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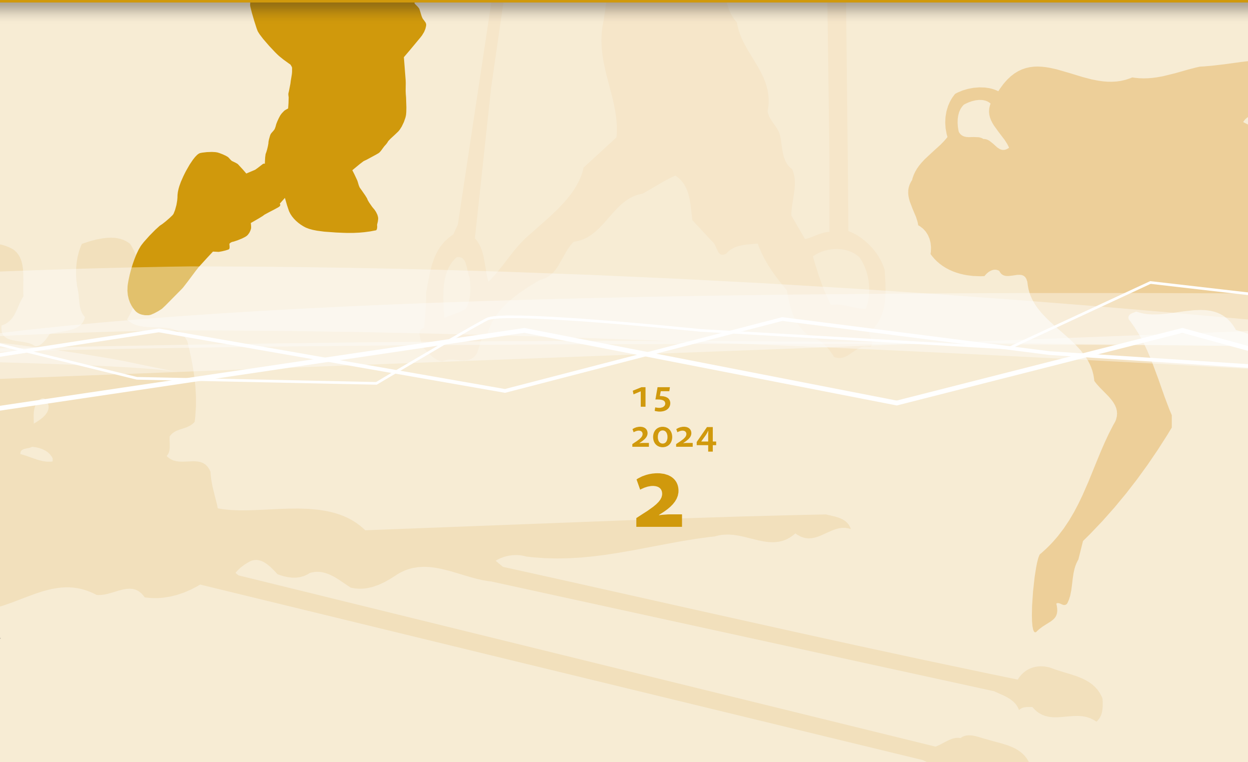

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Journal secretary contact / *Sedež:* Annales Kinesiologiae, Science and Research Centre Koper, Garibaldijeva 1, SI-6000 Koper/Capodistria
tel.: +386 5 663-77-00; fax: +386 5 663-77-10
***E-mail*:** annaleskin@zrs-kp.si
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20 YEARS OF KINESIOLOGY RESEARCH FOR QUALITY OF LIFE

The Annales Kinesiologiae volume before you, comes at a special time, as ZRS Koper marks 30 years of activity and the Institute for Kinesiological Research (IKARUS) celebrates its 20th anniversary. Founded on 16 February 2004 by Prof. Rado Pišot, with key contributions from Dr. Jurij Planinšec, Dr. Boštjan Šimunič, and Dr. Jernej Završnik, IKARUS addressed a crucial gap in kinesiology research. It expanded the focus beyond sports to the broader impact of physical activity and inactivity, reshaping the tradition of sports science in our country.

We saw sports as just the tip of the iceberg, with physical activity habits posing a greater challenge. Time proved us right—today, physical inactivity is the second leading cause of mortality, surpassing smoking and trailing only hypertension. Focused on health, we adopted a medical-natural science approach while integrating psychological and sociological aspects. Over 20 years, we built a 24-member international team, enabling a holistic approach to complex kinesiology challenges.

The IKARUS has dedicated itself to cutting-edge research and applications that contribute to understanding human movement and improving quality of life. Our work includes advanced human movement science, exploring space survival, physical inactivity, and sports injury epidemiology. Using state-of-the-art technologies, we develop preventive and health interventions to enhance well-being and complement medical practices.

We are dedicated to advancing health indicators and precision measurement tools to monitor individual progress. Our commitment to innovation also extends to education. At the University of Primorska and the International Euro-Mediterranean University, we offer accredited study programs across all three Bologna levels, including two international programs. We have also established the Faculty of Ergonomics and Kinesiology to train the next generation of kinesiology and ergonomics professionals. In addition, we have organized twelve international congresses on The Child in Motion, which will evolve into the International Congress on Human in Motion in 2025. We have completed 25 projects funded by the national science agency ARIS, with seven ongoing, and coordinated three major H2020 projects. Our over 550 SCI-indexed publications have been cited more than 22,000 times, demonstrating our global scientific impact. Additionally, we have contributed to seven BED REST studies and three Toulouse dry immersion studies, with over six years of bedrest data, advancing the understanding of human physiological adaptations.

With our dynamic energy, innovative ideas, and state-of-the-art infrastructure, we are a recognized and trusted partner in both medical and sports science, driven by our vision to improve health and quality of life. The papers in this issue offer valuable insights into modern kinesiological and sports science, covering topics such as the physical traits of young alpine skiers (Puhalj et al.), international differences in the nutritional habits of shooting athletes (Jakus et al.), the impact of mental fatigue on strength endurance in young kickboxers (Kürkcü Akgönül & Gökmen), and the effects of low-intensity BFRE training on knee function in individuals with knee impairments (Ipavec). Additionally, the papers explore the global impact of sports science on quality of life (Pišot), the application of neuroscience in neurorehabilitation (Marušič), and two decades of pioneering research at the Koper Kinesiology Research Centre (Pišot & Šimunič). Together, these studies deepen our understanding of human movement, health, and sports performance.

Enjoy reading and welcome to our laboratories and knowledge centres!

Prof Dr Rado Pišot, Editor-in-Chief,
and Prof Dr Boštjan Šimunič, Editor

20 LET KINEZIOLOŠKIH RAZISKAV ZA KAKOVOST ŽIVLJENJA

Številka revije *Annales Kinesiologiae*, ki jo imate pred seboj, izhaja ob pomembni obletnici, ZRS Koper namreč obeležuje 30 let delovanja, medtem ko Inštitut za kineziološke raziskave (IKARUS) praznuje 20. obletnico. Inštitut je nastal 16. februarja 2004 na pobudo ustanovitelja prof. Rada Pišota, s ključno podporo dr. Jurija Planinšca, dr. Boštjana Šimuniča in dr. Jerneja Završnika, z namenom zapolniti pomembno vrzel na področju kinezioloških raziskav. Prvotni poudarek delovanja inštituta se je s področja športa razširil na širše učinke telesne aktivnosti in neaktivnosti, s čimer je športni znanosti v Sloveniji začrtal novo smer.

Prepoznali smo, da je šport zgolj vrh ledene gore, večji izziv so namreč splošne gibalne navade ljudi. Skozi čas se je izkazalo, da smo imeli prav – danes je telesna neaktivnost drugi najpogostejši vzrok umrljivosti, celo pred kajenjem in le malo za hipertenzijo. S poudarkom na zdravju smo ubrali medicinsko-naravoslovni pristop ter ga dopolnili s psihološkimi in sociološkimi vidiki. V dvajsetih letih delovanja smo sestavili 24-člansko mednarodno ekipo, s katero se lahko celostno lotevamo zahtevnih kinezioloških izzivov.

IKARUS je predan vrhunskim raziskavam in inovativnim aplikacijam, ki izboljšujejo razumevanje človeškega gibanja in zvišujejo kakovost življenja. Naše delo obsega napredne raziskave človeškega gibanja, preučevanje preživetja v vesolju, telesne neaktivnosti in epidemiologije športnih poškodb. Z uporabo najsodobnejših tehnologij razvijamo preventivne in zdravstvene ukrepe, ki izboljšujejo dobro počutje in dopolnjujejo medicinsko prakso.

Osredotočeni smo na razvoj kazalnikov zdravja in natančnih merilnih orodij za spremljanje individualnega napredka. Naša predanost inovacijam sega tudi na področje izobraževanja – na Univerzi na Primorskem in Evro-sredozemski univerzi ponujamo akreditirane študijske programe na vseh treh bolonjskih stopnjah, vključno z dvema mednarodnima programoma. Poleg tega smo ustanovili Fakulteto za ergonomijo in kineziologijo, ki jo obiskujejo novi rodovi obetavnih strokovnjakov s področja kineziologije in ergonomije. V teh letih smo pripravili kar dvanajst mednarodnih kongresov Otrok v gibanju, ki jih bo leta 2025 nadgradil mednarodni kongres Človek v gibanju. S finančno pomočjo Javne agencije za znanstvenoraziskovalno in inovacijsko dejavnost ARIS smo izvedli 25 projektov, od tega jih sedem še vedno poteka, koordinirali pa smo tudi tri obsežne projekte v okviru programa H2020. Objavili smo več kot 550 člankov v revijah, indeksiranih v bazi SCI, ki so bili citirani več kot 22.000-krat, kar potrjuje znanstveni vpliv, ki ga imamo v globalnem merilu. Prav tako smo sodelovali pri sedmih raziskavah »Bed Rest« in treh študijah suhega potopa (ang. dry immersion), izvedenih v Toulousu, v okviru katerih smo zbrali za več kot šest let podatkov o mirovanju in s tem pripomogli k razumevanju fizioloških prilagoditev človeškega telesa.

Polni zagona, inovativnih idej in opremljeni z vrhunsko infrastrukturo veljamo za zanesljivega partnerja tako v medicinski kot športni znanosti, vselej pa nas vodi vizija izboljšanja zdravja in kakovosti življenja. Članki v tej številki prinašajo dragocene vpoglede v sodobno kineziološko oziroma športno znanost in obravnavajo teme, kot so telesne značilnosti mladih alpskih smučarjev (Puhalj et al.), razlike v prehranskih navadah slovenskih in tujih športnikov-strelcev (Jakus et al.), vpliv mentalne utrujenosti na vzdržljivost moči pri mladih kikbokserjih (Kürkcü Akgönül & Gökmen) ter učinki nizko intenzivne BFRE-vadbe na delovanje kolena pri osebah s poškodbami kolena (Ipavec). Obravnavajo tudi globalni vpliv športne znanosti na kakovost življenja (Pišot), uporabo nevroznanosti v nevrorehabilitaciji (Marušič) in dvajset let pionirskih raziskav v Znanstveno-raziskovalnem središču Koper (Pišot in Šimunič). Kot celota pa vsi poglabljajo razumevanje človeškega gibanja, zdravja in športne zmogljivosti.

Želimo vam prijetno branje in vas prisrčno vabimo v naše laboratorije ter središča znanja!

prof. dr. Rado Pišot, glavni in odgovorni urednik,
in prof. dr. Boštjan Šimunič, urednik

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PHYSICAL CHARACTERISTICS AS INDICATORS OF PERFORMANCE IN YOUNG ALPINE SKIERS IN SUPER-G

Stojan PUHALJ[1], Blaž LEŠNIK[2], Črtomir MATEJEK[1], Samo FOŠNARIČ[1], Tjaša KMET[2], Jurij PLANINŠEC[1]

[1]University of Maribor, Faculty of Education, Maribor, Slovenia
[2]University of Ljubljana, Faculty of Sport, Ljubljana, Slovenia

Corresponding author:
Jurij PLANINŠEC
University of Maribor, Faculty of Education, Koroška cesta 160, 2000 Maribor, Slovenia
Phone: +386 41 236 533
E-mail: jurij.planinsec@um.si

ABSTRACT

Purpose*: The aim of this study is to determine the relationship between physical characteristics and performance in young alpine skiers in the Super-G discipline.*

Methods*: A sample of 42 U16 alpine skiing competitors (23 boys and 19 girls) aged 14-15 years participated in the study. The physical characteristics were measured using the Inbody 720 Body Composition Analysis and 3D Body Scan devices. Performance data was obtained from official records of the Ski Association of Slovenia for the 2018/19 U16 competitive season. Variables such as body height, body weight, thigh circumference, waist circumference, chest circumference, shoulder circumference, muscle mass percentage, fat mass percentage, body mass index, and body fat percentage were analyzed. Pearson correlation coefficients and multiple regression analysis were used to assess the relationship between the physical characteristics and Super-G performance.*

Results*: Significant correlations were found between body weight, thigh circumference, chest circumference, muscle mass percentage, and Super-G performance in boys. For girls, waist circumference, chest circumference, and body fat percentage were significantly correlated with performance. The multiple regression model explained 73% of the variance in the boys' performance and 59% in the girls', although the model itself was not statistically significant for predicting performance.*

Conclusion*: Physical characteristics, especially muscle mass percentage and body circumferences, are significantly associated with Super-G performance in young alpine* *skiers. These findings underscore the importance of tailored training programs that consider individual physical characteristics to optimize competitive success in alpine skiing.*

***Keywords**: alpine skiing, Super-G, physical characteristics, young athletes, body composition, performance indicators.*

TELESNE ZNAČILNOSTI KOT KAZALNIK USPEŠNOSTI MLADIH ALPSKIH SMUČARJEV V SUPERVELESLALOMU

IZVLEČEK

***Namen**: Namen raziskave je ugotoviti povezanost med telesnimi značilnostmi in uspešnostjo mladih alpskih smučarjev v superveleslalomu.*

***Metode**: V raziskavi je sodelovalo 42 tekmovalcev v alpskem smučanju kategorije U16 (23 dečkov, 19 deklic) v starosti 14–15 let. Telesne značilnosti so bile izmerjene z napravama Inbody 720 za analizo telesne sestave in 3D telesnim skeniranjem. Podatki o uspešnosti so bili pridobljeni iz uradnih zapisov Smučarske zveze Slovenije za tekmovalno sezono 2018/19 v kategoriji U16. Analizirane spremenljivke so vključevale telesno višino, telesno težo, obseg stegen, obseg pasu, obseg prsnega koša, obseg ramen, delež mišične mase, delež maščobne mase, indeks telesne mase in odstotek maščobe v telesu. Za oceno povezave med telesnimi značilnostmi in uspešnostjo v superveleslalomu smo uporabili Pearsonove korelacijske koeficiente in multiplo regresijsko analizo.*

***Rezultati**: Pri dečkih so bile ugotovljene pomembne povezave med telesno težo, obsegom stegen, obsegom prsnega koša, deležem mišične mase in uspešnostjo v superveleslalomu. Pri deklicah so bile pomembne povezave med obsegom pasu, obsegom prsnega koša in deležem telesne maščobe. Model multiple regresije je pojasnil 73 % variance z uspešnostjo pri dečkih in 59 % pri deklicah, čeprav model sam po sebi ni bil statistično pomemben za napovedovanje uspešnosti.*

***Zaključek**: Telesne značilnosti, zlasti delež mišične mase in telesni obsegi, so pomembno povezane z uspešnostjo v superveleslalomu pri mladih alpskih smučarjih. Ti izsledki poudarjajo pomembnost prilagojenih vadbenih programov, ki upoštevajo posamezne telesne značilnosti za optimizacijo tekmovalnega uspeha v alpskem smučanju.*

***Ključne besede**: alpsko smučanje, superveleslalom, telesne značilnosti, mladi športniki, telesna sestava, kazalniki uspešnosti.*

INTRODUCTION

Success in alpine skiing is influenced by numerous factors, including motor skills, physical characteristics, psychological traits, and technical abilities (Ferland & Comtois, 2018; McKnight, 2018; Müller, Schwameder, Kornexl, & Raschner, 1997; Puhalj, Lešnik, Povhe, Kelc, & Matejek, 2021). Among these, physical characteristics significantly impact skier performance. However, few studies have examined the relationship between physical characteristics and competitive performance using highly accurate measurement instruments, particularly in speed disciplines.

Rajtmajer (1984) identified a correlation between manifest and latent motor skills and anthropometric characteristics in young alpine skiers. Based on this research, he defined the type of elite alpine skier, which differs from the athletic type, with narrower shoulders, wider hips, longer upper limbs, shorter stature, and pronounced distal trunk and lower limb mass, particularly thigh muscle mass. Voluminous body mass is crucial in alpine skiing as competitors have to manage their body mass, which is paramount for competitive success (Lešnik, 1999). Klika and Malina (2003) found minor differences in the physical characteristics between successful and less successful skiers aged 14-18, noting better motor skills in the successful competitors. They also observed that combining physical characteristics, motor skills, and age predicts competitive success more effectively than physical characteristics or motor skills alone. They suggested including the skiing technique as a variable in future research. Scherr et al. (2011) noted that skiers with a higher muscle mass percentage were more successful in alpine skiing. Bandalo and Lešnik (2012) found that body constitution significantly influences skiing performance, with skiers having greater body mass and height and longer and broader lower limbs achieving better results. Critical parameters like height, weight, muscle mass percentage, and fat percentage affect a skier's ability to manage the speed and technical skiing demands (Bandalo & Lešnik, 2011). Skiers with more muscle mass generate better force, which is crucial for jumping and turn control. Body composition, especially body mass, predicts factors related to force and power in young alpine skiers (Bertozzi et al., 2024). Fat percentage influences aerodynamics and endurance, while taller skiers can utilize their height for better force transfer to the skis, enabling more effective turns and excellent stability at high speeds (Bandalo & Lešnik, 2011). The influence of physical measurements on young alpine skiers' performance proved statistically significant, with height having the most critical impact, while the body fat percentage had no statistical significance for performance (Šteharnik, 2013). Bandalo (2016) reported that increased subcutaneous fat is related to the success of younger competitors, emphasizing the importance of body mass and height, muscle mass percentage, and lower limb joint diameters, especially the knee. Puhalj (2018) found that boys with higher body fat percentages and total body mass achieved better results, attributing this to simpler course setups favoring heavier competitors. Pernuš (2018) similarly found a significant relationship between body and muscle mass and competitive success in boys, while no such correlation was observed in girls.

Research and practice indicate that body constitution significantly impacts alpine skiers' competitive success (Ferland & Comtois, 2018). Alpine skiing involves full-body physical activity, requiring body and equipment control. Body weight is crucial for achieving top results. Optimal body positioning on the skis and sliding speed depend on gravitational force, terrain slope, and opposing forces. Heavier competitors thus have an advantage, contingent on the fat-free to fat mass ratio as excess fat negatively affects body control. Therefore, other variables like lower limb circumference (thigh circumference) and joint diameters (ankle and knee) are also important. Appropriate physical measurements are essential for top results, alongside proper physical preparedness and skiing technique (Bandalo & Lešnik, 2011; Lešnik & Žvan, 2007; Sands et al., 2021; Supej, 2008).

Vermeulen et al. (2017) also studied morphological characteristics and alpine skiing performance and found that female speed event specialists had more relative fat mass than technical event specialists. Regardless of gender, technical event specialists were lighter, with less relative fat mass than speed event specialists. Moderate correlations were found between speed event performance and body weight, with a higher relative fat mass linked to female speed event success, while lower ectomorphy correlated with male speed event success.

Technical skills are also crucial for alpine skiing success, involving correct skiing technique, rapid adaptation to varying snow conditions, and executing complex maneuvers (Puhalj & Lešnik, 2018). Competitors must master various skiing techniques to effectively navigate different terrains and snow conditions. Technical preparation involves precise course analysis, training on varied terrains, and improving specific technical elements like turns, jumps, and gliding. Super-G, a speed event, incorporates giant slalom and downhill elements. Super-G requires a low center of gravity and ski guidance on the sliding surface, deriving from the downhill technique. Apart from slightly shorter skis compared to downhill skiing, the equipment for Super-G is similar due to the lower speeds and better maneuverability requirements (Lešnik & Žvan, 2007). Super-G is the most demanding discipline in the U16 category (ages 14-15), gradually introducing elements of speed disciplines. The height difference between the start and finish of Super-G courses should be between 250 and 450 meters, with an average of 40 direction changes (Smučarska zveza Slovenije – Otroški program, 2019).

Understanding the relationship between physical characteristics and alpine skiing performance is crucial for developing top young skiers. Physical characteristics like body mass, height, muscle mass, and body circumferences significantly influence the skiers' ability to meet the technical and physical demands of skiing. Based on research data, coaches can better tailor the training processes to individual competitors' needs, leading to better results and reduced injury risk.

Many studies indicate that children who mature biologically faster have advantages in some sports due to more developed skeletal systems and higher skeletal age (Škof, 2016). Older boys with advanced biological development show better motor skills and strength than their peers, while girls who mature later perform better than early developers. Young alpine skiers' physical characteristics change with growth and development, particularly during puberty, impacting skiing performance. Increases in muscle mass, changes in body composition, and growth are factors to consider when planning training and preparation for competitions.

The study aimed to determine the relationship between physical characteristics and competitive performance in young alpine skiers in the U16 category in Super-G. We sought to assess the correlation of body mass and height, thigh circumference, waist circumference, chest circumference, body mass index, fat and muscle mass percentage, and all the measured body composition variables with Super-G performance. Based on previous research, we hypothesize a statistically significant relationship between body mass and height and the young alpine skiers' Super-G performance. We also hypothesize that Super-G success correlates with thigh circumference, waist circumference, chest circumference, fat and muscle mass percentage, body mass index, and body composition variables.

METHODS

Participant Sample

The sample included U16 alpine skiing competitors aged 14-15 years. The U16 category is the oldest in Slovenia's children's competitive alpine skiing program. All the study participants were registered competitors with the Ski Association of Slovenia, representing 19 ski clubs across four Slovenian ski regions. The sample consisted of 23 boys and 19 girls competing in Super-G. Parents and children were informed about the study protocol and agreed to participate.

Measurement Instruments

Measurements were conducted using the Inbody 720 Body Composition Analysis device (Inbody720, 2024), which provides precise whole-body composition analysis, including basal metabolism, muscle balance, and body fat percentage. The Inbody 720 employs direct segmental multi-frequency bioelectrical impedance analysis to measure the resistance of alternating electrical currents through different body segments. The 3D Body Scan device ([TC]2 National Science Foundation study of Harvard University, USA) ([TC]2, 2024) was used for comprehensive body scanning, providing the body circumferences, segment lengths, and joint diameters or body part measurements. Variables deemed influential on Super-G performance based on previous research were included.

Data Collection Procedure

Data collection occurred in September 2018 under controlled conditions at the Faculty of Sport in the kinesiology laboratory. Body composition variables were measured using the Inbody 720 and 3D Body Scan devices. Performance data in Super-G were obtained from the official records of the Ski Association of Slovenia for the 2018/19 U16 competitive season, which included four Super-G competitions. Points were awarded to the top 30 competitors in each race. The competitor who placed first received 100 points; second place earned 80 points; third place 60 points; fourth 50 points; fifth 45 points, sixth 40 points, seventh 36 points, eighth 32 points; ninth 29 points; tenth 26 points; eleventh 24 points, twelfth 22 points, thirteenth 20 points, fourteenth 18 points, fifteenth 16 points, and then one point less for each subsequent position, down to thirtieth place, which earned 1 point. The criterion for competition success was the total sum of points a competitor received across all four U16 Super-G competitions.

Data Processing Procedures

Body composition and Super-G performance variables were processed using IBM SPSS 23.0. Arithmetic means and standard deviations were calculated, followed by normality distribution checks using the Shapiro-Wilk test. Pearson correlation coefficients determined the relationship between individual variables and Super-G performance. Multiple regression analysis assessed the relationship between selected variable sets and Super-G performance. Assumptions of linearity, the normal distribution of the dependent variable, homoscedasticity, and multicollinearity were verified before calculating the correlations.

RESULTS

Table 1 presents the basic statistics for body composition and Super-G performance in boys, showing the most considerable within-group differences in body weight, waist circumference, shoulder diameter, muscle mass percentage, body mass index, and Super-G points, as well as minor differences in body fat percentage.

Table 1: Descriptive statistics for boys

Variables	N	Mean	Min	Max	SD
Body height	23	170.05	153	179.8	7.32
Body weight	23	60.07	39.5	79.8	10.99
Thigh circumference	23	55.47	46.3	68.3	6.57
Waist circumference	23	75.83	64.2	87.6	6.67
Chest circumference	23	89.73	78.7	102.5	6.99
Shoulder circumference	23	93.99	80.8	132.4	11.03
Muscle mass percentage	23	29.94	18.64	41.14	5.48
Fat mass percentage	23	6.56	2.3	16.2	3.54
Body mass index	23	20.86	16.65	26.49	2.68
Body fat percentage	23	9.46	7	10.8	1.03
Super-G performance	23	105.96	19	325	85.84

Table 2 shows the descriptive statistics for body composition and super-G performance in girls, with the most considerable within-group differences in body weight, thigh circumference, fat mass percentage, chest circumference, and super-G points, as well as minor differences in body height, body mass index, and muscle mass percentage.

