and bilateral group of athletes; ANGLE – ankle angle (75º, 90º, 105º); FORCE – force level (2.5, 5, 10, 20, 30, 40, 50, 60% MVC)

A three-factor ANOVA showed no statistically significant difference in the process values of the variable MDR between the dominant and non-dominant lower extremity between the unilateral and bilateral groups of athletes. There is statistical significance in the process differences in the expressed force ($F(54.864, 992.189) = 400.461$, $p < 0.0005$, $\eta p^2 = 0.663$) whose value of the variable MDR increases linearly as the force level increases, from 2.5% to 60% MVC and the interaction between the manifested level of force and the ankle angle ($F(9.727, 992.189) = 3.376$, $p < 0.0005$, $\eta p^2 = 0.032$) which is manifested by higher values of MDR at the angle of 75° compared to the angles of 90° and 105° at force levels of 2.5%, 5% and 10% MVC (Plot 19).



Plot 19. Interaction of manifested force (1 = 2.5%, 2 = 5%, 3 = 10%, 4 = 20%, 5= 30%, 6 = 40%, 7 = 50%, 8 = 60% MVC) and ankle angles (75°, 90° and 105°) between the unilateral and bilateral groups of athletes in the mean discharge rate of a motor unit (MDR)

Finally, there is a statistically significant group interaction of force, legs and groups of sports (F(4.864, 992.189) = 2.783, p = 0.018, ηp^2 = 0.013) which is manifested by a progressive increase in values between the levels of manifested forces of the variable MDR in the unilateral group of athletes in both extremities, where in the blateral group MDR values have an exponential increase in the dominant leg at force levels of 2.5 to 30% MVC (Plots 20 and 21).



Plot 20. Interaction of manifested force (1 = 2.5%, 2 = 5%, 3 = 10%, 4 = 20%, 5= 30%, 6 = 40%, 7 = 50%, 8 = 60% MVC) between the unilateral and bilateral groups of athletes in mean discharge rate of a motor unit (MDR) in the dominant lower extremety

Plot 21. Interaction of manifested force (1 = 2.5%, 2 = 5%, 3 = 10%, 4 = 20%, 5= 30%, 6 = 40%, 7 = 50%, 8 = 60% MVC) between the unilateral and bilateral groups of athletes in mean discharge rate of a motor unit (MDR) in the non-dominant lower extremety

There are no statistically significant differences in other process values of the variable MDR.

7.8 Differences in muscle force control between the dominant and non-dominant lower extremity depending on the characteristics of the unilateral sport

Tables 26, 27 and 28 show the results in the control of muscle force between the dominant and non-dominant lower extremity depending on the characteristics of unilateral sport.

Table 26. Differences in the coefficient of variation of force (COVF) between the dominant and non-dominant lower extremity depending on the characteristics of unilateral sport

Variable	**Source of variation**	**df_{time}, $df_{Error(time)}$**	**F - value**	**Sig.**	**ηp^2**
COVF	*LEG*	1.000, 108.000	0.702	0.404	0.006
	TYPE		0.537	0.465	0.005
	ANGLE	2.000, 108.000	0.043	0.958	0.001
	*LEG*TYPE*	1.000, 108.000	0.012	0.912	0.000
	*LEG*ANGLE*	2.000, 108.000	0.432	0.650	0.008
	*TYPE*ANGLE*		0.498	0.609	0.009
	LEG TYPE*ANGLE*		0.004	0.996	0.000
	FORCE	2.024, 218.646	109.548	**0.000**	0.504
	*FORCE*LEG*		0.268	0.767	0.002
	*FORCE*TYPE*		0.225	0.778	0.002
	*FORCE*ANGLE*	4.049, 218.646	0.676	0.611	0.012
	*FORCE*LEG*TYPE*	2.024, 218.646	0.280	0.759	0.003
	*FORCE*LEG*ANGLE*	4.049, 218.646	1.118	0.349	0.020
	*FORCE*TYPE*ANGLE*		0.310	0.873	0.006
	*FORCE*LEG*TYPE*ANGLE*		0.512	0.729	0.009

Legend: COVF – coefficient of variation of force; df –degree of freedom; Sig. – degree of statistical significance; ηp^2 – eta square coefficient; LEG – dominant and non-dominant leg; TYPE – kind of sport (runners, cyclists); ANGLE – ankle angle (75º, 90º, 105º); FORCE – force level (2.5, 5, 10, 20, 30, 40, 50, 60% MVC)

A three-factor ANOVA showed no statistically significant difference in the process values of the variable COVF between the dominant and non-dominant lower extremity depending on the characteristics of unilateral sport. There is statistical significance in the process differences in the expressed force ($F(2.024, 218.646) = 109.548$, $p < 0.0005$, $\eta p^2 = 0.504$). Eta square coefficient showed a high value of the effect. The variability of the force decreases linearly as the force level increases, from 2.5% to 60% MVC. There are no statistically significant differences in other process values of the variable COVF.

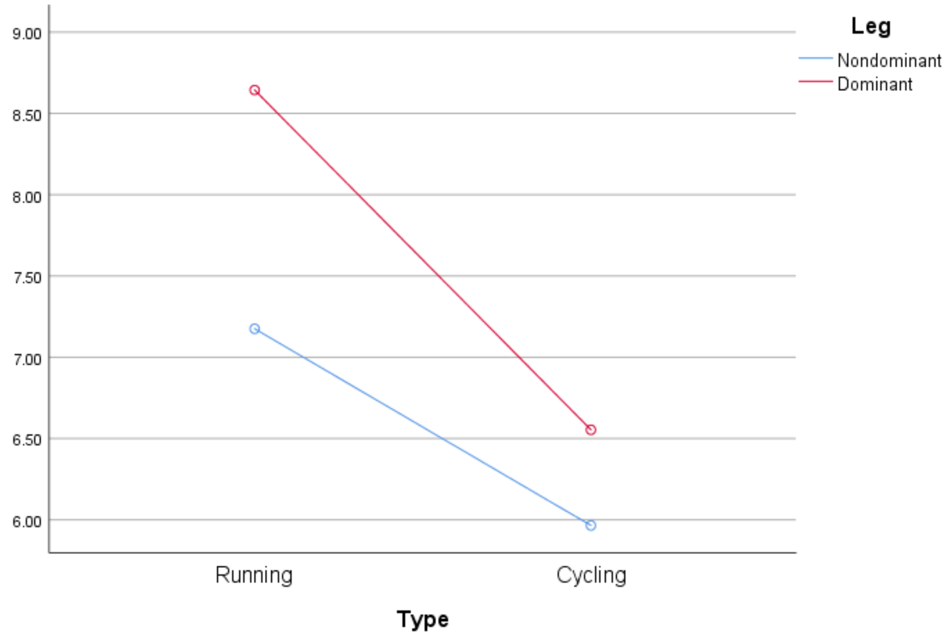
Table 27. Differences in the standard deviation of force (SDF) between the dominant and non-dominant lower extremity depending on the characteristics of unilateral sport

Variable	**Source of variation**	**df_{time}, $df_{Error(time)}$**	**F - value**	**Sig.**	**ηp^2**
SDF	*LEG*	1.000, 108.000	1.959	0.164	0.018
	TYPE		5.042	**0.027**	0.045
	ANGLE	2.000, 108.000	0.038	0.963	0.001
	*LEG*TYPE*	1.000, 108.000	0.359	0.551	0.003
	*LEG*ANGLE*	2.000, 108.000	0.072	0.931	0.001

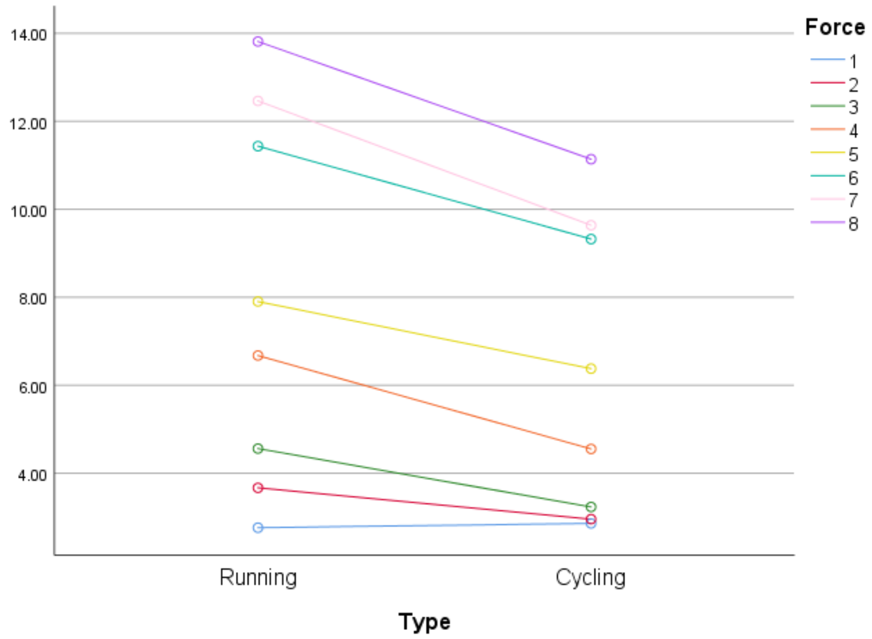
*TYPE*ANGLE*		0.034	0.967	0.001
LEG TYPE*ANGLE*		0.242	0.785	0.004
FORCE	3.352, 362.062	122.406	**0.000**	0.531
*FORCE*LEG*		0.244	0.885	0.002
*FORCE*TYPE*		2.107	0.092	0.019
*FORCE*ANGLE*	6.705, 362.062	2.232	**0.033**	0.040
*FORCE*LEG*TYPE*	3.352, 362.062	0.671	0.586	0.006
*FORCE*LEG*ANGLE*	6.705, 362.062	0.815	0.571	0.015
*FORCE*TYPE*ANGLE*		0.587	0.759	0.011
*FORCE*LEG*TYPE*ANGLE*		0.959	0.458	0.017

Legend: SD_F – standard deviation of force; df –degree of freedom; Sig. – degree of statistical significance;; ηp^2 – eta square coefficient, LEG – dominant and non-dominant leg; TYPE – kind of sport (runners, cyclists); ANGLE – ankle angle (75º, 90º, 105º); FORCE – force level (2.5, 5, 10, 20, 30, 40, 50, 60% MVC)

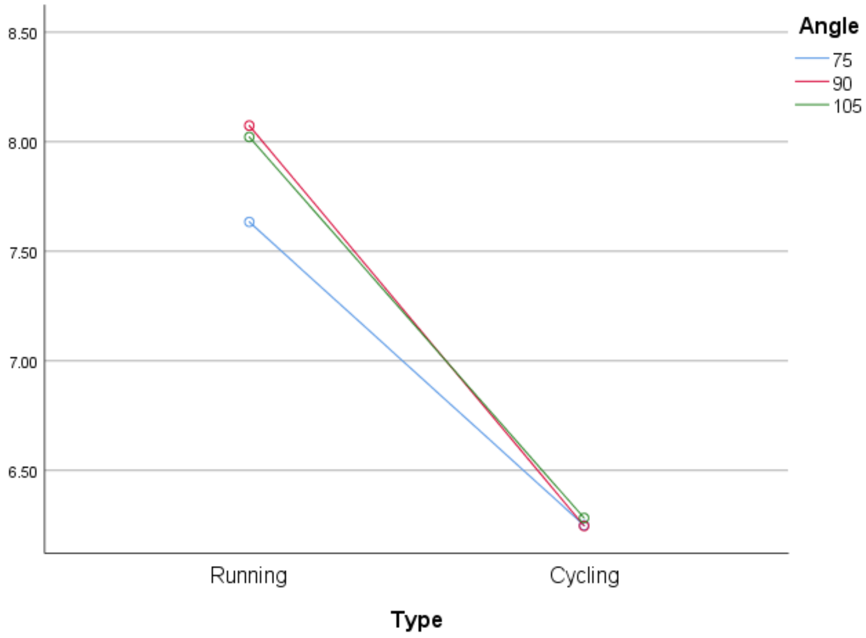
A three-factor ANOVA showed no statistically significant difference in the process values of the variable SD_F between the dominant and non-dominant lower extremity depending on the characteristics of unilateral sport, but did show differences between the characteristics of the group sports themselves ($F(1.000, 108.000) = 5.042$, $p = 0.027$, $\eta p^2 = 0.045$). Runners exhibit higher values of the variable SD_F compared to cyclists in both extremities (Plot 22), at all force levels (Plot 23) and in all ankle angles (Plot 24).



Plot 22. Interaction of the dominant and non-dominant lower extremity between unilateral groups of athletes (runners and cyclists) in standard deviation of force (SD_F)

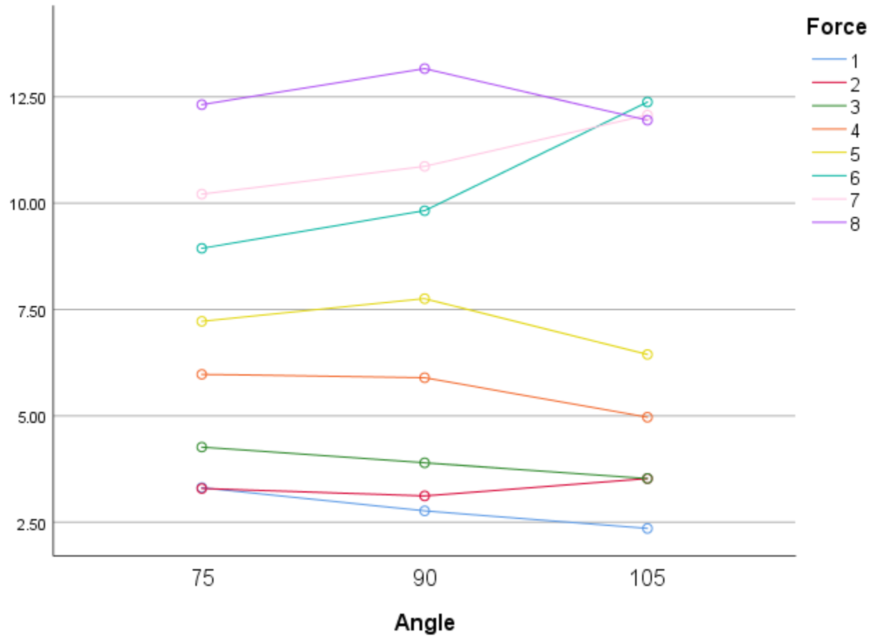


Plot 23. Interaction of manifested force (1 = 2.5%, 2 = 5%, 3 = 10%, 4 = 20%, 5= 30%, 6 = 40%, 7 = 50%, 8 = 60% MVC) between the unilateral groups of athletes (runners and cyclists) in standard deviation of force (SDF)



Plot 24. Interaction of ankle angles (75°, 90° and 105°) between the unilateral groups of athletes (runners and cyclists) in standard deviation of force (SDF)

Also, there is statistical significance in the process differences of the manifested force ($F(3.352, 362.062) = 122.406$, $p < 0.0005$, $\eta p^2 = 0.531$). Eta square coefficient showed high value of the effect. The value of the variable SD_F increases linearly as the force levels increase, from 2.5% to 60% MVC. In a group process differences there is a statistically significant interaction between the manifested force level and the angle in the ankle (F(6.705, 362.062) = 2.232, $p = 0.033$, $\eta p^2 = 0.040$) which is manifested by an impulsive increase in the value of the variable SDF in the ankle angle of 105° compared to the angle of 75° at the force level of 40% MVC (Plot 25).



Plot 25. Interaction of manifested force (1 = 2.5%, 2 = 5%, 3 = 10%, 4 = 20%, 5= 30%, 6 = 40%, 7 = 50%, 8 = 60% MVC) and ankle angles (75°, 90° and 105°) between the unilateral groups of athletes (runners and cyclists) in standard deviation of force (SDF)

There are no statistically significant differences in other process values of the variable SDF.

Table 28. Differences in the root mean square (RMS) between the dominant and non-dominant lower extremity depending on the characteristics of unilateral sport

Variable	**Source of variation**	**df_{time}, $df_{Error(time)}$**	**F - value**	**Sig.**	**ηp^2**
RMS	*LEG*	1.000, 108.000	3.869	0.051	0.035
	TYPE		1.198	0.276	0.011
	ANGLE	2.000, 108.000	0.234	0.791	0.004
	*LEG*TYPE*	1.000, 108.000	1.183	0.279	0.011
	*LEG*ANGLE*	2.000, 108.000	0.046	0.955	0.001
	*TYPE*ANGLE*		0.022	0.978	0.000
	LEG TYPE*ANGLE*		0.200	0.819	0.004
	FORCE	3.360, 362.927	273.743	**0.000**	0.717
	*FORCE*LEG*		1.434	0.229	0.013
	*FORCE*TYPE*		1.032	0.384	0.009
	*FORCE*ANGLE*	6.721, 362.927	1.286	0.210	0.023
	*FORCE*LEG*TYPE*	3.360, 362.927	1.825	0.135	0.017
	*FORCE*LEG*ANGLE*	6.721, 362.927	1.169	0.320	0.021

	*FORCE*TYPE*ANGLE*		0.602	0.747	0.011
	*FORCE*LEG*TYPE*ANGLE*		0.510	0.820	0.009

Legend: RMS – root mean square; df –degree of freedom; Sig. – degree of statistical significance; ηp^2 – eta square coefficient; LEG – dominant and non-dominant leg; TYPE – kind of sport (runners, cyclists); ANGLE – ankle angle (75º, 90º, 105º); FORCE – force level (2.5, 5, 10, 20, 30, 40, 50, 60% MVC)

A three-factor ANOVA was near to a statistically significant difference in the process values of the variable RMS between the dominant and non-dominant lower extremity depending on the characteristics of unilateral sport ($F(1.000, 108.000) = 3.869$, $p = 0.051$, $\eta p^2 = 0.035$). In runners, the dominant leg had higher values in the variable RMS compared to the non-dominant leg, as well as compared to the dominant one in cyclists. The value of the variable RMS was similar in both groups of athletes in the non-dominant leg. Also, there is a statistically significant difference in the process differences of the manifested force ($F(3.360, 362.927) = 273.743$, $p < 0.0005$, $\eta p^2 = 0.717$). Eta square coefficient showed a high value of the effect. The value of the variable RMS increases linearly as the force levels increase, from 2.5% to 60% MVC. There are no statistically significant differences in other process values of the variable RMS.

7.9 Differences in muscle force control between the dominant and non-dominant lower extremity depending on the characteristics of the bilateral sport

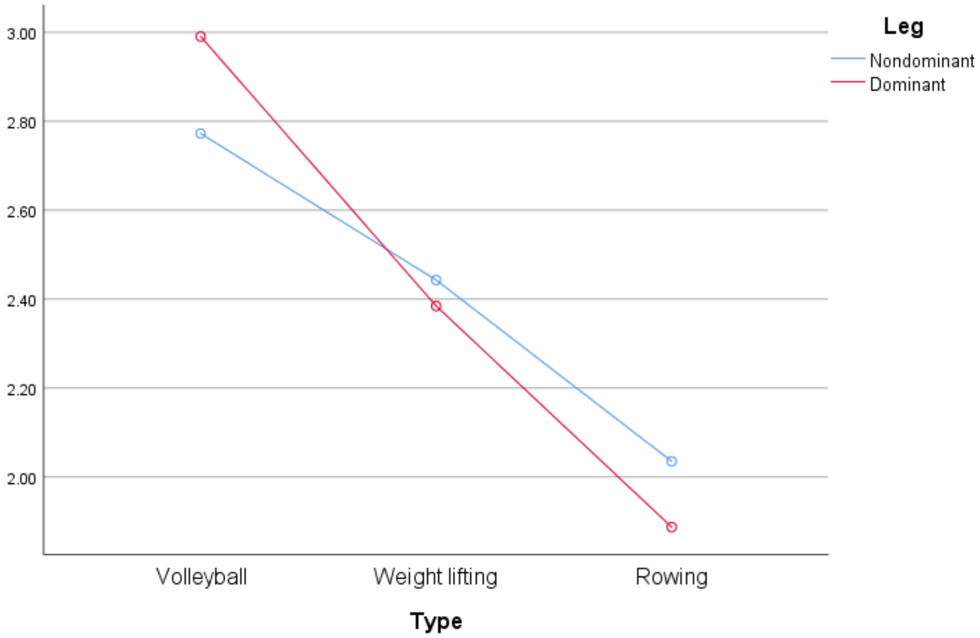
Tables 29, 30 and 31 show the results in the control of muscle strength between the dominant and non-dominant lower extremity depending on the characteristics of bilateral sports.