Table 2: Descriptive statistics for girls

Variables	N	Mean	Min	Max	SD
Body height	19	165.07	159.4	174	3.87
Body weight	19	57.88	46.5	74.8	7.29
Thigh circumference	19	57.12	48.2	71.1	5.42
Waist circumference	19	76.01	64.7	86.6	5.55
Chest circumference	19	93.56	81.9	104	5.9
Shoulder circumference	19	88.25	82.5	96.9	4.83
Muscle mass percentage	19	25.38	21.74	31.83	2.52
Fat mass percentage	19	11.45	5.1	19.3	3.91
Body mass index	19	20.82	17.44	24.74	2.23
Body fat percentage	19	13.48	12.1	15.4	0.92
Super-G performance	19	131.95	58	360	74.87

Comparison between the genders shows differences in body height, with girls averaging 165.1±3.9 cm compared to boys at 170.1±7.3 cm, and more variation in the boys' height. Body weight differences are also noted (boys 60.7±10.99 kg, girls 57.9±7.3 kg). Thigh circumference is higher in girls (57.1±5.4 cm) than in boys (55.5±6.6 cm), which is somewhat surprising given the expectation of greater lower limb muscle mass in boys. Waist circumference shows no significant difference (boys 75.8±6.7 cm, girls 76.0±5.6 cm). Boys have a smaller chest circumference (89.7±7 cm) than girls (93.6±5.9 cm) due to gender differences in body constitution. Boys' shoulder diameter is more significant (94±11 cm) than girls' (88.3±4.8 cm), with more variation in boys due to more significant biological differences in this age group.

Boys generally have a higher muscle mass percentage (29.9±5.5%) than girls (25.4±2.5%), with more significant variation in boys. Conversely, girls have a higher fat mass percentage (11.5±3.9%) than boys (6.6±3.5%). Consequently, the body fat percentage is higher in girls (13.5±0.9%) than in boys (9.5±1%). These results are expected to reflect the increased muscle mass in boys during puberty and the slightly increased fat mass in girls. The boys' body mass index is 20.9±2.7, while the girls' is 20.8±2.3, indicating no significant gender differences. Higher muscle mass positively affects overcoming physical exertion, which is considerable in alpine skiing, especially in the speed disciplines.

Table 3: Correlation of body composition variables with the boys' super-G performance (r - Pearson correlation coefficient; r^2 - determination coefficient)

Variables	r	r^2	p
Body height	0.499	0.249	0.015
Body weight	0.650	0.422	0.001
Thigh circumference	0.550	0.302	0.007
Waist circumference	0.433	0.187	0.039
Chest circumference	0.593	0.351	0.003
Shoulder circumference	0.503	0.253	0.015
Muscle mass percentage	0.711	0.505	0.000
Fat mass percentage	0.274	0.075	0.206
Body mass index	0.494	0.244	0.017
Body fat percentage	0.497	0.247	0.016

In Table 3, the Pearson correlation coefficients and determination coefficients show the relationship between the body composition variables and Super-G performance. For boys, the highest and most significant correlations ($p<0.05$) were found with body weight ($r=0.65$; $r^2=0.422$), thigh circumference ($r=0.55$; $r^2=0.302$), chest circumference ($r=0.593$; $r^2=0.351$), and muscle mass percentage ($r=0.711$; $r^2=0.505$). Moderate and significant correlations ($p<0.05$) were observed with shoulder circumference ($r=0.503$; $r^2=0.253$), waist circumference ($r=0.433$; $r^2=0.187$), body height ($r=0.499$; $r^2=0.249$), body mass index ($r=0.494$; $r^2=0.244$), and body fat percentage ($r=0.497$; $r^2=0.247$). The lowest correlation was with fat mass percentage ($r=0.274$; $r^2=0.075$), which was not statistically significant ($p>0.05$).

Table 4: Correlation of body composition variables with girls' super-G performance (r - Pearson correlation coefficient; r^2 - determination coefficient)

Variables	r	r^2	p
Body height	0.272	0.074	0.26
Body weight	0.299	0.089	0.214
Thigh circumference	0.321	0.103	0.181
Waist circumference	0.461	0.212	0.047
Chest circumference	0.419	0.175	0.075
Shoulder circumference	0.392	0.153	0.097
Muscle mass percentage	0.438	0.192	0.06
Fat mass percentage	0.218	0.047	0.37
Body mass index	0.287	0.082	0.233
Body fat percentage	0.469	0.220	0.043

The results in Table 4 show that only waist circumference ($r=0.461$; $r^2=0.212$) and body fat percentage ($r=0.469$; $r^2=0.22$) significantly correlated ($p<0.05$) with the girls' Super-G performance. No statistical significance ($p>0.05$) was noted in chest circumference ($r=0.419$; $r^2=0.175$), shoulder circumference ($r=0.392$; $r^2=0.153$), muscle mass percentage ($r=0.438$; $r^2=0.192$), and other variables with the lowest correlations.

Table 5: Multiple linear regression analysis of body composition variables with boys' and girls' U16 super-G performance

Gender	r	r^2	SE_E	t	p
Boys	0,854	0,729	60,456	0,801	0,439
Girls	0,77	0,593	71,607	0,694	0,507

Legend: r – correlation coefficient; r2 – determination coefficient; SEE – standard error of the estimate; p – statistical significance of the regression model.

The relationship between the whole set of body composition variables and U16 Super-G performance is shown in Table 5. No statistical significance was found in either regression model (boys: $p=0.439$; girls: $p=0.507$). A high correlation was noted between the body composition variables and Super-G performance in both genders, explaining 73% of the boys' and 59% of the girls' performance. In both genders, it can be concluded that individual variables do not have a significant impact on competitive performance. This is also the reason why individual predictors are not specifically presented in Table 5.

DISCUSSION

Alpine skiing is one of the most complex and specific sports, influenced by numerous factors (Ferland & Comtois, 2018; McKnight, 2018). This study examined the relationship between physical characteristics and young alpine skiers' Super-G performance. Selected parameters (body height, body weight, thigh, waist, chest, and shoulder circumferences, muscle mass percentage, fat mass percentage, body mass index, and body fat percentage) are crucial, alongside skiing technique, motor skills, talent, and environmental factors, in influencing Super-G performance.

Significant correlations were found between the body composition variables and Super-G performance in both U16 boys and girls. For the boys, performance correlated with body weight, thigh circumference, chest circumference, and muscle mass percentage. Lower correlations were noted with body height, body mass index, and body fat percentage. Among the variables, muscle mass percentage has the highest coefficient of determination, explaining 50% of the variance with the variable super-G performance. Higher muscle mass enables better force development during turns, a critical factor in competitive success, consistent with Bertozzi et al. (2024). For girls, waist circumference, chest circumference, muscle mass percentage, and body fat percentage showed the highest correlations with performance. Lower correlations were noted with thigh circumference, shoulder diameter, and body height. In girls, body fat percentage has the highest coefficient of determination, explaining 22% of the variance with the variable super-G performance. The fat mass percentage did not correlate with competitive success, contrary to findings that fat mass percentage is linked to speed discipline success in women (Vermeulen et al., 2017).

These results align with other studies in some instances. Bandalo and Lešnik (2012) found that body constitution significantly impacts younger male skiers' competitive success, with taller and heavier boys achieving better results. Lešnik (1999) emphasized the importance of body weight and control in competitive alpine skiing, which is explained by body voluminosity (body mass and circumferences). Bandalo and Lešnik (2012) noted that greater body weight in the U16 category significantly contributes to faster skiing between gates, impacting competitive success. Greater body weight aids in speed acquisition during direction changes, providing a competitive advantage, as also noted by Bertozzi et al. (2024). Supej (2008) explained that body constitution influences faster sliding on the skis, as speed increases more in heavier competitors due to gravitational force, terrain slope, and friction forces with appropriate body positioning. However, excessive weight due to high-fat mass complicates body control, a key element in alpine skiing (Lešnik, 1999). Aktaş (2024) found that body weight, height, and body mass index negatively correlate with alpine skiing performance in general.

Experts have emphasized the need to focus on activities that increase muscle mass and body weight in young competitors, appropriately adapted to their developmental stage. Skiing technique is also crucial. Snow training should prioritize refining proper turn technique over gate skiing. Effective body weight utilization and good skiing technique contribute significantly to competitive success. Furthermore, it is essential to avoid potential injuries through a correct approach to ski training for children and adolescents, as these injuries often have a decisive impact on the athlete's competitive career (Kresal, Bračun, Tönig, & Amon., 2021).

A fundamental limitation of this study is the small sample size due to the limited number of competitors in this age category. The relatively few Super-G competitions in the season also limit the study, making generalizations difficult. Future research should replicate this study with larger samples, including older and younger age groups, and examine the relationship between physical characteristics and other alpine skiing disciplines.

REFERENCES

Aktaş, B. S. (2024). The analysis of the relationship between respiratory functions and body compositions of alpine discipline and cross-country skiing athletes. *Turkish Journal of Kinesiology*, *10*(1), 34–40. https://doi.org/10.31459/turkjkin.1412306

Bandalo, M. (2016). *Dinamika sprememb morfoloških in motoričnih dimenzij mladih tekmovalcev v alpskem smučanju v obdobju od leta 2001 do 2010. [Dynamics of morphological and motor dimensions variations in young athletes in alpine skiing in the period from 2001 to 2010].* (Unpublished doctoral dissertation). Univerza v Ljubljani, Fakulteta za šport, Ljubljana

Bandalo, M. & Lešnik, B. (2011). The connection between selected anthropometric and motor variables and the competitive success of young competitors in alpine skiing. *Kinesiologia Slovenica, 17*(3), 16-31. Retrieved from https://www.kinsi.si/en/archive/2011/223/

povezanost-med-izbranimi-antropometricnimi-in-motoricnimi-spremenljivkami-s-tekmovalno-uspesnostjo-mladih-tekmovalcev-v-alpskem-smucanju

Bandalo, M. & Lešnik, B. (2012). Povečanje vpliva izbranih karakteristik na uspešnost mladih tekmovalcev v alpskem smučanju. [Increasing the Impact of Selected Characteristics on the Performance of Young Alpine Skiing Competitors]. *Šport, 60*(1/2), 136-142.

Bertozzi, F., Tenderini, D., Camuncoli, F., Simoni, G., Galli, M., & Tarabini, M. (2024). Bioimpedance vector analysis-derived body composition influences strength and power in alpine skiers. *Research Quarterly for Exercise and Sport*, *95*(3)1-7. https://doi.org/10.1080/02701367.2023.2298464

Ferland, P. M., & Comtois, A. S. (2018). Athletic profile of alpine Ski racers: a systematic review. *The Journal of Strength & Conditioning Research*, *32*(12), 3574-3583. https://doi.org/10.1519/JSC.0000000000002900

Inbody720. (2024, 16. may) Inbody. https://inbody.com/eng/product/inbody720.aspx

Klika, R., & Malina, R. (2003). Predicting skiing performance in 14-18 years old competitive alpine skiers. In E. Kornexl, E. Muller, C. Raschner, & H. Schwameder (Eds.). *Science and skiing* (pp. 13-26). E & FN Spon.

Kresal, F., Bračun, Š., Tönig, L., & Amon, M. (2021). Physical therapy recommendations for injury prevention in alpine skiing. *Annales Kinesiologiae*, *12*(1), 43-55. https://doi.org/10.35469/ak.2021.320.

Lešnik, B. (1999). *Definiranje in primerjava učinkovitosti gibalnih struktur sodobnih veleslalomskih tehnik. [Defining and Comparing the Efficiency of Motor Structures of Modern Giant Slalom Techniques].* (Unpublished doctoral dissertation). Univerza v Ljubljani, Fakulteta za šport, Ljubljana.

Lešnik, B. & Žvan, M. (2007). *Naše smučine: teorija in metodika alpskega smučanja. [Our Tracks: Theory and Methodology of Alpine Skiing].* Ljubljana: SZS – ZUTS.

McKnight, P. (2018). Alpine Skiing. In *Routledge Handbook of Strength and Conditioning* (pp. 568–582). Abingdon: Routledge.

Müller, E., Schwameder, H., Kornexl, E. & Raschner, C. (1997). *Science and skiing*. Salzburg: University of Salzburg.

Pernuš, K. (2018). *Vpliv izbranih parametrov telesne sestave na uspešnost mlajših kategorij v alpskem smučanju.* [The influence of specific body structure parametres to the success of younger categories in alpine skiing]. (Master Thesis). Retrieved from Repository of the University of Ljubljana. https://repozitorij.uni-lj.si/IzpisGradiva.php?lang=eng&id=102260

Puhalj, S. (2018). *Vrednotenje uspešnosti tekmovalnega alpskega smučanja v obdobju poznega otroštva in adolescence*. *[Evaluation of the Performance of Alpine Ski Racing in Late Childhood and Adolescence].* (Unpublished doctoral dissertation Retrieved from Repozitorij Univerze na Primorskem. https://repozitorij.upr.si/IzpisGradiva.php?lang=slv&id=10133

Puhalj, S., & Lešnik, B. (2018). The relationship between dimensions of technical knowledge of young alpine skiing competitors and competitive performance. *Annales Kinesiologiae*, *9*(1), 45-55. https://doi.org/10.35469/ak.2018.166

Puhalj, S., Lešnik, B., Povhe, A., Kelc, R., & Matejek, Č. (2021). Correlations between motor and anthropometric variables and the performance of young competitors in alpine skiing. *Annales Kinesiologiae*, *12*(2), 103-115. https://doi.org/10.35469/ak.2021.338

Rajtmajer, D. (1984). *Morfološke in motorične karakteristike kot prediktor uspeha v alpskem smučanju. [Morphological and Motor Characteristics as a Predictor of Success in Alpine Skiing.]* (Unpublished doctoral dissertation). Univerza v Ljubljani, Fakulteta za šport, Ljubljana.

Sands, W.A., R McNeal, J., Bullock, J., Schiller, T., Deck, H., Penitente, G., ... & C Bogdanis, G. (2021). Body size and composition of US National Team skiers and snowboarders. *Journal of Sports Research*, *8*(1), 16–25. https://doi.org/10.18488/journal.90.2021.81.16.25

Scherr, J., Geissler, U., Waibel, K. H., Blume, K., Maier, W., Halle, M. & Wolfarth, B. (2011). Psysiologische Einflussfaktoren im Alpinen Skirennlauf Influencing on alpine skiing performance. *Sport-Orthopadie – Sport- Traumatologie, 27*(4), (239-246). https://doi.org/10.1016/j.orthtr.2011.10.004

Smučarska zveza Slovenije [SZS]. (2019). *Alpsko smučanje – Otroški program*. [Alpine skiing - Children's program] Retrieved from https://www.sloski.si/resources/files/pdf/alpsko-smucanje/19_20/NPTS/U16_RDECI_2019-20.pdf

Supej, M. (2008). Differential specific mechanical energy as a quality parameter in racing alpine skiing. *Journal of Applied Biomechanics, 24*(2), 121–129. https://doi.org/10.1123/jab.24.2.121

Škof, B. (2016). *Šport po meri otrok in mladostnikov: Pedagoški, didaktični psiho – socialni, biološki in zdravstveni vidiki športne vadbe mladih. [Sport tailored to children and young people: Pedagogical, didactic psychology - social, biological and health aspects of young people's sports practice.].* Univerza v Ljubljani, Fakulteta za šport.

Šteharnik, M. (2013). *Vpliv telesnih mer na uspešnost mlajših kategorij v alpskem smučanju. [The Influence of Physical Conditions on Effectiveness of Younger Ages in Alpine Skiing]* (Unpublished Master Thesis). Univerza v Ljubljani, Fakulteta za šport, Ljubljana.

[TC]² (2024, 16.5.2024) 3D Body Scan device. https://www.tc2.com

Vermeulen, B., Clijsen, R., Fässler, R., Taeymans, J., D'Hondt, E., & Aerenhouts, D. (2017). Event specific body characteristics of elite alpine skiers in relation to international rankings. *Advances in Anthropology*, *7*(2), 94-106. https://doi.org/10.4236/aa.2017.72007

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DIETARY HABITS OF SHOOTING ATHLETES: A COMPARATIVE STUDY OF SLOVENIAN AND FOREIGN ATHLETES

Tadeja JAKUS[1], Nika ČERNE[1], Mojca STUBELJ[1]

[1]Faculty of Health Sciences, University of Primorska, Izola, Slovenia

Corresponding author:
Tadeja Jakus
Department of Nutritional Counseling – Dietetics,
Faculty of Health Sciences, University of Primorska, Polje 42, SI-6310 Izola, Slovenia
E-mail: tadeja.jakus@upr.si

ABSTRACT

Purpose*: Shooting is a sport in which dietary habits and the timing of meals is not often represented. The aim of this paper is to compare the dietary habits, timing of meals and training frequency of Slovenian and foreign athletes.*

Methods*: The sample included 88 shooter athletes (35 Slovenian and 53 foreign athletes), aged 14 to 60, who participate in competitions. Data by dietary habits, diet, training and BMI were collected via a questionnaire.*

Results*: Athletes train and compete most frequently using an air rifle. Foreign athletes train more often and spend more time training than Slovenian athletes ($p < 0.001$). The average BMI was 24.9 ± 4.9 kg/m^2 and was higher in athletes who competed at national level (26.8 ± 5.6 kg/m^2) compared to international level (23.0 ± 3.1 kg/m^2) ($p = 0.022$). We found a difference between the groups in lunch ($p = 0.041$), morning ($p = 0.020$) and evening ($p = 0.008$) snacks. Slovenian athletes reached for food during training less frequently than foreign athletes ($p = 0.007$). More than half of the athletes eat their first post-workout meal within 1-2 hours after training but only 8.6% of Slovenian athletes plan a meal after training, in comparison with 54.7% of foreign athletes ($p < 0.001$).*

Conclusions*: This study highlights significant differences in the timing and frequency of meals and dietary planning by Slovenian and foreign shooting athletes. Foreign* *athletes tend to train more frequently, have better nutritional planning and eat more meals after training than their Slovenian counterparts.*

Keywords: *shooting, nutrition, eating behaviour*

PREHRANSKE NAVADE ŠPORTNIKOV V STRELSTVU: PRIMERJALNA ŠTUDIJA SLOVENSKIH IN TUJIH ŠPORTNIKOV

IZVLEČEK

Namen*: Strelstvo je šport, kjer so prehranske navade in režim prehranjevanja slabo raziskani. Namen članka je primerjati prehranske navade, režim prehranjevanja in pogostnost treninga slovenskih in tujih športnikov.*

Metode*: Vzorec je vključeval 88 kategoriziranih strelcev športnikov (35 slovenskih in 53 tujih) med 14 in 60 letom starosti, ki sodelujejo na tekmovanjih. Podatki o prehranjevalnih navadah, prehrani, treningu in indeksu telesne mase (ITM) so bili zbrani z uporabo vprašalnika.*

Rezultati*: Športniki najpogosteje trenirajo in tekmujejo z zračno puško. Tuji športniki trenirajo pogosteje in več časa kot slovenski ($p < 0{,}001$). Povprečni ITM je bil 24,9 ± 4,9 kg/m² in je bil višji pri športnikih, ki tekmujejo na nacionalni ravni (26,8 ± 5,6 kg/m²) v primerjavi s svetovno ravnijo (23,0 ± 3,1 kg/m²) ($p = 0{,}022$). Ugotovili smo razlike v pogostnosti uživanja obrokov med slovenskimi in tujimi športniki pri kosilu ($p = 0{,}041$), dopoldanski ($p = 0{,}020$) in popoldanski ($p = 0{,}008$) malici. Slovenski športniki med treningom redkeje posegajo po hrani v primerjavi s tujimi ($p = 0{,}007$). Več kot polovica športnikov zaužije prvi obrok po treningu v 1–2 urah po vadbi, vendar le 8,6 % slovenskih športnikov načrtuje obrok po treningu, medtem ko to počne kar 54.7% tujih ($p < 0{,}001$).*

Zaključek*: Študija poudarja pomembne razlike v času in pogostnosti obrokov ter načrtovanju prehrane med slovenskimi in tujimi strelci. Tuji športniki pogosteje trenirajo, imajo bolje načrtovano prehrano in zaužijejo več obrokov po treningu kot njihovi slovenski kolegi.*

Ključne besede: *strelstvo, prehrana, prehranske navade*

INTRODUCTION

Shooting is one of the oldest sports disciplines in the world and has a long history in the Olympics (Molla, Sadeghi & Bayati, 2018). The history of marksmanship in Slovenia dates back to the 16th century (1562), when the society of Ljubljana sharpshooters, one of the first in Europe, is first mentioned (Shooting Union of Slovenia, 1991). Shooting is a sport with over 15 categories and is a skill-based sport where consistency, accuracy, speed shooting and concentration are key features. Strength and endurance are also important for supporting the firearm for long periods (Sports dietetians Australia, 2010). Coaches' experience shows that body sway significantly impacts performance (Mon, Zakynthinaki, & Calero, 2019), which is associated with age, body height and body mass (Hue et al., 2007). Research indicates that the average body mass of shooters is higher than in other sports (Heazlewood et al., 2016; Mon, Zakynthinaki, Cordente, Monroy & López, 2014), but this is due to lean muscle mass (Fortes de Souza, Barroso, Barbosa, Telles & Andries, 2015). Several studies have shown a positive correlation between muscle mass and shooting performance (Mon et al., 2019; Peljha, Michaelides & Collins, 2018). However, extremely low or high body mass can lead to poor muscle stability and thus contribute to poorer results (Hue et al., 2007).

Today it is known that nutrition also contributes to stable body and muscle mass, but not only that. Maintaining concentration, preventing physical and mental fatigue, and promoting adaptation to maximise the benefits from time spent in the shooting range or gym are the primary goals of shooter sport nutrition (Novan, Irianto, Komarudin & Awwaludin, 2021; Spriet & Gibala, 2004). Research shows that bioactive components in foods can influence concentration, focus and relaxation, which are important for shooters (Boyle, Lawton & Dye, 2017, Yilmaz et al., 2023, Machado, Durate, Mostarda, Irigoyen, & Rigatto, 2016). Likewise positioning meals around training sessions is useful for performance, appetite and supporting body composition. Portion-advised and well-timed meals and snacks can prevent over-eating later in the day (Jalph & Kaur, 2023). Choosing high-quality carbohydrate-based meals and snacks with small amounts of protein prior to training helps maximise energy needed by the eyes, muscles and brain for enhanced concentration and stamina (Sports dietetians Australia, 2010). During training sessions, which can last for several hours, it is also important to replenish energy and fluids. For athletes training for more than one hour, it is recommended to ensure adequate carbohydrate intake during exercise. Current nutritional guidelines for athletes advise to consume carbohydrates during exercise at different rates

(30-90 g/h) and in relation to the duration of exercise bouts (Podlogar & Wallis, 2022). In the case of shorter training sessions or competitions (< 1 h), carbohydrate mouth rinsing is recommended, as research shows that carbohydrates can be sensed in the oral cavity, causing an activation of certain brain regions, leading to stimulation of the central nervous system, as shown by improved performance (Chambers, Bridge & Jones, 2009). During training, it is also necessary to ensure adequate hydration. Sometimes, temperatures at the shooting range can be very high or low, both of which increase the risk of dehydration (Morgenthaler & Shumway, 2002). Proper hydration is critical for athletes. Ensuring adequate fluid intake before, during, and after exercise helps maintain performance and prevent dehydration, which can negatively impact focus and precision (Laxmeshwar & Hiremath, 2017). Similarly, nutrition is shown to be an important factor for recovery after exercise. Research indicates that both the timing of the first meal consumed immediately after exercise (within 2 hours of exercise) and its composition (a combination of carbohydrates and proteins) are of significance (Amawi et al., 2024; Nhung & Khanh, 2023). Therefore, planning the post-training meal ahead of the exercise itself is crucial.

From reviewing the literature, we found a very limited number of studies examining the dietary habits of shooter athletes, even though diet, as described, can impact the health and performance outcomes of athletes. Therefore, our intention was to investigate the dietary habits of athletes in relation to training, as well as the frequency of food consumption. The study highlights the importance of timing and composition of meals relative to training (before/during/after training) and aims to provide insight into optimising dietary practices tailored for shooter athletes, potentially enhancing their performance and well-being.

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METHODS

Questionnaire

The questionnaire designed for this study consisted of several sets of validated questions and covered basic socio-demographic data, nutrition and physical/sport activity. We utilised an adapted section of the European Health Interview Survey (EHIS) to evaluate eating habits, including regular diet and dietary type (Eurostat European Commission, 2018). Additionally, we incorporated elements from the pilot study for the Assessment of Nutrient Intake and Food Consumption Among Kids in Europe (PANCAKE) to analyse food and meal frequency (Ocké et al., 2012), as well as a portion of the FFQ designed to assess food intake within the Slovene population (Bizjak, Jenko-Pražnikar & Seljak, 2014). The food choices were based on a validated questionnaire for athletes (Ishikawa-Takata, Okamoto, Taguchi, 2021). The training questionnaire design was carried out by professional coaches and dietitians. The survey questionnaire was initially tested on a smaller sample of athletes to check whether the athletes understood the questions. The final questionnaire included 22 questions items relating to three different areas: demographics, nutrition and sports activity. We forwarded the e-questionnaire to the Shooting Association of Slovenia and Slovenian shooting clubs, and it was also forwarded to 9 foreign countries and their shooting association and clubs (Austria, Italy, Denmark, Norway, Russia, Croatia, Germany, Serbia and Finland). The responses regarding height and weight enabled us to calculate the athletes' body mass index (BMI). BMI is defined as a person's weight in kilogrammes divided by the square of the person's height in metres (kg/m^2).

The study protocol was approved by the Commission of the University of Primorska for Ethics in Human Subjects Research (KER UP) (No. 4264-19-6/23 and 17/01/23).

Participants

161 athletes (65 Slovenian and 96 foreign athletes) took part in the online survey. However, we subsequently excluded 73 (45%) questionnaires from the analysis due to incomplete data or participants not taking part in a competition. The final sample consisted of 88 correctly completed questionnaires, which were answered by 35 Slovenian and 53 foreign athletes.