Table 29. Differences in the coefficient of variation of force (COVF) between the dominant and non-dominant lower extremity depending on the characteristics of bilateral sport

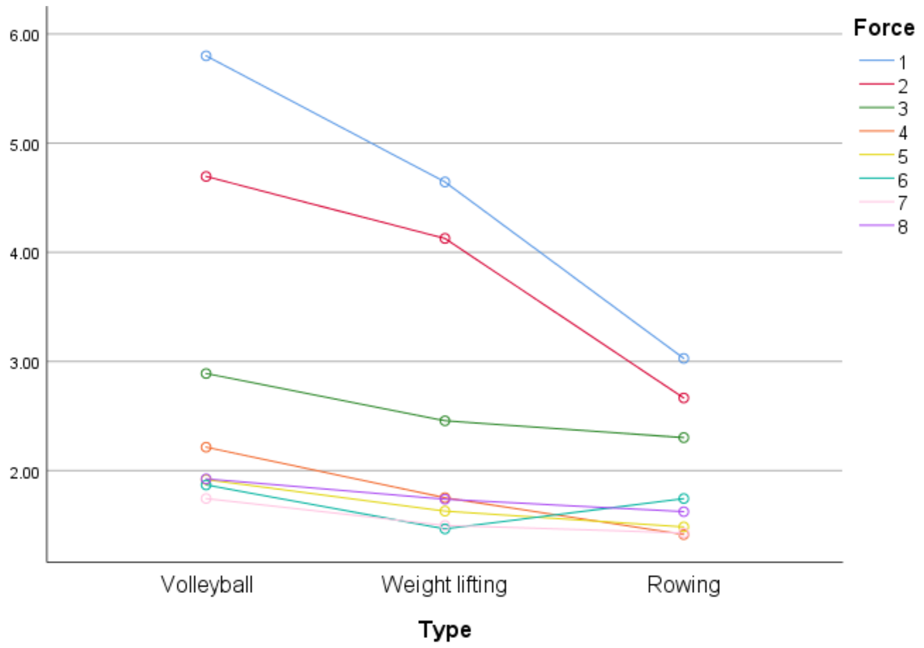
Variable	**Source of variation**	**df_{time}, $df_{Error(time)}$**	**F - value**	**Sig.**	**ηp^2**
COVF	*LEG*	1.000, 78.000	0.000	0.989	0.000
	TYPE	2.000, 78.000	4.067	**0.021**	0.094
	ANGLE		0.315	0.731	0.008
	*LEG*TYPE*		0.269	0.765	0.007
	*LEG*ANGLE*		0.030	0.970	0.001
	*TYPE*ANGLE*	4.000, 78.000	0.193	0.941	0.010
	LEG TYPE*ANGLE*		0.785	0.538	0.039
	FORCE	2.798, 218.253	35.950	**0.000**	0.315
	*FORCE*LEG*		0.103	0.950	0.001
	*FORCE*TYPE*	5.596, 218.253	1.967	0.076	0.048
	*FORCE*ANGLE*		0.880	0.504	0.022
	*FORCE*LEG*TYPE*		0.951	0.455	0.024
	*FORCE*LEG*ANGLE*		0.314	0.920	0.008
	*FORCE*TYPE*ANGLE*	11.192, 218.253	0.361	0.971	0.018
	*FORCE*LEG*TYPE*ANGLE*		0.623	0.811	0.031

Legend: COV$_F$ – coefficient of variation of force; df –degree of freedom; Sig. – degree of statistical significance; ηp^2 – eta square coefficient; LEG – dominant and non-dominant leg; TYPE – kind of sport (weightlifters, volleyball players, rowers); ANGLE – ankle angle (75º, 90º, 105º); FORCE – force level (2.5, 5, 10, 20, 30, 40, 50, 60% MVC)

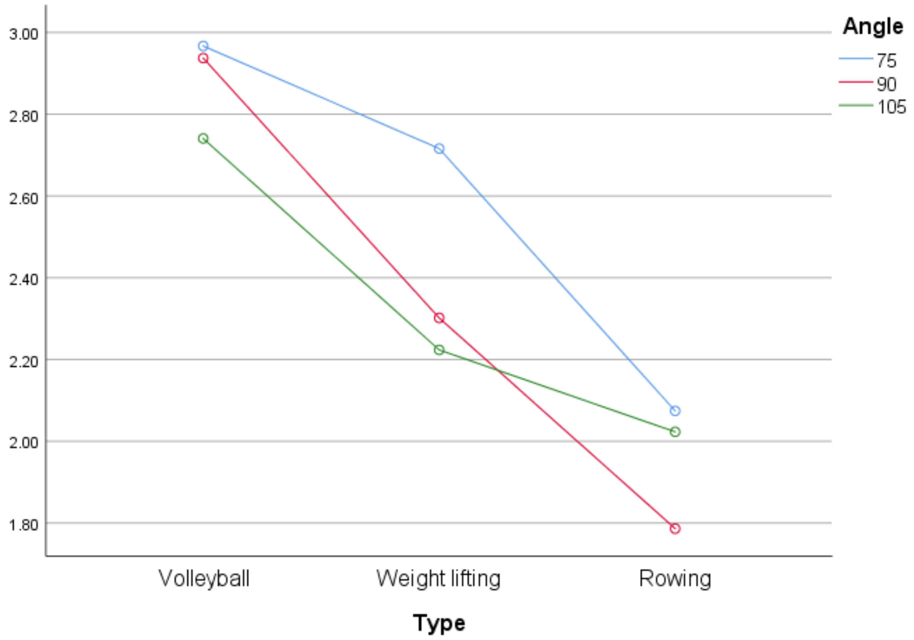
A three-factor ANOVA showed no statistically significant difference in the process values of the variable COV$_F$ between the dominant and non-dominant lower extremity depending on the characteristics of bilateral sport, but there is a statistically significant difference between sport groups themselves ($F(2.000, 78.000) = 4.067$, $p = 0.021$, $\eta p^2 = 0.094$). Volleyball players showed higher values of the COV$_F$ variable compared to weightlifters and rowers in both extremities (Plot 26), at all force levels (Plot 27) and all the angles (Plot 28). The rowers manifested the most stable force. These differences between the types of sports are more pronounced in the dominant leg.



Plot 26. Interaction of the dominant and non-dominant lower extremity between bilateral groups of athletes (volleyball, weightlifters and rowers) in the coefficient of variation of force (COV$_F$)



Plot 27. Interaction of manifested force (1 = 2.5%, 2 = 5%, 3 = 10%, 4 = 20%, 5= 30%, 6 = 40%, 7 = 50%, 8 = 60% MVC) between the bilateral groups of athletes (volleyball, weightlifters and rowers) in the coefficient of variation of force (COV_F)



Plot 28. Interaction of ankle angles (75°, 90° and 105°) between the bilateral groups of athletes (volleyball, weightlifters and rowers) in the coefficient of variation of force (COV_F)

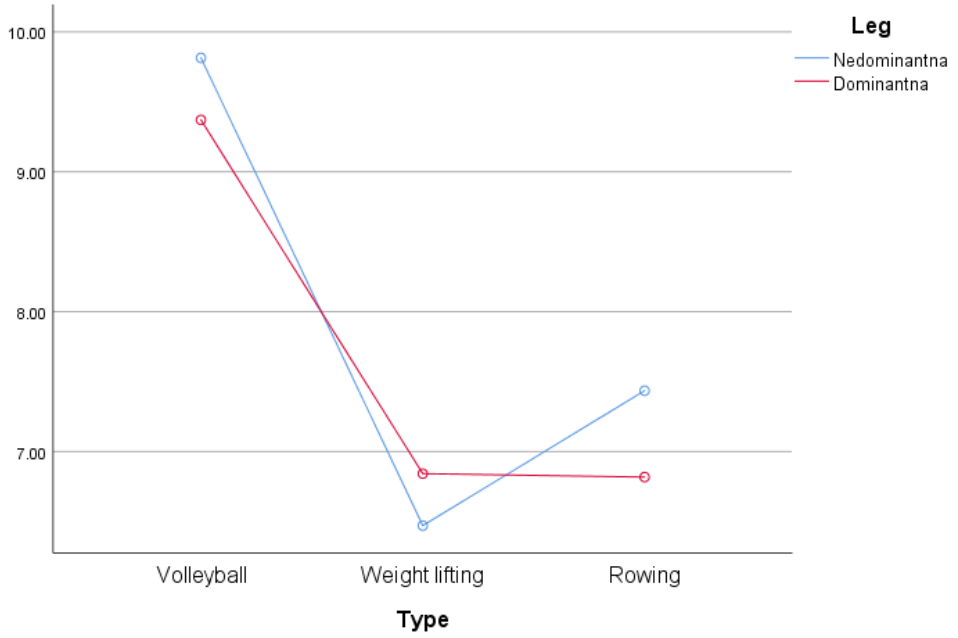
Also, there is a statistically significant difference in the process differences of the manifested force ($F(2.798, 218.253) = 35.950$, $p < 0.0005$, $\eta p^2 = 0.315$). Eta square coefficient showed a high value of the effect. The value of the variable COV_F decreases linearly as the force levels increase, from 2.5% to 60% MVC. There are no statistically significant differences in other process values of the variable COV_F.

Table 30. Differences in the standard deviation of force (SD_F) between the dominant and non-dominant lower extremity depending on the characteristics of bilateral sport

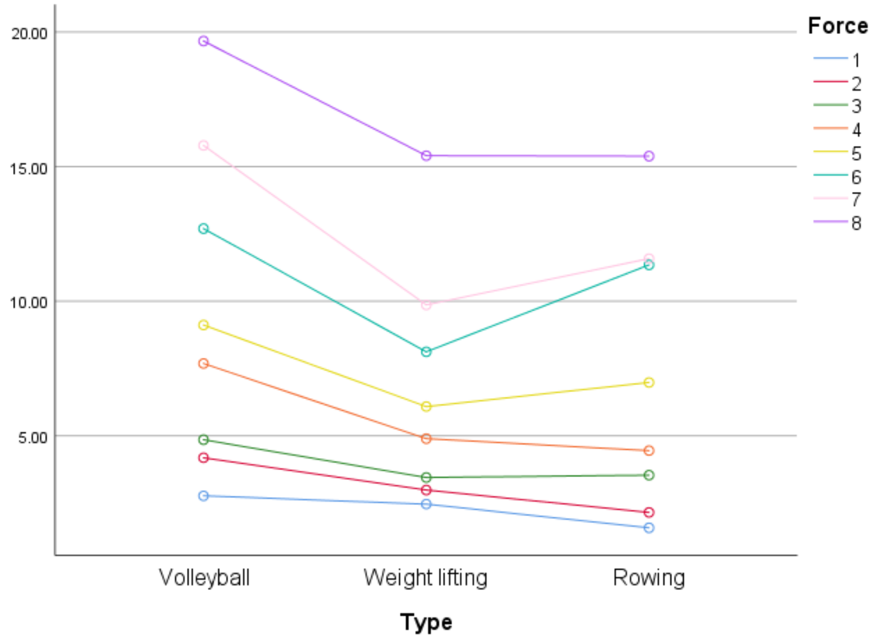
Variable	**Source of variation**	**df_{time}, $df_{Error(time)}$**	**F - value**	**Sig.**	**ηp^2**
SD_F	*LEG*	1.000, 78.000	0.040	0.841	0.001
	TYPE	2.000, 78.000	7.174	**0.001**	0.155
	ANGLE		0.054	0.947	0.001
	*LEG*TYPE*		0.149	0.862	0.004
	*LEG*ANGLE*		0.039	0.962	0.001
	*TYPE*ANGLE*	4.000, 78.000	0.158	0.959	0.008
	LEG TYPE*ANGLE*		0.587	0.673	0.029
	FORCE	2.580, 201.238	43.060	**0.000**	0.356
	*FORCE*LEG*		0.241	0.839	0.003
	*FORCE*TYPE*	5.160, 201.238	1.684	0.138	0.041
	*FORCE*ANGLE*		0.285	0.925	0.007
	*FORCE*LEG*TYPE*		0.951	0.451	0.024
	*FORCE*LEG*ANGLE*		0.282	0.927	0.007
	*FORCE*TYPE*ANGLE*	10.320, 218.253	0.640	0.783	0.032
	*FORCE*LEG*TYPE*ANGLE*		0.447	0.925	0.022

Legend: SD_F – standard deviation of force; df –degree of freedom; Sig. – degree of statistical significance; ηp^2 – eta square coefficient; LEG – dominant and non-dominant leg; TYPE – kind of sport (weightlifters, volleyball players, rowers); ANGLE – ankle angle (75º, 90º, 105º); FORCE – force level (2.5, 5, 10, 20, 30, 40, 50, 60% MVC)

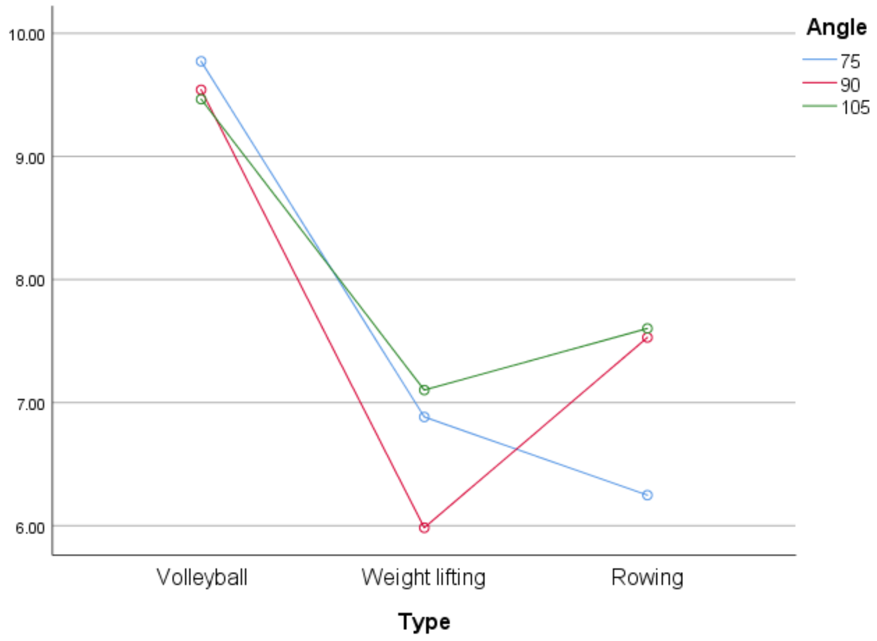
A three-factor ANOVA showed no statistically significant difference in the process values of the variable SD_F between the dominant and non-dominant lower extremity depending on the characteristics of bilateral sport, but there is a statistically significant difference between sport groups themselves ($F(2.000, 78.000) = 7.1747$, $p = 0.001$, $\eta p^2 = 0.155$). Volleyball players showed statistically significantly higher values of the SD_F variable compared to weightlifters and rowers in both extremities (Plot 29), at all force levels (Plot 30) and all ankle angles (Plot 31).



Plot 29. Interaction of the dominant and non-dominant lower extremity between bilateral groups of athletes (volleyball, weightlifters and rowers) in the standard deviation of force (SD_F)



Plot 30. Interaction of manifested force (1 = 2.5%, 2 = 5%, 3 = 10%, 4 = 20%, 5= 30%, 6 = 40%, 7 = 50%, 8 = 60% MVC) between the bilateral groups of athletes (volleyball, weightlifters and rowers) in the standard deviation of force (SD_F)



Plot 31. Interaction of ankle angles (75°, 90° and 105°) between the bilateral groups of athletes (volleyball, weightlifters and rowers) in the standard deviation of force (SD_F)

Also, there is a statistically significant difference in the process differences of the manifested force ($F(2.580, 201.238) = 43.060$, $p < 0.0005$, $\eta p^2 = 0.356$). Eta square coefficient showed a high value of the effect. The value of the variable SD_F increases linearly as the force levels increase, from 2.5% to 60% MVC. There are no statistically significant differences in other process values of the variable SD_F.

Table 31. Differences in the root mean square (RMS) between the dominant and non-dominant lower extremity depending on the characteristics of bilateral sport

Variable	**Source of variation**	**df_{time}, $df_{Error(time)}$**	**F - value**	**Sig.**	**ηp^2**
RMS	*LEG*	1.000, 78.000	0.000	0.996	0.000
	TYPE	2.000, 78.000	0.498	0.610	0.013
	ANGLE		0.596	0.554	0.015
	*LEG*TYPE*		0.384	0.682	0.010
	*LEG*ANGLE*		0.123	0.884	0.003
	*TYPE*ANGLE*	4.000, 78.000	0.298	0.878	0.015
	LEG TYPE*ANGLE*		0.566	0.688	0.028
	FORCE	3.422, 266.492	114.219	**0.000**	0.594
	*FORCE*LEG*		0.265	0.874	0.003
	*FORCE*TYPE*	6.845, 266.492	1.643	0.125	0.040
	*FORCE*ANGLE*		1.215	0.295	0.030
	*FORCE*LEG*TYPE*		0.500	0.831	0.013
	*FORCE*LEG*ANGLE*		1.116	0.340	0.028
	*FORCE*TYPE*ANGLE*	13.689, 266.492	0.719	0.752	0.036
	*FORCE*LEG*TYPE*ANGLE*		0.768	0.701	0.038

Legend: RMS – root mean square; df –degree of freedom; Sig. – degree of statistical significance; ηp^2 – eta square coefficient; LEG – dominant and non-dominant leg; TYPE – kind of sport (weightlifters, volleyball players, rowers); ANGLE – ankle angle (75º, 90º, 105º); FORCE – force level (2.5, 5, 10, 20, 30, 40, 50, 60% MVC)

A three-factor ANOVA showed no statistically significant difference in the process values of the variable RMS between the dominant and non-dominant lower extremity depending on the characteristics of bilateral sport. There is a statistically significant difference in the process differences of the manifested force ($F(3.422, 266.492) = 114.219$, $p < 0.0005$, $\eta p^2 = 0594$). Eta square coefficient showed a high value of the effect. The value of the variable RMS increases linearly as the force level increases, from 2.5% to 60% MVC. There are no statistically significant differences in other process values of the variable RMS.

7.10 Differences in motor units activation between the dominant and non-dominant lower extremity depending on the characteristics of the unilateral sport

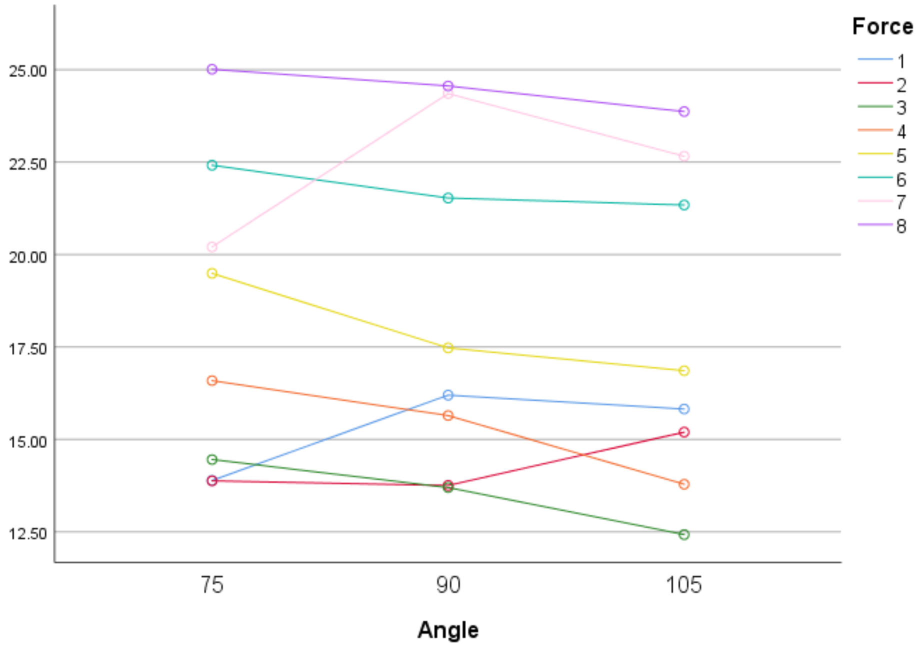
Tables 32, 33 and 34 show the results in the activation of motor units between the dominant and non-dominant lower extremities depending on the characteristics of unilateral sport.

Table 32. Differences in the coefficient of variation of the interspike interval of a motor unit (COV_{ISI}) between the dominant and non-dominant lower extremity depending on the characteristics of unilateral sport

Variable	**Source of variation**	**df_{time}, $df_{Error(time)}$**	**F - value**	**Sig.**	**ηp^2**
COV_{ISI}	*LEG*	1.000, 108.000	0.080	0.778	0.001
	TYPE		0.129	0.720	0.005
	ANGLE	2.000, 108.000	0.258	0.773	0.005
	*LEG*TYPE*	1.000, 108.000	0.115	0.735	0.001
	*LEG*ANGLE*	2.000, 108.000	0.465	0.629	0.009
	*TYPE*ANGLE*		0.038	0.867	0.003
	LEG TYPE*ANGLE*		0.143	0.867	0.003
	FORCE	4.681, 505.544	71.708	**0.000**	0.399
	*FORCE*LEG*		1.015	0.405	0.009
	*FORCE*TYPE*		2.123	0.066	0.019
	*FORCE*ANGLE*	9.362, 218.646	2.170	**0.021**	0.039
	*FORCE*LEG*TYPE*	4.681, 218.646	1.524	0.185	0.014
	*FORCE*LEG*ANGLE*	9.362, 218.646	1.298	0.233	0.023
	*FORCE*TYPE*ANGLE*		0.827	0.596	0.015
	*FORCE*LEG*TYPE*ANGLE*		1.265	0.251	0.023

Legend: COV_{ISI} – coefficient of variation of the interspike interval of a motor unit; df –degree of freedom; Sig. – degree of statistical significance; ηp^2 – eta square coefficient; LEG – dominant and non-dominant leg; TYPE – kind of sport (runners, cyclists); ANGLE – ankle angle (75º, 90º, 105º); FORCE – force level (2.5, 5, 10, 20, 30, 40, 50, 60% MVC)

A three-factor ANOVA showed no statistically significant difference in the process values of the variable COV_{ISI} between the dominant and non-dominant lower extremity depending on the characteristics of unilateral sport. There is a statistically significant difference in the process differences of the manifested force (F(4.681, 505.544) = 71.708, $p < 0.0005$, $\eta p^2 = 0399$). Eta square coefficient showed a high value of the effect. The value of the variable COV_{ISI} increases linearly as the force level increases, from 10% to 60% MVC. There is also a statistically significant interaction between the level of the manifested force and the ankle angle (F(9.362, 218.646) = 2.170, $p = 0.021$, $\eta p^2 = 0.039$) which is manifested by lower values COV_{ISI} at the angle of 75° compared to angles of 90° and 105° at force levels of 2.5% and 50% MVC (Plot 32).



Plot 32. Interaction of manifested force (1 = 2.5%, 2 = 5%, 3 = 10%, 4 = 20%, 5= 30%, 6 = 40%, 7 = 50%, 8 = 60% MVC) and ankle angles (75°, 90° and 105°) in coefficient of variation of the interspike interval of a motor unit (COV_{ISI}) between the unilateral group of athletes

The interaction between the manifested force and the type of sport is on the verge of statistical significance (F(4.681, 505.544) = 1.123, $p = 0.066$, $\eta p^2 = 0.019$). There are no statistically significant differences in other process values of the variable COV_{ISI}.

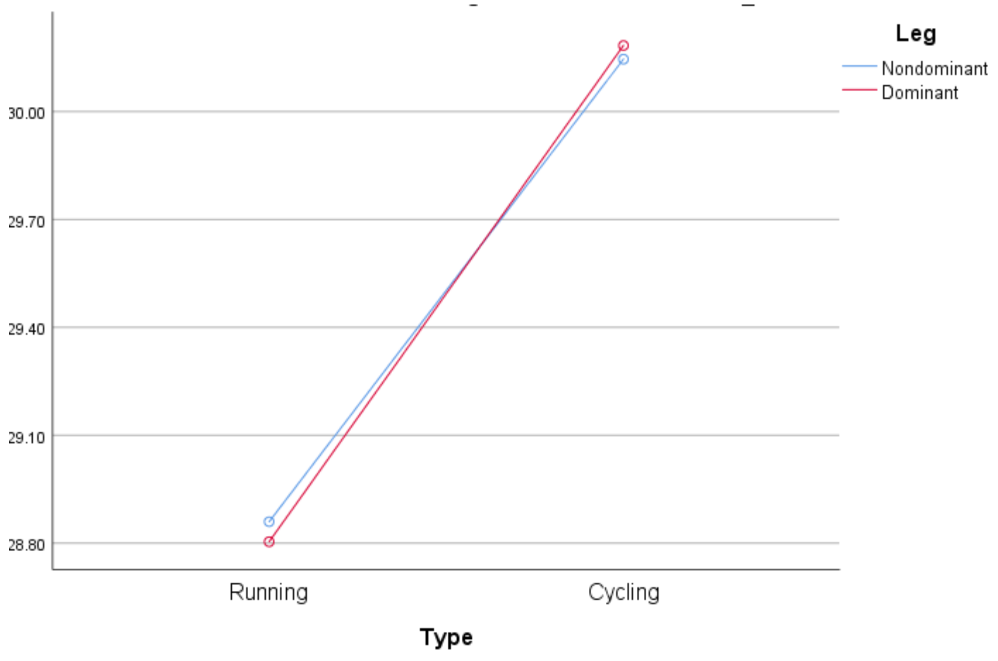
Table 33. Differences in the standard deviation of the interspike interval of a motor unit (SD_{ISI}) between the dominant and non-dominant lower extremity depending on the characteristics of unilateral sport

Variable	**Source of variation**	**df_{time}, $df_{Error(time)}$**	**F - value**	**Sig.**	**ηp^2**
SD_{ISI}	*LEG*	1.000, 108.000	0.000	0.995	0.000
	TYPE		0.909	0.343	0.008
	ANGLE	2.000, 108.000	0.174	0.840	0.003
	*LEG*TYPE*	1.000, 108.000	0.395	**0.001**	0.973
	*LEG*ANGLE*	2.000, 108.000	0.137	0.872	0.003

*TYPE*ANGLE*		0.693	0.502	0.013
LEG TYPE*ANGLE*		0.052	0.950	0.001
FORCE	5.396, 582.724	16.265	**0.000**	0.131
*FORCE*LEG*		1.704	0.126	0.016
*FORCE*TYPE*		2.846	0.096	0.017
*FORCE*ANGLE*	10.791, 582.724	1.826	**0.048**	0.033
*FORCE*LEG*TYPE*	5.396, 582.724	1.134	0.341	0.010
*FORCE*LEG*ANGLE*	10.791, 582.724	1.283	0.232	0.023
*FORCE*TYPE*ANGLE*		0.801	0.637	0.015
*FORCE*LEG*TYPE*ANGLE*		0.456	0.928	0.008

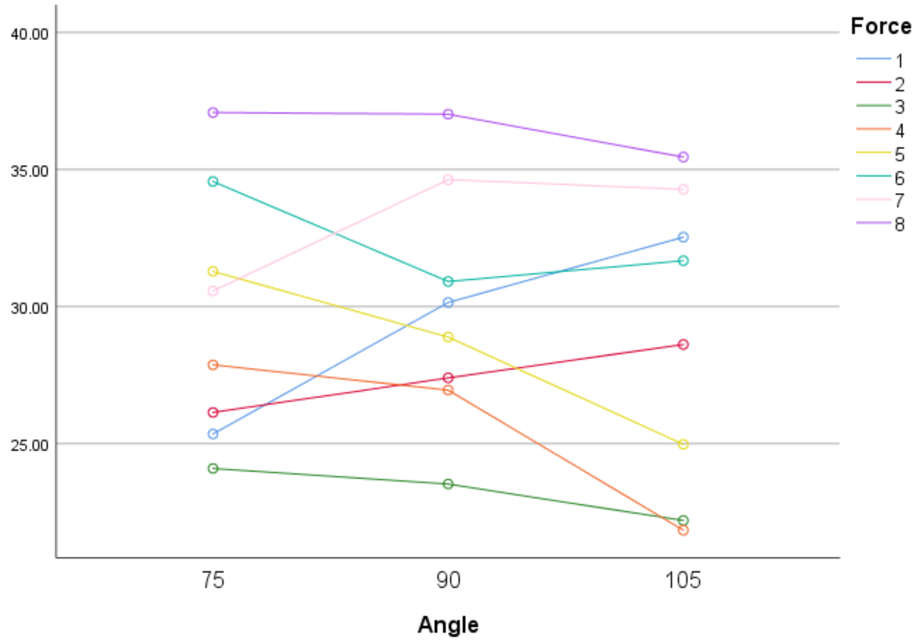
Legend: SD_{ISI} – standard deviation of the interspike interval of a motor unit; df –degree of freedom; Sig. – degree of statistical significance; ηp^2 – eta square coefficient; LEG – dominant and non-dominant leg; TYPE – kind of sport (runners, cyclists); ANGLE – ankle angle (75º, 90º, 105º); FORCE – force level (2.5, 5, 10, 20, 30, 40, 50, 60% MVC)

A three-factor ANOVA showed no statistically significant difference in the process values of the variable SD_{ISI} between the dominant and non-dominant lower extremity depending on the characteristics of unilateral sport, but did exhibit significance in group process differences between the lower extremities and the characteristics of the sport ($F(1.000, 108.000) = 0.395$, $p = 0.001$, $\eta p^2 = 0.973$). Runners exhibit significantly lower values of the variable SD_{ISI} than cyclists in both extremities (Plot 33).



Plot 33. Interaction of the dominant and non-dominant lower extremity between unilateral groups of athletes (runners and cyclists) in standard deviation of the interspike interval of a motor unit (SD_{ISI})

There is aslo a statistically significant difference in the process differences of the manifested force ($F(5.396, 582.724) = 16.265$, $p < 0.0005$, $\eta p^2 = 0.131$), where the standard deviation of the interspike interval of a motor unit increases linearly as the force level increases, from 2.5% to 60% MVC, as well as in the interaction of the anke angle and the manifested force ($F(10.791, 582.724) = 1.826$, $p = 0.048$, $\eta p^2 = 0.033$) which is manifested by lower values of SD_{ISI} in the angle of 75° compared to the angles of 90° and 105° at the force level of 2.5% and higher values of SD_{ISI} in the angle of 75° compering to the angles of 90° and 105° at the force level of 20% MVC (Plot 34).



Plot 34. Interaction of manifested force (1 = 2.5%, 2 = 5%, 3 = 10%, 4 = 20%, 5= 30%, 6 = 40%, 7 = 50%, 8 = 60% MVC) and ankle angles (75°, 90° and 105°) in standard deviation of the interspike interval of a motor unit (SD_{ISI}) between the unilateral group of athletes

There are no statistically significant differences in other process values of the variable SD_{ISI}.

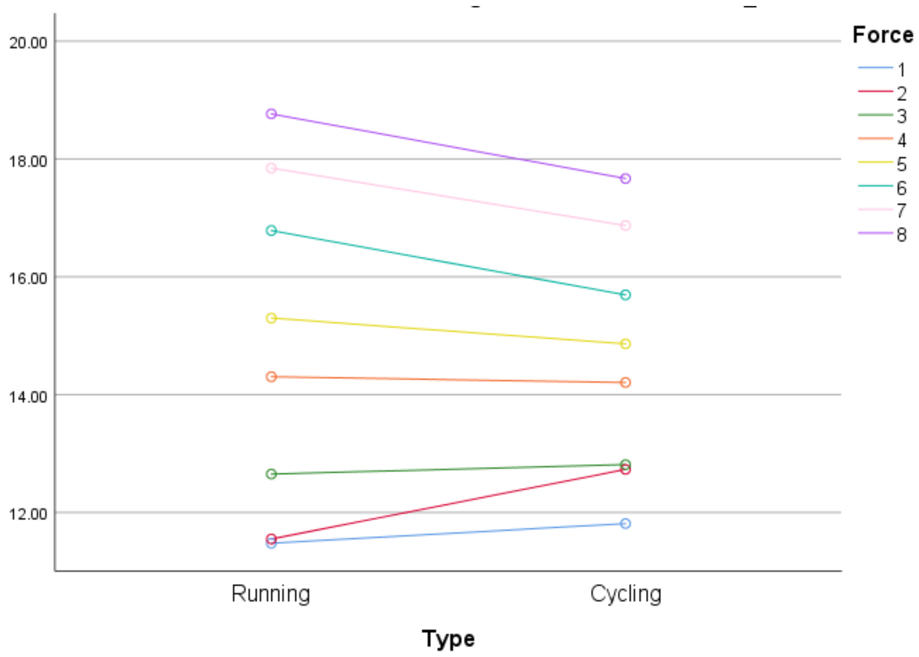
Table 34. Differences in the mean discharge rate of a motor unit (MDR) between the dominant and non-dominant lower extremity depending on the characteristics of unilateral sport

Variable	**Source of variation**	**df_{time}, $df_{Error(time)}$**	**F - value**	**Sig.**	**ηp^2**
MDR	*LEG*	1.000, 108.000	0.490	0.486	0.005
	TYPE		0.965	0.497	0.004
	ANGLE	2.000, 108.000	0.345	0.709	0.006
	*LEG*TYPE*	1.000, 108.000	0.304	0.583	0.003
	*LEG*ANGLE*	2.000, 108.000	0.128	0.880	0.002
	*TYPE*ANGLE*		0.046	0.955	0.001
	LEG TYPE*ANGLE*		0.014	0.986	0.000
	FORCE	4.682, 505.626	149.300	**0.000**	0.580
	*FORCE*LEG*		0.994	0.418	0.009
	*FORCE*TYPE*		4.066	**0.002**	0.036
	*FORCE*ANGLE*	9.363, 505.626	3.204	**0.001**	0.056

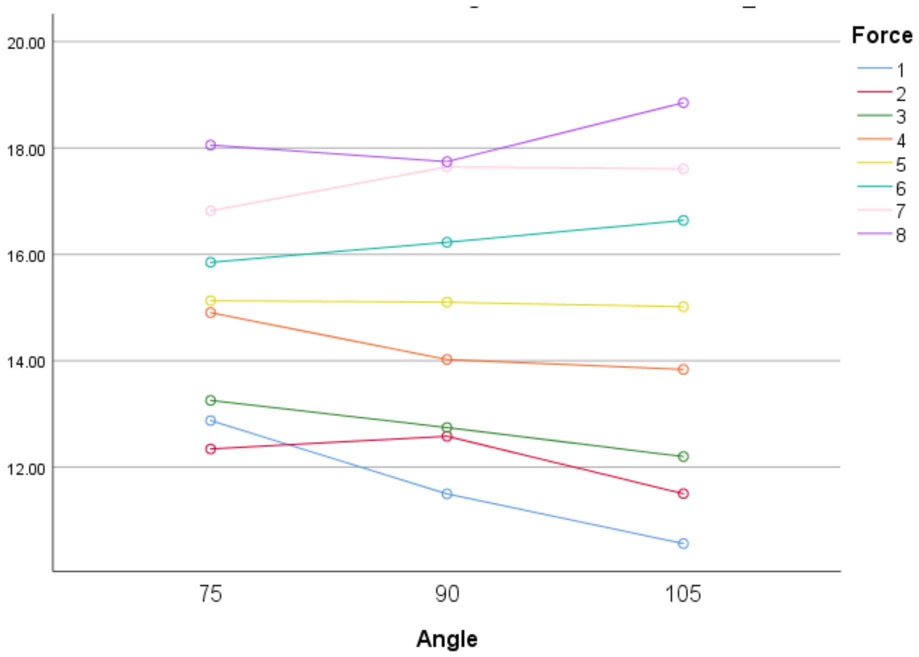
*FORCE*LEG*TYPE*	4.682, 505.626	0.829	0.523	0.008
*FORCE*LEG*ANGLE*	9.363, 505.626	0.962	0.473	0.017
*FORCE*TYPE*ANGLE*		0.687	0.727	0.013
*FORCE*LEG*TYPE*ANGLE*		0.982	0.455	0.018

Legend: MDR – mean discharge rate of a motor unit; df –degree of freedom; Sig. – degree of statistical significance; ηp^2 – eta square coefficient; LEG – dominant and non-dominant leg; TYPE – kind of sport (runners, cyclists); ANGLE – ankle angle (75º, 90º, 105º); FORCE – force level (2.5, 5, 10, 20, 30, 40, 50, 60% MVC)

A three-factor ANOVA showed no statistically significant difference in the process values of the variable MDR between the dominant and non-dominant lower extremity depending on the characteristics of unilateral sport. There is a statistically significant difference in the process differences of the manifested force ($F(4.682, 505.626) = 149.300$, $p < 0.0005$, $\eta p^2 = 0.580$), where the mean discharge rate of a motor unit increases linearly as the force level increases, from 10% to 60% MVC. In group process values, there is a statistical difference in the interaction of the force level and the characteristics of the sport ($F(4.682, 505.626) = 4.066$, $p = 0.002$, $\eta p^2 = 0.036$) which is manifested by higher values of the MDR variable in runners compared to cyclists, except at the force level of 5% MVC (Plot 35), as well as in the interaction of the level of manifested force and the ankle angle ($F(9.363, 505.626) = 3.204$, $p = 0.001$, $\eta p^2 = 0.056$) which is manifested by higher values of the variable MDR in the angle of 75° compering to the angles of 90° and 105° at the force level of 2.5% MVC (Plot 36). There are no statistically significant differences in other process values of the variable MDR.



Plot 35. Interaction of manifested force (1 = 2.5%, 2 = 5%, 3 = 10%, 4 = 20%, 5= 30%, 6 = 40%, 7 = 50%, 8 = 60% MVC) in mean discharge rate of a motor unit (MDR) between the unilateral group of athletes



Plot 36. Interaction of manifested force (1 = 2.5%, 2 = 5%, 3 = 10%, 4 = 20%, 5= 30%, 6 = 40%, 7 = 50%, 8 = 60% MVC) and ankle angles (75°, 90° and 105°) in mean discharge rate of a motor unit (MDR) between the unilateral group of athletes

7.11 Differences in motor units activation between the dominant and non-dominant lower extremity depending on the characteristics of the bilateral sport

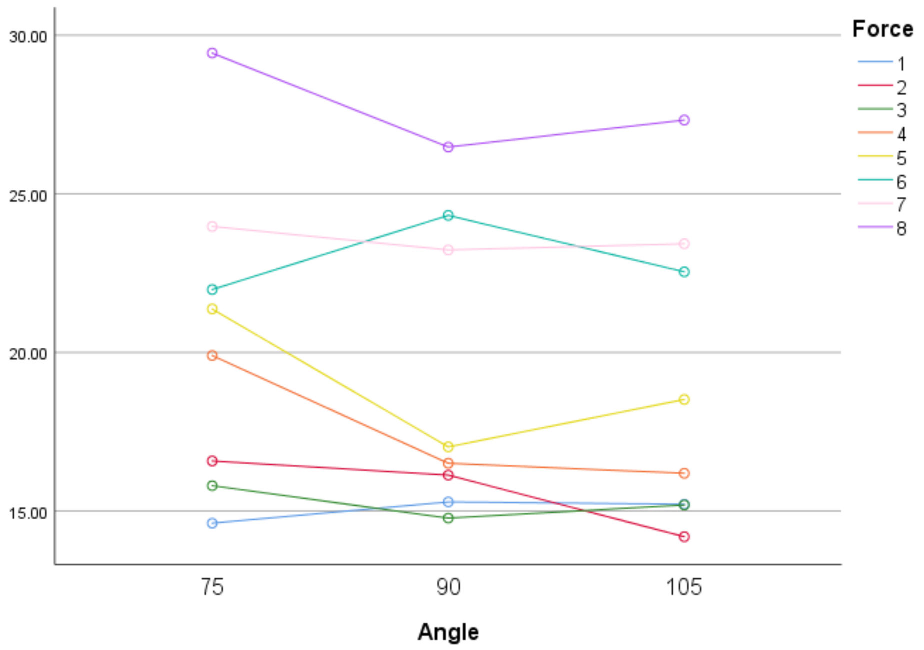
Tables 35, 36 and 37 show the results in the activation of motor units between the dominant and non-dominant lower extremity depending on the characteristics of bilateral sports.

Table 35. Differences in the coefficient of variation of the interspike interval of a motor unit (COV_{ISI}) between the dominant and non-dominant lower extremity depending on the characteristics of bilateral sport

Variable	**Source of variation**	**df_{time}, $df_{Error(time)}$**	**F - value**	**Sig.**	**ηp^2**
COV_{ISI}	*LEG*	1.000, 78.000	1.084	0.301	0.014
	TYPE	2.000, 78.000	2.014	0.140	0.049
	ANGLE		0.723	0.488	0.018
	*LEG*TYPE*		0.613	0.544	0.015
	*LEG*ANGLE*		0.288	0.751	0.007
	*TYPE*ANGLE*	4.000, 78.000	0.089	0.986	0.005
	LEG TYPE*ANGLE*		0.840	0.504	0.041
	FORCE	5.621, 438.477	33.508	**0.000**	0.300
	*FORCE*LEG*		0.882	0.503	0.011
	*FORCE*TYPE*	11.243, 438.477	1.190	0.291	0.030
	*FORCE*ANGLE*		2.391	**0.007**	0.058
	*FORCE*LEG*TYPE*		1.106	0.354	0.028
	*FORCE*LEG*ANGLE*		1.151	0.319	0.029
	*FORCE*TYPE*ANGLE*	22.486, 438.477	1.206	0.236	0.058
	*FORCE*LEG*TYPE*ANGLE*		1.159	0.280	0.056

Legend: COV_{ISI} – coefficient of variation of the interspike interval of a motor unit; df –degree of freedom; Sig. – degree of statistical significance; ηp^2 – eta square coefficient; LEG – dominant and non-dominant leg; TYPE – kind of sport (weightlifters, volleyball players, rowers); ANGLE – ankle angle (75º, 90º, 105º); FORCE – force level (2.5, 5, 10, 20, 30, 40, 50, 60% MVC)

A three-factor ANOVA showed no statistically significant difference in the process values of the variable COV_{ISI} between the dominant and non-dominant lower extremity depending on the characteristics of bilateral sport. There is a statistically significant difference in the process differences of the manifested force ($F(5.621, 438.477) = 33.508$, $p < 0.0005$, $\eta p^2 = 0.300$). Eta square coefficient showed a high value of the effect. The value of the variable COV_{ISI} increases linearly as the force level increases, from 2.5% to 60% MVC. There is also a statistically significant interaction between the level of the manifested force and the ankle angle ($F(11.243, 438.477) = 2.391$, $p = 0.007$, $\eta p^2 = 0.058$) which is manifested by higher values of COV_{ISI} at the angle of 75° compared to the angles of 90° and 105° at force levels of 20% and 30% MVC (Plot 37).