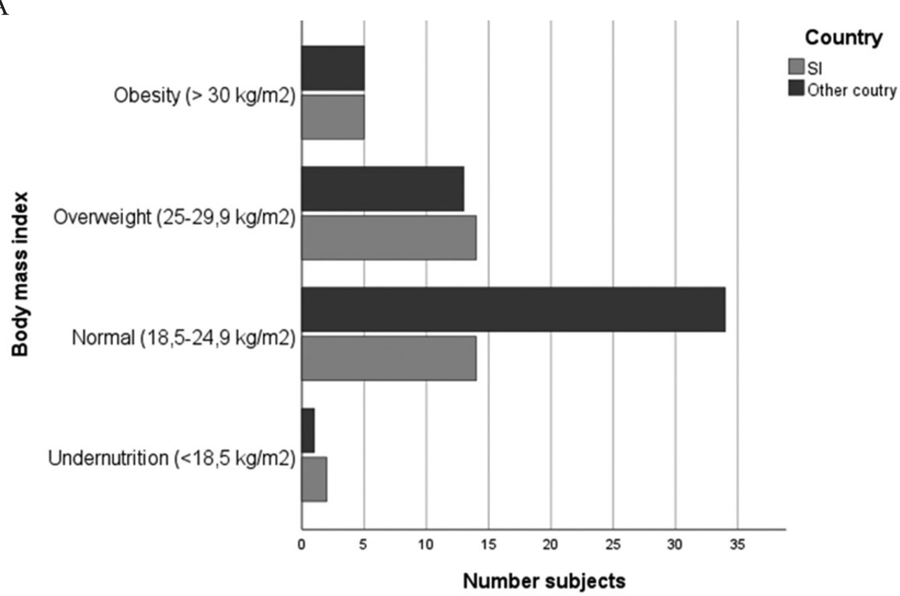
Statistical analyses

The collected data were processed using the IBM-SPSS statistical software version 22.0. Quantitative data analysis was based on descriptive statistics. Normal distribution was assessed using skewness and kurtosis coefficients. To analyse differences in body mass index (BMI) between genders, we used an independent t-test and calculated Cohen's d to assess the effect size. For other variables, we performed the non-parametric Mann-Whitney and Kolmogorov-Smirnov test to compare athletes' groups and used the Wendt formula to calculate the effect sizes (rb). For comparing correlations between BMI and nutrition characteristics, we used the Spearman rho coefficient indicating significant correlations at $p < 0.05$.

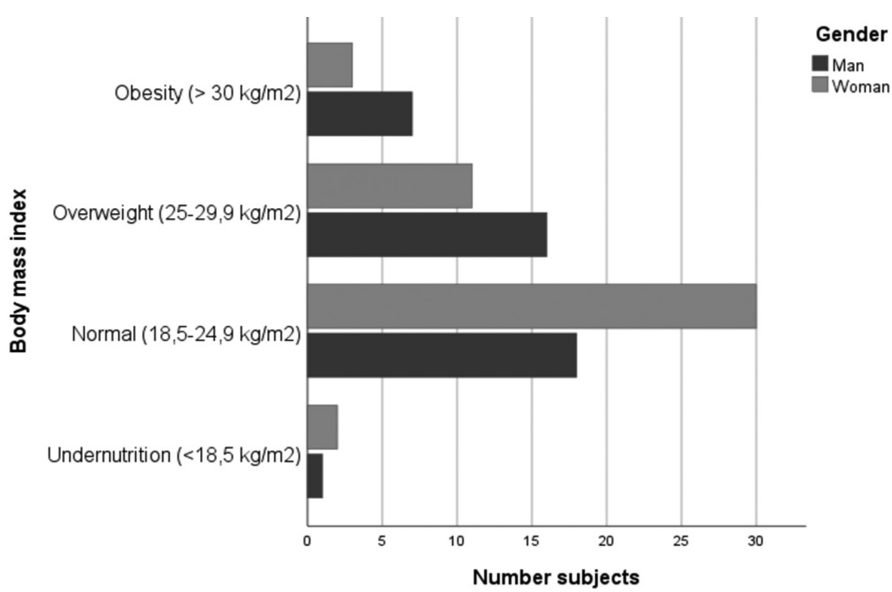
RESULTS

A total of 42 men (48%) and 46 women (52%) took part in the survey. The average age of the participants was 30.6 ± 14.0 years. Of these, 70.5% of the athletes were in the 20-60 age group , 27.3% were adolescents (14-20 years) and 2.3% were older adults (> 60 years). We no found differences in body weight (77.3 ± 16.3 kg vs. 70.9 ± 15.6 kg), BMI (25.8 ± 5.1 kg/m^2 vs. 24.9 ± 4.9 kg/m^2) and height (173 ± 8 cm vs. 171 ± 8 cm) between Slovenians and foreigners. Differences in BMI were found between genders (men: 26.0 ± 4.8 kg/m^2, women: 23.8 ± 4.8 kg/m^2; $t = 2.358$, $d = 0,724$, $p = 0.021$) and between participants in world championships (23.0 ± 3.1 kg/m^2) and national competitions (26.8 ± 5.6 kg/m^2) ($Z = 2.332$, $r_b= 0.585$, $p = 0.022$). The distribution of athletes into BMI groups based on nationality, gender and competition is shown in Figure 1.

A



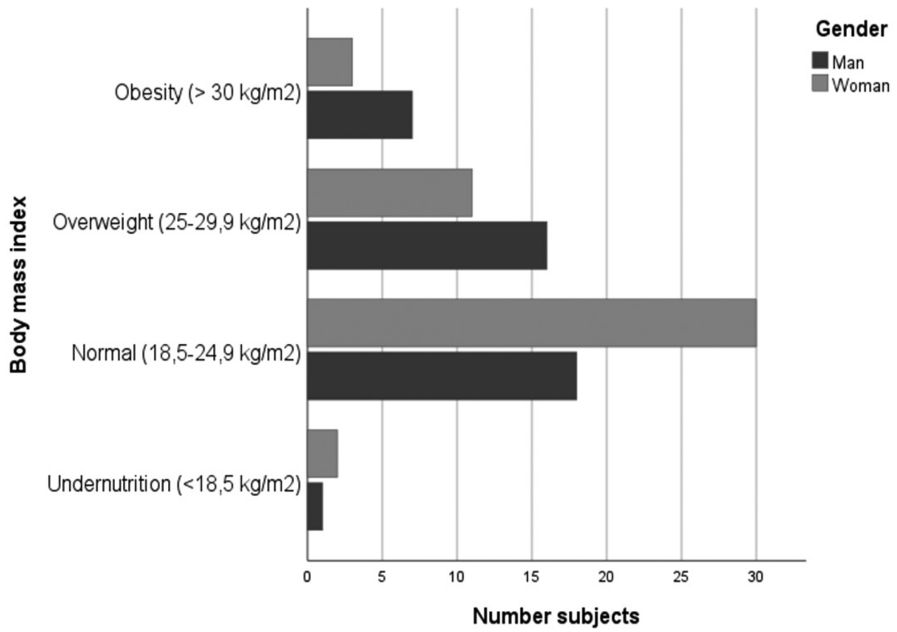
B



A: Comparison of the body mass index of Slovenian and foreign athletes; B: Comparison of the body mass index of athletes by gender;

Fig. 1 A,B: Body mass index.

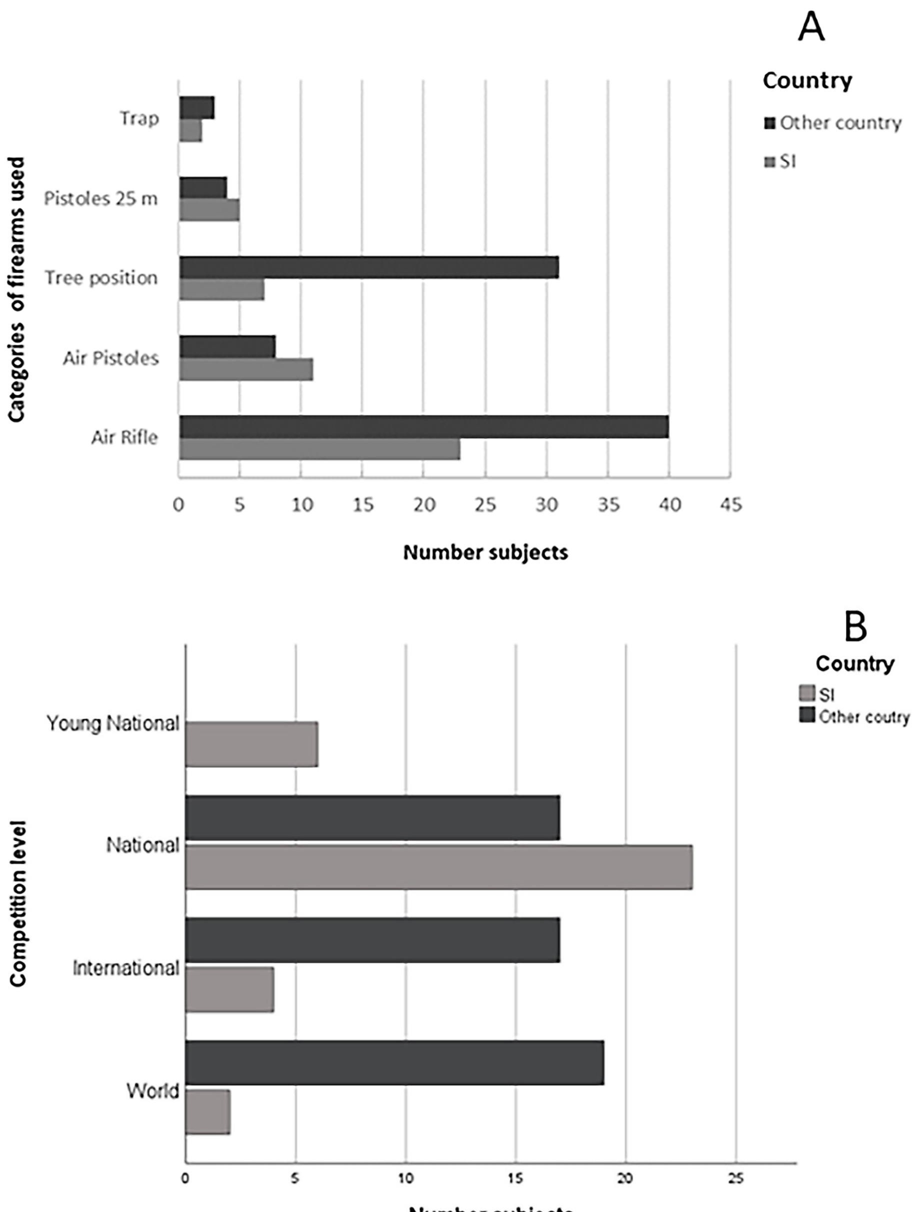
C



C: Comparison of BMI by competition level.

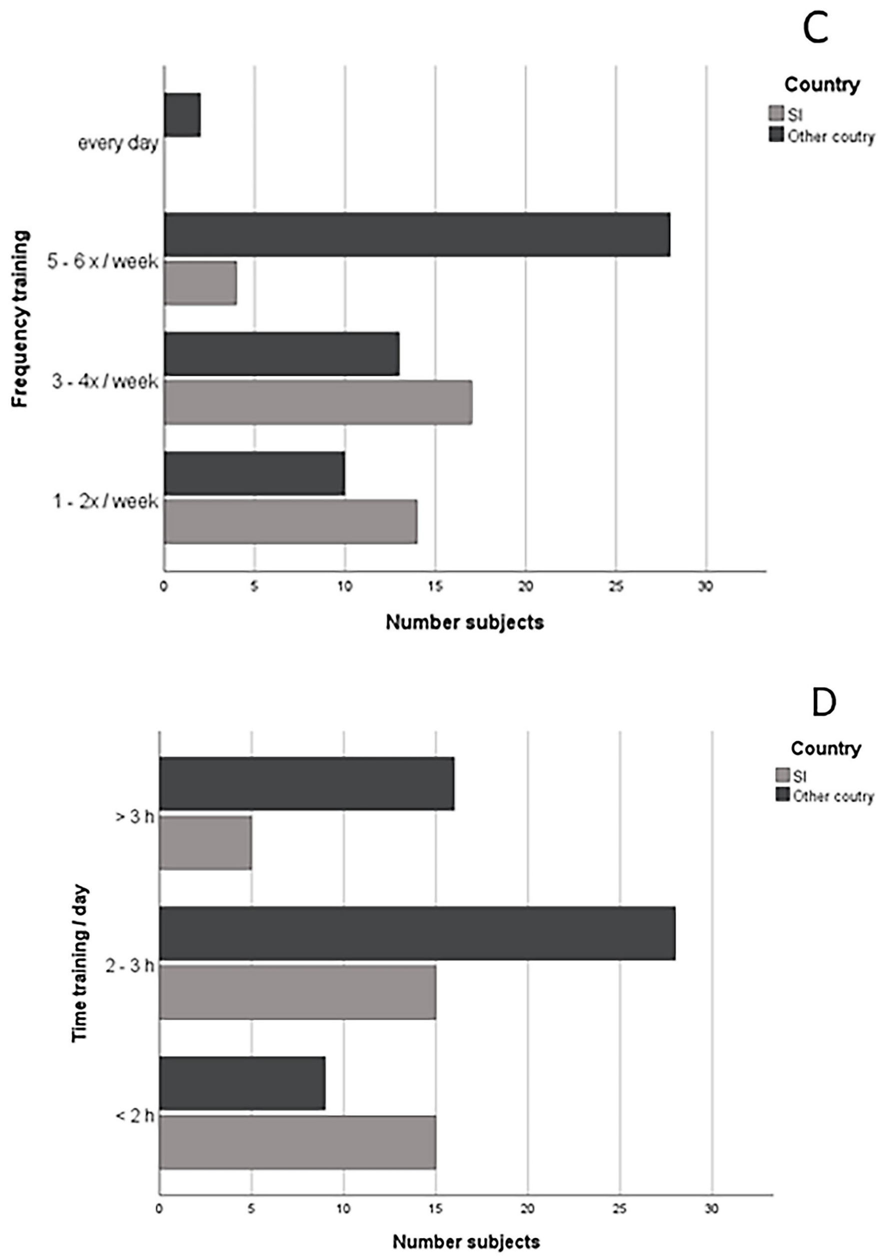
Fig. 1 C: Body mass index.

The athletes train and compete most frequently with an air rifle (Fig. 2A). The two groups differ according to the time they spend training ($Z = -3.682$, $r_b = 0.441$, $p < 0.001$). Foreign athletes train more frequently and spend more time training than Slovenian athletes (Fig. 2C and 2D). However, the time they spend on training is related to the level of competition ($rho = -0.478$, $p < 0.001$). There were also differences between the groups in terms of participation in competitions ($Z = -4.939$, $r_b = 0.585$, $p < 0.001$). Most foreign athletes participate in international competitions (35.8%), while Slovenian athletes participate more often in national competitions (65.7%) (Fig. 2B).



A: Comparison of the firearms categories used by Slovenian and foreign athletes; B: Comparison of the competition level of Slovenian and foreign athletes

Figure 2 A,B: Training characteristic.



C: Comparison of the training frequency (in days) of Slovenian and foreign athletes; D: Comparison of the duration of training (in days) of Slovenian and foreign athletes

Figure 2 C,D: Training characteristic.

Dietary habits of athletes

All Slovenian athletes are omnivores, while among foreign athletes, 74% are omnivores, 13% are vegetarians, the rest have various alternative diets. The frequency of meal consumption is presented in Table 1.

All athletes eat dinner regularly (80.7%), while 61.4% of athletes eat breakfast regularly. We found a difference between the groups at lunch ($Z = -2.045$, $r_b = 0.139$, $p = 0.041$), but otherwise foreign athletes ate lunch slightly less often than Slovenian athletes (83.0% vs. 97.1%). There was also a difference in the morning snack ($Z = -3.117$, $r_b = 0.364$, $p = 0.020$): 58.4% of foreign athletes do not eat it, while it is a favourite meal among Slovenian athletes and is eaten by 51.4%. The exact opposite trend can be observed for the afternoon snack ($Z = -2.632$, $r_b = 0.313$, $p = 0.008$), where we also found a statistically significant medium negative correlation with BMI (rho = -0.288, $p = 0.006$). On average, athletes consumed 1.7 ± 0.8 L of fluid per day, of which Slovenian athletes consumed 1.6 ± 0.8 L/day and foreign athletes 1.8 ± 0.8 L/day ($Z = -1.956$, $r_b = 0.085$, $p = 0.496$).

Regarding the timing of training, half of the athletes (50%) ate a meal 1-2 hours before training and a quarter (25%) ate a meal less than one hour before training, we found no differences between the groups. However, we found differences in the choice of food for the pre-workout meal. Slovenian athletes consumed pasta ($Z = -2.058$, $r_b = 0.242$, $p = 0.040$), potatoes ($Z = -1.985$, $r_b = 0.226$, $p = 0.050$) and red meat ($Z = -2.409$, $r_b = 0.284$, $p = 0.016$) more often before training than foreign athletes (Table 2), although the effect sizes for these differences indicate small to moderate significance.

The two groups differ in terms of food intake during training ($Z = -2.697$, $r_b = 0.263$, $p = 0.007$), i.e. Slovenian athletes consume meals less frequently than foreign athletes (11.4% vs. 37.7%), and a total of 72.7% do not consume any food during training. Fluid intake during training is mainly based on water, which is consumed by 80% of Slovenian athletes and 94% of foreign athletes. Athletes consumed on average 0.3 ± 0.2 L/h during training and we found no differences between the groups ($Z = -1.414$, $r_b = 0.176$, $p = 0.157$). Slovenian athletes do not drink coffee, tea or energy drinks, and even among foreign athletes less than 4% do.

Most Slovenian athletes (60%) eat their first post-workout meal within 1-2 hours after training, while more than half (52.8%) of foreign athletes eat their first post-workout meal immediately after training. Another striking difference is that only 8.6% of Slovenian athletes plan a meal after training, while as many

Table 1: Meal frequency

Meal and frequency of consumption	SI N (%)	Other countries N (%)	Total N (%)	p
Breakfast				0.922
Every day	20 (57.1)	33 (62.3)	54 (61.4)	
Occasionally	8 (22.9)	7 (13.2)	15 (17.0)	
Never	6 (17.1)	13 (24.5)	19 (21.6)	
Morning snack				**0.020**
Every day	18 (51.4)	11 (20.8)	29 (33.0)	
Occasionally	7 (20.0)	11 (20.8)	18 (20.5)	
Never	10 (28.6)	31 (58.4)	41 (46.6)	
Lunch				**0.041**
Every day	34 (97.1)	44 (83.0)	78 (88.6)	
Occasionally	1 (2.9)	7 (13.2)	8 (9.1)	
Never	0 (0)	2 (3.8)	2 (2.3)	
Evening snack				**0.008**
Every day	6 (17.1)	24 (45.3)	30 (34.1)	
Occasionally	11 (31.4)	13 (24.5)	24 (27.3)	
Never	18 (51.4)	16 (30.2)	34 (38.6)	
Dinner				0.066
Every day	25 (71.4)	46 (86.8)	71 (80.7)	
Occasionally	7 (20.0)	6 (11.3)	13 (14.8)	
Never	3 (8.6)	1 (1.9)	4 (4.5)	
Time meals before training				0.261
>3 h	4 (11.4)	8 (15.1)	12 (13.6)	
2-3 h	5 (14.3)	5 (9.4)	10 (11.4)	
1-2 h	21 (60)	23 (43.4)	44 (50)	
<1 h	5 (14.3)	17 (32.1)	22 (25)	
Meals enduring training				**0.007**
Yes	4 (11.4)	20 (37.7)	24 (27.3)	
No	31 (88.6)	33 (62.3)	64 (72.7)	
Time meals after training				0.740
<1h	14 (40.0)	28 (52.8)	42 (47.7)	
1-2 h	21 (60.0)	17 (32.1)	38 (43.2)	
>2h	0 (0.0)	8 (15.1)	8 (9.1)	
Meal planning after training				**<0.001**
Yes	3 (8.6)	29 (54.7)	32 (36.4)	
No	32 (91.4)	24 (45.3)	56 (63.6)	

Occasionally: 2-6 days per week; Never: never eats this meal.

as 54.7% of foreign athletes do so ($Z = -4.379$, $r_b = 0.461$, $p < 0.001$). The effect size ($r_b = 0.461$) indicates a moderate to large practical significance. This result indicates a significant difference in dietary habits, as foreign athletes are significantly more likely to plan a meal after training compared to their Slovenian counterparts.

Table 2: Food consumption frequency before training.

Number of meals	SI N (%)	Other countries N (%)	Total N (%)	p
Fruits				0.323
Often	12 (34.3)	24 (45.3)	36 (40.9)	
Occasionally	18 (51.4)	23 (43.4)	41 (46.6)	
Never	5 (14.3)	6 (11.3)	11 (12.5)	
Vegetable salad				0.141
Often	15 (42.9)	17 (32.1)	32 (36.4)	
Occasionally	14 (40.0)	19(35.8)	33 (37.5)	
Never	6 (17.1)	17 (32.1)	23 (26.1)	
Soup				0.110
Often	11 (31.4)	10 (18.9)	21 (23.9)	
Occasionally	15 (42.9)	22 (41.5)	37 (42.0)	
Never	9 (25.7)	21 (39.6)	30 (34.1)	
Potato				**0.050**
Often	18 (51.4)	17 (32.1)	35 (39.8)	
Occasionally	13 (37.1)	24 (45.3)	37 (42.0)	
Never	4 (11.4)	12 (22.6)	16 (18.2)	
Pasta				**0.040**
Often	19 (54.3)	20 (37.7)	39 (44.3)	
Occasionally	13 (37.1)	18 (34.0)	31 (35.2)	
Never	3 (8.6)	15 (28.3)	18 (20.5)	
Rice				0.390
Often	18 (51.4)	24 (45.3)	42 (47.7)	
Occasionally	13 (37.1)	18 (34.0)	31 (35.2)	
Never	4 (11.4)	11 (20.8)	15 (17.0)	
White meat				0.116
Often	20 (57.1)	26 (49.1)	46 (52.3)	
Occasionally	13 (37.1)	11 (20.8)	24 (27.3)	
Never	2 (5.7)	16 (30.2)	18 (20.5)	

Number of meals	SI N (%)	Other countries N (%)	Total N (%)	p
Red meat				**0.016**
Often	11 (31.4)	12 (22.6)	23 (26.1)	
Occasionally	20 (57.1)	19 (35.8)	39 (44.3)	
Never	4 (11.4)	22 (41.5)	26 (29.5)	
Fish				0.634
Often	2 (5.7)	11 (20.8)	13 (14.8)	
Occasionally	24 (68.6)	19(35.8)	43 (48.9)	
Never	9 (25.7)	23(43.4)	32 (36.4)	
Milk drinks				0.068
Often	7 (20.0)	22 (41.5)	29 (33.0)	
Occasionally	20 (57.1)	22 (41.5)	42 (47.7)	
Never	8 (22.9)	9 (17.0)	17 (19.3)	
Nuts				0.079
Often	7 (20.0)	19 (35.8)	26 (29.5)	
Occasionally	19 (54.3)	26 (49.1)	45 (51.1)	
Never	9 (25.7)	8 (15.1)	17 (19.3)	

Often: every day; Occasionally: 2-6 days per week; Never: never eats these foods before training.

DISCUSSION

Research shows that body mass can have an influence on body sway during a shot and is therefore linked to shooting success (Mon et al., 2014, 2019). A higher BMI with less body fat can lead to more strength and stability in the joints of the lower limbs, resulting in better static balance in athletes (Kerr & Stewart, 2008). Also, in our case, we have shown that the average BMI of the athletes is slightly above the cut-off that defines a normal value, but due to the reduced body composition measurements, we cannot know whether this is at the expense of body fat or muscle mass. However, the fact is that 12.5% of the athletes had a BMI > 30 kg/m^2, which could have influenced poorer results. Individuals with a BMI over 30 kg/m^2 are less likely to remain in a stable condition and are more likely to become obese than those who are not (BMI < 30 kg/m^2) (Hills & Parker, 1991; McKean, 2010). It is generally recognised that BMI is related to dietary habits and eating patterns.

We have shown that there is a difference in nutrition between Slovenian and foreign athletes. Slovenian athletes are more likely to have a mid- morning snack and lunch, while foreign athletes are more likely to have an afternoon snack. These meals are usually also the meals that athletes eat before training, so they are an important source of energy for successful training. Athletes most often eat a meal 1-2 hours before training. According to the basic recommendations for sports nutrition, in this case the meal should consist of 1-2 g carbohydrate/kg body weight and 0.3 g protein/kg body weight, and fat intake should be limited (Kerksick et al., 2018). We have shown that athletes often reach for carbohydrate-containing foods and meat before training. We found a difference between the two groups in the consumption of potatoes ($p = 0.05$), pasta ($p = 0.04$) and red meat ($p = 0.02$), which Slovenians consume more often than foreigners. The foods mentioned correspond to the above-mentioned nutrient groups in the guidelines, but it would also be necessary to analyse the quantitative intake, as it often happens that athletes consume too much protein and fat and not enough carbohydrates (Baranauskas, Jablonskienė, Abaravičius, & Stukas, 2020)dietary supplementation and body composition of elite athletes. Materials and Methods: The research subjects were 76.7% of Lithuanian elite athletes (N = 247).

Athletes usually spend more than 2 hours/day on the shooting range; during training they usually do not touch food and consume little liquid (0.3 L/h), in most cases water. Shooters may avoid drinking during competition so that they do not have to take bathroom breaks. However, the benefits of being well hydrated far outweigh the disadvantages (Sports dietetians Australia, 2010). Studies show that the consumption of moderate amounts of carbohydrates during exercise leads to a significant increase in psychometric parameters in sports shooters, mainly due to a reduction in false and delayed reactions (Lachtermann et al., 1999). The combination of low fluid intake during training (0.3 L/h) and daily fluid intake (1.7 ± 0.8 L/day) can lead to dehydration. Dehydration can impair focus and concentration and have a negative impact on skills and coordination (Adan, 2012). Shooters should drink adequate fluids to maintain good hydration levels during training and competition (Sports dietetians Australia, 2010). In both groups of athletes, the daily fluid intake was found to be below the recommended values (2 L/day), although the fluid requirements vary depending on the athletes' size and gender as well as the environmental conditions (e.g. hot, humid weather, which can be common during training and competition). Sports drinks may be useful as part of a fluid plan during events as the fluid, carbohydrate and electrolyte mix can improve fluid absorption from the gut, improve mental focus and promote fluid retention (Pérez-Castillo et al., 2023).