Plot 37. Interaction of manifested force (1 = 2.5%, 2 = 5%, 3 = 10%, 4 = 20%, 5= 30%, 6 = 40%, 7 = 50%, 8 = 60% MVC) and ankle angles (75°, 90° and 105°) in coefficient of variation of the interspike interval of a motor unit (COV_{ISI}) between the unilateral group of athletes

Table 36. Differences in the standard deviation of the interspike interval of a motor unit (SD_{ISI}) between the dominant and non-dominant lower extremity depending on the characteristics of bilateral sport

Variable	Source of variation	df_{time}, $df_{Error(time)}$	F - value	Sig.	ηp^2
SD_{ISI}	*LEG*	1.000, 78.000	0.545	0.463	0.007
	TYPE	2.000, 78.000	1.954	0.149	0.048
	ANGLE		0.312	0.733	0.008
	*LEG*TYPE*		0.291	0.748	0.007
	*LEG*ANGLE*		0.486	0.617	0.012
	*TYPE*ANGLE*	4.000, 78.000	0.264	0.900	0.013
	LEG TYPE*ANGLE*		1.222	0.308	0.059
	FORCE	5.385, 420.034	14.147	**0.000**	0.154
	*FORCE*LEG*		0.274	0.937	0.004
	*FORCE*TYPE*	10.770, 420.034	1.589	0.101	0.039
	*FORCE*ANGLE*		1.036	0.413	0.026
	*FORCE*LEG*TYPE*		0.690	0.745	0.017
	*FORCE*LEG*ANGLE*		0.661	0.772	0.017
	*FORCE*TYPE*ANGLE*	21.540, 420.034	0.540	0.956	0.027
	*FORCE*LEG*TYPE*ANGLE*		0.676	0.861	0.034

Legend: SD_{ISI} – standard deviation of the interspike interval of a motor unit; df –degree of freedom; Sig. – degree of statistical significance; ηp^2 – eta square coefficient; LEG – dominant and non-dominant leg; TYPE – kind of sport (weightlifters, volleyball players, rowers); ANGLE – ankle angle (75º, 90º, 105º); FORCE – force level (2.5, 5, 10, 20, 30, 40, 50, 60% MVC)

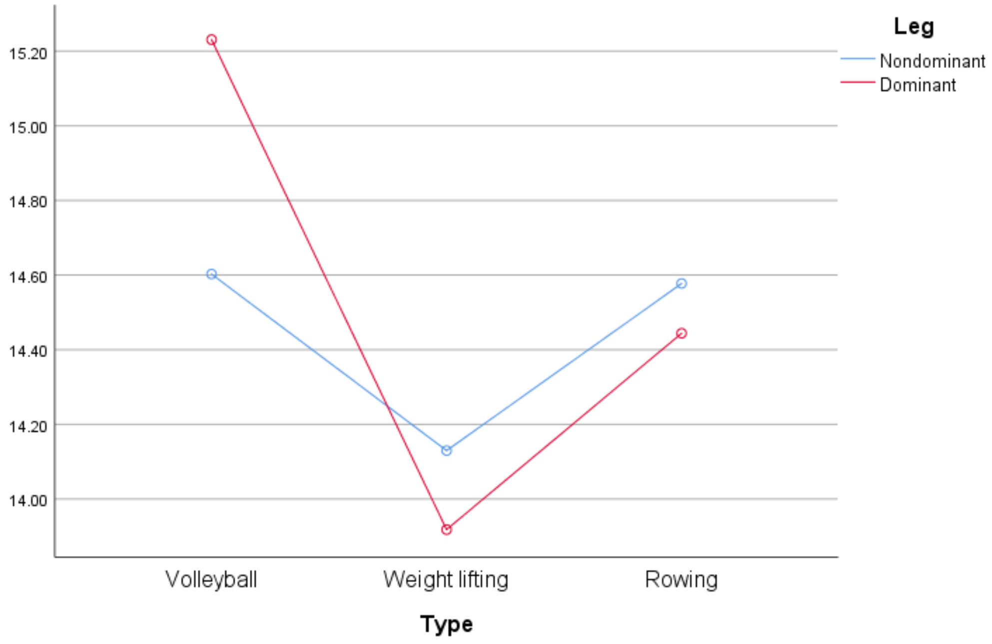
A three-factor ANOVA showed no statistically significant difference in the process values of the variable SD_{ISI} between the dominant and non-dominant lower extremity depending on the characteristics of bilateral sport. There is a statistically significant difference in the process differences of the manifested force (F(5.385, 420.034) = 14.147, $p < 0.0005$, $\eta p^2 = 0.154$). Eta square coefficient showed a high value of the effect. The value of the variable SD_{ISI} increases linearly as the force level increases, from 2.5% to 60% MVC. There are no statistically significant differences in other process values of the variable SD_{ISI}.

Table 37. Differences in the mean discharge rate of a motor unit (MDR) between the dominant and non-dominant lower extremity depending on the characteristics of bilateral sport

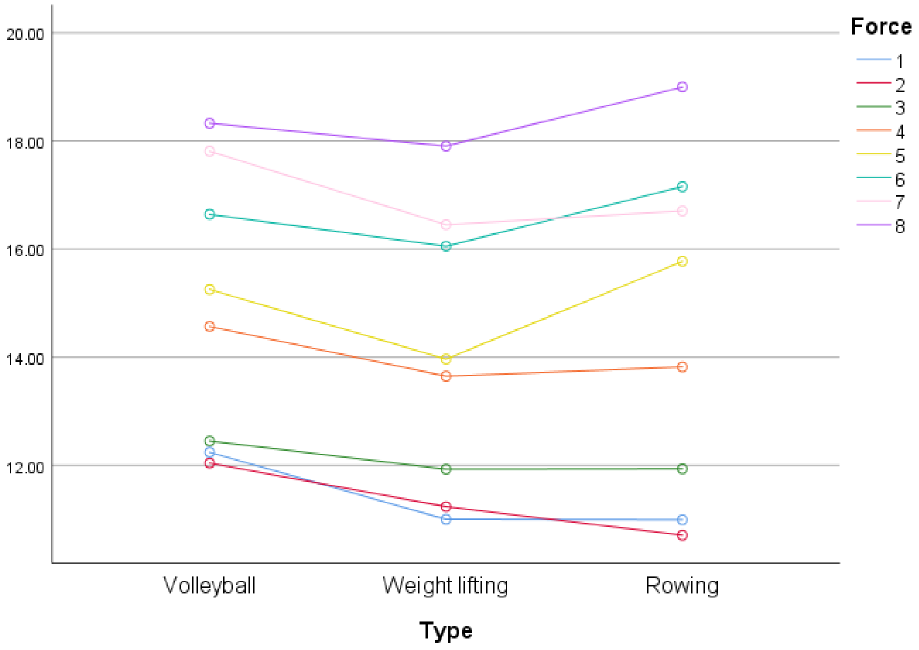
Variable	**Source of variation**	**df_{time}, $df_{Error(time)}$**	**F - value**	**Sig.**	**ηp^2**
MDR	*LEG*	1.000, 78.000	0.052	0.819	0.001
	TYPE	2.000, 78.000	4.942	**0.010**	0.112
	ANGLE		0.924	0.401	0.023
	*LEG*TYPE*		1.146	0.323	0.029
	*LEG*ANGLE*		0.923	0.402	0.023
	*TYPE*ANGLE*	4.000, 78.000	0.249	0.909	0.013
	LEG TYPE*ANGLE*		0.411	0.800	0.021
	FORCE	4.363, 340.291	88.767	**0.000**	0.532
	*FORCE*LEG*		1.763	0.130	0.022
	*FORCE*TYPE*	8.725, 340.291	0.927	0.500	0.023
	*FORCE*ANGLE*		0.859	0.559	0.022
	*FORCE*LEG*TYPE*		0.480	0.883	0.012
	*FORCE*LEG*ANGLE*		0.825	0.590	0.021
	*FORCE*TYPE*ANGLE*	17.451, 340.291	1.129	0.323	0.055
	*FORCE*LEG*TYPE*ANGLE*		0.952	0.514	0.047

Legend: MDR – mean discharge rate of a motor unit; df –degree of freedom; Sig. – degree of statistical significance; ηp^2 – eta square coefficient; LEG – dominant and non-dominant leg; TYPE – kind of sport (weightlifters, volleyball players, rowers); ANGLE – ankle angle (75º, 90º, 105º); FORCE – force level (2.5, 5, 10, 20, 30, 40, 50, 60% MVC)

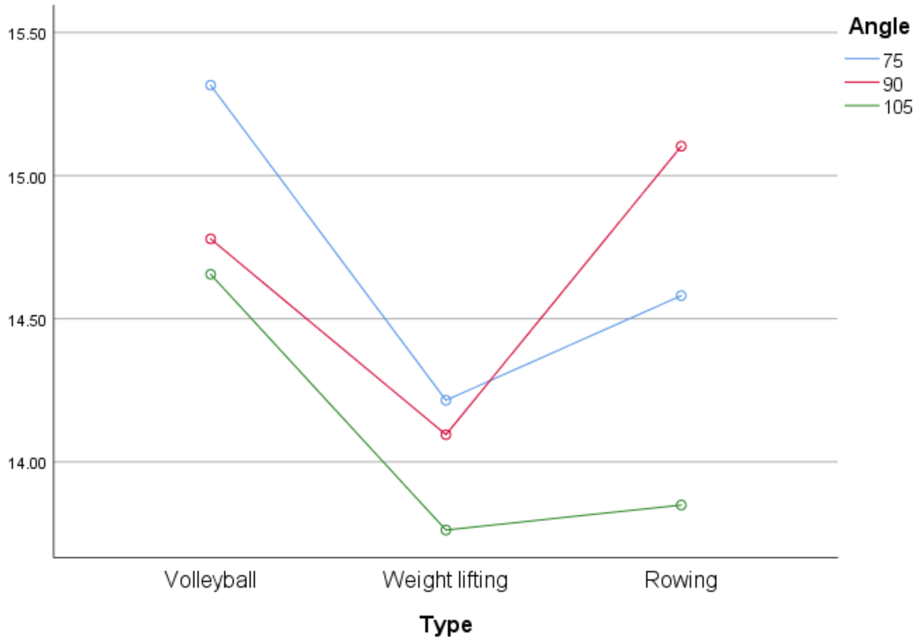
The three-factor ANOVA showed that there is no statistically significant difference in the process values of the variable MDR between the dominant and non-dominant lower extremity depending on the characteristics of bilateral sport, but that there is one between the sports themselves (F(2.000, 78.000) = 4.942, $p = 0.010$, $\eta p^2 = 0.112$). Volleyball players show significantly higher values of the MDR variable in the dominant leg compared to weightlifters and rowers (Plot 38), similar values in the applied force, while in weightlifters compared to rowers the value of the variable MDR is higher at the ankle angle of 105° (elongated TA muscle) (Plot 39).



Plot 38. Interaction of the dominant and non-dominant lower extremity between bilateral groups of athletes (weightlifters, volleyball players, rowers) in mean discharge rate of a motor unit (MDR)



Plot 39. Interaction of manifested force (1 = 2.5%, 2 = 5%, 3 = 10%, 4 = 20%, 5= 30%, 6 = 40%, 7 = 50%, 8 = 60% MVC) between the bilateral group of athletes (weightlifters, volleyball players, rowers) in mean discharge rate of a motor unit (MDR)



Plot 40. Interaction of ankle angles (75°, 90° and 105°) between the bilateral group of athletes (weightlifters, volleyball players, rowers) in mean discharge rate of a motor unit (MDR)

Also, there is a statistically significant difference in the process differences of the manifested force ($F(4.363, 340.291) = 88.767$, $p < 0.0005$, $\eta p^2 = 0.532$). Eta square coefficient showed a high value of the effect. The value of the variable MDR increases linearly as the force level increases, from 5% to 60% MVC. There are no statistically significant differences in other process values of the variable MDR.

8. DISCUSSION

Tables 8, 9 and 10 show the results in the control of muscle strength between the dominant and non-dominant lower extremity in the unilateral group of athletes. A review of the obtained results shows that there is no difference in any of the variables that define the difference in the control of muscle strength between the dominant and non-dominant lower extremity in a unilateral group of athletes, the relative amplitude of force variability (CoV_F), the absolute amplitude of the variability of force (SD_F) and the effective value of the manifested force (RMS). In all defined variables, there is a statistically significant difference between the levels of manifested force. The value of the variable increases linearly (CoV_F), actually decteases (SD_F, RMS) with an increase in force from 2.5% to 60% MVC ($p < 0.0005$). In group process values for SD_F and RMS there is a statistically significant interaction in the level of manifested force and ankle angle, which is manifested in a sharp increase in the value of the variable SD_F in the ankle angle 105° (elongated muscle TA) in relation to the angle 75° (shortened muscle TA) at the force level of 40% and 50% MVC ($p = 0.021$), actually higher values of the variable RMS in the angle 75° compering to angle 105° at low values of force, 2.5%, 10% and 20% MVC ($p = 0.039$).

Tables 11, 12 and 13 show the results in the control of muscle strength between the dominant and non-dominant lower extremity in the bilateral group of athletes. A review of the obtained results shows that there is no difference in any of the variables that define the difference between the dominant and non-dominant lower extremity in the bilateral group of athletes, the relative amplitude of force variability (CoV_F), the absolute amplitude of the variability of force (SD_F) and the effective value of the manifested force (RMS), nor in the force expressed depending on the length of the muscle. In all defined variables, there is a statistically significant difference between the levels of manifested force. The force increases linearly (CoV_F), actually dicreases (SD_F, RMS) with an increase in force from 2.5% to 60% MVC as in the unilateral group of athletes ($p < 0.0005$).

Several studies have shown that there are no differences in the lower extremities during the performance of dynamic contractions (Hotta et al., 2007), isokinetic strength of the knee extensor and jumping tasks (Östenberg, Roos, Ekdahl, & Roos, 1998) and unilateral squats (McCurdy, & Langford, 2005). Also, in the studies where isometric muscle contraction was monitored, no statistically significant difference was observed between the lower extremities during the performance at low isometric contractions, 10% and 20% MVC (Oshita, & Yano, 2010, 2011). In an earlier study where quadriceps muscle activation was monitored while performing isometric force at 25%, 50%, 75% and 100% MVC asymmetry between the extremities was also not observed (Jakobi, & Cafarelli, 1998), while in the study by Burnett et al. (2011) of the five monitored muscles in the lower extremities, asymmetry was found only in the hamstring muscle when performing the sitting task. Recent research of dynamic tasks of dorsal and plantar flexions has also shown a lack of asymmetry in the lower extremities (Yamaguchi et al., 2019; Yen et al., 2018). Considering older research, during the monitoring of isometric contractions at low levels of force, they also showed the absence of asymmetry in the extremities (Semmler, & Nordstrom, 1995). Also, the results of the latest research that studied muscle variability, as well as the behavior of motor units, when performing isometric contractions at force levels at 5% to 60% MVC, showed a lack of asymmetry in the manifested force due to, as the authors state, equal discharge of motor units in activated muscles between the extremities (Petrović et al., 2022).

On the other hand, there are studies that have shown the existence of asymmetry during the performance of moderate isometric contractions in the lower extremities, 30% MVC (Oshita, & Yano, 2010, 2011), and in the upper extremities (Adam et al., 1998). In addition, in performing isometric contractions at high intensity force, 70% MVC, the variability of force was significantly higher in the dominant hand compared to the non-dominant one (Mitchell et al., 2017). In research Beuter (2000) the dominant side exhibited greater force variability, higher power in the range of 7 - 12 Hz and higher mean frequencies, while Sainburg and Kalakani (2000) and Yamauchi (2004) noticed a more coordinated performance of the movement with the dominant hand. It can be noticed that the largest number of studies with observed differences between the extremities was conducted by examining the upper extremities. This non-compliance in the results between studies found in the upper and lower extremities may be due to reduced interhemispheric inhibition in the lower extremities due to the stronger influence of spinal cord circles on lower extremity movements, which were observed in monitoring brain region activation in the sudy Volz et al. (2015). These authors observed that unilateral arm movements were associated with increased laterlization, stronger excitatory drive on the active contralateral arm in the primary motor cortex by premotor areas, and more pronounced inhibition of M1 inactive ipsilateral arm compared to the foot movements.

However, in this study, the variability of the force did not differ between the extremities at any of the levels of the expressed submaximal force, 2.5% to 60% MVC, neither in the unilateral nor in the bilateral group of subjects, nor depending on the length of the TA muscle. One of the main reasons for the lack of asymmetry between the extremities may be due to the implementation of measurements on a healthy population of participants with sports experience who have been shown to have more symmetry due to the adopted automatization of movement by a properly guided training process than the non-athletes (DeAdder, 2020) or brain efficacy to activate synergist muscles that aid in performing the correct movement of the target muscle (Salem et al., 2003). For example, there was a statistically significant difference between the limbs between the asymmetric and symmetric groups of subjects in the isokinetic knee extension, where in the asymmetric group of subjects the asymmetry in the extensions was four times greater than in the symmetric group (Bond et al., 2017). Moreover, some previous studies obtained a statically significant difference between lower limbs in athletes while performing bilateral tasks, but these differences were not observed in the same groups of athletes when performing unilateral tasks (Howard, & Enoka, 1991; Luk et al., 2014). For example, weightlifters showed statistically significant less asymmetry than long jumpers, while differences between the dominant and non-dominant extremities were not expressed when preforming unilateral tasks (Luk et al., 2014). The author explains these diffreneces as the influence of the training natures of these two sports, where long jumpers have an increased use of one leg during the training process.

In our opinion, the lack of differences between extremities found in this research points to an equal use of both extremities while performing sports-related tasks which are a part of their training process. The differences obtained during bilateral performance testing were not a part of this study and further research is needed to confirm these states in these sports groups.

Tables 14, 15 and 16 show the results in the activation of motor units between the dominant and non-dominant lower extremity in the unilateral group of athletes. A review of the obtained results shows that there is no difference in any of the variables that define the difference in the activation of motor units between the dominant and non-dominant lower extremity in the unilateral group of athletes, the relative amplitude of the variability of the interspike interval of the motor unit (CoV_{ISI}), the absolute amplitude of the variability of the interspike interval of the motor unit (SD_{ISI}) and the mean value of the released action potential rate for each recognized motor unit (MDR). In all defined variables, there is a statistically significant difference between the levels of manifested force. The interspike interval of the motor unit increases linearly (CoV_F, SD_F, RMS) with increasing force from 2.5% to 60% MVC ($p < 0.0005$). In group process values, there is a statistically significant interaction in the level of manifested force and ankle angle, which is manifested by a lower value of the variable COV_{ISI} in the angle 75° (shortened muscle TA) in relation to other angles at the force level of 2.5% and 50% MVC ($p = 0.034$), lower value of the variable SD_{ISI} in the angle of 75° in relation to the other angles at the force levels of 2.5% and 50% MVC, higher values of the variable SD_{ISI} in the angle of 75° in relation to the other angles at the force level 30% MVC, as well as smaller values of the variable SD_{ISI} in the angle of 105° in relation to the other angles at the force level of 20% MVC ($p = 0.040$) and a higher value of the variable MDR in the angle 75° in relation to the other angles at force levels of 2.5% and 10% MVC ($p < 0.0005$).

Tables 17, 18 and 19 show the results in the activation of motor units between the dominant and non-dominant lower extremity in the bilateral group of athletes. A review of the obtained results shows that there is no difference in any of the variables that define the difference in the activation of motor units between the dominant and non-dominant lower extremity in the bilateral group of athletes, the relative amplitude of the variability of the interspike interval of the motor unit (CoV_{ISI}), the absolute amplitude of the variability of the interspike interval of the motor unit (SD_{ISI}) and the mean value of the released action potential rate for each recognized motor unit (MDR), nor in the force expressed depending on the length of the muscle. In all defined variables, there is a statistically significant difference between the levels of manifested force. The interspike interval of the motor unit increases linearly (CoV_F, SD_F, RMS) with increasing force from 2.5% до 60% MVC as in the unilateral group of athletes ($p < 0.0005$). In group process values, there is a statistically significant interaction in the level of manifested force and lower extremities, which is manifested by higher values of the MDR variable in the dominant leg compared to the non-dominant one, except at the force level 30% MVC ($p = 0.006$).

By monitoring the behavior of motor units, Adam et al. (1998) have found that motor units in the dominant hand have a lower average of firing rates and lower thresholds activation than those in the non-dominant hand. Also, during isometric contractions, pairs of motor units were discharged with a higher degree of synchronization in the dominant hand compared to the non-dominant one, while no statistically significant differences were found in the variability of motor unit discharge, nor in their threshold activation (Kamen et al., 1992; Schmied et al., 1994). On the other hand, adjusting the discharge rate and variability in the discharge time of motor unit activity in the *biceps brachii* muscle during continuous submaximal contractions requiring force or position control did not differ between the extremities, either in left-handed (Gould et al., 2016) or right-handed prticipants (Mottram et al., 2005). On the other hand, it is noted that the discharge rate during isometric contractions of low forces may affects the coherence of motor units below 15 Hz (Christou, Rudro, Enoka, Meyer, & Enoka, 2007).

The results of present research are similar with the research by Petrović et al. (2022) where independent input (CoV_{ISI}) showed great similarity between the extremities. In addition, the average discharge rate of motor units in the TA muscle at force levels 5 to 60% MVC, was similar for both legs. However, the difference between extremities in the behaviors of motor units was not different in the unilateral group of athletes in any motor unit's variable, but has shown differences in the average discharge rate of motor units in group process values between force and legs in bilateral athletes at higher values of force, 40 to 60% MVC. The lack of statistical significance in unilateral athletes may be due to the impact of their training process. For example, in the study of Semmler and Nordstrom (1998), skill-trained participants did not exhibit differences between extremities in common drive, while the untrained and strength-trained participants, which did not perform tasks during testing, did. The differences obtained in bilateral athletes in this research might be due to the number of motor units involved, the upper limit of motor unit activation and the task being performed (Castronovo et al., 2018; Dideriksen, Negro, Enoka, & Farina, 2012; Watanabe et al., 2013). In bilateral athletes there were fewer motor units found than in unilateral athelets as this can be due to the thickness of their skin compared to the unilaterals, which may have affected the reduced activation of motor units. Also, the required exerted force in this research was submaximal while twsting procedure, which is not a part of the training process in the monitored sports groups. The differences exerted at 30% MVC are in line with some previous research where larger force oscillations during submaximal contractions were more present in the dominant leg than in the non-dominant one at the force level at 30% MVC, while differences were not manifested at force levels of 10% and 20% MVC (Adam et al., 1998; Oshita, & Yano, 2010, 2011; Semmler, & Nordstrom, 1995). Moreover, in studies with a difference between the extremities, greater force variability has been shown in the non-dominant hand due to the higher average of firing rate of motor units and a higher activation threshold of motor units at the force level of 30% MVC (Adam et al., 1998). Also, Del Vecchio et al. (2019) came to the conclusion that strength training affects the increase in the discharge rate of the motor unit, the reduction of the limiting force of activation of motor units, as well as a similar input-output increase of motor neurons. In present research, the dominant leg of the bilateral group of athletes exhibited a higher discharge rate of motor units at force levels 40 to 60% MVC, which shows that the dominant leg is superior at performing tasks at higher levels of force (Mitchell et al., 2017; Del Vecchio, Casolo, et al., 2019). On the other hand, the non-dominant leg in the bilateral group of athletes showed a higher discharge rate of motor units compared to the dominant one at the force level at 30% MVC. Authors state that the non-dominant leg is responsible for maintaining balance when landing or maintaining a stable upright posture, as well as the supporting the leg in dominant activities (Gabbard, & Hart, 1996; Peters, 1988). In relation to the differences between sports caused by the training process, previous research showed no significant differences in CoV for force between groups, but did reveal a significantly lower tremor RMS amplitude in subjects with a training process related to the training task performance compared to the subjects who trained strength but not of the target muscles (Semmler, & Nordstrom, 1998b).

Based on everything mentioned above, the differences in the bilateral group of athletes can be attributed to the normal organization of neural activity, where the dominant leg is superior to the non-dominant one due to daily adopted actions, with a tendency to adopt the necessary skills in the non-dominant leg depending on the specifics of bilateral sports, in order to maintain balance in the landings or a stable upright body position. On the other hand, the absence of these differences in the unilateral group of athletes indicates the impact of sports on the development and activation of neural drive to act independently and equally on the activation of motor units, given that movements in this group of athletes are always performed without the cooperation of the other leg.

Tables 20, 21 and 22 show results in the control of muscle strength between the dominant and non-dominant lower extremity between the unilateral and bilateral groups of athletes. A review of the results shows that there is no difference in any of the variables that define the difference in muscle strength control between the dominant and non-dominant lower extremity between the unilateral and bilateral groups of athletes, relative amplitude of force variability (CoV_F), the absolute amplitude of the variability of force (SD_F) and the effective value of the manifested force (RMS). There is a statistically significant difference between groups of athletes in the variable RMS which is manifested by higher values of absolute force in both extremities in the unilateral group of athletes compared to the bilateral group ($p < 0.0005$). Also, there is a statistically significant difference in all defined variables between the levels of manifested force. The force increases linearly (CoV_F), actually decreases ($SD_{F,}$ RMS) with an increase in force from 2.5% to 60% MVC ($p < 0.0005$). In group process values there is a statistically significant interaction in the level of manifested force and group of athletes, which is manifested by a greater variability of force at the level of force of 2.5% in the bilateral group of athletes and at the level of force of 60% MVC in the unilateral group of athletes ($p = 0.038$), greater standard deviation of force at the force level of 60% MVC in the bilateral group of athletes ($p < 0.0005$) and higher values of absolute force in both extremities in the unilateral group of athletes compared to the bilateral group ($p < 0.0005$). Among others, there is a statistically significant interaction in the level of manifested force and anke angles, which is manifested by lower values of absolute force at low levels of force (2.5% to 20% MVC) at the angle of 105° (elongated muscle TA) compared to 75° (shortened muscle TA) and 90° (anatomical length of TA muscle) in both groups of athletes ($p = 0.049$).

Tables 23, 24 and 25 show the results in motor unit activation between the dominant and non-dominant lower extremity between unilateral and bilateral groups of athletes. A review of the obtained results shows that there is no difference in any of the variables that define the difference in the activation of motor units between the dominant and non-dominant lower extremity in the bilateral group of athletes, the relative amplitude of the variability of the interspike interval of the motor unit (CoV_{ISI}), the absolute amplitude of the variability of the interspike interval of the motor unit (SD_{ISI}) and the mean value of the action potential release rate for each recognized motor unit (MDR). In variables CoV_{ISI} ($p = 0.002$) and SD_{ISI} ($p = 0.006$) there is a statistically significant difference between groups of athletes and it is manifested by higher values of CoV_{ISI} in both extremities in the bilateral group of athletes in relation to the unilateral, at the levels of force of 5%, 10%, 20% and 60% MVC and at all ankle angles ($p = 0.002$), as well as higher values of SD_{ISI} in both extremities in the bilateral group of athletes in relation to the unilateral one, at all levels of force and at all ankle angles ($p = 0.006$). Also, in all defined variables there is a statistically significant difference between the levels of manifested force. The intespike interval of the motor unit increases linearly ($CoV_{ISI,}$ SD_{ISI}, MDR) with an increase in force from 2.5% to 60% MVC ($p < 0.005$). Among others, there is a statistically significant interaction in the level of manifested force and ankle angles, which is manifested by higher values of COV_{ISI} at the 75° angle, compared to 90° and

105° at force levels of 20% and 30% MVC ($p = 0.007$), higher values of SD_{ISI} at the 75° angle in relation to the 90° and 105° angles at force levels of 20% and 30% MVC ($p = 0.049$) and higher values MDR at the 75° angle in relation to the 90° and 105° at force levels 2.5%, 5% and 10% MVC ($p < 0.0005$). Finally, there is a statistically significant group interaction of strength, legs, groups of sports and angles where the unilateral group of athletes exhibits a lower value of the variable SD_{ISI} in both extremities in relation to the bilateral group of athletes with a greater difference in the dominant leg, as well as at all levels of force with the largest difference in the level of force of 60% MVC in relation to the bilateral group of athletes. Also, smaller values of the variable were expressed of SD_{ISI} in all ankle angles in the unilateral group of athletes ($p = 0.024$), as well as a statistically significant group interaction of force, leg and group sports in the variable MDR which is manifested by a linear progressive increase in the values of the variable MDR in the unilateral group of athletes in both extremities, where in the bilateral group the MDR values show a impermanent increase in the dominant leg at force levels of 2.5 to 30% MVC ($p = 0.018$).

The authors from previous research came to the data that in kinematic parameters the dominant leg of athletes in some sports exhibits statistically higher values in the measured parameters in relation to the non-dominant leg (Bini, & Hume, 2014; Dörge et al., 2002; Fort-Vanmeerhaeghe et al., 2015; Kobayashi et al., 2010; Nunome et al., 2006; Pappas et al., 2015; Sinsurin et al., 2017; Siqueira et al., 2002; Smak et al., 1999; Smith et al., 2009; Tucker, & Hanley, 2020). On the other hand, the results of other studies have shown that in some parameters the non-dominant leg is superior to the dominant one (Ball, 2011; Ludwig et al., 2017). Also, the asymmetry between the extremities in some studies was more pronounced at a higher intensity of tasks (Bini, & Hume, 2014). In addition, there are studies that have shown a lack of asymmetry in athletes, while this asymmetry existed in non-athletes (Siqueira et al., 2002), as well as the existence of asymmetry in pre-adolescence top athletes, while this difference was not observed in top athletes at a later age (DeAdder, 2020). The authors, who monitored the activation of EMG muscles, are of the opinion that the differences in the extremities that occur during kinematic measurements are a consequence of a poor intersegmental movement of the non-dominant leg, and not a muscle activity (Bauer, 1983; Orchard et al., 2002). Some more research confirms the differences in the organization of MU between different groups of sports where in the groups of sports with present development of strength in the training process, weightlifters, in the tibialis muscle MU was less frequent, while in the group of sports with an endurance training program, long-distance runners, MUs were more frequent (Cracraft & Petajen, 1977).

The results of this study indicate that in athletes there is no asymmetry in the lower extremities in the variables that define the control of muscle force. One of the key reasons may be that a properly conducted training process leads to equal adoption of movements and equal strengthening of both extremities (Wennerfeldt, 2013; Bini et al., 2017; Girard et al., 2017). The difference in relative and absolute force between groups of athletes, where the bilateral group of athletes exhibits greater variability in force, can be attributed to the adoption of movements characteristic of the sport during the training process. Runners and cyclists are characterized by constant support on one leg, where the muscles responsible for stabilizing the ankle, as well as maintaining balance, are trained to work more effectively, without additional tremor, to act on the resistance of the environment and thus be more stable at low levels of force. Also, given that the unilateral group of athletes has constant contact with the ground with one foot and thus requires action by the muscles of only the activated leg, the fact that the unilateral group of athletes exhibits greater effective force than the bilateral group of athletes is justified, which is also confirmed by some previous studies (Cracraft, & Petajan, 1977; Semmler, & Nordstrom, 1998b). It is known that the contraction of both extremities simultaneously, bilaterally, produces less force due to the uneven organization of the neuromuscular system when both cerebral hemispheres are activated at the same time (Howard, & Enoka, 1991) and thus, given the nature of athletes from the bilateral group, it can be attributed to the fact that this group of athletes, due to the specifics of sports, is not trained to act effectively with one foot on the ground, or that the neuromuscular system is not trained to act unilaterally.

In Petrović et al. (2022) it was concluded that the independent input (CoV_{ISI}) is under the influence of the target force. The relationship between variables COV_{ISI} and CoV_F shows whether the variability of force during moderate submaximal isometric contractions is related to the capacity to provide a stable nerve drive. In this research, it can be noticed that this connection between the mentioned variables does exist. The unilateral group of athletes showed lower values of CoV_F and CoV_{ISI} in relation to the bilateral athletes. A difference that appeared at the level of force 60% MVC, where the bilateral group of athletes was more stable than the unilateral, but with a greater standard deviation, indicates the possibility of movement compensating with the help of synergist muscles, since independent intake at the level of force of 60% MVC was in favor of the unilateral group of athletes. Earlier research also shows that athletes from the group of bilateral athletes showed asymmetry in relation to the unilateral group of athletes (Cracraft, & Petajan, 1977; Semmler, & Nordstrom, 1998b; Yamaguchi et al., 2019). This claim is supported by the results obtained in this study, where the values of the MDR variable were different between the extremities in the bilateral group of athletes compared to the unilateral group of athletes.

Tables 26, 27 and 28 show the results in the control of muscle strength between the dominant and non-dominant lower extremity depending on the characteristics of unilateral sport. A review of the obtained results shows that there is no difference in any of the variables that define the difference in muscle force control between the dominant and non-dominant lower extremity depending on the characteristics of unilateral sports, relative amplitude of force variability (CoV_F), the absolute amplitude of the variability of force (SD_F) and the effective value of the manifested force (RMS). There is a statistically significant difference depending on the characteristics of the sport where runners exhibit higher values of the variable SD_F in relation to cyclists in both extremities, at all levels of force and at all angles of the ankle ($p = 0.027$). In all defined variables, there is a statistically significant difference between the levels of exerted force. The force increases linearly (CoV_F), actualliy decreases (SD_F, RMS) with an increase in force from 2.5% to 60% MVC ($p < 0.0005$). In group process values for SD_F there is a statistically significant interaction in the level of manifested force and angle in the ankle, which is manifested by a sharp increase in the value of the variable SD_F in the angle of the ankle of 105° (elongated muscle TA) in relation to the angle of 75° (shortened muscle TA) at the level of force 40% MVC ($p = 0.033$).

Tables 32, 33 and 34 show the results in the activation of motor units between the dominant and non-dominant lower extremity depending on the characteristics of unilateral sports. A review of the obtained results shows that there is a difference in the group process values of the variable SD_{ISI} which is manifested by significantly lower values of the absolute amplitude of the variability of the interspike interval of the motor unit (SD_{ISI}) in runners compared to cyclists in both extremities ($p = 0.001$). Also, in all defined variables there is a statistically significant difference between the levels of exerted force. The interspike interval of the motor unit increases linearly (CoV_{ISI}, SD_{ISI}, MDR) with an increase in force from 2.5% to 60% MVC ($p < 0.0005$). In the group process values there is a statistically significant interaction in the level of manifested force and the group of athletes, which is manifested by higher values of the variable MDR in runners compared to cyclists, except at the level of force 5% MVC ($p = 0.001$). Among others, there is a statistically significant interaction in the level of manifested force and angle in the ankle, which is manifested by lower values COV_{ISI} at the 75° angle (shortened muscle TA) compared to the 90°and 105° angles at force levels of 2.5% and 50% MVC ($p = 0.021$) lower values SD_{ISI} at the 75° angle (shortened muscle) in relation to the 90° and 105° angles at the force level of 2.5% and higher values SD_{ISI} at the 75° angle in relation to 90° and 105° angles at the force level of 20% MVC ($p = 0.048$) and higher values of the variable MDR at a 75° angle in relation to 90° and 105° angles at the force level of 2.5% MVC ($p = 0.001$).

Asymmetry in the lower extremities has been studied in runners in previous research and the research has shown that it can affect performance (Carpes, Mota, & Faria, 2010; Cavagna, 2006; Vagenas, & Hoshizaki, 1991, 1992) and increase the risk of injuries (Croisier, Forthomme, Namurios, Vanderthommen, & Crielaard, 2002; Knapik, Bauman, Jones, Harris, & Vaughan, 1991; Orchard, Marsden, Lord, & Garlick, 1997; Tyler, Nicholas, Campbell, & McHugh, 2001). A series of studies have confirmed the existence of imbalances in the lower extremities in runners in vertical force (Pappas et al., 2015; Rumpf et al., 2014), in the time spent in flight and the time of foot contact with the ground (Ball, 2011; Karamanidis et al., 2003), as well as in the maximal speed (Korhonen et al., 2010). Authors explain this difference as a consequence of the greater strength and coordination abilities of the dominant leg (Niu et al., 2011; Sadeghi et al., 2000). On the other hand, in the study by Siqueira et al. (2002) runners did not show asymmetry in strength between the legs, but in non-athletes this difference was statistically significant. Other research has also shown that there is a greater symmetry in trained runners compared to recreational runners (Cavanagh, Pollock, & Landa, 1977).

In cyclists, research has shown similar results, where asymmetry in force and torque was observed when pedaling (Carpes, Rossato, Faria, & Mota, 2007; Daly et al., 2004; Smak et al., 1999), as well as the absence of asymmetry (Flanagan, & Harrison, 2007). Muscle activation during the follow-up cycle of the one leg did not differ between the dominant and non-dominant leg of cyclists (Carpes et al., 2010), thus claiming that in the lower extremities neural control cannot be different between the legs. In cyclists, research also confirms that the asymmetry between the extremities when turning the pedals depends on the level of training (Smak et al., 1999).

The results of this study did not show a statistically significant difference between limbs in runners in the variables that define muscle strength control, but it was on the verge of existence in the variable RMS. By reviewing the plot trend of the movement of the value of the effective force (RMS) it can be noticed that the dominant leg has higher values in the variable RMS in relation to the non-dominant leg, as well as in relation to the dominant one in cyclists ($p = 0.051$). In this regard, this difference in the extremities can be attributed to a better neural organization of the CNS in the dominant leg. In runners who showed large asymmetries in the lower extremities, movement compensations were observed when performing the maximum speed sprint in the kinematics of the hip, knee and ankle joints (Exell, Irwin, Gittoes, & Kerwin, 2012). In this study, the sample of participants belonged to the group of athletes with experience, and perhaps statistically significant differences between the extremities for this reason could not be observed. On the other hand, higher values in absolute strength in runners compared to cyclists indicate a greater effort to perform the target task. Moreover, runners showed a higher discharge rate of motor units compared to cyclists, which indicates better muscular ability of runners (Del Vecchio, Casolo, et al., 2019). Since previous research has shown that the increase in the muscle force also leads to an increase in the discharge rate of motor units (Adam et al., 1998; Del Vecchio, Casolo, et al., 2019), it can be assumed that the training process for runners influences the better organization of the neural organization of the CNS. Taking into consideration the training process, training for runners includes dynamic movements expressed in small jumps, allowing runners to develop better muscle ability to maintain body stability. On the other hand, the lack of differences between the extremities of cyclists can be attributed to the nature of this sport, where all movements involved in turning the pedals are cyclical, and the equal amplitude of movements due to pedal rotation. Since training adopts these movements, it neutralizes the possibility of asymmetry or improves symmetry (Carpes et al., 2010).

Tables 29, 30 and 31 show the results in the control of muscle strength between the dominant and non-dominant lower extremity depending on the characteristics of the bilateral sport. A review of the obtained results shows that there is no difference in any of the variables that define the difference in the control of muscle strength between the dominant and non-dominant lower extremity, as well as in the angle in the ankle (depending on the length of the TA muscle) depending on the characteristics of the bilateral sport, the relative amplitude of force variability (CoV_F), the absolute amplitude of the variability of force (SD_F) and the effective value of the manifested force (RMS). In variables CoV_F and SD_F there is a statistically significant difference depending on the characteristics of the sport where volleyball players show higher values of relative variability ($p = 0.021$) and absolute forces ($p = 0.001$) in relation to weightlifters and rowers between both extremities, at all levels of force and at all ankle angles. In all defined variables, there is a statistically significant difference between the levels of manifested force. The force increases linearly for CoV_F, but actually decreases for SD_F and RMS, with an increase in force from 2.5% to 60% MVC ($p < 0.0005$).

Tables 35, 36 and 37 show the results in the activation of motor units between the dominant and non-dominant lower extremity depending on the characteristics of bilateral sports. Reviewing the obtained results, it can be noticed that, depending on the characteristics of the sport, there is a difference in the variable MDR, which is manifested by higher values of the variable in volleyball players in the dominant leg compared to weightlifters and rowers. It is also manifested in similar values at all target forces, while in weightlifters the value of the variable MDR is higher than in rowers in the long length of the muscle, the angle in the ankle being 105° ($p = 0.010$). Also, in all defined variants, there is a statistically significant difference between the levels of manifested forces. The interspike interval of the motor unit increases linearly ($CoV_{ISI,}$ SD_{ISI}, MDR) with an increase in force from 2.5% to 60% MVC ($p < 0.0005$). In group process values there is a statistically significant interaction in the level of manifested force and angle in the ankle, which is manifested by higher values of COV_{ISI} in the angle of 75° (shortened muscle TA) compared to the angles 90° and 105° at force levels of 20% and 30% MVC ($p = 0.007$).

Although volleyball belongs to a bilateral group of sports where contact with the ground in jumps and landings on two legs should be at the same time, previous research has shown that there is a higher risk of injuries in the dominant leg (Zahradnik, Jandacka, Uchytil, Farana, & Hamill, 2015). The authors attribute the reason to the fact that in volleyball 35% of unilateral landings end on the left leg, and 10% on the right leg in right-footed volleyball players (Tillman, Hass, Brunt, & Bennett, 2004). Also, Niu et al. (2011) noticed a more efficient strategy in the ankle when landing on the non-dominant leg compared to the dominant one, as well as greater flexion in the knee joint of the non-dominant leg. Thus, the authors confirm the fact of reducing the risk of injuries in non-dominant leg in volleyball players (Sinsurin et al., 2017).

Differences between the extremities in the bilateral group of athletes were noticed in weightlifters, but only in the cooperation of both extremities, but not between extremities when the dominant and non-dominant legs were compared separately (Luk et al., 2014). Also, weightlifters showed greater strength in performing tasks in cooperation with both extremities than long jumpers who were more successful in performing unilateral tasks. These authors explain that this difference is due to greater muscle contraction when jumping on both legs and reduced muscle activation. Moreover, better synchronization of motor units in weightlifters than in the untrained subjects has also been reported (Milner-Brown & Lee, 1975).

No statistically significant differences in lumbar-pelvic kinematics were found in rowers during rowing (Buckeridge et al., 2012), as well as in the force between the lower extremities (Parkin et al., 2001). As was the case in weightlifters, rowers also had more strength through combined use of both lower extremities (Secher et al., 1988).

The results of this research showed that volleyball players show greater force variability compared to other athletes from the bilateral group of sports. The authors ascribe the reduced ability of volleyball players to maintain stable muscle strength to the nature of sport, in which the surface is dynamic and thus enhances the neuromuscular function of the peripheral and central nervous system to process, regulate and respond to the situation and environment (Hewett, Paterno, & Myer, 2002). This is especially visible in volleyball players whose predominant use of one hand when hitting the ball can further cause the rotations of the body around the longitudinal axis and thus prevent landing on both legs at the same time, so the compensation of movements in landings is needed. Besides this, previous research has shown that a bilateral deficit significantly affects the height of a jump, where the height of the jump in two-legged jumps is lower than in one-legged jumps (Challis, 1998; Soest, Roebroeck, Bobbert, Huijing, & Schenau, 1985). This phenomenon has been observed in the literature before, where it was confirmed that there is less mechanical work on one leg during jumping with two legs than during jumping on one leg (Challis, 1998; Soest et al., 1985) and that the bilateral deficit is influenced by neural factors (Howard, & Enoka, 1991). This spontaneous use of one leg in volleyball jumps and landings can be considered a consequence of the brain efficiency in reducing the duplication of simultaneous neural hemisphere activation (Corballis, 2009; Ghirlanda et al., 2009) and the compensation of the movements (Salem et al., 2003). On the other hand, this absence of differences between the extremities in weightlifters and rowers is probably due to the training process where the conditions are such that the cooperation of both extremities is mandatory in the performance of movements, so bilateral relief was observed in the performance of bilateral tasks (Howard, & Enoka, 1991; Secher, Rørsgaard, & Secher, 1978). These statements about the impact of the training process on better neural organization has been confirmed in studies on weightlifters and rowers (Milner-Brown & Lee, 1975; N. H. Secher et al., 1988).

The present study did not address the differences in the limbs during bilateral movements, but previous research suggests that it is possible to obtain clearer data on the asymmetry in this group of athletes using bilateral types of tests. However, volleyball players show less stability in both extremities and higher values of the MDR variable in the dominant leg compared to weightlifters and rowers, which indicates the possible impact of the training process on the change in the neural organization of the CNS.