Despite the popularity of energy and caffeinated drinks in recent years, we have shown that athletes only use caffeinated drinks to a very limited extent during training, which is a good thing. Consuming caffeinated drinks may have a negative effect in this sport, since it is very important that heart rate is as slow as possible in order to have high concentration and avoid hand tremors. Consuming coffee or caffeine containing beverages within 1-2 hours before and during the competition increases heart rate, hinders aiming during shooting and extends trigger-squeezing times (Diler & Erikoğlu Örer, 2021). On the other hand, eating foods which contain natural compounds that mimic the effects of beta blockers can help calm the nervous system, lower the heart rate or relieve anxiety. For shooting athletes, it is potentially beneficial to include magnesium--rich foods (seeds, nuts, whole grains) (Boyle et al., 2017), flavonol-rich foods such as green or black tea (Yilmaz et al., 2023) and dark chocolate (Machado et al., 2016), tryptophan-rich foods (turkey, eggs, cheese, nuts) (Richard et al., 2009) in their diet. These foods are known to help reduce heart rate, blood pressure and anxiety, while facilitating relaxation and focus.

Nutrition after training is very important from the point of view of regeneration. Recent studies suggest that a recovery meal within 2 hours of exercise, as opposed to a meal that is not consumed, improves recovery (Amawi et al., 2024) and some authors recommend that athletes should consume a carbohydrate- and protein-rich meal or snack within 30 minutes of exercise or competition to improve muscle protein synthesis and promote recovery (Nhung & Khanh, 2023). In our case, 40% of Slovenian and 52% of foreign athletes ate a meal in the first hour after training, but not even a tenth of Slovenian athletes plan what they eat after training, in comparison to more than half of foreign athletes ($p<0.001$).

Although our study presents the eating habits of Slovenian and foreign athletes, there are some limitations. BMI was used as a measure of body size. For more accurate data, it would be reasonable to use a metric providing a more precise assessment of body composition than BMI. This can be evaluated through skinfold measurements, bioelectrical impedance analysis, or DEXA scans. We also only have data on the selection of foods before/during training, but not their quantity. It would also be necessary to analyse the quantitative intake in order to discuss adequate intake. An important aspect of future research also remains the consumption of foods that influence concentration, heart rate, and stress at shooter athletes.

CONCLUSION

This study provides a comparative insight into the dietary habits of Slovenian and foreign shooting athletes, highlighting significant differences in the timing and frequency of meals and dietary planning. Foreign athletes tend to train more frequently, have better nutritional planning and eat more meals after training than their Slovenian counterparts. Since our research has shown that the dietary habits of foreign shooters differ significantly from our own, these results give rise to concern that the diet of Slovenian shooters could be somewhat neglected. The literature emphasises the importance of nutrition for achieving optimal athletic performance, and these results could serve as a warning to Slovenian athletes, coaches and sports nutritionists about the need to focus more on nutrition, drink enough fluids during training and plan meals carefully after training.

REFERENCES

Adan, A. (2012). Cognitive Performance and dehydration. *Journal of the American College of Nutrition*, *31*(2), 71–78. https://doi.org/10.1080/07315724.2012.10720011.

Amawi, A., AlKasasbeh, W., Jaradat, M., Almasri, A., Alobaidi, S., Hammad, A. A., … Ghazzawi, H. (2024). Athletes' nutritional demands: A narrative review of nutritional requirements. *Frontiers in Nutrition*, *10*, 1331854. https://doi.org/10.3389/fnut.2023.1331854.

Baranauskas, M., Jablonskienė, V., Abaravičius, J. A., & Stukas, R. (2020). Actual Nutrition and Dietary Supplementation in Lithuanian Elite Athletes. *Medicina*, *56*(5), 247. https://doi.org/10.3390/medicina56050247.

Bizjak, M., Jenko-Pražnikar, Z., & Seljak, B. K. (2014). Development and validation of an electronic FFQ to assess food intake in the Slovene population. *Public health nutrition, 17*(8), 1729-1737. https://doi.org/10.1017/S1368980013002577.

Boyle, N. B., Lawton, C., & Dye, L. (2017). The effects of magnesium supplementation on subjective anxiety and stress—A systematic review. *Nutrients, 9*(5), 429. https://doi.org/10.3390/nu9050429.

Chambers, E. S., Bridge, M. W., & Jones, D. A. (2009). Carbohydrate sensing in the human mouth: Effects on exercise performance and brain activity. *The Journal of Physiology*, *587*(8), 1779–1794. https://doi.org/10.1113/jphysiol.2008.164285.

Diler, K., & Erikoğlu Örer, G. (2021). The effect of caffeine consumed before competition on heart rate, trigger squeeze time and shooting score in air pistol athletes. *Pakistan Journal of Medical and Health Sciences*, *15*(11), 3202–3205. https://doi.org/10.53350/pjmhs2115113202.

Eurostat European Commission. (2018). European Health Interview Survey (EHIS wave 3) Methodological manual. Publications Office of the European Union.

Retrieved from https://ec.europa.eu/eurostat/cache/metadata/en/hlth_det_esms.htm (26.11.2024).

Fortes de Souza, S. D., Barroso, R., Barbosa, A. C., Telles, T., & Andries, J. O. (2015). Anthropometric parameters of cadets among different military sports. *International Journal of Morphology, 33*(3), 831–834. https://doi.org/10.4067/S0717-95022015000300004.

Heazlewood, I. T., Walsh, J., Climstein, M., Adams, K., Sevene, T., & DeBeliso, M. (2016). Differences in participant motivation based on category of body mass index and gender. In M.-T. Leung & L. M. Tan (Eds.), *Applied Psychology Readings* (pp. 125–135). Springer Singapore. https://doi.org/10.1007/978-981-10-2796-3_9

Hills, A. P., & Parker, A. W. (1991). Gait characteristics of obese children. *Archives of Physical Medicine and Rehabilitation*, *72*(6), 403–407.

Hue, O., Simoneau, M., Marcotte, J., Berrigan, F., Doré, J., Marceau, P., … Teasdale, N. (2007). Body weight is a strong predictor of postural stability. *Gait & Posture*, *26*(1), 32–38. https://doi.org/10.1016/j.gaitpost.2006.07.005.

Jalph, J., & Kaur, G. (2023). Importance of diet and nutrition for athletes performance. *Journal of Sports Science and Nutrition*, *4*(2), 159–160. https://doi.org/10.33545/27077012.2023.v4.i2c.204.

Kerksick, C. M., Wilborn, C. D., Roberts, M. D., Smith-Ryan, A., Kleiner, S. M., Jäger, R., … Kreider, R. B. (2018). ISSN exercise & sports nutrition review update: Research & recommendations. *Journal of the International Society of Sports Nutrition*, *15*(1), 38. https://doi.org/10.1186/s12970-018-0242-y.

Kerr, A. D. & Stewart, D. A. (2008). Body composition in sport. In *Applied anatomy and biomehanics in sport.* (2nd ed., p. 366). Blackwell Publishing.

Lachtermann, E., Passarge, B., Gnauck G., Zuchold, H. D., Wolf, G. K., Rodziewicz, M., & Jung, K. (1999). Enhancement of sport shooting performance with short chain carbohydrates—A clinical approach. *Ernährung, 23*(9), 363–370.

Laxmeshwar, B. & Hiremath, S.R. (2017). Proper nutrition for athletes. *International Journal of Physical Education, 10*(1-2), 34–45. https://doi.org/10.15740/HAS/IJPE/10.1and2/34-45.

Machado Durate, A.A., Mostarda, C., Irigoyen, M.C., & Rigatto, K. (2016). A single dose of dark chocolate increases parasympathetic modulation and heart rate variability in healthy subjects. *Revista de Nuttricao*, *29*(6). https://doi.org/10.1590/1678-98652016000600002.

McKean, M. (2010). Training for improved balance and reduced body sway. *Australian Pistol Shooters Bulletin. May*, 7–9. Retrieved from https://research.usc.edu.au/esploro/outputs/journalArticle/Training-for-improved-balance-and-reduced/99450255602621/filesAndLinks?index=0.

Molla, Y., Sadeghi, H., & Bayati, A. (2018). The comparison of static balance among the elite shooters of the Iranian National Rifle and Pistol Shooting Team with an emphasis on principle anthropometric indicators. *Journal of Clinical Physiotherapy Research*, *3*(3). https://doi.org/10.22037/jcpr.v3i3.21496.

Mon, D., Zakynthinaki, M. S., & Calero, S. (2019). Connection between performance and body sway/morphology in juvenile Olympic shooters. *Journal of Human Sport and Exercise*, *14*(1). https://doi.org/10.14198/jhse.2019.141.06.

Mon, D., Zakynthinaki, M. S., Cordente, C. A., Monroy Antón, A., & López Jiménez, D. (2014). Validation of a Dumbbell Body Sway Test in olympic air pistol shooting. *PLoS ONE*, *9*(4), e96106. https://doi.org/10.1371/journal.pone.0096106

Morgenthaler, A. B. & Shumway, F. D. (2002). Indoor shooting range. *ASHRAE Journal, 44*(12), 44–47.

Nhung, L. & Khanh, S. (2023). The Impact of Nutrient Timing on Athletic Performance: A case of Hanoi Athletes in Vietnam. *Journal of Food Science and Human Nutrition,2*(1), 1–9. Retrieved from https://gprjournals.org/journals/index.php/JFSHN/article/view/151.

Novan, A. N., Irianto, A. I. N., Komarudin, K., & Awwaludin, N. P. (2021). Effects of progressive muscle relaxation on concentration and performance scores of 10m shooters. *Journal Pendidikaan Jasmani Dan Olahraga, 6*(2). https://doi.org/10.17509/jpjo.v6i2.31630.

Ocké, M., de Boer, E., Brants, H., van der Laan, J., Niekerk, M., van Rossum, C., ... & Maly, M. (2012). PANCAKE–Pilot study for the assessment of nutrient intake and food consumption among kids in Europe. *EFSA Supporting Publications*, 9(9), 339E. https://doi.org/10.2903/sp.efsa.2012.EN-339.

Peljha, Z., Michaelides, M., & Collins, D. (2018). The relative importance of selected physical fitness parameters in olympic clay target shooting. *Journal of Human Sport and Exercise*, *13*(3). https://doi.org/10.14198/jhse.2018.133.06.

Pérez-Castillo, Í. M., Williams, J. A., López-Chicharro, J., Mihic, N., Rueda, R., Bouzamondo, H., & Horswill, C. A. (2023). Compositional Aspects of beverages designed to promote hydration before, during, and after exercise: concepts revisited. *Nutrients*, *16*(1), 17. https://doi.org/10.3390/nu16010017.

Podlogar, T., & Wallis, G. A. (2022). New Horizons in Carbohydrate Research and Application for Endurance Athletes. *Sports Medicine*, *52*(S1), 5–23. https://doi.org/10.1007/s40279-022-01757-1.

Richard, D. M., Dawes, M. A., Mathias, C. W., Acheson, A., Hill-Kapturczak, N., & Dougherty, D. M. (2009). L-tryptophan: basic metabolic functions, behavioral research and therapeutic indications. International Journal of Tryptophan Research, 2, IJTR-S2129. https://doi.org/10.4137/IJTR.S2129.

Shooting Union of Slovenia. (1991, January 6). *Zgodovinski oris strelstva na slovenskem*. Retrieved from https://www.strelska-zveza.si/sl/informacije/60--zgodovina/53-zgodovina-strelstva-na-slovenskem.html.

Sports dietetians Australia. (2010). *Food for your sport- shooting*. Retrieved from https://www.sportsdietitians.com.au/factsheets/food-for-your-sport/shooting/.

Spriet, L. L., & Gibala, M. J. (2004). Nutritional strategies to influence adaptations to training. *Journal of Sports Sciences*, *22*(1), 127–141. https://doi.org/10.1080/0264041031000140608.

Yilmaz, U., Buzdagli, Y., Lütfü, P. M., Bakir, Y., Ozhanci, B., Alkazan, S., & Ucar, H. (2023). Effect of single or combined caffeine and L-Theanine supplementation on shooting and cognitive performance in elite curling athletes: A double-blind, placebo-controlled study. *Journal of the International Society of Sports Nutrition, 20 (1)*. https://doi.org/10.1080/15502783.2023.2267536.

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THE ACUTE EFFECT OF MENTAL FATIGUE ON STRENGTH ENDURANCE IN YOUNG KICKBOXERS

Esra KÜRKCÜ AKGÖNÜL[1], Gökmen ÖZEN[2]

[1]Dokuz Eylul University, Physical Education and Sport, Izmir, Türkiye
[2] Çanakkale Onsekiz Mart University, Physical Education and Sport, Çanakkale, Türkiye

Corresponding Author:
Gökmen ÖZEN
Çanakkale Onsekiz Mart University, Physical Education and Sport, Çanakkale, Türkiye
Phone: +905056466329
E-mail: gokmenozen44@gmail.com

ABSTRACT

This study was conducted to examine the acute effects of Mental Fatigue (MF) on strength endurance in well-trained young kickboxers. A total of 17 female/male athletes (age: 15.76±1.44 years; height: 167.06±8.63 cm; body weight: 62.03±10.63 kg) participated. The Repeated Measurement Design was used. Accordingly, the participants had 3 sessions; pre-preparation, control, and mental fatigue. In the pre-preparation session, demographic information and one repetition maximum (1RM) for bench press (BP) and squat (SQ) exercises were taken. The athletes' strength endurance was performed until 60% of 1RM exhaustion; the number of repetitions (NOR) and movement time (MT) were recorded. In the MF session, the participants were subjected to a 30-minute Stroop task before the strength test. In order to determine the differences in NOR and MT between the sessions and the differences in measurements according to gender, the Paired sample t-test was used. The presence of MF significantly reduced SQ-NOR by 34.5%, SQ-MT by 36.88%, BP-NOR by 22.71%, and BP-MT by 28.27% ($p<0.05$). Based on gender, MF had a significant negative effect on SQ-NOR, SQ-MT, and BP-MT in women and men and on BP-NOR only in women athletes ($p<0.05$). As a result of the research, 30-min MF application negatively affects the lower and upper extremity strength endurance performance in young kickboxers. In this respect, young kickboxers should avoid activities that will cause mental fatigue such as using digital screens or *solving questions or puzzles for social media purposes for 30 min or more before training and competition, which will prevent possible muscular performance loss.*

Keywords: *endurance, kickboxing, mental fatigue, strength, young athlete*

AKUTNI UČINEK DUŠEVNE UTRUJENOSTI NA VZDRŽLJIVOST MOČI PRI MLADIH KIKBOKSERJIH

IZVLEČEK

Študija je bila izvedena zaradi proučitve akutnih učinkov mentalne utrujenosti (MF) na vzdržljivost moči pri dobro treniranih mladih kikbokserjih. Sodelovalo je 17 športnic in športnikov (starost: 15,76 ± 1,44 leta; višina: 167,06 ± 8,63 cm; telesna teža: 62,03 ± 10,63 kg). Uporabljena je bila metoda ponovljenih meritev. V skladu s tem so udeleženci opravili tri treninge: predpripravo, kontrolo in psihično utrujenost. V predpripravi so bili zbrani demografski podatki in največja mogoča hitrost ene ponovitve (1RM) pri vajah z dvigom na klop (BP) in sklece (SQ). Športniki so vzdržljivost moči izvajali do 60-odstotne izčrpanosti 1RM, beležili so število ponovitev (NOR) in čas gibanja (MT). V seji MF so udeleženci pred testom moči opravili 30-minutno Stroopovo nalogo. Za ugotavljanje razlik v NOR in MT med sejami in razlik v meritvah glede na spol je bil uporabljen t-test za parne vzorce. Uporaba MF je pomembno zmanjšala SQ-NOR za 34,5 %, SQ-MT za 36,88 %, BP-NOR za 22,71 % in BP-MT za 28,27 % (p<0,05). Glede na spol je MF pomembno negativno vplivala na SQ-NOR, SQ-MT in BP-MT pri ženskah in moških in na BP-NOR samo pri športnicah (p<0,05). Rezultat raziskave je, da 30-minutna uporaba MF negativno vpliva na vzdržljivostno zmogljivost moči spodnjih in zgornjih okončin pri mladih kikbokserjih. V zvezi s tem se morajo mladi kikbokserji 30 minut ali več pred treningom in tekmovanjem izogibati dejavnostim, ki povzročajo duševno utrujenost, kot so uporaba digitalnih zaslonov ali reševanje vprašanj ali ugank v okviru družbenih omrežij, kar prepreči morebitno izgubo mišične zmogljivosti.

Ključne besede: *vzdržljivost, kikboksing, psihična utrujenost, moč, mladi športnik*

INTRODUCTION

Mental Fatigue (MF), a psychobiological condition, occurs due to prolonged intense cognitive activities with behavioral and physiological symptoms (Job & Dalziel, 2000); it causes a lack of energy (Boksem & Tops, 2008) and decreased motivation (Boksem, Meijman, & Lorist, 2006). MF can also alter brain activity (Wascher et al., 2014; Cook, O'Connor, Lange, & Steffener, 2007; Hopstaken, van der Linden, Bakker, & Kompier, 2015). Therefore, MF negatively affects cognitive functioning and performance (Marcora, Staiano & Manning, 2009; Möckel, Beste, & Wascher, 2015; Wascher et al., 2014). Although the factors affecting performance in sports vary for each branch, they can be generally divided into three categories: physical, cognitive, and psychological. Although performance can be maintained simultaneously with these factors during exercise, athletes struggle separately with each factor that will negatively affect their performance (Aras, Yiğit, Kayam, Arslan, & Akça, 2020). With the long duration of this struggle, it can be said that sporting activities cause both physical and MF in the body. Sievertsen, Gino, and Piovesan (2016) found that training activities reduce cognitive test performance by 0.9% for each hour of the day; additionally, they reported that a 20-30-min break increased it by 1.7%. According to the literature, it can be said that the length of educational activities at school, the frequency of breaks, and the length of breaks are all related to MF. Sports competitions, intense physical training, and the stress of the intense exam period can cause various psychological stresses such as the need to focus for a long time, the need to maintain the level of perception, and difficulty making decisions under the pressure of the opponent, as well as physical strain in athletes (Kızıltoprak, 2019). Combat sports such as kickboxing especially require superior attention and concentration, so the cognitive robustness and readiness of athletes can directly affect performance management. In addition, if the athlete is at an elite-level status, it is thought that mental fatigue may cause a decrease in the maximum performance (Knicker, Renshaw, Oldham, & Cairns, 2011).

Fatigue is not only caused by the neuromuscular system (Van Cutsem, De Pauw, Marcora, Meeusen & Roelands, 2017a), but also by mental causes (Sharon & Denise, 2003). Therefore, the concept of fatigue can be defined as physical fatigue when it affects the strength capacity of the muscle after a physical task and MF when it increases the level of burnout after performing a cognitive task for a certain period of time. Although physical fatigue and MF may seem different, they are mechanisms that affect each other and any disruption in the mechanism may affect the effort spent on contraction and the perceived level of difficulty (Chaudhuri & Behan, 2004). In this respect, in order to ensure continuity in strength, athletes should be able to cope with both MF and physical fatigue.

It is noteworthy that there are few MF studies in the literature covering the effect on sportive performance, and when the studies are examined, it can be seen that prolonged cognitive efforts have a negative effect on attention, movement tracking, and cognitive control (Boksem & Tops, 2008). In addition, scientific research reported that the level of MF is directly proportional to the duration of the cognitive task performed and it can be said that athletes who are exposed to cognitive tasks for a long time have more MF. The relationship between MF and athletic performance was first mentioned by Angelo Mosso in 1891, who reported that MF decreases muscle strength (Giulio et al., 2006). During some mental tests (Stroop, etc.), the anterior supplementary motor area and anterior cingulate cortex (ASC) were found to be activated in the brain (Mostofsky & Simmonds, 2008); activation of these areas was associated with the degree of rating of perceived exertion (RPE) (De Morree, Klein, & Marcora, 2012). Therefore, MF is considered one of the important determinants of performance in sports and exercise.

Several tests in literature, such as time-clamped self-paced running and cycling protocols and the yo-yo intermittent recovery test, have shown that MF reduces endurance performance. These tests can be characterized by an increase in the time to completion, a decrease in self-selected power output/speed, or a decrease in the time to exhaustion (Van Cutsem, Marcora, De Pauw, Bailey, Meeusen & Roelands, 2017b). In studies on the effect of MF on athletic performance, it has been reported that MF negatively affects endurance performance; high-level athletes are more resistant to MF (Martin et al., 2016). Although different results are obtained in the literature depending on the level of the athlete, all the results show that MF causes more performance decline in recreational athletes. Although these results show that competitive athletes are less affected by MF, considering that success at this level is achieved based on very small differences, it is a significant possibility that the stress of athletes who train at a high level may cause MF, which could negatively affect performance (Russell, Jenkins, Smith, Halson, & Kelly, 2019).

Kickboxing (KBX) is a sport discipline that includes both punching and kicking movements and their combinations (Cynarski & Zieminski, 2010). KBX athletes need the highest level of strength ability among the motoric characteristics. Strength is an important motoric feature in sportive performance in all branches (Atıs, Yerlikaya, Can, & Atlı, 2023) and the long duration of competitions in KBX also requires endurance ability. In order for the athlete to be superior to his/her opponent, superior strength and endurance are required; at the same time, it can be said that he/she should have superior mental performance in order to react to the punches and kicks from the opponent at the right moment. Practices related to this are an important element in the physical and mental development of the athlete and can be effective in building strength and defense stability. In addition, athletes must have a high level of endurance, both physically and mentally.

Recently, MF has become a popular topic and this study was planned because of the lack of studies on this concept and the results on the effect of this concept on performance in strength and combat sports. It is also a matter of interest how much the performances of elite level KBX athletes are affected by the MF that may occur due to the stress experienced in daily life, social life, educational life, and as a result of continuous training. Therefore, the aim of the study was to investigate the effect of MF on lower and upper extremity strength endurance in elite-level young kickboxing athletes.

METHOD

Study Design and Participants

Licensed athletes who have been training regularly for 5 days a week for at least two years, aged 14-18, 9 females and 8 males totaling 17 kickboxing athletes (age: 15.76 ± 1.44 years; height: 167.06 ± 8.63 cm; body weight: 62.03 ± 10.63 kg) were included in this study. Participants who were on regular medication, had a health problem in the last 6 months, or were injured were excluded from the study. Their parents read and signed the informed consent form on behalf of all the participants. The tests performed in the sessions were conducted in accordance with the principles of the Declaration of Helsinki and permission was obtained from the Çanakkale University School of Graduate Studies Scientific Research and Publication Ethics Committee (09.05.2024 date and 07/37 number). The participants were instructed to avoid caffeine, alcohol consumption, and high-intensity exercise in the 24 hours before the tests. The use of sports supplements was restricted during the tests. Descriptive statistics of the participants' body weight, height, and body mass index (BMI) data are presented in Table 1.

Table 1. Descriptive statistics of the physical properties data of the participants

Variables	N	Mean	Sd	Min	Max
Age (year)	17	15.76	1.44	14.00	18.00
Height (cm)	17	167.06	8.63	155.00	185.00
Body weight (kg)	17	62.02	10.63	44.00	89.00
BMI (kg/m2)	17	22.10	2.32	17.85	26.49

Sd: Standard deviation, Min: Minimum; Max: Maximum

Procedures

In the study, which used a control group experimental research design, the participants were tested in the same order during the experimental tests (Control and Mental Fatigue sessions). In the study, the protocols were performed in the same way in all sessions and the tests were carried out between 16.00 and 19.00 in the evening, during the athletes' usual training hours. A total of three sessions were carried out: Preparation (PRE), Control (CON), and Mental Fatigue (MF). Three-day wash-out periods was given between the sessions. In all sessions, general warm-up, testing, and cool-down were performed respectively. A bench press (BP) test was used to assess the upper body strength and a squat (SQ) test was used to assess the lower body strength. During the sessions, 10 min rest was given between the upper and lower body strength tests. In the PRE session, demographic information was obtained, body weight and height measurements were taken, the Stroop test was performed and the 1RM values of the participants were determined. In the CON session, the total number of repetitions (NOR) and the movement time (MT) in seconds were recorded until the participants were exhausted at 60% of the 1RM value. In the MF session, the NOR and MT of the participants at 60% of the 1RM BP-SQ value were recorded after a 30-min Stroop test. The athletes were required to follow the same dietary regime for 24 hours before each test day and to avoid caffeine, alcohol consumption and vigorous exercise.