9. CONCLUSION

Based on the results of this research, and in accordance with the set subject, goals, tasks and hypotheses, the following conclusions can be made:

1. A statistically significant difference in the control of muscle force between the dominant and non-dominant lower extremity in the unilateral group of athletes **was not confirmed**, so **Hypothesis H_1**, which states that “there is a statistically significant difference in muscle strength control between the dominant and non-dominant lower extremity in the unilateral group of athletes” **can be completely rejected.**
2. A statistically significant difference in the control of muscle force between the dominant and non-dominant lower extremity in the bilateral group of athletes **was not confirmed**, so **Hypothesis H_2**, which states that “there is a statistically significant difference in muscle strength control between the dominant and non-dominant lower extremity in the bilateral group of athletes” **can be completely rejected.**
3. A statistically significant difference in the activation of motor units between the dominant and non-dominant lower extremity in the unilateral group of athletes **was not confirmed**, so **Hypothesis H_3**, which states that “there is a statistically significant difference in the activation of motor units between the dominant and non-dominant lower extremity in the unilateral group of athletes” **can be completely rejected.**
4. A statistically significant difference in all variables that define the activation of motor units between the dominant and non-dominant lower extremity in the bilateral group of athletes **was not confirmed**, except in the process values of the variable mean discharge rate of the motor unit and the manifested muscule force between the dominant and non-dominant lower extremity in the bilateral group of athletes, so **Hypothesis H_4**, which states that ”there is a statistically significant difference in the activation of motor units between the dominant and non-dominant lower extremity in the bilateral group of athletes” **can be partially accepted.**
5. A statistically significant difference in the control of muscle force between the dominant and non-dominant lower extremity between unilateral and bilateral groups of athletes **was not confirmed**, but there are statistically significant differences in all

variables that define muscle strength control between unilateral and bilateral groups of athletes, so **Hypothesis H_5**, which states that “there is a statistically significant difference in muscle force control between the dominant and non-dominant lower extremity between unilateral and bilateral groups of athletes” **can be partially accepted.**

6. A statistically significant difference in the activation of motor units between the dominant and non-dominant lower extremity between unilateral and bilateral groups of athletes **was not confirmed**, except in the absolute value of the interspike interval of the motor unit and the mean discharge rate of the motor unit between the dominant and non-dominant lower extremity between unilateral and bilateral groups of athletes, so **Hypothesis H_6** which states that “there is a statistically significant difference in the activation of motor units between the dominant and non-dominant lower extremity between unilateral and bilateral groups of athletes” **can be partially accepted.**
7. A statistically significant difference in the control of muscle force between the dominant and non-dominant lower extremity depending on the characteristics of unilateral sport **was not confirmed**, but there is a statistically significant difference in absolute force depending on the characteristics of the unilateral sport, so **Hypothesis H_7**, which states that “there is a statistically significant difference in muscle force control between the dominant and non-dominant lower extremity depending on the characteristics of unilateral sport” **can be partially accepted.**
8. A statistically significant difference in the control of muscle force between the dominant and non-dominant lower extremity depending on the characteristics of the bilateral sport **was not confirmed**, but there are statistically significant differences in relative and absolute force depending on the characteristics of the bilateral sport, so **Hypothesis H_8**, which states that “there is a statistically significant difference in muscle force control between the dominant and non-dominant lower extremity depending on the characteristics of bilateral sport” **can be partially accepted.**
9. A statistically significant difference in all variables that define the activation of motor units between the dominant and non-dominant lower extremity depending on the characteristics of unilateral sport **was not confirmed**, except in the absolute value of the interspike interval of the motor unit and the mean discharge rate of the motor unit between the dominant and non-dominant lower extremity depending on the

characteristics of the unilateral sport, so **Hypothesis H_9**, which states that “there is a statistically significant difference in the activation of motor units between the dominant and non-dominant lower extremity depending on the characteristics of unilateral sport” **can be partially accepted.**

10. A statistically significant difference in motor unit activation between the dominant and non-dominant lower extremity depending on the characteristics of the bilateral sport **was not confirmed**, but there are statistically significant differences in the mean discharge rate of the motor unit depending on the characteristics of the bilateral sport, so **Hypothesis H_{10}**, which states that “there is a statistically significant difference in the activation of motor units between the dominant and non-dominant lower extremity depending on the characteristics of bilateral sport” **can be partially accepted.**

The results of this study show that there is no difference in the control of muscle strength between the lower extremities in healthy athletes. There is a tendency that the training process may influence different effects of the neural control of the CNS between the extremities in sports with emphasis on the use of one side of the body. Also, the results showed that the requirements of the specificity of sport affect the change in the control of muscle strength and neurocontrol of the CNS. Additional research is needed to confirm these results and expand knowledge about the impact of the training process on muscle strength control and motor unit behavior in other sports.

10. IMPORTANCE OF THE RESEARCH

The difference in the variability of muscle force and the activation of motor units in the lower extremities in bilateral and unilateral group of sports were the topic of research in a very limited number of studies. Also, the number of participants was not sufficient or it did not include different groups of sports.

The results of this research provide new knowledge and information on the activation of MU, as well as the difference in the muscle force variation between the lower extremities among athletes. Given that statistically significant differences were found in certain variables that define the control of muscle force and activation of motor units between the dominant and non-dominant lower extremity in unilateral and bilateral groups of athletes, this research has expanded the theoretical knowledge of the CNS's influence on movement control, and whether force variability was influenced by the training process or neural control in the bilateral and unilateral groups of sports.

The results can help trainers in determining the dominant side of the lower extremity and applying them in the training process to improve the ability of players to equally move in both directions or help them decide on an appropriate selection of positions for their players in certain sports. Also, the predominant use of one side of the body can cause functional deformity. Thus, by monitoring muscle activity between the extremities, it is possible to detect deformities and correct them in a timely manner through the training process.

In addition, the results of the research can serve as a basis for future research that will follow the force variability and the activation of motor units in other sports and muscle groups. Also, as the speed of activation of motor neurons and the maximum speed of the motor unit discharge largely depends on individual human abilities, it is necessary to determine the connection between muscle structure and the activation and behavior of motor units in athletes in future research.

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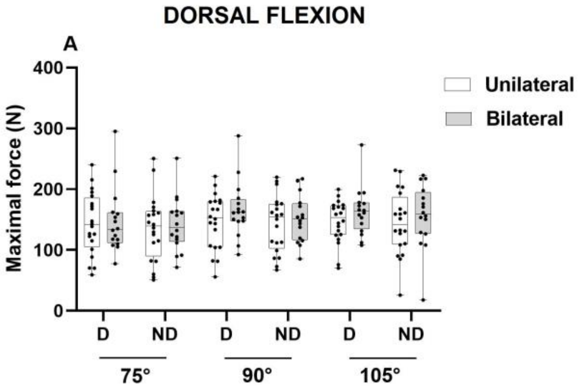
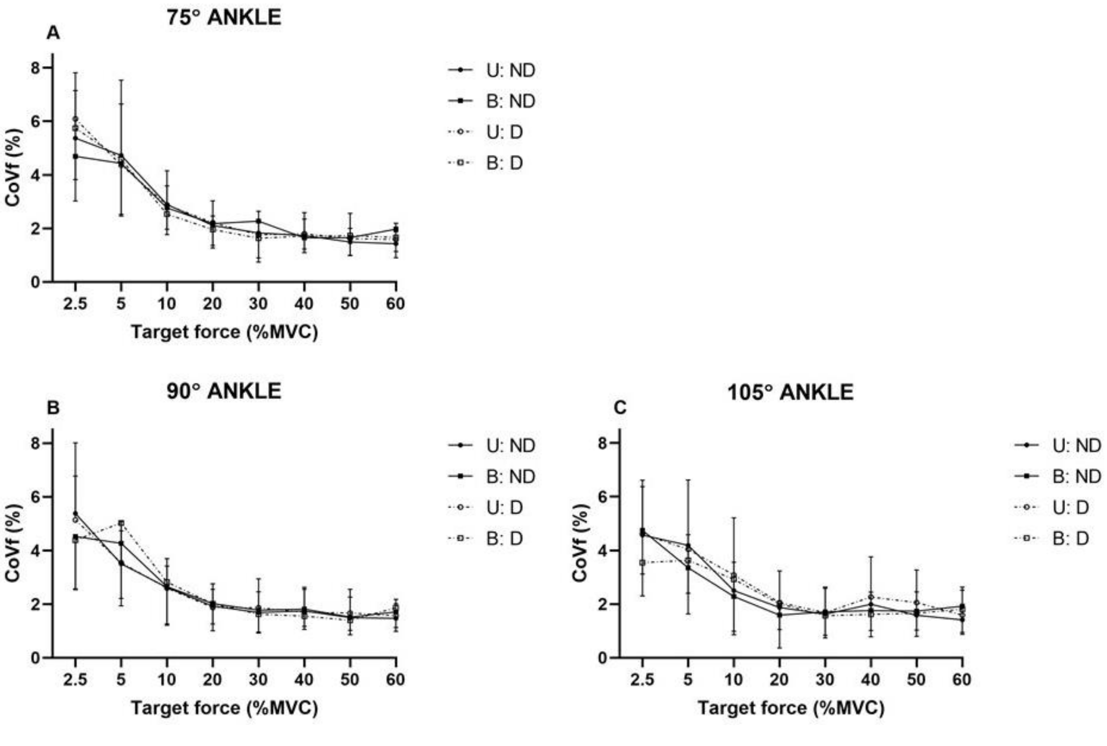
12. APPENDIX

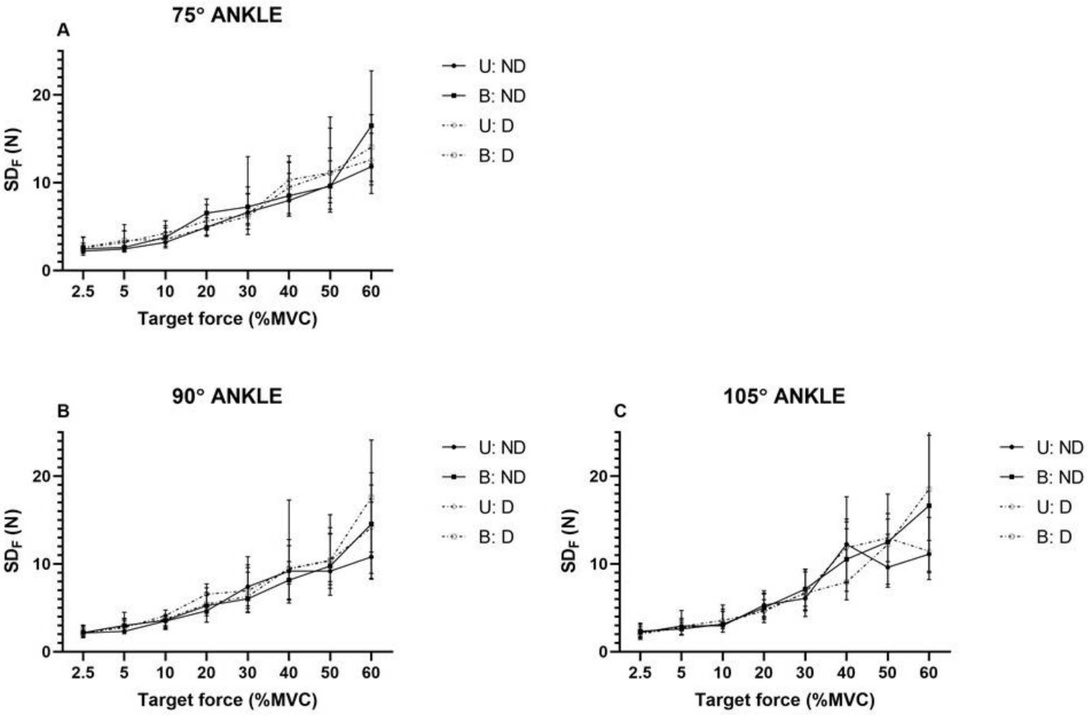
Annex 1: Variables defining the exerted maximum voluntary force, muscle force control and activation of Motor units



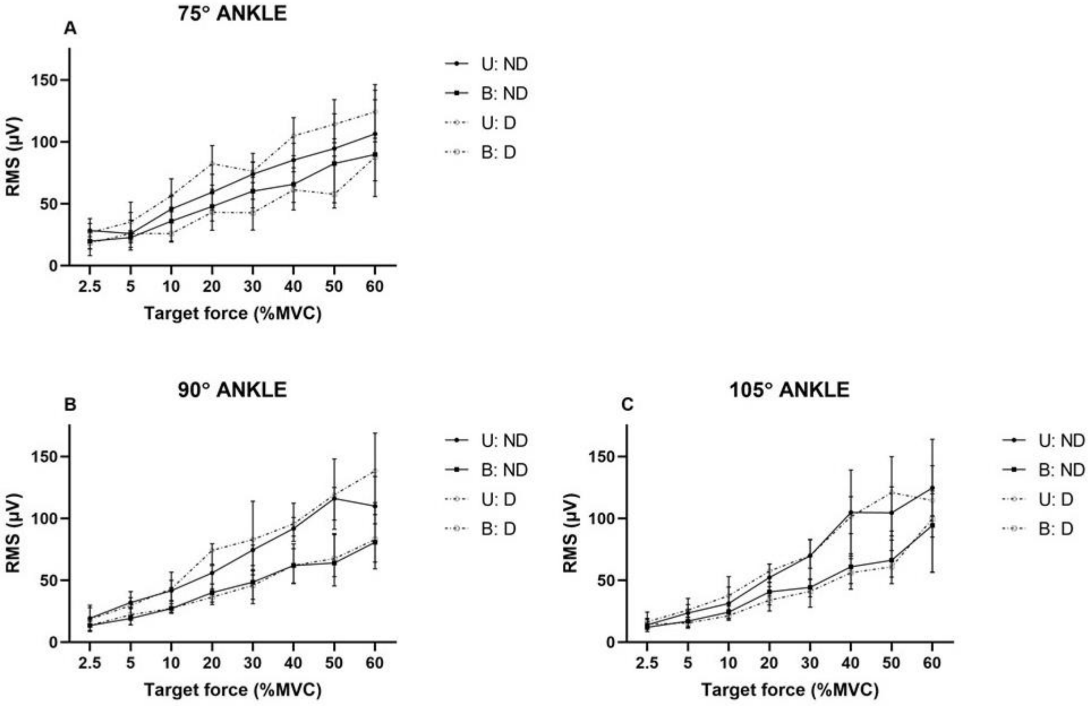
Plot 41. Maximum voluntary force exerted during dorsal flexion between the dominant (D) and non-dominant (ND) leg, at the ankle angles of 75°, 90° and 105° in unilateral (white) and bilateral (gray) groups of athletes



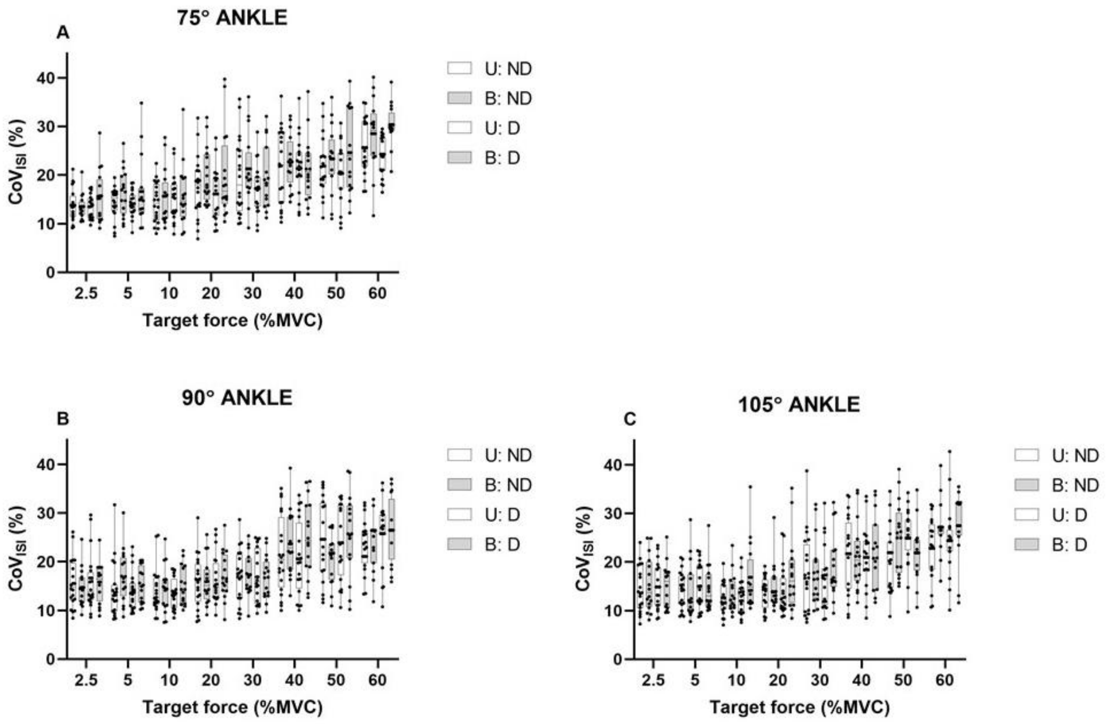
Plot 42. Coefficient variation of force (COV$_F$) at the force levels of 2.5, 5, 10, 20, 30, 40, 50 and 60% MVC between the dominant (D) and non-dominant (ND) leg, at the ankle angles of 75°, 90° and 105° in unilateral (U) and bilateral (B) groups of athletes



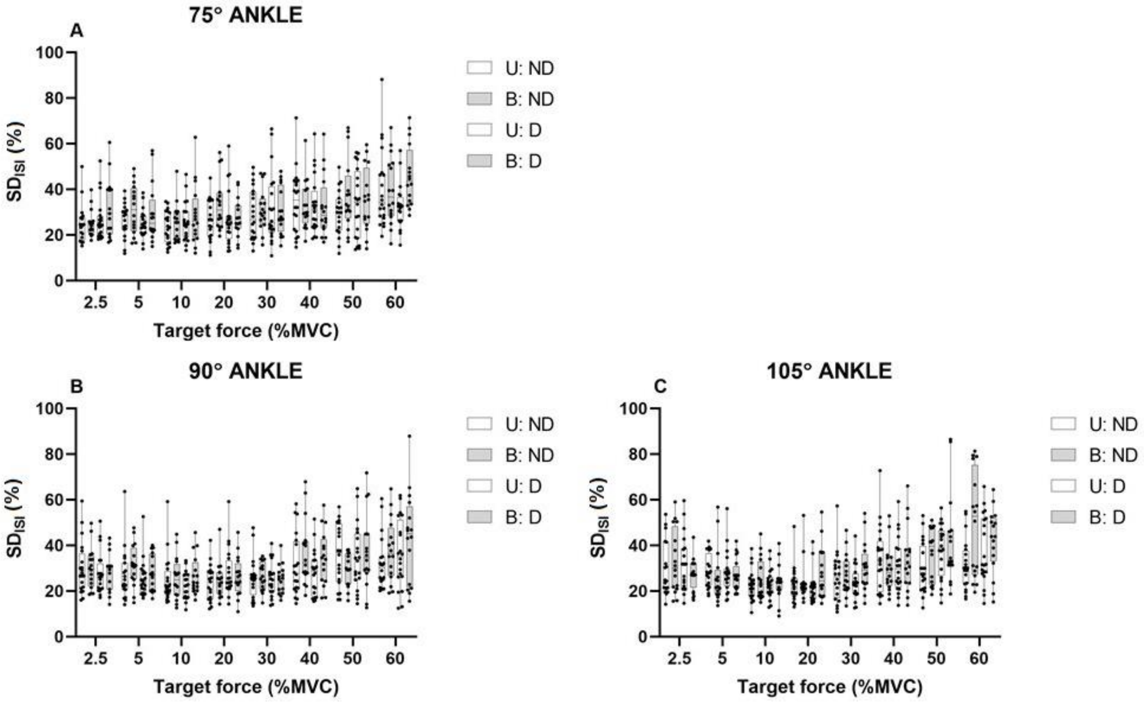
Plot 43. Standard deviation of force (SD_F) at the force levels of 2.5, 5, 10, 20, 30, 40, 50 and 60% MVC between the dominant (D) and non-dominant (ND) leg, at the ankle angles of 75°, 90° and 105° in unilateral (U) and bilateral (B) groups of athletes



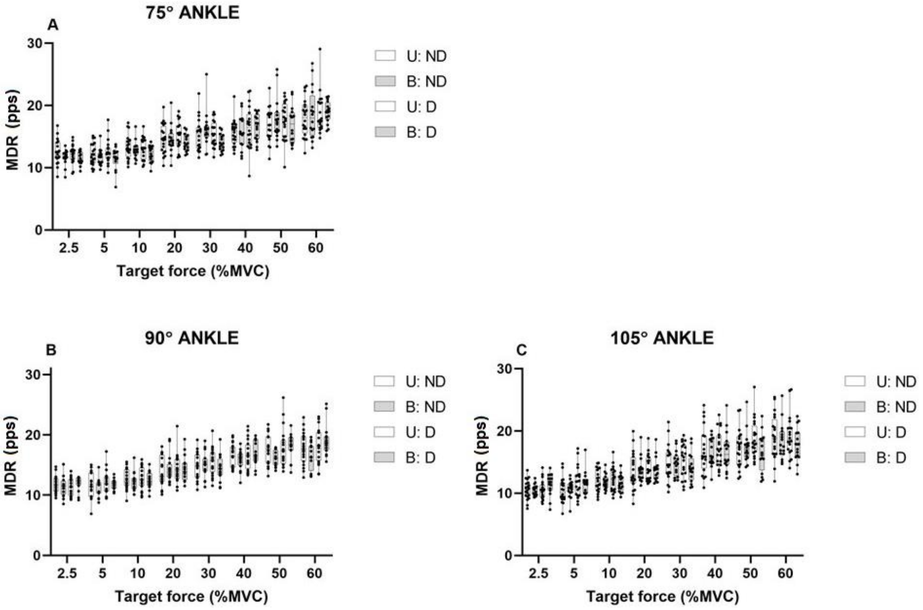
Plot 44. Root mean square (RMS) at the force levels of 2.5, 5, 10, 20, 30, 40, 50 and 60% MVC between the dominant (D) and non-dominant (ND) leg, at the ankle angles of 75°, 90° and 105° in unilateral (U) and bilateral (B) groups of athletes



Plot 45. Coefficient of variation of the interspike interval of a motor unit (COV$_{ISI}$) at the force levels of 2.5, 5, 10, 20, 30, 40, 50 and 60% MVC between the dominant (D) and non-dominant (ND) leg, at an ankle angles of 75°, 90° and 105° in unilateral (U) and bilateral (B) groups of athletes



Plot 46. Standard deviation of the interspike interval of a motor unit (SD$_{ISI}$) at the force levels of 2.5, 5, 10, 20, 30, 40, 50 and 60% MVC between the dominant (D) and non-dominant (ND) leg, at an ankle angles of 75°, 90° and 105° in unilateral (U) and bilateral (B) groups of athletes



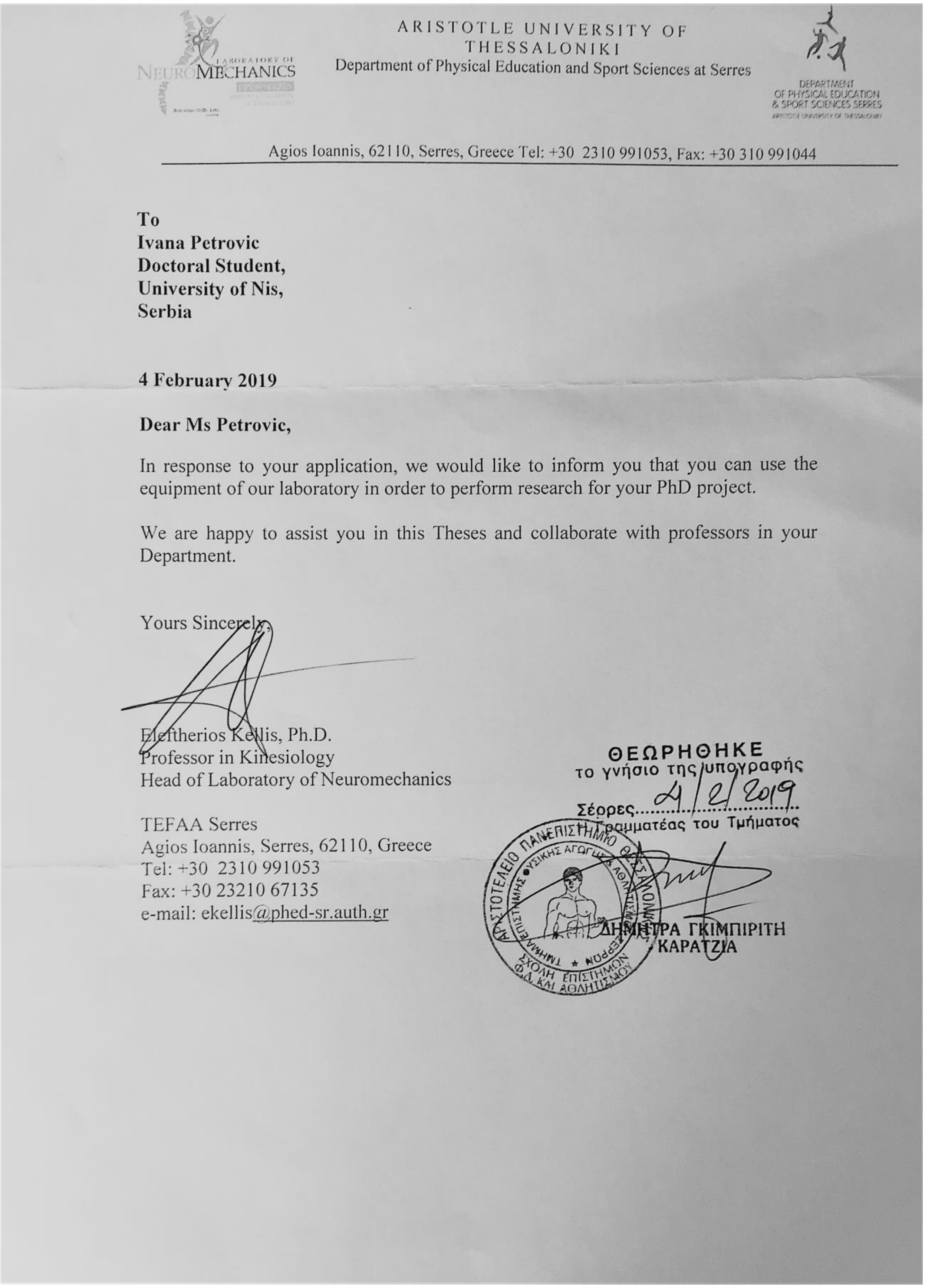
Plot 47. Mean discharge rate of motor units (MDR) at the force levels of 2.5, 5, 10, 20, 30, 40, 50 and 60% MVC between the dominant (D) and non-dominant (ND) leg, at the ankle angles of 75°, 90° and 105° in unilateral (U) and bilateral (B) groups of athletes

Annex 2: Questionnaire for determining the lower extremity dominance (Van Melick et al., 2017)

Questions for determining leg dominance	**Left**	**Right**
If you were asked to shoot a ball on a target, which leg would you use to shoot the ball?		
If you had to pick up marbles while standing and put the marbles in a box, which foot would you use to pick them up?		
When you had to trace a figure drawn on the floor, which foot would you use?		
Which foot would you use if you had to stomp out a small fire while standing?		
If you were asked to stand on one leg, on which leg would you stand?		
Which foot would you use to smooth sand while standing?		
If you had to step up onto a chair, which foot would you place on the chair first?		
Which foot would you use to stomp an insect while you were standing?		
If you were to balance on one foot on a railway track, which foot would you use?		
If you had to hop on one foot, which foot would you use?		
Which foot would you use to help push a shovel into the ground while digging?		
During relaxed standing, people initially put most of their weight on one foot, leaving the other leg slightly bent. Which foot do you put most of your weight on first?		
Are you right or left handed?		
Questions for inclusion/exclusion	**Yes**	**No**
Have you ever had an anterior cruciate ligament rupture and/or reconstruction?		
Have you underwent any surgery to legs and/or lower back in the past 3 years? If yes, what kind of surgery and when?		
In this moment, do you suffer from an injury to your lower back, hip, leg, ankle or foot?		
Do you use medication which may influence your balance?		
Do you suffer from a disease which may affect you balance and/or coordination?		
In the past, have you had any special training which stimulates the use of a certain leg in a certain situation or activity? (Sports and/or work related?)		

Is there a reason why your leg preference has changed, such as an injury?		

Annex 3: Consent of the institution for the realization of the research



NEUROMECHANICS
LABORATORY OF

ARISTOTLE UNIVERSITY OF
THESSALONIKI
Department of Physical Education and Sport Sciences at Serres

DEPARTMENT
OF PHYSICAL EDUCATION
& SPORT SCIENCES SERRES
ARISTOTLE UNIVERSITY OF THESSALONIKI

Agios Ioannis, 62110, Serres, Greece Tel: +30 2310 991053, Fax: +30 310 991044

To
Ivana Petrovic
Doctoral Student,
University of Nis,
Serbia

4 February 2019

Dear Ms Petrovic,

In response to your application, we would like to inform you that you can use the equipment of our laboratory in order to perform research for your PhD project.

We are happy to assist you in this Theses and collaborate with professors in your Department.

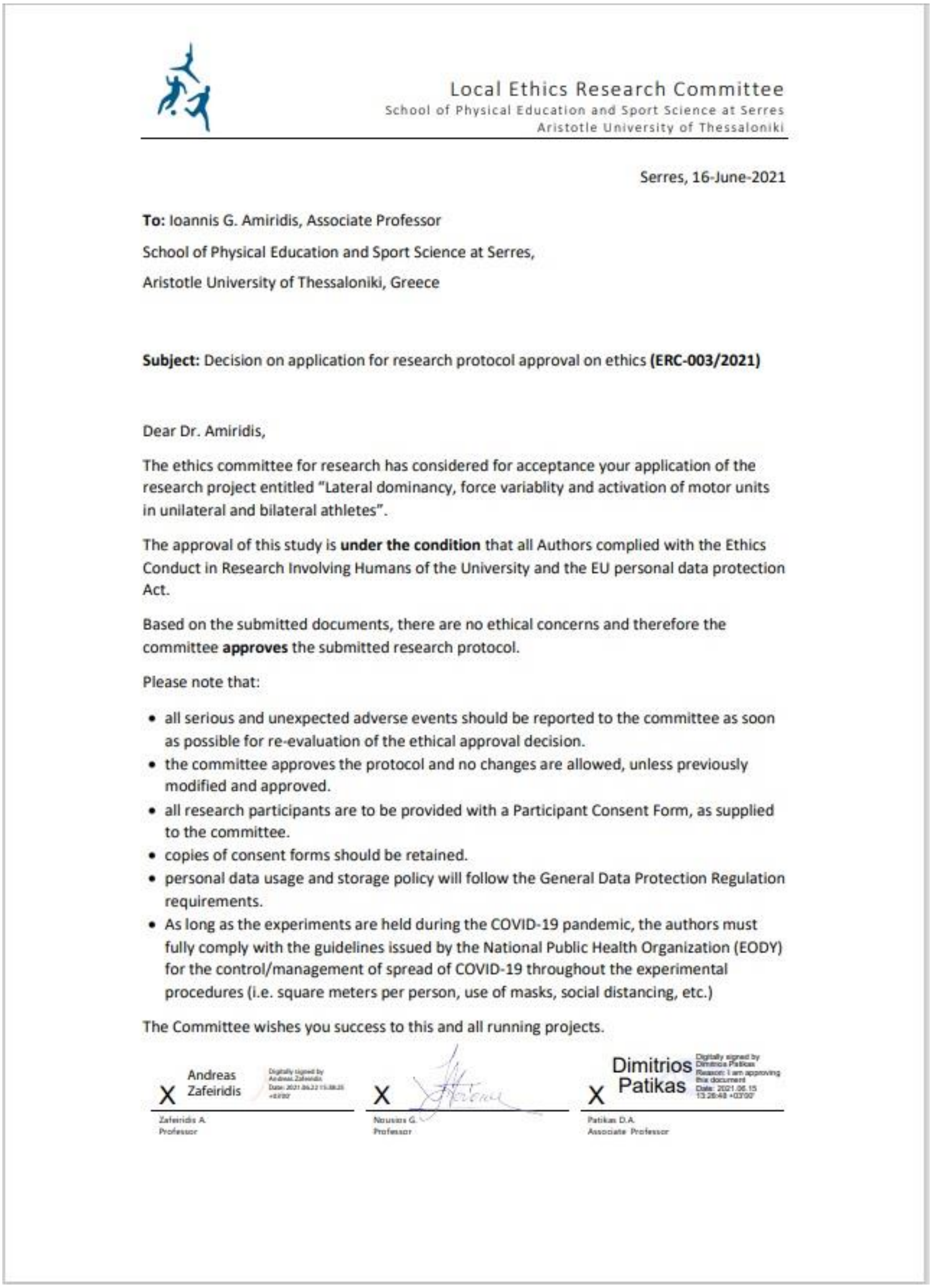
Yours Sincerely,

Eleftherios Kellis, Ph.D.
Professor in Kinesiology
Head of Laboratory of Neuromechanics

TEFAA Serres
Agios Ioannis, Serres, 62110, Greece
Tel: +30 2310 991053
Fax: +30 23210 67135
e-mail: ekellis@phed-sr.auth.gr

ΘΕΩΡΗΘΗΚΕ
το γνήσιο της υπογραφής
Σέρες 4/2/2019
Η Γραμματέας του Τμήματος
ΔΗΜΗΤΡΑ ΓΚΙΜΠΙΡΙΤΗ
ΚΑΡΑΤΖΙΑ

Annex 4: Approval of the Ethics Committee of the Department of Physical Education and Sports Sciences in Serres Aristotle University of Thessaloniki, Greece



Local Ethics Research Committee
School of Physical Education and Sport Science at Serres
Aristotle University of Thessaloniki

Serres, 16-June-2021

To: Ioannis G. Amiridis, Associate Professor
School of Physical Education and Sport Science at Serres,
Aristotle University of Thessaloniki, Greece

Subject: Decision on application for research protocol approval on ethics **(ERC-003/2021)**

Dear Dr. Amiridis,

The ethics committee for research has considered for acceptance your application of the research project entitled "Lateral dominancy, force variablity and activation of motor units in unilateral and bilateral athletes".

The approval of this study is **under the condition** that all Authors complied with the Ethics Conduct in Research Involving Humans of the University and the EU personal data protection Act.

Based on the submitted documents, there are no ethical concerns and therefore the committee **approves** the submitted research protocol.

Please note that:

- all serious and unexpected adverse events should be reported to the committee as soon as possible for re-evaluation of the ethical approval decision.
- the committee approves the protocol and no changes are allowed, unless previously modified and approved.
- all research participants are to be provided with a Participant Consent Form, as supplied to the committee.
- copies of consent forms should be retained.
- personal data usage and storage policy will follow the General Data Protection Regulation requirements.
- As long as the experiments are held during the COVID-19 pandemic, the authors must fully comply with the guidelines issued by the National Public Health Organization (EODY) for the control/management of spread of COVID-19 throughout the experimental procedures (i.e. square meters per person, use of masks, social distancing, etc.)

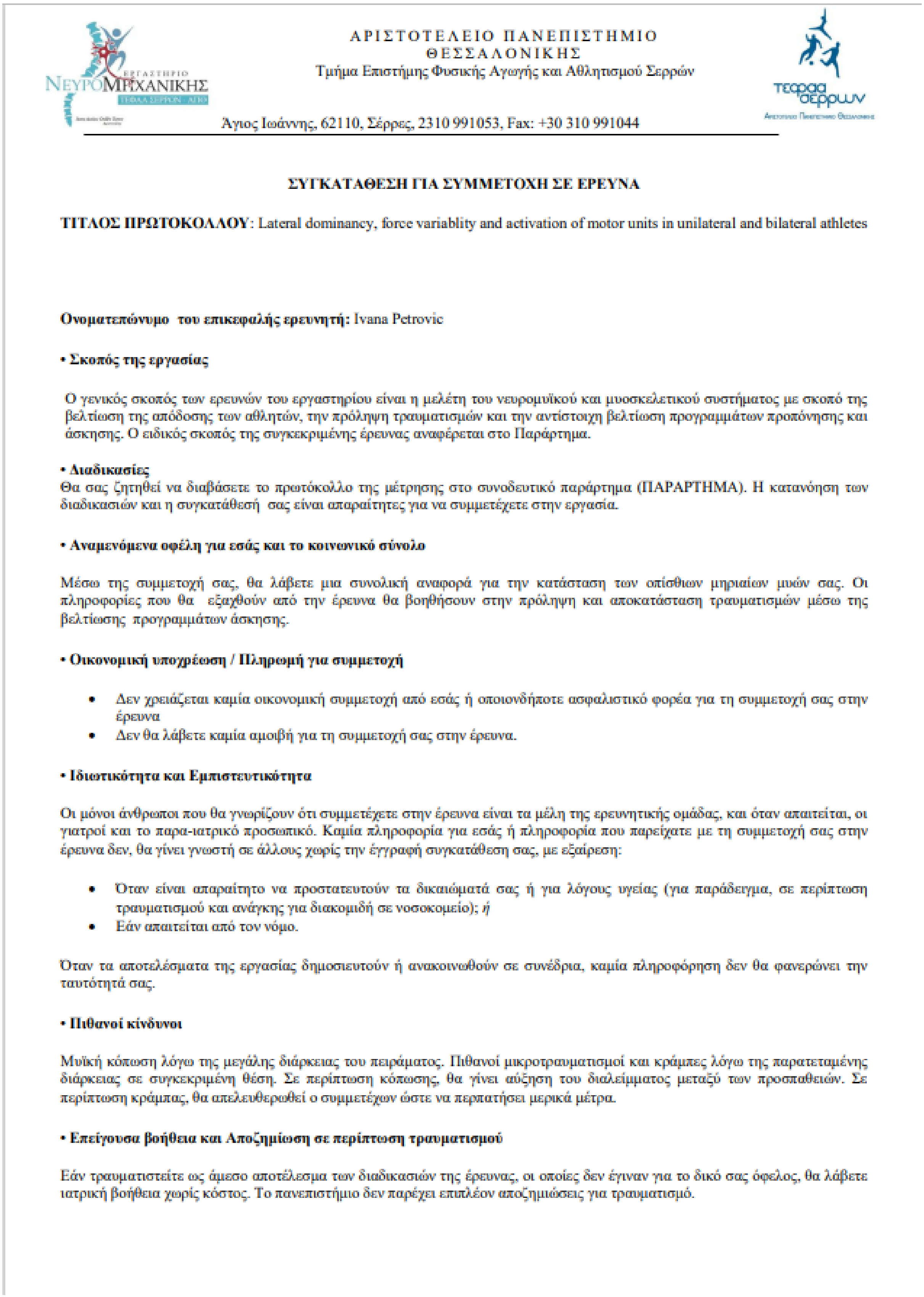
The Committee wishes you success to this and all running projects.

X Andreas Zafeiridis
Digitally signed by Andreas Zafeiridis
Date: 2021.06.22 [illegible]
Zafeiridis A.
Professor

X
Nousios G.
Professor

X Dimitrios Patikas
Digitally signed by Dimitrios Patikas
Reason: I am approving this document
Date: 2021.06.15 13:26:48 +03'00'
Patikas D.A.
Associate Professor

Annex 5: Consent of the participants to participate in the research



ΑΡΙΣΤΟΤΕΛΕΙΟ ΠΑΝΕΠΙΣΤΗΜΙΟ
ΘΕΣΣΑΛΟΝΙΚΗΣ
Τμήμα Επιστήμης Φυσικής Αγωγής και Αθλητισμού Σερρών

Άγιος Ιωάννης, 62110, Σέρρες, 2310 991053, Fax: +30 310 991044

ΣΥΓΚΑΤΑΘΕΣΗ ΓΙΑ ΣΥΜΜΕΤΟΧΗ ΣΕ ΕΡΕΥΝΑ

ΤΙΤΛΟΣ ΠΡΩΤΟΚΟΛΛΟΥ: Lateral dominancy, force variablity and activation of motor units in unilateral and bilateral athletes

Ονοματεπώνυμο του επικεφαλής ερευνητή: Ivana Petrovic

• Σκοπός της εργασίας

Ο γενικός σκοπός των ερευνών του εργαστηρίου είναι η μελέτη του νευρομυϊκού και μυοσκελετικού συστήματος με σκοπό της βελτίωση της απόδοσης των αθλητών, την πρόληψη τραυματισμών και την αντίστοιχη βελτίωση προγραμμάτων προπόνησης και άσκησης. Ο ειδικός σκοπός της συγκεκριμένης έρευνας αναφέρεται στο Παράρτημα.

• Διαδικασίες

Θα σας ζητηθεί να διαβάσετε το πρωτόκολλο της μέτρησης στο συνοδευτικό παράρτημα (ΠΑΡΑΡΤΗΜΑ). Η κατανόηση των διαδικασιών και η συγκατάθεσή σας είναι απαραίτητες για να συμμετέχετε στην εργασία.

• Αναμενόμενα οφέλη για εσάς και το κοινωνικό σύνολο

Μέσω της συμμετοχή σας, θα λάβετε μια συνολική αναφορά για την κατάσταση των οπίσθιων μηριαίων μυών σας. Οι πληροφορίες που θα εξαχθούν από την έρευνα θα βοηθήσουν στην πρόληψη και αποκατάσταση τραυματισμών μέσω της βελτίωσης προγραμμάτων άσκησης.

• Οικονομική υποχρέωση / Πληρωμή για συμμετοχή

- Δεν χρειάζεται καμία οικονομική συμμετοχή από εσάς ή οποιονδήποτε ασφαλιστικό φορέα για τη συμμετοχή σας στην έρευνα
- Δεν θα λάβετε καμία αμοιβή για τη συμμετοχή σας στην έρευνα.

• Ιδιωτικότητα και Εμπιστευτικότητα

Οι μόνοι άνθρωποι που θα γνωρίζουν ότι συμμετέχετε στην έρευνα είναι τα μέλη της ερευνητικής ομάδας, και όταν απαιτείται, οι γιατροί και το παρα-ιατρικό προσωπικό. Καμία πληροφορία για εσάς ή πληροφορία που παρείχατε με τη συμμετοχή σας στην έρευνα δεν, θα γίνει γνωστή σε άλλους χωρίς την έγγραφή συγκατάθεση σας, με εξαίρεση:

- Όταν είναι απαραίτητο να προστατευτούν τα δικαιώματά σας ή για λόγους υγείας (για παράδειγμα, σε περίπτωση τραυματισμού και ανάγκης για διακομιδή σε νοσοκομείο); *ή*
- Εάν απαιτείται από τον νόμο.

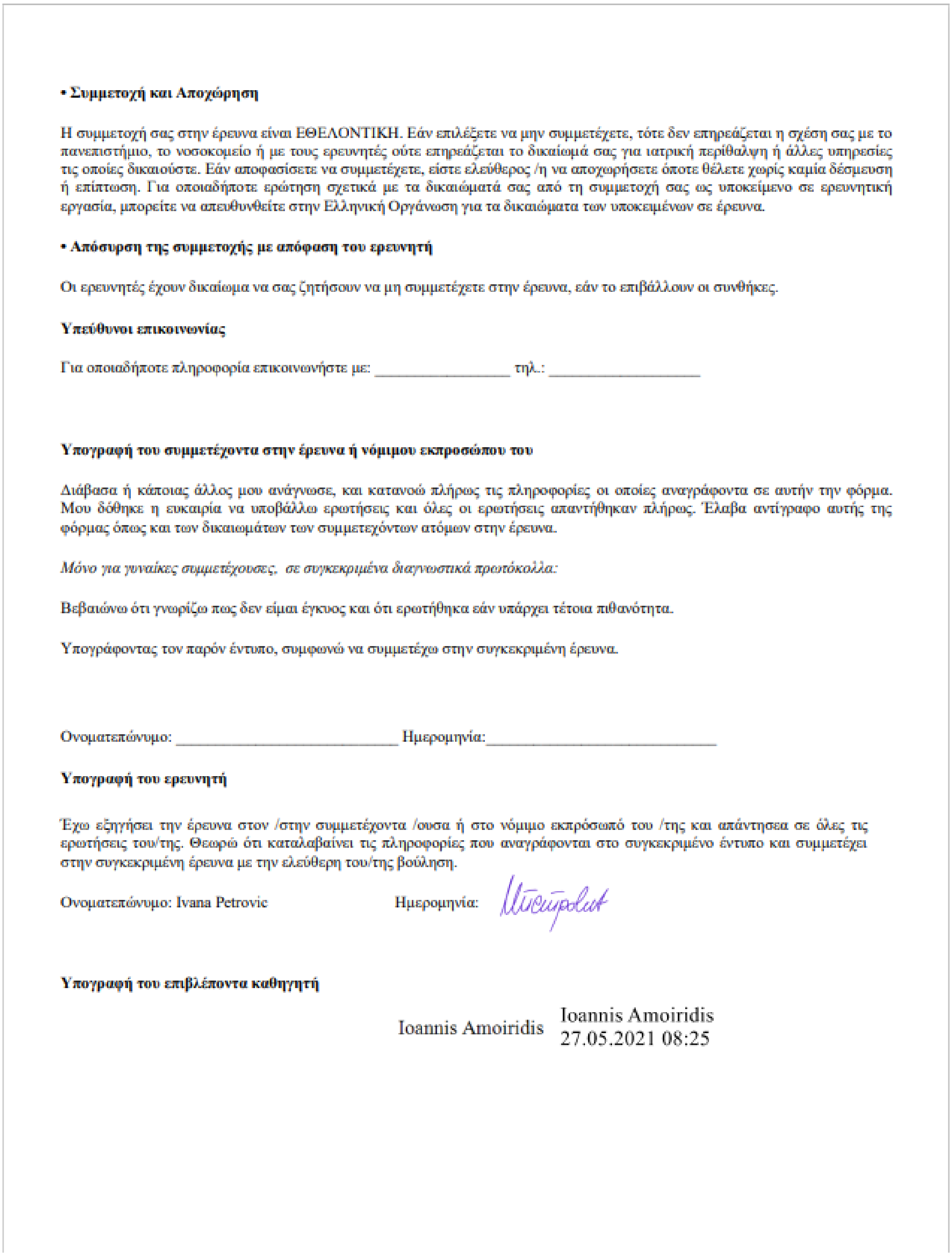
Όταν τα αποτελέσματα της εργασίας δημοσιευτούν ή ανακοινωθούν σε συνέδρια, καμία πληροφόρηση δεν θα φανερώνει την ταυτότητά σας.