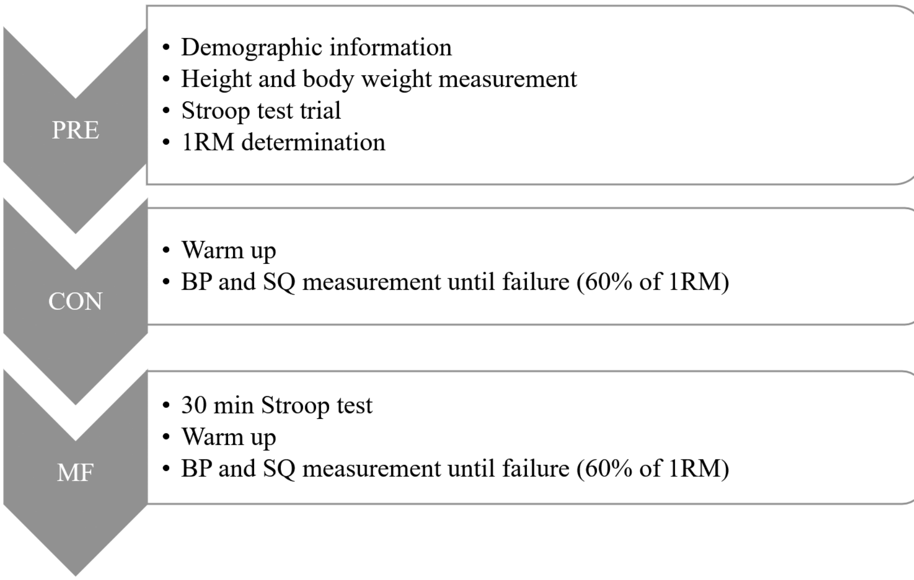

Figure 1. Application Flow Chart

One-repetition Maximum (1RM) Test

After requesting the demographic information of the participants and recording their body height and weight, the 1RM test was performed to determine the maximal weight they could lift in one repetition in order to determine the weights to be used in the strength assessments. In the tests performed separately for BP and SQ movements, the specified protocol was followed:

The 1RM test is recognized as the gold standard for assessing muscle strength under non-laboratory conditions (Levinger et al., 2009). The initial warm-up for the strength endurance test was performed as 8-10 repetitions at 50% of the 1RM determined in the preparation phase, followed by 3-5 repetitions at 75% of the 1RM. Participants then completed one repetition at 95% of the 1RM with a constant movement tempo of 3s eccentric / 3s concentric. After each trial, the weight was increased by 2.5-10 kg until the 1RM was reached, depending on whether the participants successfully lifted the weight. 5-min rest intervals were adopted between the 1RM strength trials to recover well.

Strength Endurance Test

In the CON and MF sessions, a strength endurance test was performed to assess the strength endurance of the participants. The athletes first performed a general warm-up at a heart rate of 130 for 5 min, followed by a special warm-up with 15 repetitions at 20%, 10 repetitions at 40%, 5 repetitions at 60%, and 3 repetitions at 80% of the 1RM at a movement tempo of 3s eccentric / 3s concentric. The concentric phase was performed at the highest possible speed in each repetition (Wilk, Golas, Krzysztofik, Nawrocka, & Zajac, 2019). All the repetitions were performed without jumping, concentric, and without pausing. During all the sessions, the following parameters were recorded:

1. Number of repetitions of Squat (SQ-NOR)
2. Movement time of Squat (SQ-MT)
3. Number of repetitions of Bench Press (BP-NOR)
4. Movement time of Bench Press (BP-MT)

Mental Fatigue Test (Stroop Test)

The Stroop test is a type of neuro-psychological test that evaluates the function of the prefrontal region of the brain (Stroop, 1935). The Stroop test consists of three different parts: control, congruent, and incongruent trials. The Stroop task was assessed using the Inquisit Lab 6 program. Participants sitting in front of the computer were asked to press the "D", "F", "J", or "K" buttons, which were color-matched and written as a note on the screen, in order to give the fastest possible response. The word that appears on the computer screen is in color and states the name of four basic colors; blue, red, yellow, and green; this has to be answered correctly and as soon as possible with the help of the pre-determined keys. The Stroop test included incongruent trials, in which a colored word image was presented in a different color than that of the word (e.g., the word "red" was shown in black), congruent trials, in which words were presented printed in the same ink color as that of the word (e.g., the word "red" was shown in red), and control trials consisting of colored shapes. In this task, stimuli did not disappear from the screen until a response was made and a 500 ms interval was given between one stimulus and the next. When the participants answered correctly, the stimuli disappeared and a new stimulus appeared; however, when participants answered incorrectly, an "X" mark appeared on the screen and was immediately followed by a new stimulus (Faria, Frois, Fortes, Bertola, & Albuquerque, 2024). If the word does not match the color, the time to answer is much longer than in the normal situation. The total time, reaction time, and error rates were recorded after 30 minutes of testing. For an acceptable response, responses given within 200 and 2000 ms after stimulus presentation were considered correct. Responses that were not within the time interval and responses given by pressing the wrong color button were considered incorrect.

Data Analysis

The data were analyzed in SPSS 25 and a Paired Sample t-test with Bonferroni corrected was used to compare the number of repetitions and movement time values between the trials. The normality of the data was tested using the Skewness-Kurtosis test and the data was found to be in a normal distribution (±1.5). The significance level was accepted as $p<0.05$.

RESULTS

Since the Skewness-Kurtosis values of the BP and SQ test results and the MF test total time and reaction times were between -1.5/+1.5, it was determined that the data was normally distributed (Tabachnick & Fidell, 2013). Descriptive statistics of the demographic information of the participants are presented in Table 2.

Table 2. Descriptive statistics of the demographic information of the participants

Variables	Categories	N	f (%)	Variables	Categories	N	f (%)
Gender	Female	9	52.9	**Coach Type**	Enthusiastic/ Job-maker	14	82.4
	Male	8	47.1		Tame/ Good-natured	3	17.6
Sports age	0-1 year	4	23.5	**Branches**	K1	8	47.1
	2-4 year	8	47.1		Low Kick	5	29.4
	≥5 year	5	29.4		Full Contact	4	23.5

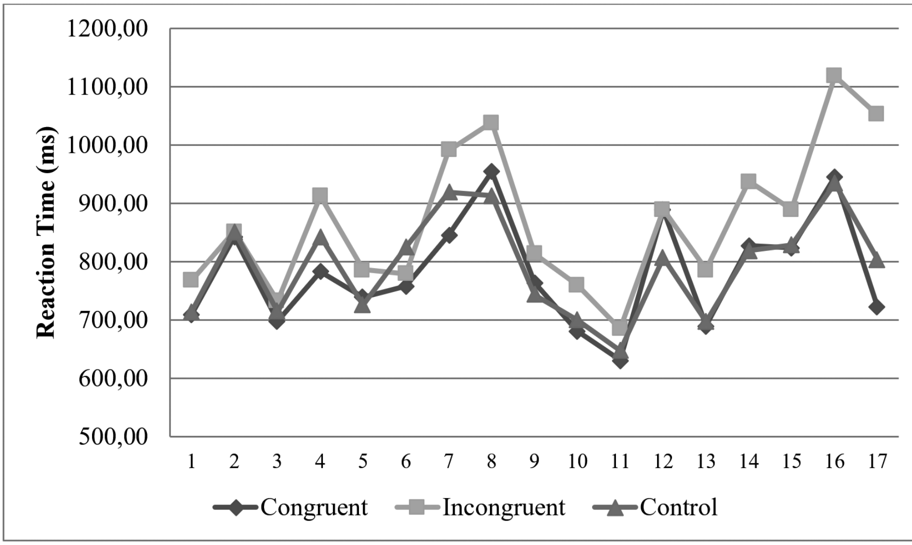

Figure 2. Reaction time of participants during the Stroop test

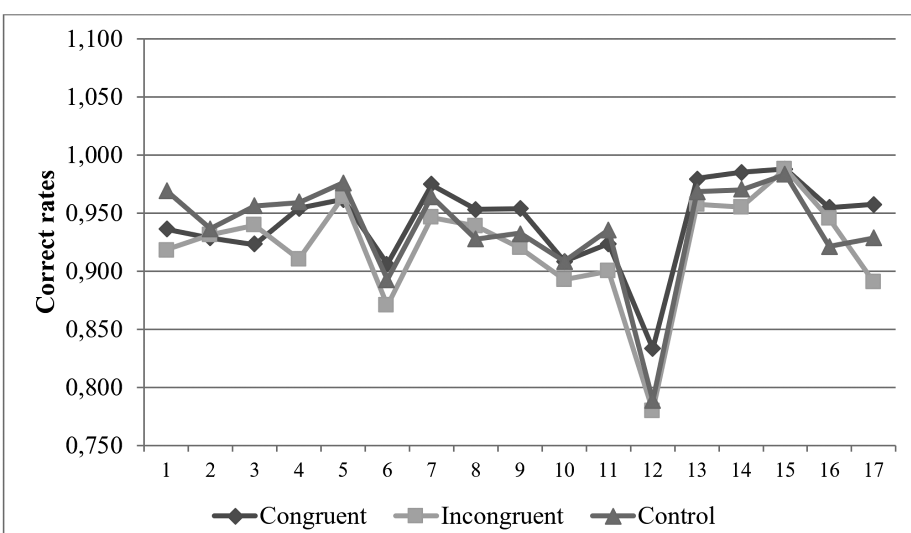

Figure 3. Correct rates of participants during the Stroop test

The data indicates that 52.9% of the participants were female. 76.5% of them had a sports age of 2 years or more. 47.1% of them fought in the K1 branch, 29.4% in the low kick branch, and 23.5% in the full contact branch.

The reaction times and correct rates demonstrated by the participants in the MF session are presented below.

The statistical data on the participants' strength endurance number of repetitions (NOR) and movement time (MT) measured for SQ and BP in the CON and MF sessions are presented in the figure and table below.

According to the data, it was determined that the presence of MF had a significant effect on SQ-NOR with a 34.5% decrease, on SQ-MT with 36.88%, on BP-NOR with 22.71% and on BP-MT with 28.27% in young kickboxers ($p<0.05$).

The statistical data on the mean number of repetitions of strength endurance (NOR) and movement time (MT) measured for SQ and BP in the CON and MF sessions of the participants, according to gender are presented in the figure and table below.

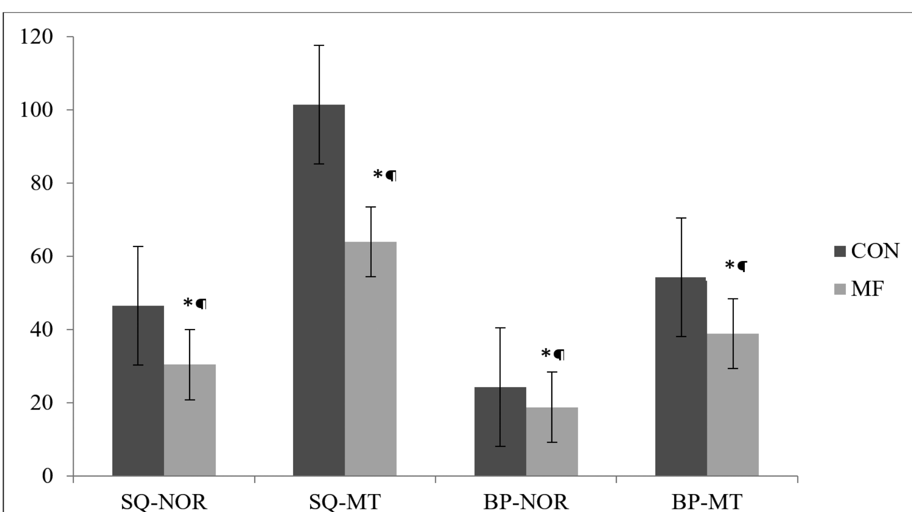

Figure 4. Difference between mean Squat (SQ) and Bench Press (BP) Number of Repetitions (NOR) and Movement Time (MT) in CON and MF Session

Table 3. Paired sample t-test results for the mean strength endurance measured for SQ and BP in CON and MF sessions

Variable	Session	N	Mean	Sd	%	t	p
SQ-NOR (rep)	CON	17	46.53	18.38	34.5	3.661	0.002*
	MF	17	30.47	10.53			
SQ-MT (s)	CON	17	101.41	29.26	36.88	4.649	0.000*
	MF	17	64.00	22.09			
BP-NOR (rep)	CON	17	24.35	8.61	22.71	3.773	0.002*
	MF	17	18.82	7.13			
BP-MT (s)	CON	17	54.29	17.40	28.27	5.264	0.000*
	MF	17	38.94	15.08			

*p<0.05; Sd: Standard deviation; SQ: Squat; BP: Bench Press; SQ-NOR: Number of repetitions of Squat; SQ-MT: Movement time of Squat; BP-NOR: Number of repetitions of Bench press; BP-MT: MoWvement time of Bench press, rep: repetition.

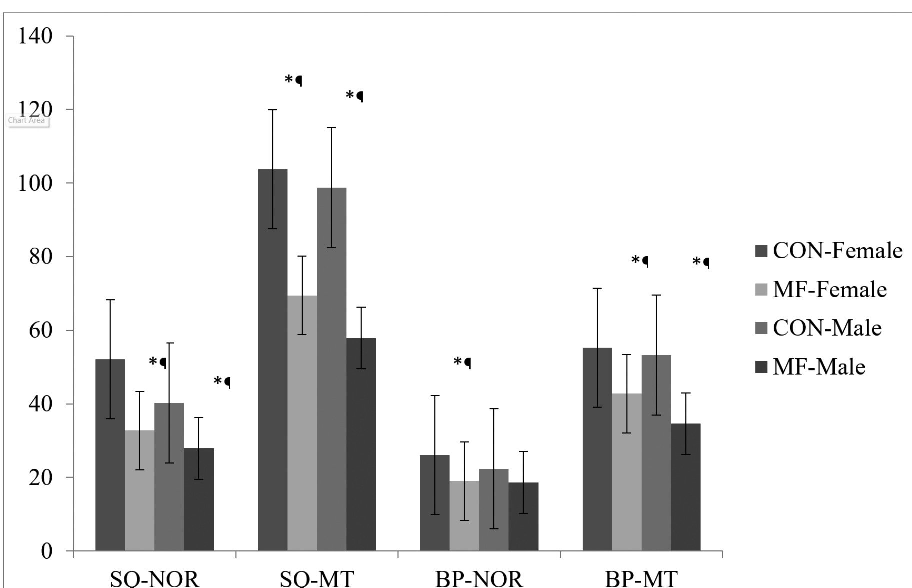

Figure 5. The difference between the mean number of repetitions (NOR) and movement time (MT) of Squat (SQ) and Bench Press (BP) in CON and MF sessions according to gender

Table 4. Paired sample t-test results of the strength endurance averages measured for SQ and BP in the CON and MF sessions, according to gender

Variable	Gender	Session	N	Mean	Sd	%	t	p
SQ-NOR	Female	CON	9	52.11	21.86	37.09	2.624	**0.030***
		MF	9	32.78	11.50			
	Male	CON	8	40.25	11.88	30.73	2.767	**0.028***
		MF	8	27.88	9.39			
SQ-MT	Female	CON	9	103.78	36.82	33.08	2.720	**0.026***
		MF	9	69.44	21.51			
	Male	CON	8	98.75	19.84	41.38	3.961	**0.005***
		MF	8	57.88	22.49			
BP-NOR	Female	CON	9	26.11	7.56	27.23	3.076	**0.015***
		MF	9	19.00	5.98			
	Male	CON	8	22.38	9.80	16.75	2.280	0.057
		MF	8	18.63	8.68			
BP-MT	Female	CON	9	55.22	14.89	22.53	3.714	**0.006***
		MF	9	42.78	13.20			
	Male	CON	8	53.25	20.89	34.96	3.802	**0.007***
		MF	8	34.63	16.76			

*p<0.05; Sd: Standard deviation; SQ: Squat; BP: Bench Press; SQ-NOR: Number of repetitions of Squat; SQ-MT: Movement time of Squat; BP-NOR: Number of repetitions of Bench press; BP-MT: Movement time of Bench press, CON: Control; MF: Mental Fatigue.

According to the data, when the NOR and MT of the SQ and BP were analyzed on the basis of gender, it was found that MF had a significant effect on SQ-NOR, SQ-MT, and BP-MT in both women and men ($p<0.05$), while there was a significant decrease in BP-NOR in female athletes ($p<0.05$) but no significant effect on BP-NOR in male athletes ($p>0.05$). The decreasing effect of MF caused a significantly greater decrease in female athletes than male athletes in NOR, while it was found that male athletes had a significantly greater decrease in MT than female athletes ($p<0.05$).

DISCUSSION

This study examined the acute effects of MF on the strength endurance performance of well-trained male and female kickboxing athletes. According to the results, the presence of MF significantly decreases SQ-NOR (34.5%), SQ-MT (36.88%), BP-NOR (22.71%), and BP-MT (28.27%) in young kickboxers. Task duration has an important effect on the reduction of sports performance due to mental fatigue. It is known that tasks lasting less than 30 min have no effect on exercise performance, though they do reduce cognitive capacity (Hagger, Wood, Stiff, & Chatzisarantis, 2010; Graham, Sonne, & Bray, 2014). In this respect, 30 min of the Stroop test applied for mental fatigue in the study decreased performance. In athletes exposed to prolonged mental fatigue, the ratio of perceived exertion increased (Marcora, Staiano, & Manning, 2009; Pageaux, 2014; Van Cutsem et al., 2017a). However, from a neurophysiological point of view, mental fatigue negatively affects physical effort and decreases motivation (Rudebeck, Walton, Smyth, Bannerman, & Rushworth, 2006; Walton, Kennerley, Bannerman, Phillips, & Rushworth, 2006). Therefore, it could be that the prolonged Stroop test applied to the athletes also affected brain regions related to the cognitive aspects of central motor command and deactivated the facilitative system that encourages athletes to act.

According to a study conducted by Cao et al. (2022) on basketball players, similar to the results of the current research, it shows that MF impairs technical performance such as free throw, three-point shooting, and turnovers, as well as mental performance such as making the first move, intuitiveness, and decision-making. It is known that MF practices have negative effects not only in basketball but in other branches as well. Recent studies aiming to understand the MF phenomenon have shown that it is detrimental to endurance skills such as cycling, running, yo-yo, motor skills such as accuracy, speed and finishing time, and decision-making skills such as making mistakes and slower reaction time (Van Cutsem et al., 2017b; Pageaux & Lepers, 2018; Habay et al., 2021). In another study, MF impairs sport-specific psychomotor performance in football, badminton, basketball, table tennis, cricket, and other sports (Habay et al., 2021).

In another study conducted by Coutinho et al. (2017) on football players, they reported that MF impairs physical and tactical performance, negatively affects the athletes' ability to use environmental information and the players' positioning. Smith et al. (2016) found a decrease in distance traveled on the yo-yo test and technical performance following mental fatigue from a 30-minute incongruent Stroop test in football players. In a study by Pageaux and Lepers

(2016) on active adolescent endurance athletes investigating the effects of MF on cognitive and aerobic performance, it was found that a 30-minute Stroop test negatively affected the maximum oxygen intake and running speed; the rating of the perceived exertion level is also high. As a result, they reported that mental fatigue impairs aerobic and cognitive performance in active male endurance athletes. In the literature, as a result of the negative consequences of MF applications on the endurance performance of athletes in all branches, a negative effect on kickboxing athletes is expected.

While there are studies that show a decrease in sports performance after MF application, there are also studies that show no effect, though they are very few in number. However, Vrijkotte et al. (2018) showed that mental fatigue has a negative impact on cycling performance. In the study conducted by Silva-Cavalcante et al. (2018) with 8 recreational male road cyclists, after 90 minutes of AX-CPT testing, they found no effect on the visual analogue scale, RPE, 5-second maximal voluntary contraction with 30-second rests in the quadriceps muscle, electrical muscle stimulation and 4 km time trial cycling performance. Proost et al. (2023) reported that MF did not affect RPE or movement-related cortical potential (MRCP) during leg extension. The researchers reported that this situation could be related to the lack of performance output; also, the increase in alpha power in the experimental group may be linked to a focused internal attention mechanism to reduce the feeling of fatigue. Similarly, Filipas, Mottola, Tagliabue, and La Torre (2018) reported that 60 minutes of Stroop or solving math problems had no effect on heart rate (HR), rating of perceived exertion (RPE), and 1500-meter rowing performance in young rowers. In line with these results, although the presence of MF does not affect sports performance, when the studies are taken as a whole, it can be inferred that mental fatigue negatively affects sports performance in general and it can be said that the possibility of negative results is higher. If a more detailed inference needs to be made, it is thought that the results may differ in terms of test type, application time, the athletic level of the athletes, and the measured characteristics (endurance, speed, etc.).

In the current study, when the effect of MF on sports performance was examined on a gender basis, it was observed that it had a negative effect on both genders. Contrary to this result, Pereira et al. (2015) found in their study that elderly women fatigued the upper extremity more with incremental mental activity applied during continuous postural contractions; they emphasized that women are more sensitive than men. In line with the different results in the literature, it is thought that the effects of mental practices on a gender basis cannot be predicted. However, considering that women are more psychologically sensitive, it is estimated that the performance of female athletes may deteriorate more than male athletes during long-term mental practices for long-distance athletes. However, this needs to be proven by scientific studies.

The duration of the activity that causes mental fatigue has a significant impact on the deterioration of sports performance. When the studies conducted in this context are examined, Smith, Marcora, and Coutts (2015) examined the effect of the AX-CPT test applied for 90 min on intermittent running performance and reported that the athletes' perceived difficulty level was high, running speed and oxygen consumption significantly decreased, and this negative effect of cognitive fatigue was mediated by the perception of high effort. In the study conducted by Terentjeviene et al. (2018) on 30 healthy adult male athletes, it was reported that after 120 minutes of Go / No Go, there was a decrease in motivation and hand grip strength, and an increase in reaction time, perceived workload and frontal cortex activity. Le Mansec, Pageaux, Nordez, Dorel, and Jubeau (2018) reported that 90 minutes of AX-CPT application resulted in a decrease in ball speed and total score, an increase in the number of errors, an increase in RPE, and a decrease in the rate of hitting the target in 22 experienced male table tennis athletes. Contrary to these results, Rozand, Pageaux, Marcora, Papaxanthis, and Lepers (2014), supporting the thesis on the effect of practice time on performance, reported that the 27-minute Stroop test did not affect isokinetic strength, RPE, HR, and voluntary maximum contraction in adult men. In line with the results obtained, it can be said that mental fatigue does not occur following periods under 30 minutes, regardless of the test type, measured feature, and sport branch.

From another perspective, just as cognitive practices have a negative effect on sports performance, it has been revealed in studies in the literature that sports loads also have a negative effect on mental performance. Mancı et al. (2023) revealed that elite basketball players showed better cognitive performance than amateur players after 4 sets of 30s sprint intervals. As a result of the negative effects of applications in both directions, it can be concluded that cognitive and physical performance cannot be considered separately from each other. In this sense, both the mental and the physical aspects must be well supported in all planning and programs for sports performance. It is known that there is a negative relationship between the long-term use of technological devices and executive functions (Warsaw et al., 2021). Social media use requires constant attention as it involves listening, writing, and reading; therefore, spending long periods of time on smartphones can also cause mental fatigue (Russell et al., 2019; Fortes et al., 2020). When the studies on the subject are examined, using social media before a sports performance for at least 30 minutes impairs the decision-making skills in professional football players (Fortes et al., 2020). It has also been reported that smartphone use before training sessions in football negatively affects both technical and endurance performance (Greco, Tambolini, Ambruosi, & Fischetti, 2017). In line with these results, athletes need to be able to manage their self-control mechanisms regarding the use of technological devices just before training or competition in order to prevent mental fatigue. If coaches and parents pay attention to this issue, it will allow the factors that negatively affect the athletes' sports performance to be reduced and the performance to be kept at an optimum level. In terms of the negative effects of long-term cognitive activities, 20 mg dopamine (DA) and 8 mg noradrenaline (NA) supplementation applied before the MF delays the onset of the MF and improves cognitive performance (Arenales Arauz et al., 2024). In this context, both athletes and individuals with cognitive tasks can minimize the negative effects of cognitive fatigue by taking DA and NA supplements. The use of NA and DA may help increase endurance performance in order to make long-term performance outputs more efficient.

CONCLUSION

Based on the results of this study, it has been revealed that mental fatigue negatively affects the strength endurance of kickboxers, one of the strength sports. Many coaches and sports trainers attach importance to the training process for performance development; however, when acute studies are examined, factors that negatively affect performance should also be taken into consideration. Mental fatigue emerges as an acute factor that negatively affects performance, and when looking at studies in the literature, it is known that mental fatigue negatively affects performance in many branches. In this respect, before training or competition, regardless of whether you are a woman or a man, it is necessary to avoid activities that may cause mental fatigue. It is essential for coaches and sports trainers to pay attention to this situation when creating and implementing programs.

PRACTICAL IMPLICATIONS

While there have been efforts to increase exercise and sports performance for a long time, studies continue to identify factors that negatively affect performance and precautions that can be taken. Mental fatigue and what to do about it is one of them. This study was conducted on kickboxing athletes and their muscular endurance performance was examined.

– This study was conducted on young individuals. Wascher and Getzmann (2014) found that performance declined in the older participants but not in the young after an 80-min task, so the results of this study may vary for older individuals. Therefore, future studies should be conducted separately with adults.

– Gender is also an important factor in MF. Therefore, gender comparisons can be made in studies examining the effects of MF applications on sports performance.

– Applications that may cause MF before exercise may negatively affect performance; Therefore, coaches and athletes should avoid such practices just before training and competition. Appropriate methods and techniques can be developed for athletes who cannot achieve self-control in this regard.

– The effect of MF on sports performance may vary depending on the sports level of the athletes; it is thought that high-level athletes have better cognitive control and their responses to cognitive tasks may be better. Therefore, research should be conducted separately on amateur and professional athletes.

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REFERENCES

Aras, D., Yiğit, S., Kayam, S., Arslan, E., & Akça, F. (2020). Effects of cognitive fatigue on exercise and sport performance. *Spormetre The Journal of Physical Education and Sport Sciences*, *18*(1), 1-32.

Arenales Arauz, Y. L., Habay, J., Ocvirk, T., Mali, A., Russell, S., Marusic, U., ... Roelands B. (2024). The interplay of brain neurotransmission and mental fatigue: A research protocol. *PLoS One. 19*(9), e0310271. https://doi.org/10.1371/journal.pone.0310271.

Atış, İ., Yerlikaya, G., Can, İ., & Atlı, A. (2023). Investigation of the acute effect of dry cup application on some performance parameters in young kickboxers. *Çanakkale Onsekiz Mart University Journal of Sports Science, 6*(2), 1-11.

Boksem, M. A., Meijman, T. F., & Lorist, M. M. (2006). Mental fatigue, motivation and action monitoring. *Biological Psychology, 72*(2), 123-132. https://doi.org/10.1016/j.biopsycho.2005.08.007.

Boksem, M. A. S. & Tops, M. (2008). Mental fatigue: costs and benefits. *Brain Research Reviews 59*(1), 125-139. https://doi.org/10.1016/j.brainresrev.2008.07.001.

Cao, S., Geok, S. K., Roslan, S., Sun, H., Lam, S. K., & Qian, S. (2022). Mental fatigue and basketball performance: a systematic review. *Frontiers in Psychology*, *12*, 819081. https://doi.org/10.3389/fpsyg.2021.819081.

Chaudhuri, A., & Behan, P. O. (2004). Fatigue in neurological disorders. *Lancet, 363*(9413), 978-988. https://doi.org/10.1016/S0140-6736(04)15794-2.

Cook, D. B., O'Connor, P. J., Lange, G., & Steffener, J. (2007). Functional neuroimaging correlates of mental fatigue induced by cognition among chronic fatigue syndrome patients and controls. *Neuroimage*, *36*(1), 108–122. https://doi.org/10.1016/j.neuroimage.2007.02.033.

Coutinho, D., Gonçalves, B., Travassos, B., Wong, D. P., Coutts, A. J., & Sampaio, J. E. (2017). Mental fatigue and spatial references impair soccer players' physical and tactical performances. *Frontiers in Psychology*, *8*, 283443. https://doi.org/10.3389/fpsyg.2017.01645.

Cynarski, W. J., & Zieminski, P. (2010). Holland's primacy in World of K-1 kick-boxing organization. *Ido – Ruchdla Kultury / Movement for Culture*, *10*(1), 31-35.

De Morree, H. M., Klein, C., & Marcora, S. M. (2012). Perception of effort reflects central motor command during movement execution. *Psychophysiology, 49*(9), 1242-1253. https://doi.org/10.1111/j.1469-8986.2012.01399.x.

Faria, L. O., Frois, T., Fortes, L. D. S., Bertola, L., & Albuquerque, M. R. (2024). Evaluating the Stroop Test with older adults: Construct validity, short term test-retest reliability, and sensitivity to mental fatigue. *Perceptual and Motor Skills*, *131*(4), 1120-1144. https://doi.org/10.1177/00315125241253425.

Filipas, L., Mottola, F., Tagliabue, G., & La Torre, A. (2018). The effect of mentally demanding cognitive tasks on rowing performance in young athletes. *Psychology of Sport & Exercise, 39*, 52-62. https://doi.org/10.1016/j.psychsport.2018.08.002.

Fortes, L. S., De Lima-Junior, D., Fiorese, L., Nascimento-Júnior, J. R., Mortatti, A. L., & Ferreira, M. E. (2020). The effect of smartphones and playing video games on decision-making in soccer players: a crossover and randomised study. *Journal of Sports Sciences, 38*(5), 552-558. https://doi.org/10.1080/02640414.2020.1715181.

Giulio, C. D., Daniele F., & Tipton C. M. (2006). Angelo Mosso and muscular fatigue: 116 years after the first congress of physiologists: IUPS commemoration. *Advances in Physiology Education, 30*(2), 51-57. https://doi.org/10.1152/advan.00041.2005.

Graham, J. D., Sonne, M. W., & Bray, S. R. (2014). It wears me out just imagining it! Mental imagery leads to muscle fatigue and diminished performance of isometric exercise. *Biological Psychology*, 103, 1–6. https://doi.org/10.1016/j.biopsycho.2014.07.018.

Greco, G., Tambolini, R., Ambruosi, P., & Fischetti, F. (2017). Negative effects of smartphone use on physical and technical performance of young footballers. *Journal of Physical Education and Sport, 17*(4), 2495-2501. https://doi.org/10.7752/jpes.2017.04280.

Habay, J., Van Cutsem, J., Verschueren, J., De Bock, S., Proost, M., De Wachter, J., ... Roelands, B. (2021). Mental fatigue and sport-specific psychomotor performance: A systematic review. *Sports Medicine. 51*, 1527–1548. https://doi.org/10.1007/s40279-021-01429-6.

Hagger, M. S., Wood, C., Stiff, C., & Chatzisarantis, N. L. (2010). Ego depletion and the strength model of self-control: A meta-analysis. *Psychological Bulletin. 136*, 495–525. https://psycnet.apa.org/doi/10.1037/a0019486.

Hopstaken, J. F., van der Linden, D., Bakker, A. B., & Kompier, M. A. (2015). A multifaceted investigation of the link between mental fatigue and task disengagement. *Psychophysiology*, *52*, 305–315. https://doi.org/10.1111/psyp.12339.

Job, R. & Dalziel, J. (2000). Defining fatigue as a condition of the organism and distinguishing it from habituation, adaptation, and boredom. In: P. A. Hancock, & P. A. Desmond (Eds.), *Stress, workload and fatigue* (p. 466–475). Mahwah: Lawrence Erlbaum Associates.

Kızıltoprak, S. (2019). Fatigue and recovery in football. *Turkish Journal of Sports Medicine*, *55*(2), 172-185.

Knicker, A. J., Renshaw, I., Oldham, A. R., & Cairns, S. P. (2011). Interactive processes link the multiple symptoms of fatigue in sport competition. *Sports Medicine*, *41*(4), 307-328. https://doi.org/10.2165/11586070-000000000-00000.

Le Mansec, Y., Pageaux, B., Nordez, A., Dorel, S., & Jubeau, M. (2018). Mental fatigue alters the speed and the accuracy of the ball in table tennis. *Journal of Sports Science, 36*(23), 2751-2759. https://doi.org/10.1080/02640414.2017.1418647.

Levinger, I., Goodman, C., Hare, D. L., Jerums, G., Toia, D., & Selig, S. (2009). The reliability of the 1rm strength test for untrained middle-aged individuals. *Journal of Science and Medicine in Sport, 12*(2), 310–316. https://doi.org/10.1016/j.jsams.2007.10.007.

Mancı, E., Herold, F., Günay, E., Güdücü, Ç., Müller, N. G., & Bediz, C. Ş. (2023). The influence of acute sprint interval training on the cognitive performance of male basketball players: an investigation of expertise-related differences. *International Journal of Environmental Research and Public Health, 20*(6), 4719. https://doi.org/10.3390/ijerph20064719.

Marcora, S. M., Staiano, W., & Manning, V. (2009). Mental fatigue impairs physical performance in humans. *Journal of Applied Physiology. 106*(3), 857–864. https://doi.org/10.1152/japplphysiol.91324.2008.

Martin, K., Staiano, W., Menaspa, P., Hennessey, T., Marcora, S., Keegan, R., … Rattray, B. (2016). Superior inhibitory control and resistance to mental fatigue in professional road cyclists. *PloS One*, *11*(7) e0159907. https://doi.org/10.1371/journal.pone.0159907.

Möckel, T., Beste, C., & Wascher, E. (2015). The effects of time on task in response selection an erp study of mental fatigue. *Scientific Reports. 5*, 10113. https://doi.org/10.1038/srep10113.

Mostofsky, S. H., & Simmonds, D. J. (2008). Response inhibition and response selection: Two sides of the same coin. *Journal of Cognitive Neuroscience, 20*(5), 751-761. https://doi.org/10.1162/jocn.2008.20500.

Pageaux, B. (2014). The psychobiological model of endurance performance: An effort-based decision-making theory to explain self-paced endurance performance. *Sports Medicine*. *44*, 1319–1320. https://doi.org/10.1007/s40279-014-0198-2.

Pageaux, B. & Lepers, R. (2016). Fatigue induced by physical and mental exertion increases perception of effort and impairs subsequent endurance performance. *Frontiers in Physiology. 7*(587). https://doi.org/10.3389/fphys.2016.00587.

Pageaux, B., & Lepers, R. (2018). The effects of mental fatigue on sport-related performance. *Progress in. Brain Research. 240,* 291–315. https://doi.org/10.1016/bs.pbr.2018.10.004.

Pereira, H. M., Spears, V. C., Schlinder-Delap, B., Yoon, T., Harkins, A., Nielson, K. A., ... Hunter, S. K. (2015). Sex differences in arm muscle fatigability with cognitive demand in older adults. *Clinical Orthopaedics and Related Research, 473*, 2568-2577. https://doi.org/10.1007/s11999-015-4205-1.

Proost, M., Habay, J., De Wachter, J., De Pauw, K., Marusic, U., Meeusen, R., ... & Van Cutsem, J. (2023). The impact of mental fatigue on a strength endurance task: is there a role for the movement-related cortical potential?. *Medicine and Science in Sports and Exercise. 56*(3), 435-445. https://doi.org/10.1249/mss.0000000000003322.

Rozand, V., Pageaux, B., Marcora, S. M., Papaxanthis, C., & Lepers, R. (2014). Does mental exertion alter maximal muscle activation? *Frontiers in Human Neuroscience, 26*(8), 755. https://doi.org/10.3389/fnhum.2014.00755.

Rudebeck, P. H., Walton, M. E., Smyth, A. N., Bannerman, D. M., & Rushworth, M. F. (2006). Separate neural pathways process different decision costs. *Nature Neuroscience*. *9*, 1161–1168. https://doi.org/10.1038/nn1756.

Russell, S., Jenkins, D., Smith, M., Halson, S., & Kelly, V. (2019). The application of mental fatigue research to elite team sport performance: New perspectives. *Journal of Science and Medicine in Sport*, *22*(6), 723-728. https://doi.org/10.1016/j.jsams.2018.12.008.

Sharon, A. P., & Denise, L. S. (2003). Exercise physiology for health, fitness and performance. 2th ed. San Francisco: Benjamin Cummings Publishing.

Sievertsen, H. H., Gino, F., & Piovesan, M. (2016). Cognitive fatigue influences students' performance on standardized tests. *Proceedings of the National Academy of Sciences*, *113*(10), 2621-2624. https://doi.org/10.1073/pnas.1516947113.

Silva-Cavalcante, M. D., Couto, P. G., Azevedo, R. A., Silva, R. G., Coelho, D. B., Lima-Silva, A. E., & Bertuzzi, R. (2018). Mental fatigue does not alter performance or neuromuscular fatigue development during self-paced exercise in recreationally trained cyclists. *European Journal of Applied Physiology, 118*(11), 2477-2487. https://doi.org/10.1007/s00421-018-3974-0.

Smith, M. R., Marcora, S. M., & Coutts, A. J. (2015). Mental fatigue impairs intermittent running performance. *Medicine & Science in Sports & Exercise, 47*(8), 1682-1690. https://doi.org/10.1249/MSS.0000000000000592.

Smith, M. R., Coutts, A. J., Merlini, M., Deprez, D., Lenoir, M., & Marcora, S. M. (2016). Mental fatigue impairs soccer-specific physical and technical performance. *Medicine and science in sports and exercise, 48*(2), 267-276. https://doi.org/10.1249/MSS.0000000000000762.

Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology, 18*(6), 643–662. https://psycnet.apa.org/doi/10.1037/h0054651.

Tabachnick, B. G., & Fidell, L. S. (2013). Using multivariate statistics (6th ed.). Boston: Pearson.

Terentjeviene, A., Maciuleviciene, E., Vadopalas, K., Mickeviciene, D., Karanauskiene, D., Valanciene, D., …. & Skurvydas, A. (2018). Prefrontal cortex activity predicts mental fatigue in young and elderly men during a 2 h "Go/No Go" task. *Frontiers in Neuroscience, 12,* 620. https://doi.org/10.3389/fnins.2018.00620.

Van Cutsem, J., De Pauw, K., Marcora, S., Meeusen, R., & Roelands, B. (2017a). A caffeine-maltodextrin mouth rinse counters mental fatigue. *Psychopharmacology 235*, 947–958. https://doi.org/10.1007/s00213-017-4809-0.

Van Cutsem, J., Marcora, S., De Pauw, K., Bailey, S., Meeusen, R., & Roelands, B. (2017b). The effects of mental fatigue on physical performance: A systematic review. *Sports Medicine 47*(8), 1569-1588. doi.org/10.1007/s40279-016-0672-0.

Vrijkotte, S., Meeusen, R., Vandervaeren, C., Buyse, L., Van Cutsem, J., Pattyn, N., & Roelands, B. (2018). Mental fatigue and physical and cognitive performance during a 2-bout exercise test. *International Journal of Sports Physiology and Performance, 13*(4), 510-516. https://doi.org/10.1123/ijspp.2016-0797.

Walton, M. E., Kennerley, S. W., Bannerman, D. M., Phillips, P. E., & Rushworth, M. F. (2006). Weighing up the benefits of work: Behavioral and neural analyses of effort-related decision making. *Neural Networks. 19*(8), 1302–1314. https://doi.org/10.1016/j.neunet.2006.03.005.

Warsaw, R. E., Jones, A., Rose, A. K., Newton-Fenner, A., Alshukri, S., & Gage, S. H. (2021). Mobile technology use and its association with executive functioning in healthy young adults: A systematic review. *Frontiers in Psychology, 12*, 643542. https://doi.org/10.3389/fpsyg.2021.643542.

Wascher, E., & Getzmann, S. (2014). Rapid mental fatigue amplifies age-related attentional deficits. *Journal of Psychophysiology 28*(3), 215-224. https://doi.org/10.1027/0269-8803/a000127.

Wascher, E., Rasch, B., Sanger, J., Hoffmann, S., Schneider, D., Rinkenauer, G., ... Gutberlet, I. (2014). Frontal theta activity reflects distinct aspects of mental fatigue. *Biological Psychology. 96*, 57–65. https://doi.org/10.1016/j.biopsycho.2013.11.010.

Wilk, M., Golas, A., Krzysztofik, M., Nawrocka, M., & Zajac, A. (2019). The effects of eccentric cadence on power and velocity of the bar during the concentric phase of the bench press movement. *Journal of Sports Science and Medicine. 18*(2), 191–197. Retrieved from https://pmc.ncbi.nlm.nih.gov/articles/PMC6543996/.

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THE EFFECTS OF LOW-LOAD BFRE TRAINING ON SELF-REPORTED KNEE FUNCTION AND PAIN INTENSITY IN INDIVIDUALS WITH KNEE IMPAIRMENT

Matej IPAVEC[1]

[1]Department of Physiotherapy, Faculty of Health Sciences, University of Ljubljana, Slovenia

Corresponding author:
Matej Ipavec
Department of Physiotherapy, Faculty of Health Sciences, University of Ljubljana,
Zdravstvena pot 5, SI-1000 Ljubljana, Slovenia
Phone: + 386 40 540 420
E-mail: matej.ipavec@zf.uni-lj.si

ABSTRACT

Purpose: *The aim of this study was to investigate the influence of low-load (LL) blood flow restriction exercise (BFRE) on orthopedic patients with knee joint injuries, focusing on the subjective assessment of knee joint function and the perception of pain in the knee joint.*

Methods: *The participants were divided into an LL-BFRE group and a sham LL-BFRE group (SLL-BFRE). The training program to strengthen the quadriceps femoris muscle was carried out for four weeks with three training sessions per week. The LL-BFRE group trained with blood flow obstruction through the active muscles using an inflatable cuff, while the SLL-BFRE group trained without blood flow obstruction. Before and after the training program, knee joint function was assessed using the Lysholm questionnaire, and the intensity of knee pain during the training program was measured using a numerical scale.*

Results: *In the LL-BFRE group, the exercise program did not cause a significant improvement ($p = 0.359$), which was from 74.1 ± 15.1 points to 79.1 ± 15.0 points (7%) in the subjective assessment of knee joint function, whereas it improved significantly ($p < 0.001$) by 17% from 70.8 ± 16.8 points to 82.9 ± 14.0 points in the SLL-BFRE groups. We found no significant differences in pain intensity between the LL-BFRE and SLL-BFRE groups during the training program.*

Conclusions: *The results do not support the hypothesis that LL-BFRE exercises would lead to greater improvements in knee joint function and pain perception compared to standard exercises of the same intensity. These findings highlight the need for further research to optimize training protocols and confirm their effectiveness across diverse patient groups.*

Keywords: *Quadriceps femoris muscle, Arthrogenic muscle inhibition, Ischemic exercise, Lysholm knee scoring scale, Knee joint function*

VPLIV ISHEMIČNE VADBE NA SAMOOCENO FUNKCIJE KOLENA IN INTENZIVNOST BOLEČINE PRI POSAMEZNIKIH Z OKVARO KOLENA

IZVLEČEK

Namen: *Proučiti vpliv ishemične vadbe pri osebah s poškodbo kolenskega sklepa, pri čemer smo se usmerili na subjektivno oceno funkcije kolenskega sklepa in stopnjo občutenja bolečine v predelu kolenskega sklepa.*

Metode: *Pacienti so bili razdeljeni v ishemično in placebo skupino. Vadbeni program za krepitev štiriglave stegenske mišice je potekal štiri tedne s po tremi vadbenimi enotami na teden. Ishemična skupina je vadila z oviranim pretokom krvi, povzročenim z napihljivo manšeto, placebo skupina pa z navidezno oviranim pretokom krvi. Pred vadbo in po njej so preiskovanci ocenili funkcijo kolenskega sklepa z Lysholmovim vprašalnikom. Intenziteto bolečine v kolenu so s številsko lestvico sistematično ocenjevali med vadbenim programom.*

Rezultati: *Preiskovanci ishemične skupine z vadbenim programom niso dosegli značilnega (p = 0,359) povečanja subjektivne ocene funkcije kolenskega sklepa s 74,1 ± 15,1 točke na 79,1 ± 15,0 točke (7 %), medtem ko se je ta v placebo skupini značilno (p < 0,001) izboljšala za 17 % s 70,8 ± 16,8 točke na 82,9 ± 14,0 točke. Značilnih razlik v intenziteti bolečine med ishemično in placebo skupino med vadbenim programom nismo zaznali.*

Zaključki: *Naše ugotovitve ne potrjujejo izhodiščne hipoteze, da ishemična vadba povzroči večje izboljšanje subjektivne ocene funkcije kolenskega sklepa in občutenja bolečine v predelu kolenskega sklepa kot standardna vadba z enako intenziteto. Ti izsledki poudarjajo potrebo po nadaljnjih raziskavah za optimizacijo vadbenih protokolov in potrditev njihove učinkovitosti pri različnih skupinah pacientov.*

Ključne besede: *šibkost štiriglave stegenske mišice, artrogena mišična inhibicija, ishemična vadba, Lysholmov vprašalnik, funkcija kolenskega sklepa*

INTRODUCTION

Knee joint injuries are among the most common joint injuries (Gage, McIlvain, Collins, Fields, & Dawn Comstock, 2012), and the frequency of surgical treatment is increasing (Adams, Logerstedt, Hunter-Giordano, Axe, & Snyder-Mackler, 2012; Van Kampen, 2013). As life expectancy continues to increase, the amount of time adults dedicate to sports activities is also increasing, likely leading to an increase in the incidence of knee joint injuries in older adults (Gage et al., 2012). The knee joint is most commonly injured in young athletes, especially female athletes who are at increased risk due to anatomical, hormonal, neuromuscular, and biomechanical factors (Gage et al., 2012). The most common knee injuries include torn ligaments, meniscus damage, and patellofemoral dislocations (Austermuehle, 2001)

Weakness of the Quadriceps femoris (QF) muscle is frequently observed after traumatic knee joint injuries, surgical procedures, and in patients with arthritis (Rice & McNair, 2010). The strength and endurance of the QF muscle are critical for normal knee function, so restoring muscle strength and endurance is essential for achieving good functional status after a knee injury (Hart, Pietrosimone, Hertel, & Ingersoll, 2010). Weakness of the QF muscle can have a range of consequences, such as incomplete knee extension, gait abnormalities, atrophy of the QF muscle, joint laxity, and persistent anterior knee pain (Sonnery-Cottet et al., 2019).

The inability to fully activate the QF muscle can most likely be attributed to arthrogenic muscle inhibition (AMI), a process that prevents the full activation of the muscle due to neuromuscular inhibition (Sonnery-Cottet et al., 2019). Factors influencing the development of AMI include joint swelling, inflammation, pain, soft tissue injury, and joint laxity (Rice & McNair, 2010). QF muscle weakness due to post-traumatic AMI reduces the ability to generate muscle force and impairs effective muscle control, which is particularly important during the eccentric loading of the knee joint during walking (Hart et al., 2010). AMI occurs in various knee joint pathologies with deficits in QF muscle activation, including osteoarthritis, rheumatoid arthritis, anterior knee pain, patellar injuries, ACL injuries and reconstructions, meniscus injuries, and/or meniscectomy, and patients undergoing knee arthroscopy (Rice & McNair, 2010).

Reducing AMI remains a priority in knee rehabilitation as the strength and endurance of the QF muscles are critical to knee function (Rice & McNair, 2010). One of the rehabilitation goals following knee injury or surgery is therefore to restore the lost QF muscle strength to pre-injury or pre-surgery levels (Hart et al., 2010). Strength training is an important part of training in most sports, as well as in injury prevention and rehabilitation (Wernbom, Augustsson, & Raastad, 2008). It is particularly important for people who have a higher risk of additional injuries due to muscle weakness.

When focusing on muscle hypertrophy during strength training, it is important to consider factors such as the number of repetitions and sets, rest intervals, speed of exertion, and training frequency. However, the most important factor is the training load for athletes or rehabilitation patients (Bird, Tarpenning, & Marino, 2005). This load is usually determined prior to the training or rehabilitation process using the 1RM (one repetition maximum) method, which represents the maximum weight a person can lift in a single effort (Garber et al., 2011; Wernbom et al., 2008). To induce hypertrophy in the skeletal muscles, the training load should be at least 60-80% of the individual 1RM (Garber et al., 2011; Wernbom, Järrebring, Andreasson, & Augustsson, 2009).

In acute injuries or following knee surgery, particularly in individuals with anterior knee pain and AMI, high-intensity joint loading with heavy weights is contraindicated due to pain and the risk of re-injury (Abe et al., 2012; Grønfeldt, Lindberg Nielsen, Mieritz, Lund, & Aagaard, 2020; Loenneke & Abe, 2012; Loenneke et al., 2012; Patterson et al., 2019). Therefore, in the early phase of rehabilitation after injury or surgery, only low-intensity isometric exercises for the QF muscle, body weight exercises, active-assisted exercises, and neuromuscular electrical stimulation are performed instead of heavy loads (Shaw, McEvoy, & McClelland, 2002). However, the results are often unsatisfactory because the intensity of the muscle effort is too low to stimulate muscle hypertrophy.

However, the literature suggests that low-load (LL) resistance exercise training combined with blood flow restriction (BFRE) is as effective as standard resistance training with a moderate or high load (>70–80% 1 RM) when it comes to muscle hypertrophy and strength gains in individuals with ACL and other isolated joint injuries (Centner & Lauber, 2020; Grønfeldt et al., 2020; Hughes, Paton, Rosenblatt, Gissane, & Patterson, 2017; Kacin & Stražar, 2011).

LL-BFRE training has been shown to be effective following ACL surgery, demonstrating significant improvements in QF muscle endurance (Kacin & Stražar, 2011; Žargi, Drobnič, Stražar, & Kacin, 2018) and has shown improvements in QF muscle torque development (Nielsen et al., 2017). In addition, it has been shown to be effective in preventing muscle atrophy after surgery (Ohta et al., 2003; Takarada, Takazawa, & Ishii, 2000) and atrophy due to limb unloading (Clark, Fernhall, & Ploutz-Snyder, 2006).

In addition to benefits in surgical recovery, LL-BFRE has been shown to reduce pain and improve knee function in patients suffering from anterior knee pain (Korakakis, Whiteley, & Epameinontidis, 2018), rheumatoid arthritis (Rodrigues et al. 2020) and osteoarthritis (Parekh, Vaghela, & Mehta, 2024). Recent results have also shown the effectiveness of LL-BFRE training in the rehabilitation process following ACL reconstruction, where it significantly improves muscle activity and function compared to traditional rehabilitation protocols (Jung, Kim, Nam, Kim, & Moon, 2022).

The aim of this study was therefore to investigate the effect of LL-BFRE in patients with knee joint injuries. Two main objectives were set: 1) to determine whether there is a difference in the subjective assessment of knee joint function between patients who have undergone LL-BFRE training and those who have received sham LL-BFRE training (SLL-BFRE), and 2) to assess whether there is a difference in the perception of pain in the knee joint between these two groups.

METHODS

The study was approved by the Medical Ethics Committee of the Republic of Slovenia (No. 0120-496/2018/8) and was conducted in accordance with the Declaration of Helsinki. All the included patients signed a written informed consent for voluntary participation after receiving detailed written and verbal information about the study. Patient recruitment took place at the Orthopedic Department of the University Medical Center Ljubljana, while all performance tests and exercise training interventions were performed at the University Laboratory for Physiotherapy Research.

Participants

A total of 36 orthopedic patients with QF weakness were initially recruited for the study. During the course of the intervention, three patients withdrew due to personal or health-related reasons, resulting in a final sample size of 33 participants, who were divided into two intervention groups.

The LL-BFRE group consisted of 16 (6 males and 10 females) orthopedic patients (39.3 ± 10.5 years. 171.4 ± 7.8 cm. 69.1 ± 13.8 kg) who exercised with restricted blood flow (cuff pressure 120-140 mmHg), while the SLL-BFRE group consisted of 17 (7 males and 10 females) orthopedic patients (39.6 ± 9.5 years. 174 ± 12.8 cm. 174 ± 12.8 kg) who exercised with apparently restricted blood flow (a cuff pressure of 20 mmHg).

The required sample size was determined using a two-way ANOVA model to ensure at least 80% power at an alpha level of 0.05 for detecting significant time × group interactions. The calculation showed that at least 18 participants per group were required for statistical validity. Despite three withdrawals, the final sample size remained sufficient for analysis within this clinical population.