• Πιθανοί κίνδυνοι

Μυϊκή κόπωση λόγω της μεγάλης διάρκειας του πειράματος. Πιθανοί μικροτραυματισμοί και κράμπες λόγω της παρατεταμένης διάρκειας σε συγκεκριμένη θέση. Σε περίπτωση κόπωσης, θα γίνει αύξηση του διαλείμματος μεταξύ των προσπαθειών. Σε περίπτωση κράμπας, θα απελευθερωθεί ο συμμετέχων ώστε να περπατήσει μερικά μέτρα.

• Επείγουσα βοήθεια και Αποζημίωση σε περίπτωση τραυματισμού

Εάν τραυματιστείτε ως άμεσο αποτέλεσμα των διαδικασιών της έρευνας, οι οποίες δεν έγιναν για το δικό σας όφελος, θα λάβετε ιατρική βοήθεια χωρίς κόστος. Το πανεπιστήμιο δεν παρέχει επιπλέον αποζημιώσεις για τραυματισμό.



• Συμμετοχή και Αποχώρηση

Η συμμετοχή σας στην έρευνα είναι ΕΘΕΛΟΝΤΙΚΗ. Εάν επιλέξετε να μην συμμετέχετε, τότε δεν επηρεάζεται η σχέση σας με το πανεπιστήμιο, το νοσοκομείο ή με τους ερευνητές ούτε επηρεάζεται το δικαίωμά σας για ιατρική περίθαλψη ή άλλες υπηρεσίες τις οποίες δικαιούστε. Εάν αποφασίσετε να συμμετέχετε, είστε ελεύθερος /η να αποχωρήσετε όποτε θέλετε χωρίς καμία δέσμευση ή επίπτωση. Για οποιαδήποτε ερώτηση σχετικά με τα δικαιώματά σας από τη συμμετοχή σας ως υποκείμενο σε ερευνητική εργασία, μπορείτε να απευθυνθείτε στην Ελληνική Οργάνωση για τα δικαιώματα των υποκειμένων σε έρευνα.

• Απόσυρση της συμμετοχής με απόφαση του ερευνητή

Οι ερευνητές έχουν δικαίωμα να σας ζητήσουν να μη συμμετέχετε στην έρευνα, εάν το επιβάλλουν οι συνθήκες.

Υπεύθυνοι επικοινωνίας

Για οποιαδήποτε πληροφορία επικοινωνήστε με: ________________ τηλ.: __________________

Υπογραφή του συμμετέχοντα στην έρευνα ή νόμιμου εκπροσώπου του

Διάβασα ή κάποιας άλλος μου ανάγνωσε, και κατανοώ πλήρως τις πληροφορίες οι οποίες αναγράφοντα σε αυτήν την φόρμα. Μου δόθηκε η ευκαιρία να υποβάλλω ερωτήσεις και όλες οι ερωτήσεις απαντήθηκαν πλήρως. Έλαβα αντίγραφο αυτής της φόρμας όπως και των δικαιωμάτων των συμμετεχόντων ατόμων στην έρευνα.

Μόνο για γυναίκες συμμετέχουσες, σε συγκεκριμένα διαγνωστικά πρωτόκολλα:

Βεβαιώνω ότι γνωρίζω πως δεν είμαι έγκυος και ότι ερωτήθηκα εάν υπάρχει τέτοια πιθανότητα.

Υπογράφοντας τον παρόν έντυπο, συμφωνώ να συμμετέχω στην συγκεκριμένη έρευνα.

Ονοματεπώνυμο: __________________________ Ημερομηνία:___________________________

Υπογραφή του ερευνητή

Έχω εξηγήσει την έρευνα στον /στην συμμετέχοντα /ουσα ή στο νόμιμο εκπρόσωπό του /της και απάντησεα σε όλες τις ερωτήσεις του/της. Θεωρώ ότι καταλαβαίνει τις πληροφορίες που αναγράφονται στο συγκεκριμένο έντυπο και συμμετέχει στην συγκεκριμένη έρευνα με την ελεύθερη του/της βούληση.

Ονοματεπώνυμο: Ivana Petrovic Ημερομηνία:

Υπογραφή του επιβλέποντα καθηγητή

Ioannis Amoiridis
Ioannis Amoiridis
27.05.2021 08:25

13. AUTHOR'S BIOGRAPHY

Ivana Petrović was born on April 1, 1987 in Niš. She finished primary and secondary school in Niš with great success, as well as the Faculty of Sports and Physical Education at the University of Niš, in 2011, with an average grade of 9.39 (nine, 39/10). She defended her final thesis, entitled "Thermoregulation during long distances running" with the grade 10.00 (ten). In the 2016/2017 academic year, she started her doctoral academic studies at the Faculty of Sports and Physical Education, University of Niš and passed all of her exams on time, with an average grade of 9.50 (nine, 50/10). In the 2018/2019 academic year, she enrolled in the third year of doctoral academic studies and prepared her doctoral dissertation project in the Laboratory of Neuromechanics at the Department of Sport and Physical Education in Serres of Aristotle University of Thessaloniki (Greece).

She started her first employment at the Ministry of Defense in Niš in 2014. Since 2015, she has been serving in the Ministry of Defense in Belgrade as a Physical Education Officer, where she has been carrying out practical and theoretical training, planning and organizing of physical exercise programs, testing physical abilities and organizing the preparation of athletes for competitions. She is also engaged in the implementation of practical classes in winter conditions where she teaches classes in skiing, as well as in the implementation of testing the physical abilities of members of the Serbian Army in the capacity of Inspector by invitation, hired by the Inspectorate of the Ministry of Defense.

Ever since her pioneer days, she has been involved in athletics and has been successful in the disciplines of 600m, 800m, 1500m, 3000m, 3000m steeplechase and 5000m. She is a winner of national medals in all disciplines. She was at the national championship in the disciplines of mountain running and the 3000m steeplechase in 2017. In the same year, she became a member of the national team of the Republic of Serbia and participated in the European Team Championship in Israel, Tel Aviv. In addition, she is a permanent member of the military team of the Ministry of Defense and the Serbian Army and has participated in many national and international competitions, including the 53rd World Military Cross-Country Championship held in Hungary, Lake Balaton 2017, and the 54th World Military

Cross-Country Skiing Championship held in Austria, Hochfilzen in 2018. She is currently a member of “Leposavić“ athletic club from Leposavić. The best results achieved in the disciplines are: 2.17.58 (800m); 4.37.12 (1500m); 10.05.62 (3000m) and 11.34.46 (3000 m steeplechase).

During her bachelor studies, based on the achieved top sports results and excellent average scores during her studies, she was a scholarship holder of the City of Niš. As one of the best undergraduate students, she received a scholarship and completed her eighth semester in Norway, Trondheim (2010), where she participated in the Puzzle Conference in Sweden as a part of an exchange between the University of Trondheim and Malmö. In addition, in 2011 she took part in the student "Work and Travel" program and spent six months in the United States, New York. As the only selected student of the University of Niš, in 2018 she applied for an Erasmus + Scholarship and completed the fifth semester of her Doctoral Academic Studies at the Department of Sports and Physical Education in Serres, Aristotle University of Thessaloniki (Greece). During her studies, she was involved in volunteer work and worked on the development of physical and motor skills of children with special needs. She also worked as a coach in a private sports school, training children aged four to 12. She speaks, reads and writes in English and Greek fluently. In addition to English and Greek, she speaks Norwegian as well.

List of published research in international and domestic journals

1. **Petrović, I.**, & Marinković, M. (2018). Influence of Morphological Characteristics on Running Performance of Endurance Athletes. *Facta Universitatis, Series: Physical Education and Sport*, *16*(1), 095-106. **M24**

2. **Petrović, I.**, Stanković, D., & Petrović, I. (2018). Relationship of Aerobic Abilities and Agility with Military Physical Tasks in the Serbian Armed Forces. In Pantelić, S. (Ed.), *XXI International Scientific Conference „FIS COMMUNICATIONS 2018“in physical education, sport and recreation“,* Book of proceedings (pp. 215-220). Niš: Faculty of Sport and Physical Education. **M51**

3. Stanković, D., **Petrović, I.**, & Petrović, I. (2018). Influence of Muscular Strength on Military Physical Tasks in the Serbian Armed Forces. In Pantelić, S. (Ed.), *XXI International Scientific Conference „FIS COMMUNICATIONS 2018“in physical education, sport and recreation“,* Book of proceedings (pp. 184-190). **M51**

Niš: Faculty of Sport and Physical Education.

4. **Petrović, I.**, Utvić, N., & Stanković, R. (2018). The relationship of motor-based anaerobic capacity tests with various sports activities: a systematic review. *Sport Science, 11*(2), 128-140.

5. **Petrović, I.**, & Marinković, M. (2018). Effects of Different Types of Exercise Programs on Arterial Blood Pressure of the Elderly. *Facta Universitatis, Series: Physical Education and Sport, 16*(4), 725-737. **M24**

6. Stanković, D., Raković, A., Petković, E., **Petrović, I.** & Savanović, V. (2019). Analysis of Somatotype of Top Young Race Walkers by Means of the Health-carter Method. *Facta Universitatis, Series: Physical Education and Sport, 17*(3), 609-618. **M24**

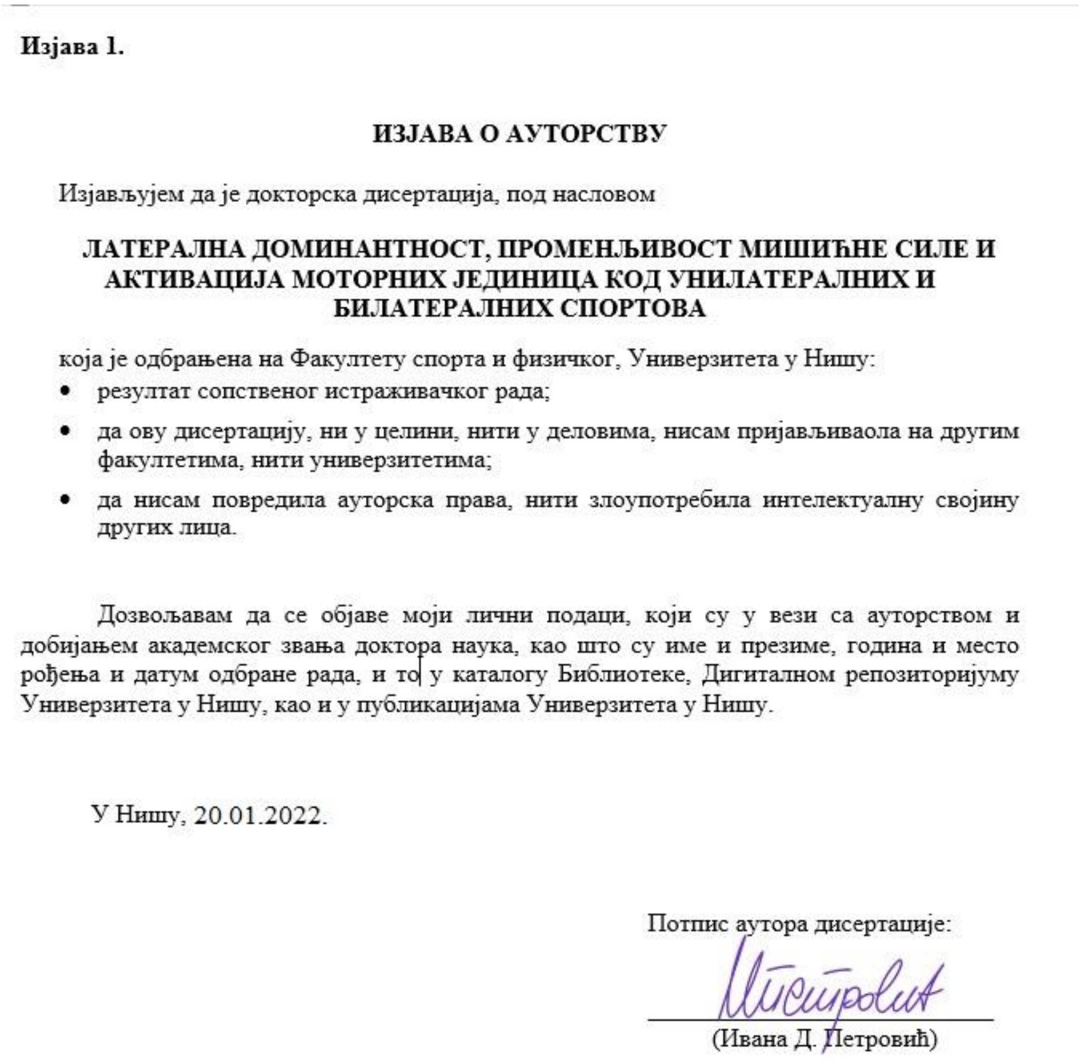
7. **Petrović, I.** (2020). Does the female athlete triad really exist? *Facta Universitatis, Series: Physical Education and Sport, 18*(1), 037-048. **M24**

8. **Petrović, I.**, & Stanković, D. (2021). Manifestation of Laterality on Lower Extremities in Athletes. In Stojiljković, N. (Ed.), *XXIII International Scientific Conference „FIS COMMUNICATIONS 2021"in physical education, sport and recreation",* Book of proceedings (pp. 56-61). Niš: Faculty of Sport and Physical Education. **M51**

9. **Petrović, I.**, Amiridis, I. G. Kellis, E., & Stanković, D. (2021). Dominance-induced Modifications on Maxumal Force and Neural Activation of th Ankle Muscles. *Facta Universitatis, Series: Physical Education and Sport, 19*(3) 271-283. **M24**

10. **Petrović, I.**, Amiridis, A.G., Holobar, A., Trypidakis, G., Kellis, E., & Enoka, RM (2022). Leg Dominance Does Not Influence Maximal Force, Force Steadiness, or Motor Unit Discharge Characteristics [u stampi]. *Medicine & Science in Sports & Exercise.* **IF=5.411** **M21**

14. STATEMENTS BY THE AUTHOR



Изјава 1.

ИЗЈАВА О АУТОРСТВУ

Изјављујем да је докторска дисертација, под насловом

ЛАТЕРАЛНА ДОМИНАНТНОСТ, ПРОМЕНЉИВОСТ МИШИЋНЕ СИЛЕ И АКТИВАЦИЈА МОТОРНИХ ЈЕДИНИЦА КОД УНИЛАТЕРАЛНИХ И БИЛАТЕРАЛНИХ СПОРТОВА

која је одбрањена на Факултету спорта и физичког, Универзитета у Нишу:

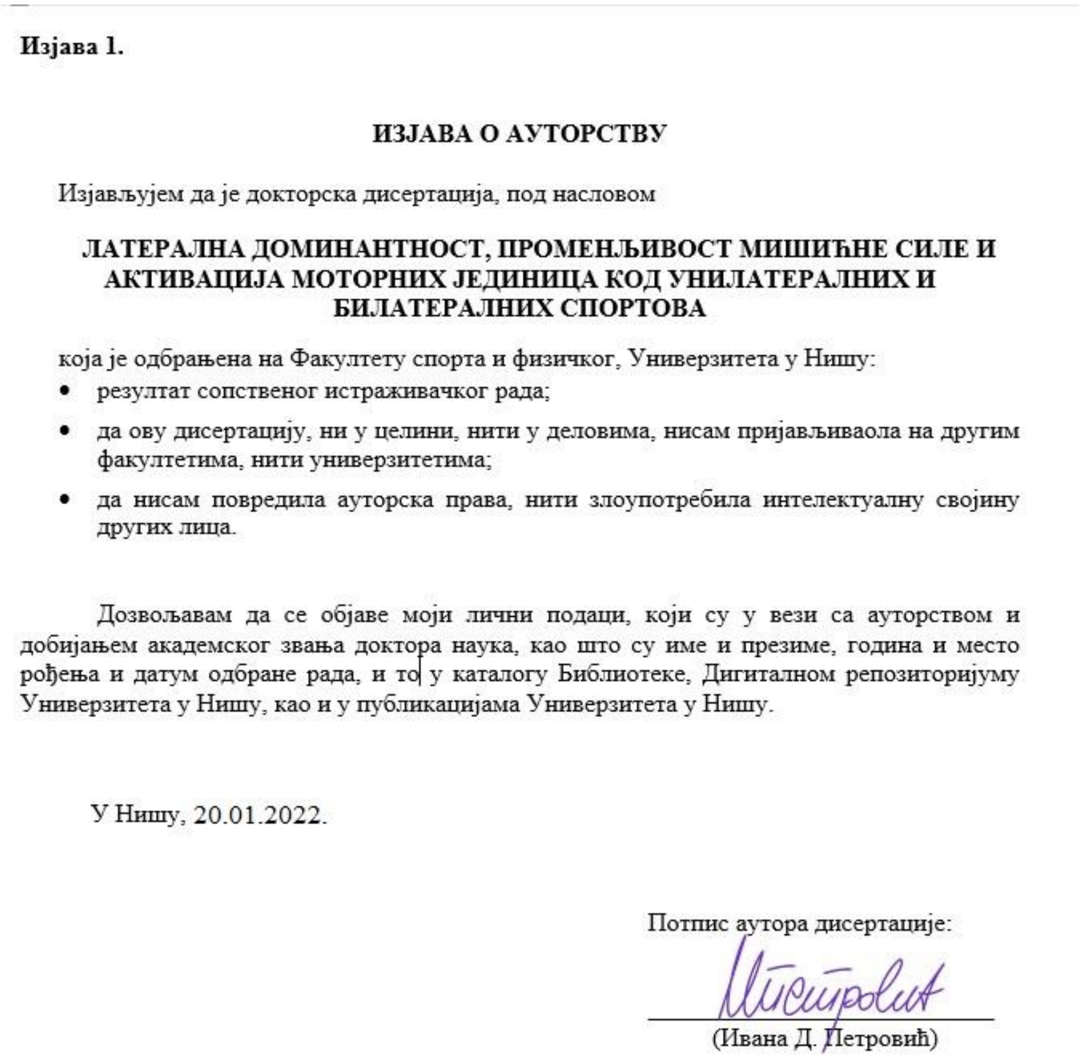
- резултат сопственог истраживачког рада;
- да ову дисертацију, ни у целини, нити у деловима, нисам пријављиваола на другим факултетима, нити универзитетима;
- да нисам повредила ауторска права, нити злоупотребила интелектуалну својину других лица.

Дозвољавам да се објаве моји лични подаци, који су у вези са ауторством и добијањем академског звања доктора наука, као што су име и презиме, година и место рођења и датум одбране рада, и то у каталогу Библиотеке, Дигиталном репозиторијуму Универзитета у Нишу, као и у публикацијама Универзитета у Нишу.

У Нишу, 20.01.2022.

Потпис аутора дисертације:

(Ивана Д. Петровић)



Изјава 1.

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ЛАТЕРАЛНА ДОМИНАНТНОСТ, ПРОМЕНЉИВОСТ МИШИЋНЕ СИЛЕ И АКТИВАЦИЈА МОТОРНИХ ЈЕДИНИЦА КОД УНИЛАТЕРАЛНИХ И БИЛАТЕРАЛНИХ СПОРТОВА

која је одбрањена на Факултету спорта и физичког, Универзитета у Нишу:

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- да ову дисертацију, ни у целини, нити у деловима, нисам пријављиваола на другим факултетима, нити универзитетима;
- да нисам повредила ауторска права, нити злоупотребила интелектуалну својину других лица.

Дозвољавам да се објаве моји лични подаци, који су у вези са ауторством и добијањем академског звања доктора наука, као што су име и презиме, година и место рођења и датум одбране рада, и то у каталогу Библиотеке, Дигиталном репозиторијуму Универзитета у Нишу, као и у публикацијама Универзитета у Нишу.

У Нишу, 20.01.2022.

Потпис аутора дисертације:

(Ивана Д. Петровић)

ИЗЈАВА О КОРИШЋЕЊУ

Овлашћујем Универзитетску библиотеку „Никола Тесла“ да у Дигитални репозиторијум Универзитета у Нишу унесе моју докторску дисертацију, под насловом:

ЛАТЕРАЛНА ДОМИНАНТНОСТ, ПРОМЕНЉИВОСТ МИШИЋНЕ СИЛЕ И АКТИВАЦИЈА МОТОРНИХ ЈЕДИНИЦА КОД УНИЛАТЕРАЛНИХ И БИЛАТЕРАЛНИХ СПОРТОВА

Дисертацију са свим прилозима предала сам у електронском облику, погодном за трајно архивирање.

Моју докторску дисертацију, унету у Дигитални репозиторијум Универзитета у Нишу, могу користити сви који поштују одредбе садржане у одабраном типу лиценце Креативне заједнице (Creative Commons), за коју сам се одлучила.

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