Before starting the study, the participants completed a general health questionnaire to identify possible contraindications to performing BFRE training, as well as the Lysholm questionnaire, which allowed patients to subjectively assess knee joint function (Lysholm & Tegner, 2007).

Inclusion criteria

The inclusion criteria were:

- Individuals with AMI of the QF muscle as a result of knee joint injury or surgery, which occurred at least six months prior (e.g., ACL injury, meniscus injury, or other intra-articular structures, patellofemoral pain syndrome, etc.),
- A difference (≥ 15%) in peak torque during voluntary isometric muscle contraction between the healthy and injured knee joints was used to confirm AMI.

Exclusion criteria

The exclusion criteria were:

- Cardiovascular, respiratory, and metabolic disease or impairment,
- Presence of pain > 3 on the visual analog scale (VAS) during the activities planned as part of the study,
- Persons younger than 18 or older than 55 years,
- A history of peripheral or central thromboembolic events,
- Radiculopathies and peripheral neurological disorders of the lower limbs.

Intervention

A counterbalanced quasi-randomization of the patients was performed to match the patients between groups by age, gender, body mass index, total score on the Lysholm Knee Scoring Scale for the self-assessment of knee function (Lysholm & Tegner, 2007), and the proportional deficit in torque achieved during maximum voluntary isometric contraction (MVIC) between the injured and non-injured leg.

The training program was carried out over a period of four weeks, with the participants completing three training sessions per week, for a total of 12 sessions. The participants trained with the maximum mechanical resistance they could overcome with 30 repetitions (30 repetitions maximum; 30 RM). All the training sessions were supervised by an experienced physiotherapist and included an exercise for the QF muscle in a closed kinetic chain with a leg press machine (Barbarian-Line BB-9091, Germany) (Figure 1) and an exercise for the QF muscle in an open kinetic chain with a knee extension machine (Sokol Gym, Slovenia) (Figure 2). Before the first training session, the 30 RM load was determined individually for each participant.

Figure 1: Exercise for the quadriceps femoris muscle in a closed kinetic chain using a leg press machine

Figure 2: Exercise for the quadriceps femoris muscle in an open kinetic chain using a knee extension machine

Participants in the LL-BFRE group exercised with restricted blood flow using an asymmetric inflatable cuff (University of Ljubljana and Iskra Medical d.o.o., Slovenia) applied to the proximal part of the thigh as previously described by (Ipavec, Grapar Žargi, Jelenc, & Kacin, 2019). The pressure was regulated with a pneumatic system for reducing blood flow (Ischemic Trainer, University of Ljubljana, and Iskra Medical d.o.o, Slovenia). Participants in the SLL-BFRE group followed the same training protocol, with the difference that the cuff was inflated to a lower pressure (20 mmHg), which did not affect normal blood flow to the active muscles. The cuff size (width and length) for both groups was selected to match the participants' thigh length and circumference.

Given the influence of limb anthropometric characteristics on blood flow reduction under the cuff (Jessee et al., 2016; Loenneke et al., 2012), the cuff pressure was adjusted individually for each participant. The initial cuff pressure was set at 120 mmHg and was increased if necessary. If the thigh circumference exceeded 58 cm, the pressure was increased by 10 mmHg. Additionally, if the skinfold thickness exceeded 23 mm, the pressure was increased by another 10 mmHg. Thus, the minimum pressure used in the study was 120 mmHg, while the maximum pressure reached 140 mmHg.

After the initial warm-up, which consisted of 10-12 repetitions at a minimum load, the cuff was inflated with air to an individualized pressure of 120-140 mmHg and left on the resting muscle for 30 seconds. After 30 s, the training session began with leg presses and knee extensions, each consisting of four sets with a decreasing number of repetitions (20, 15, 15, and 10 repetitions). Each repetition included a controlled 2-second concentric and 2-second eccentric contraction to ensure an equal time under tension for all the participants. This cadence was maintained throughout the sets using a metronome. Between sets one and two, as well as three and four, there was a 30-s rest break without reperfusion (cuff ON). In the rest period between sets two and three, a 45-second muscle reperfusion was performed (cuff OFF). A similar BFRE training protocol was successfully used in previous studies with knee patients (Fitschen et al., 2014; M. Jessee et al., 2017; Rossow et al., 2012). A schematic representation of the training session is shown in (Figure 3). The patients were asked not to change their routine of regular daily activities during the intervention and to keep a diary.

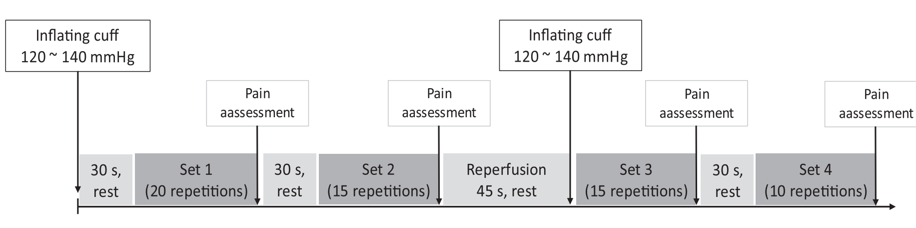


Figure 3: Training Protocol with Knee Joint Pain Intensity Assessment

Pain Intensity Assessment in the Knee Joint

Participants rated the intensity of their knee joint pain before the start of each training session and after each exercise series using a 10-point numerical rating scale (Figure 3). A score of 0 meant that there was no pain, while a score of 10 represented the worst pain the participants had ever experienced in their lives. For the statistical analysis of knee pain intensity, we calculated the average pain score for both exercises (leg press and knee extension) for each individual week of the training period (weeks 1-4).

Lysholm Assessment of Knee Joint Function

In order to obtain a subjective assessment of knee joint function, the participants completed the Lysholm questionnaire, which evaluates eight domains: limp, support, locking, instability, pain, swelling, stair climbing, and squatting (Lysholm & Tegner, 2007). A higher score indicates better knee function, with a maximum score of 100 indicating optimal results and no functional impairment. The participants completed the questionnaire before the baseline measurements and again after completing the strengthening program.

Statistical Analysis

Statistical analysis of the data was done using SPSS version 23.0 (IBM SPSS Statistics, Chicago, IL, USA). The normality of the data distribution was tested using the Shapiro-Wilk's test. Most of the variables were normally distributed and the rest were logarithmically transformed before further statistical analysis.

To compare the means, we used a parametric analysis, a t-test for independent samples, and a two-way 2 × 2 (time × group) factor analysis of variance (ANOVA) for repeated measures on one factor (time). In case of a significant effect of either factor or their interaction, a post-hoc pair-wise comparison was made using Tukey's honestly significant difference (HSD) test. Partial eta squared was used to estimate the effect size, interpreting the results as follows: 0.01 = small effect, 0.06 = medium effect, and 0.14 or higher = large effect (Cohen, 2013). The significance level was set at $p < 0.05$ for all the tests. All the values are presented as mean ± standard deviation, unless stated otherwise.

RESULTS

There were no significant differences ($p > 0.05$) detected between the LL-BFRE and SLL-BFRE groups in anthropometric characteristics for age, body height, body mass, and body mass index (BMI) (Table 1).

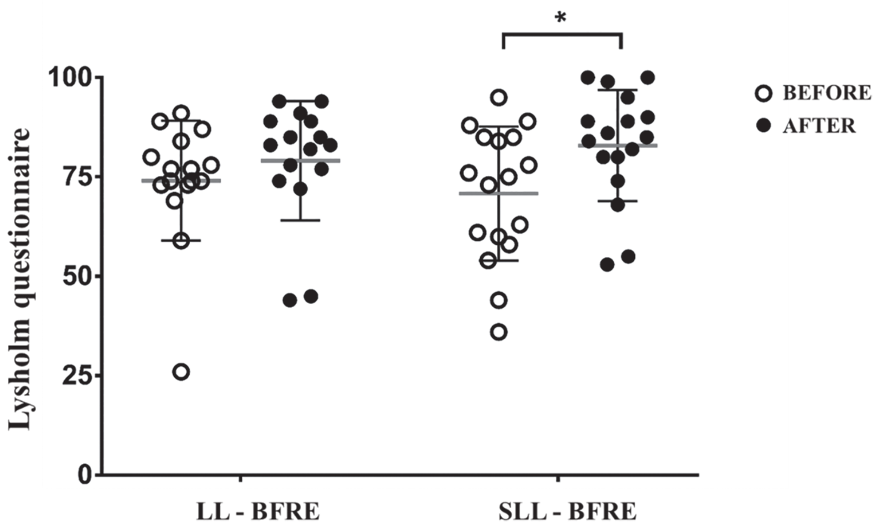
Table 1: Anthropometric characteristics of the patients

		N	Age (years)	Body height (cm)	Body mass (kg)	BMI (kg/m²)
LL-BFRE	M	6	44.3 ± 6.8	176.0 ± 4.3	81.5 ± 12.9	26.2 ± 3.4
	F	10	36.3 ± 11.4	168.6 ± 8.3	61.6 ± 7.7	21.6 ± 1.7
	Total	16	39.3 ± 10.5	171.4 ± 7.8	69.1 ± 13.8	23.3 ± 3.3
SLL-BFRE	M	7	38.6 ± 5.3	184.9 ± 7.8	87.7 ± 13.8	25.6 ± 3.0
	F	10	40.4 ± 11.9	166.4 ± 9.7	63.6 ± 11.5	23.0 ± 4.2
	Total	17	39.6 ± 9.5	174 ± 12.8	73.5 ± 17.2	24.1 ± 3.8

Legend: N = number, M = male, F = female, BMI = body mass index.

For the Lysholm questionnaire, a significant effect of time was observed ($F = 22.872$; $p < 0.001$) with a substantial effect size ($\eta^2 = 0.424$), while the effect of the group was not significant ($F = 0.003$; $p = 0.954$; $\eta^2 = 0.050$). There was a trend toward a significant interaction between the two factors ($F = 3.916$; $p = 0.056$; $\eta^2 = 0.112$) (Figure 4).

Post-hoc pair-wise comparisons revealed that the total Lysholm score in the LL-BFRE group increased from 74.1 ± 15.1 points to 79.1 ± 15.0 points ($p = 0.359$), although this change was not statistically significant. In contrast, in the SLL-BFRE group, the total Lysholm score significantly increased ($p < 0.001$) with training, from 70.8 ± 16.8 points to 82.9 ± 14.0 points.



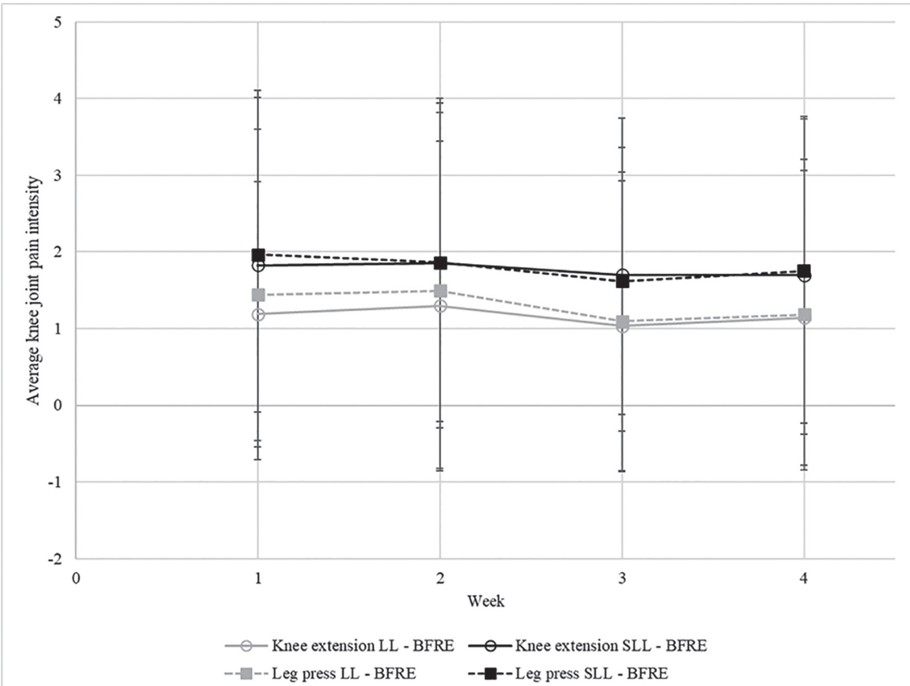
Legend: LL-BFRE - low-load blood flow restriction group, SLL-BFRE – sham low-load blood flow restriction group. * – significant effect of time ($p < 0.05$).

Figure 4: Subjective assessment of knee joint function (Lysholm questionnaire) for the LL-BFRE and SLL-BFRE groups before and after the exercise program.

During the leg press exercise, the pain levels in the LL-BFRE group changed from 1.4 ± 2.2 to 1.2 ± 2.0 points, while in the SLL-BFRE group, they changed from 2.0 ± 2.1 to 1.7 ± 2.0 points.

The effect of time was not significant ($F = 2.279$; $p = 0.084$; $\eta^2 = 0.068$), nor was the effect of the group ($F = 0.520$; $p = 0.476$; $\eta^2 = 0.016$), and their interaction was also not significant ($F = 0.149$; $p = 0.929$; $\eta^2 = 0.004$) (Figure 5).

During the knee extension exercises, the pain levels in the LL-BFRE group changed from 1.2 ± 1.7 to 1.1 ± 1.9 points, while in the SLL-BFRE group, they changed from 1.8 ± 2.3 to 1.7 ± 2.1 points. The effect of time was not significant ($F = 0.618$; $p = 0.604$; $\eta^2 = 0.019$), nor was the effect of the group ($F = 0.793$; $p = 0.379$; $\eta^2 = 0.024$), and their interaction was also not significant ($F = 0.059$; $p = 0.980$; $\eta^2 = 0.001$) (Figure 5).



Legend: LL-BFRE – low-load blood flow restriction group, SLL-BFRE – sham low-load blood flow restriction group.

Figure 5: The average knee joint pain intensity values during leg press and knee extension exercises throughout the four-week training program

DISCUSSION

The aim of this study was to investigate the influence of LL-BFRE exercise on patients with knee joint injuries, focusing on subjective knee joint function and knee pain intensity.

An improvement in subjective knee function was observed in both the LL-BFRE and SLL-BFRE groups, as assessed using the Lysholm questionnaire. However, the improvement was only statistically significant in the SLL-BFRE group ($p < 0.001$), with a 17% increase from 70.8 ± 16.8 to 82.9 ± 14.0 points. In contrast, the LL-BFRE group improved by 7% from 74.1 ± 15.1 to 79.1 ± 15.0 points, but this change was not statistically significant ($p = 0.359$).

There was a trend toward a significant interaction between time and group ($p = 0.056$), suggesting potential differences in how the two interventions influence knee function over time. However, this trend did not reach statistical significance, limiting the conclusions about the comparative efficacy of the two training modalities. Furthermore, no differences in the intensity of knee pain were observed between the LL-BFRE and SLL-BFRE groups throughout the training program.

Subjective Assessment of Knee Joint Function

The score of the Lysholm questionnaire is the sum of the scores in eight categories: limping, support, locking of the knee, instability, pain, swelling, stair climbing, and squatting. The maximum possible score is 100, with higher scores indicating better knee function (Collins, Misra, Felson, Crossley, & Roos, 2011; Lysholm & Tegner, 2007).

There are very few clinical studies that analyze pain or functional status after interventions with BFRE training. Jørgensen and Mechlenburg (2021) mainly attributed the improvement in knee joint function that they observed in a patient with rheumatoid arthritis after a 12-week BFRE training program to increased QF muscle strength. BFRE training induced tissue hypoxia, the accumulation of metabolites, and the swelling of muscle cells, resulting in increased protein synthesis, the recruitment of type II muscle fibers, stimulation of local and systemic anabolic hormone synthesis, and the activation of muscle satellite cells (Hwang & Willoughby, 2019; Jørgensen & Mechlenburg, 2021). It is assumed that these physiological adaptations can enhance muscle performance, joint stability, and proprioception, alleviating chronic pain and compensatory movement patterns. Clinically, these changes translate into improved functional capacity, reduced disability, and better performance in daily activities, emphasizing the holistic benefits of BFRE training in rehabilitation (Jørgensen & Mechlenburg, 2021).

Ke et al. (2022) conducted a study similar to ours on a sample of patients following partial meniscectomy. One group received routine rehabilitation, while the other received routine rehabilitation in combination with LL-BFRE exercises. The Lysholm questionnaire scores in the study by Ke et al. (2022) improved significantly in both groups 4 and 8 weeks after surgery ($p < 0.01$). Further analysis showed that the Lysholm scores were significantly higher in the LL-BFRE group than in the control group ($p < 0.01$). The results of our study are not consistent with those of Ke et al. (2022), as we found that the Lysholm score improved more in the SLL-BFRE group than in the LL-BFRE group. There are several possible reasons for this discrepancy. The baseline condition of the participants in the SLL-BFRE group was lower, with a baseline Lysholm score of 70.8 ± 16.8 points, compared with 74.1 ± 15.1 points in the LL-BFRE group. However, this difference was not statistically significant ($p > 0.05$).

The results may also have been influenced by the heterogeneity of the patients and the sample size (16 patients in the LL-BFRE group and 17 in the SLL-BFRE group). In addition, the placebo effect may have had a positive impact on the participants' perception of pain and joint function, as belief in treatment may lead to positive physiological changes. Furthermore, random fluctuations in the natural healing process or spontaneous recovery after various knee injuries may have contributed to the results.

Other factors, such as the degree of motivation and the active participation of the patients in the study, may also have played a role. Social factors such as the level of support from the participants' home environment or the level of stress they were exposed to, which were outside the control of the study, may also have influenced the results. Therefore, further research is needed to investigate these variables.

Liu and Wu (2023) conducted a study on individuals with patellofemoral pain syndrome and investigated the effects of soft tissue mobilization with various metal tools in combination with BFRE exercises on knee joint function. The participants were divided into a control and a BFRE exercise group, with the number of sets increasing over the four-week period (from 3 to 6 sets), with each set consisting of 30 to 15 repetitions and rest periods ranging from 30 to 60 seconds. The training sessions were performed twice a week with a cuff applied to the proximal thigh. The pressure in the cuff was between 20 and 50 mmHg, well below the 120 to 140 mmHg used in our study. The participants completed the Lysholm questionnaire before and after the exercise program and the results showed a significant improvement in knee function in both groups ($p < 0.05$). However, no significant differences were found between the ischemic group and the control group.

An important consideration concerns the cuff pressure used in the study, which was almost comparable to the pressure applied in our SLL-BFRE group. This raises the critical question of whether true ischemia was achieved in their study. Cuff pressure is a key factor influencing the perceived exertion and muscle soreness during BFRE exercise. The pressures used in the studies vary greatly and range from 50 mmHg (Kubota, Sakuraba, Koh, Ogura, & Tamura, 2011; Liu & Wu, 2023) to 300 mmHg (Cook, Clark, & Ploutz-Snyder, 2007). Both exertion and pain have been shown to increase proportionally with higher cuff pressure (Jessee et al., 2017), as well as with variations in cuff size and design (Ipavec et al., 2019; Jessee et al., 2016). Given these variations, it is important to question whether the lower pressures used in some studies, such as Liu and Wu's, were sufficient to induce true ischemia, or whether they more closely mimicked the conditions in the placebo groups, as seen in our study. Further investigation into optimal cuff pressure is critical to ensure consistency in BFRE research and to better understand the relationship between cuff pressure, pain intensity, and exercise effectiveness.

Level of Knee Joint Pain Intensity

The intensity of knee joint pain is an important factor to consider when intervening with BFRE. Pain intensity can affect the participants' adherence to the exercise program and impact the overall rehabilitation outcomes. Studies investigating BFRE training, particularly at low loads, have shown that pain intensity and muscle discomfort vary depending on the cuff pressure, individual condition, and type of exercise (Jessee et al., 2017).

In our study, the intensity of knee pain was assessed using a numerical pain rating scale, with the participants reporting their pain before and after each exercise set. The results showed no significant differences in pain intensity between the LL-BFRE and SLL-BFRE groups during the exercise program, suggesting that LL-BFRE exercise did not exacerbate knee joint pain compared to SLL-BFR.

Li, Shaharudin, and Abdul Kadir (2021) conducted a meta-analysis in which they examined the effects of BFRE exercise on muscle performance and knee joint pain in people with knee injuries. They found that LL-BFRE exercise can improve muscle performance and reduce pain in these individuals. In particular, LL-BFRE training may offer similar benefits to high-load resistance training with a lower risk of injury and pain (Li et al., 2021).

In the study by Rodrigues et al. (2020), they investigated the effects of two resistance training protocols, LL-BFRE and high-load resistance training (HL-RT), on pain levels in women with rheumatoid arthritis. Using the visual analog scale (VAS), the study showed that the LL-BFRE group experienced a significant reduction in pain, with the VAS scores decreasing by 51.41% from a pre-intervention score of 4.73 to 2.30 post-intervention ($p = 0.002$). In contrast, the HL-RT group showed no significant change in the pain scores. The VAS scores decreased by only 2.07% (from 3.22 to 3.15), indicating an insignificant effect ($p=0.969$).

Li et al. (2021) observed that knee joint pain significantly decreased during, immediately after, and 24 hours after exercise in subjects who had undergone ACL reconstruction, suggesting that BFRE training may have a hypoalgesic effect. This effect is thought to be due to increased beta-endorphin levels and decreased pain sensitivity up to 24 hours after training (Li et al., 2021).

Similarly, Reina-Ruiz et al. (2023) found that LL-BFRE training produced better results in reducing knee pain than HL-RT in individuals with various knee pathologies, including rheumatoid arthritis, osteoarthritis, and patellofemoral pain syndrome. This effect could be related to the use of high cuff pressure, which triggers a hypoalgesic mechanism during exercise and thus increases the pain threshold (Jessee et al., 2017, Hughes et al., 2019).

Hughes et al. (2019) conducted a study in which participants performed unilateral leg presses twice a week, with at least 48 hours between sessions. The training program lasted 8 weeks. Participants were divided into a control group, which performed HL-RT, and an LL-BFRE group. The HL-RT group performed 3 sets of 10 repetitions with 30-second rest periods between sets at 70% 1RM, according to the recommended protocol for improving muscle strength. The LL-BFRE group completed 4 sets (30, 15, 15 and 15 repetitions) with 30-second rest periods at 30% 1RM. The knee pain was assessed after each set using the Borg CR10+ scale. The knee pain was highest in both groups during the first session at 1.38 ± 0.96 in the LL-BFRE group and 3.43 ± 1.64 in the control group but decreased significantly after the fourth and sixth sessions and remained low for the remainder of the program. It is noteworthy that knee pain was significantly lower in the LL-BFRE group compared to the HL-RT group during all the sessions, confirming the results of Ke et al. (2022). This could be due to the reduced external load during LL-BFRE exercise resulting in less stress on the knee joint and reduced joint loading, which is consistent with the conclusions of Li et al. (2021) and Reina-Ruiz et al. (2023) that LL-BFRE exercise can reduce knee pain in individuals with knee injuries.

Ke et al. (2022) also investigated the effect of BFRE exercises on knee joint pain in individuals after partial meniscectomy. Using the VAS to assess pain, they found significant improvements ($p<0.01$) in both groups at 4 and 8 weeks after surgery. The VAS scores for the BFRE group decreased from 2.95 ± 0.85 immediately after surgery to 1.00 ± 0.33 at 4 weeks and 0.42 ± 0.51 at 8 weeks, while the scores for the control group decreased from 2.84 ± 1.01 to 2.05 ± 0.97 and 1.42 ± 0.77, respectively. Further analysis showed that the BFRE group had significantly lower VAS scores than the control group at both 4 and 8 weeks after surgery ($p < 0.01$). These results suggest that LL-BFRE training can significantly alleviate knee joint pain in patients after partial meniscectomy, which is consistent with the findings of Li et al. (2021) and Reina-Ruiz et al. (2023), who also reported that LL-BFRE training can reduce knee pain in individuals with knee injuries.

Liu and Wu (2023) used the VAS in their study to assess the sensation of pain in the knee joint. When comparing the control and BFRE groups, they found a significant difference in pain intensity before the exercise program and after the first exercise session ($p < 0.05$), as the BFRE group achieved a greater improvement in pain level assessment compared to the control group. When comparing the VAS results before the exercise program, after the first exercise session, and after four weeks of the exercise program, a significant difference was found between the groups ($p < 0.05$), as the subjects in the BFRE group achieved a greater improvement in the VAS results than the subjects in the control group.

Based on the findings of Reina-Ruiz et al. (2023), Ke et al. (2022), Li et al. (2021), Liu and Wu (2023), and Hughes et al. (2019), it appears that LL-BFRE exercise can significantly improve the perception of knee joint pain. In our study, we did not find a significant change in pain intensity in any of the groups as a result of the training. The reason for the different results is most likely due to the significantly lower baseline pain intensity of our participants, which was 1.2 ± 1.7 in the LL-BFRE group and 1.8 ± 2.3 in the SLL-BFRE group during the knee extension exercise, 1.4 ± 2.2 for the leg press exercise in the LL-BFRE group and 2.0 ± 2.1 in the SLL-BFRE group, compared to other studies in which the baseline pain intensity in the ischemic groups was 4.73 (Reina-Ruiz et al, 2023), 2.95 ± 0.85 (Ke et al., 2022) and 1.38 ± 0.96 (Hughes et al., 2019), while in the control groups, it was 2.59 (Reina-Ruiz et al., 2023), 2.84 ± 1.01 (Ke et al., 2022), and 3.43 ± 1.64 (Hughes et al., 2019). It appears that pain was not an important symptom of muscle inhibition during exercise in our subjects and therefore did not change significantly with exercise, in contrast to other studies.

CONCLUSIONS

This study investigated the effect of LL-BFRE exercises on patients with knee joint injuries, specifically focusing on the subjective assessment of knee joint function using the Lysholm questionnaire and knee joint pain perception. Our results revealed improvements in subjective knee joint function in both the LL-BFRE and SLL-BFRE groups, with the SLL-BFRE group demonstrating greater improvement.

The reasons for this outcome are multifactorial, including potential baseline differences, a smaller and heterogeneous sample, and the challenges of clinical implementation. Despite these limitations, this study demonstrates the feasibility and tolerability of both exercise protocols, as evidenced by the low and comparable pain levels between the groups throughout the intervention. As one of the few clinical investigations in this domain, these findings provide preliminary insights into BFRE applications in rehabilitation. Future research with larger, more homogeneous samples and extended follow-up periods is necessary to confirm these findings and further refine exercise protocols to enhance functional recovery.

REFERENCES

Abe, T., Loenneke, J. P., Fahs, C. A., Rossow, L. M., Thiebaud, R. S., & Bemben, M. G. (2012). Exercise intensity and muscle hypertrophy in blood flow-restricted limbs and non-restricted muscles: A brief review. *Clinical Physiology and Functional Imaging*, *32*(4), 247–252. https://doi.org/10.1111/j.1475-097X.2012.01126.x.

Adams, D., Logerstedt, D. S., Hunter-Giordano, A., Axe, M. J., & Snyder-Mackler, L. (2012). Current concepts for anterior cruciate ligament reconstruction: A criterion-based rehabilitation progression. *Journal of Orthopaedic & Sports Physical Therapy, 42*(7), 601-614. https://doi.org/10.2519/jospt.2012.3871.

Austermuehle, P. D. (2001). Common knee injuries in primary care. *The Nurse Practitioner*, *26*(10), 26, 32-38, 41-45.

Bird, S. P., Tarpenning, K. M., & Marino, F. E. (2005). Designing resistance training programmes to enhance muscular fitness: A review of the acute programme variables. *Sports Medicine, 35*, 841-851. https://doi.org/10.2165/00007256-200535100-00002.

Centner, C., & Lauber, B. (2020). A systematic review and meta-analysis on neural adaptations following blood flow restriction training: What we know and what we don't know. *Frontiers in Physiology*, *11*, 887. https://doi.org/10.3389/fphys.2020.00887.

Clark, B. C., Fernhall, B., & Ploutz-Snyder, L. L. (2006). Adaptations in human neuromuscular function following prolonged unweighting: I. Skeletal muscle contractile properties and applied ischemia efficacy. *Journal of Applied Physiology, 101*(1), 256-263. https://doi.org/10.1152/japplphysiol.01402.2005.

Cohen, J. (2013). *Statistical power analysis for the behavioral sciences*. Cambridge: Academic press. https://doi.org/10.4324/9780203771587.

Collins, N. J., Misra, D., Felson, D. T., Crossley, K. M., & Roos, E. M. (2011). Measures of knee function: International Knee Documentation Committee (IKDC) Subjective Knee Evaluation Form, Knee Injury and Osteoarthritis Outcome Score (KOOS), Knee Injury and Osteoarthritis Outcome Score Physical Function Short Form (KOOS-PS), Knee Outcome Survey Activities of Daily Living Scale (KOS-ADL), Lysholm Knee Scoring Scale, Oxford Knee Score (OKS), Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC), Activity Rating Scale

(ARS), and Tegner Activity Score (TAS). *Arthritis Care & Research*, *63*(S11), S208-228. https://doi.org/10.1002/acr.20632.

Cook, S. B., Clark, B. C., & Ploutz-Snyder, L. L. (2007). Effects of exercise load and blood-flow restriction on skeletal muscle function. *Medicine & Science in Sports & Exercise 39*(10), 1708-1713. https://doi.org/10.1249/mss.0b013e31812383d6.

Fitschen, P. J., Kistler, B. M., Jeong, J. H., Chung, H. R., Wu, P. T., Walsh, M. J., & Wilund, K. R. (2014). Perceptual effects and efficacy of intermittent or continuous blood flow restriction resistance training. *Clinical Physiology and Functional Imaging*, *34*(5), 356–363. https://doi.org/10.1111/cpf.12100.

Gage, B. E., McIlvain, N. M., Collins, C. L., Fields, S. K., & Dawn Comstock, R. (2012). Epidemiology of 6.6 million knee injuries presenting to United States Emergency Departments from 1999 through 2008. *Academic Emergency Medicine*, *19*(4), 378–385. https://doi.org/10.1111/j.1553-2712.2012.01315.x.

Garber, C. E., Blissmer, B., Deschenes, M. R., Franklin, B. A., Lamonte, M. J., Lee, I. M., … Medicine, A. C. of S. (2011). American College of Sports Medicine position stand. Quantity and quality of exercise for developing and maintaining cardiorespiratory, musculoskeletal, and neuromotor fitness in apparently healthy adults: Guidance for prescribing exercise. *Medicine & Science in Sports & Exercise, 43*(7), 1334-1359. https://doi.org/10.1249/MSS.0b013e318213fefb.

Grønfeldt, B. M., Lindberg Nielsen, J., Mieritz, R. M., Lund, H., & Aagaard, P. (2020). Effect of blood-flow restricted vs heavy-load strength training on muscle strength: Systematic review and meta-analysis. *Scandinavian Journal of Medicine & Science in Sports, 30*(5), 837-848. https://doi.org/10.1111/sms.13632.

Hart, J. M., Pietrosimone, B., Hertel, J., & Ingersoll, C. D. (2010). Quadriceps activation following knee injuries: A systematic review. *Journal of Athletic Training, 45*(1), 87-97. https://doi.org/10.4085/1062-6050-45.1.87.

Hughes, L., Paton, B., Rosenblatt, B., Gissane, C., & Patterson, S. D. (2017). Blood flow restriction training in clinical musculoskeletal rehabilitation: A systematic review and meta-analysis. *British Journal of Sports Medicine*, *51*(13), 1003–1011. https://doi.org/10.1136/bjsports-2016-097071.

Hughes, L., Patterson, S. D., Haddad, F., Rosenblatt, B., Gissane, C., McCarthy, D., … Paton, B. (2019). Examination of the comfort and pain experienced with blood flow restriction training during post-surgery rehabilitation of anterior cruciate ligament reconstruction patients: A UK National Health Service trial. *Physical Therapy in Sport*, *39*, 90–98. https://doi.org/10.1016/j.ptsp.2019.06.014.

Hwang, P. S., & Willoughby, D. S. (2019). Mechanisms Behind Blood Flow-Restricted Training and its Effect Toward Muscle Growth. *Journal of Strength and Conditioning Research 33*, S167-S179. https://doi.org/10.1519/JSC.0000000000002384.

Ipavec, M., Grapar Žargi, T., Jelenc, J., & Kacin, A. (2019). Efficiency of pneumatic tourniquet cuff with asymmetric pressure distribution at rest and during isometric muscle action. *Journal of Strength and Conditioning Research 33*(9), 2570-2578. https://doi.org/10.1519/JSC.0000000000002678.

Jessee, M. B., Buckner, S. L., Dankel, S. J., Counts, B. R., Abe, T., & Loenneke, J. P. (2016). The influence of cuff width, sex, and race on arterial occlusion: Implications for blood flow restriction research. *Sports Medicine*, *46*(6), 913–921. https://doi.org/10.1007/s40279-016-0473-5.

Jessee, M., Dankel, S., Buckner, S., Mouser, J., Mattocks, K., & Loenneke, J. (2017). The cardiovascular and perceptual response to very low load blood flow restricted exercise. *International Journal of Sports Medicine*, *38*(08), 597–603. https://doi.org/10.1055/s-0043-109555.

Jørgensen, S. L., & Mechlenburg, I. (2021). Effects of low-load blood-flow restricted resistance training on functional capacity and patient-reported outcome in a young male suffering from reactive arthritis. *Frontiers in Sports and Active Living*, *3*, 798902. https://doi.org/10.3389/fspor.2021.798902.

Jung, W.-S., Kim, S.-H., Nam, S.-S., Kim, J.-W., & Moon, H.-W. (2022). Effects of rehabilitation exercise with blood flow restriction after anterior cruciate ligament reconstruction. *Applied Sciences*, *12*(23), 12058. https://doi.org/10.3390/app122312058.

Kacin, A., & Strazar, K. (2011). Frequent low-load ischemic resistance exercise to failure enhances muscle oxygen delivery and endurance capacity. *Scandinavian Journal of Medicine & Science in Sports, 21*(6), 231-241. https://doi.org/10.1111/j.1600-0838.2010.01260.x.

Ke, J., Zhou, X., Yang, Y., Shen, H., Luo, X., Liu, H., … Zhang, X. (2022). Blood flow restriction training promotes functional recovery of knee joint in patients after arthroscopic partial meniscectomy: A randomized clinical trial. *Frontiers in Physiology*, *13*, 1015853. https://doi.org/10.3389/fphys.2022.1015853.

Kubota, A., Sakuraba, K., Koh, S., Ogura, Y., & Tamura, Y. (2011). Blood flow restriction by low compressive force prevents disuse muscular weakness. *Journal of Science and Medicine in Sport, 14*(2), 95-99. https://doi.org/10.1016/j.jsams.2010.08.007.

Korakakis, V., Whiteley, R., & Epameinontidis, K. (2018). Blood Flow Restriction induces hypoalgesia in recreationally active adult male anterior knee pain patients allowing therapeutic exercise loading. *Physical Therapy in Sport, 32*, 235-243. https://doi.org/10.1016/j.ptsp.2018.05.021.

Li, S., Shaharudin, S., & Abdul Kadir, M. R. (2021). Effects of blood flow restriction training on muscle strength and pain in patients with knee injuries: A meta-analysis. *American Journal of Physical Medicine & Rehabilitation*, *100*(4), 337–344. https://doi.org/10.1097/PHM.0000000000001567.

Liu, Y., & Wu, L. (2023). Effect of instrument-assisted soft tissue mobilization combined with blood flow restriction training on function, pain and strength of patients with patellofemoral joint pain. *BMC Musculoskeletal Disorders*, *24*(1), 698. https://doi.org/10.1186/s12891-023-06701-6.

Loenneke, J. P., & Abe, T. (2012). Does blood flow restricted exercise result in prolonged torque decrements and muscle damage? *European Journal of Applied Physiology, 112*, 3445–3446. https://doi.org/10.1007/s00421-012-2312-1.

Loenneke, J. P., Fahs, C. A., Rossow, L. M., Sherk, V. D., Thiebaud, R. S., Abe, T., … Bemben, M. G. (2012). Effects of cuff width on arterial occlusion: Implications for blood flow restricted exercise. *European Journal of Applied Physiology, 112*, 2903-2912. https://doi.org/10.1007/s00421-011-2266-8.

Lysholm, J., & Tegner, Y. (2007). Knee injury rating scales. *Acta Orthopaedica, 78*(4), 445–453. https://doi.org/10.1080/17453670710014068.

Nielsen, J. L., Frandsen, U., Prokhorova, T., Bech, R. D., Nygaard, T., Suetta, C., & Aagaard, P. (2017). Delayed effect of blood flow–restricted resistance training on rapid force capacity. *Medicine & Science in Sports & Exercise*, *49*(6), 1157–1167. https://doi.org/10.1249/MSS.0000000000001208.

Ohta, H., Kurosawa, H., Ikeda, H., Iwase, Y., Satou, N., & Nakamura, S. (2003). Low-load resistance muscular training with moderate restriction of blood flow after anterior cruciate ligament reconstruction. *Acta Orthopaedica, 74*(1), 62-68. https://doi.org/10.1080/00016470310013680.

Parekh, S., Vaghela, N., & Mehta, D. (2024). Effectiveness of blood flow restriction training versus resistive exercises on pain, strength of quadriceps muscle, physical function in osteoarthritic knee patients. *International Journal of Health Sciences and Research*, *14*(4), 9–15. https://doi.org/10.52403/ijhsr.20240403.

Patterson, S. D., Hughes, L., Warmington, S., Burr, J., Scott, B. R., Owens, J., … Loenneke, J. (2019). Blood flow restriction exercise: Considerations of methodology, application, and safety. *Frontiers in Physiology*, *10*, 533. https://doi.org/10.3389/fphys.2019.00533.

Reina-Ruiz, Á. J., Martínez-Cal, J., Molina-Torres, G., Romero-Galisteo, R.-P., Galán-Mercant, A., Carrasco-Vega, E., & González-Sánchez, M. (2023). Effectiveness of blood flow restriction on functionality, quality of life and pain in patients with neuromusculoskeletal pathologies: A systematic review. *International Journal of Environmental Research and Public Health*, *20*(2), 1401. https://doi.org/10.3390/ijerph20021401.

Rice, D. A., & McNair, P. J. (2010). Quadriceps arthrogenic muscle inhibition: Neural mechanisms and treatment perspectives. *Seminars in Arthritis and Rheumatism, 40*(3), 250-266. https://doi.org/10.1016/j.semarthrit.2009.10.001.

Rodrigues, R., Ferraz, R. B., Kurimori, C. O., Guedes, L. K., Lima, F. R., de Sá-Pinto, A. L., … Roschel, H. (2020). Low-Load Resistance Training With Blood-Flow Restriction in Relation to Muscle Function, Mass, and Functionality in Women With Rheumatoid Arthritis. *Arthritis Care & Research*, *72*(6), 787–797. https://doi.org/10.1002/acr.23911.

Rossow, L. M., Fahs, C. A., Loenneke, J. P., Thiebaud, R. S., Sherk, V. D., Abe, T., & Bemben, M. G. (2012). Cardiovascular and perceptual responses to blood-flow-restricted resistance exercise with differing restrictive cuffs. *Clinical Physiology and Functional Imaging*, *32*(5), 331–337. https://doi.org/10.1111/j.1475-097X.2012.01131.x.

Shaw, T., McEvoy, M., & McClelland, J. (2002). An australian survey of in--patient protocols for quadriceps exercises following anterior cruciate ligament reconstruction. *Journal of Science and Medicine in Sport*, *5*(4), 291–296. https://doi.org/10.1016/S1440-2440(02)80017-2.

Sonnery-Cottet, B., Saithna, A., Quelard, B., Daggett, M., Borade, A., Ouanezar, H., … Blakeney, W. G. (2019). Arthrogenic muscle inhibition after ACL reconstruction: A scoping review of the efficacy of interventions. *British Journal of Sports Medicine*, *53*(5), 289–298. https://doi.org/10.1136/bjsports-2017-098401.

Takarada, Y., Takazawa, H., & Ishii, N. (2000). Applications of vascular occlusion diminish disuse atrophy of knee extensor muscles. *Medicine and Science in Sports and Exercise 32*(12), 2035-2039. Retrieved from https://journals.lww.com/acsm-msse/fulltext/2000/12000/applications_of_vascular_occlusion_diminish_disuse.11.aspx.

Van Kampen, A. (2013). The knee joint in sports medicine. *International Orthopaedics*, *37*(2), 177–179. https://doi.org/10.1007/s00264-013-1774-z.

Wernbom, M., Augustsson, J., & Raastad, T. (2008). Ischemic strength training: A low-load alternative to heavy resistance exercise? *Scandinavian*

Journal of Medicine & Science in Sports, 18(4), 401-416. https://doi.org/10.1111/j.1600-0838.2008.00788.x.

Wernbom, M., Järrebring, R., Andreasson, M. A., & Augustsson, J. (2009). Acute effects of blood flow restriction on muscle activity and endurance during fatiguing dynamic knee extensions at low load. *Journal of Strength and Conditioning Research 23*(8) 2389-2395. https://doi.org/10.1519/JSC.0b013e3181bc1c2a.

Žargi, T., Drobnič, M., Stražar, K., & Kacin, A. (2018). Short-Term preconditioning with blood flow restricted exercise preserves quadriceps muscle endurance in patients after anterior cruciate ligament reconstruction. *Frontiers in Physiology, 9*, 1150. https://doi.org/10.3389/fphys.2018.01150.

REPORTS AND REVIEWS
POROČILA IN OCENE

REPORTS AND REVIEWS/POROČILA IN OCENE, 197–202

6th International Scientific Conference
"EXERCISE AND QUALITY OF LIFE - EQOL 2024"
"THE GLOBAL IMPACT OF SPORT SCIENCE"

Novi Sad, Serbia, 11–13 April 2024

Reflecting on the valuable insights and discussions that emerged during the 6th International Scientific Conference entitled "Exercise and Quality of Life - EQOL 2024", we would like to provide some key information about this year's conference. The attendance of 392 registered participants from 47 countries, who presented a total of 184 papers over three days, showed an organizational record in all respects. It certainly reflects a progression from previous years and highlights the need for scientific events such as conferences and congresses to take place in-person. A significant scientific contribution was made by the diverse group of planned and invited lectures, which presented the latest developments and touched upon new problems observed in the field of kinesiology and sports science. More details about the conference can be found at: https://eqol.rs/.

The use of information technology, its advantages and its dangers, is undoubtedly becoming increasingly important and is likely to remain a genuine research paradigm in the future. The applications of IT in sport, preventive measures and health interventions still require scientific reflection and a forward-looking perspective, emphasizing the significance of the basic science of kinesiology.

The Institute for Kinesiology Research at ZRS Koper participated as a partner in organizing the conference this year and played an important role by presenting eight scientific papers and a keynote lecture by one of its researcher. Organizing such a diverse and dynamic event was challenging yet rewarding for everyone involved. The scientific novelties presented were significant, and the connections established during the conference represent a significant added value in the fostering of new international institutional collaborations.

Therefore, special thanks goes to the dedicated team of organizers and the students of the Faculty of Sports and Physical Education, who were a key force in ensuring the success of the conference. We hope to have the opportunity to collaborate again at the next EQOL in 2027.

Saša Pišot

6. mednarodna znanstvena konferenca VADBA IN KAKOVOST ŽIVLJENJA– EQOL 2024 GLOBALNI VPLIV ŠPORTNE ZNANOSTI

Novi Sad, Srbija, 11.–13. april 2024

Ob razmisleku o novostih in plodnih razpravah med 6. mednarodno znanstveno konferenco Vadba in kakovost življenja – EQOL 2024 navajamo nekaj ključnih informacij. Sodelovalo je 392 registriranih udeležencev iz 47 držav, ki so v treh dneh konference predstavili skupno 184 prispevkov, kar v vseh pogledih potrjuje uspeh organizatorjev. To gotovo izraža napredek v primerjavi s preteklimi leti in poudarja potrebo po znanstvenih dogodkih, kot so konference in kongresi v živo. Pomemben znanstveni prispevek je bil dosežen z raznovrstno skupino plenarnih in uvodnih predavanj, v katerih so predavatelji predstavili najnovejši razvoj ter obravnavali nove probleme, opažene na področju kineziologije in športne znanosti. Več podrobnosti o konferenci najdete na povezavi https://eqol.rs/.

Uporaba informacijske tehnologije, njene prednosti in opozarjanje na nevarnosti nedvomno postajajo vse pomembnejši in bodo verjetno ostali pomembna raziskovalna paradigma v prihodnosti. Aplikacije IT, namenjene vrhunskemu in rekreacijskemu športu, preventivi in intervenciji, gotovo zahtevajo znanstveni razmislek in usmerjen pogled naprej, kar poudarja pomen temeljne znanosti o kineziologiji.

Inštitut za kineziološke raziskave pri ZRS Koper je letos sodeloval kot partner pri organizaciji konference in imel pomembno vlogo s predstavitvijo osmih znanstvenih prispevkov in plenarnim predavanjem. Organizacija tako vsebinsko raznovrstnega in dinamičnega dogodka je bila zahtevna, hkrati pa nagrajujoča za vse vključene. Predstavljene so bile pomembne znanstvene novosti, nova poznanstva, vzpostavljena med konferenco, pa so velika dodana vrednost za spodbujanje novih mednarodnih institucionalnih sodelovanj.

Za ta uspešno izvedeni dogodek gre posebna zahvala predani ekipi organizatorjev in študentom Fakultete za šport in telesno vzgojo iz Novega Sada, ki so pomembno pripomogli k uspešni izvedbi konference. Upamo, da bomo imeli priložnost ponovno sodelovati na naslednji konferenci EQOL leta 2027.

Saša Pišot

LEVERAGING NEUROSCIENTIFIC DISCOVERIES FOR NEUROREHABILITATION PRODUCTS AND SERVICES

Piran, Slovenia, 16–20 July 2024

The TBrainBoost Summer School 1.0, held on July 16–20, 2024, in Piran, Slovenia, brought together students, researchers, and industry professionals to explore innovative applications of neuroscience in neurorehabilitation. The program featured an intensive series of workshops, lectures, and hands-on training designed to translate neuroscientific research into practical solutions for rehabilitation technologies and services.

The event opened with a keynote lecture on personalized exergaming for post-stroke rehabilitation, which set a collaborative and forward-thinking tone. Throughout the week, the participants explored various topics, including motor-cognitive training throughout the lifespan, technology-driven fatigue management, robotics in healthcare innovation, and physiotherapy for Parkinson's disease.

Central to the program was project development, with students refining their ideas with support from experienced mentors. Highlights included a start-up initiative aimed at enhancing physiotherapy practices and a prototype device designed for ACL rehabilitation. These projects showcased the potential for transforming scientific research into viable healthcare products.

The participants gained hands-on experience through practical workshops on EEG-based dementia testing and perturbation-based balance training for fall prevention. Discussions on measuring muscle mass and strength loss in older adults underscored the relevance of personalized health solutions for an aging population.

The summer school concluded with project presentations, where participants demonstrated significant progress and received expert feedback. A closing ceremony celebrated their achievements and encouraged future innovation and collaboration in neurorehabilitation research.

About the TBrainBoost project

The overall objective of TBrainBoost is to boost international and intersectoral mobility and improve the links between academia, business, and society in the field of healthy aging. TBrainBoost will achieve this through a series of secondments between academic institutions and businesses working in the field of healthy aging, as well as a number of educational activities. Based on our methodology, researchers from this multidisciplinary field will enhance their entrepreneurial skills and competences while bringing their valuable research expertise to the industry, while R&I talents will gain new insights and skills to create the structural changes that are required to set strong foundations for academy-business collaboration in the future. All the intersectoral secondments will also place an emphasis on benefiting institutions from widening countries, namely empowering talents from Slovenia and Malta with opportunities to learn from colleagues in Germany, the Netherlands, and Belgium. Ultimately, the TBrainBoost project will create a reality where scientists and R&I talents from all parts of the spectrum intuitively share knowledge, experience, and skills to boost their personal profiles, work for the benefit of the aging society, and drive our economies.

Uroš Marušič

REPORTS AND REVIEWS/POROČILA IN OCENE, 197–202

UPORABA NEVROZNANSTVENIH ODKRITIJ ZA IZDELKE IN STORITVE V NEVROREHABILITACIJI

Piran, Slovenija, 16.–20. julij 2024

Poletna šola TBrainBoost 1.0, ki je potekala od 16. do 20. julija 2024 v Piranu v Sloveniji, je združila študente, raziskovalce in strokovnjake iz industrije, da bi raziskali inovativne aplikacije nevroznanosti v nevrorehabilitaciji. Program je vključeval intenzivno serijo delavnic, predavanj in praktičnega usposabljanja, namenjenih prenosu nevroznanstvenih raziskav v praktične rešitve za rehabilitacijske tehnologije in storitve.

Dogodek se je začel z uvodnim predavanjem o prilagojenem igranju aktivnih iger (ang. exergaming) za rehabilitacijo po možganski kapi, ki je vzpostavilo sodelovalno atmosfero in vzpodbudilo razmišljanje o prihodnosti. Udeleženci so ves teden raziskovali različne teme, med drugim motorično-kognitivno usposabljanje v celotnem življenjskem obdobju, tehnološko podprto obvladovanje utrujenosti, robotiko pri inovacijah v zdravstvu in fizioterapijo pri Parkinsonovi bolezni.

Osrednji del programa je bil razvoj projektov, v katerih so študentje ob podpori izkušenih mentorjev izpopolnjevali svoje zamisli. Med najpomembnejšimi dosežki sta bila zagonska pobuda za izboljšanje fizioterapevtskih praks in prototip naprave, namenjene rehabilitaciji kolčne vezi. Ti projekti so pokazali možnosti za preoblikovanje znanstvenih raziskav v izvedljive zdravstvene izdelke.

Udeleženci so pridobili praktične izkušnje na praktičnih delavnicah o testiranju parametrov demence na podlagi EEG merjenja in treningu ravnotežja na podlagi perturbacij za preprečevanje padcev. Razprave o merjenju mišične mase in izgubi moči pri starejših odraslih so poudarile pomen personaliziranih zdravstvenih rešitev za starajoče se prebivalstvo.

Poletna šola se je končala s predstavitvami projektov, pri katerih so udeleženci pokazali pomemben napredek in prejeli povratne informacije strokovnjakov. Na zaključni slovesnosti so proslavili svoje dosežke ter spodbudili prihodnje inovacije in sodelovanje na področju raziskav v nevrorehabilitaciji.

O projektu TBrainBoost

Cilj projekta TBrainBoost je spodbujati mednarodno in medsektorsko mobilnost ter izboljšati povezave med akademskim okoljem, gospodarstvom in družbo na področju zdravega staranja. TBrainBoost bo to dosegel s pomočjo številnih izmenjav strokovnjakov med akademskimi institucijami in podjetji, ki delujejo na področju zdravega staranja, in različnimi izobraževalnimi dejavnostmi. Na podlagi naše metodologije bodo raziskovalci s tega multidisciplinarnega področja okrepili svoje podjetniške veščine in kompetence ter svojo dragoceno raziskovalno strokovnost prenesli v industrijo, medtem ko bodo talenti za raziskave in inovacije pridobili nova spoznanja in veščine za ustvarjanje strukturnih sprememb, ki so potrebne za vzpostavitev trdnih temeljev za prihodnje sodelovanje med akademsko sfero in gospodarstvom. Vse medsektorske izmenjave strokovnjakov bodo poudarjale tudi koristi za institucije iz držav širjenja, in sicer z opolnomočenjem talentov iz Slovenije in z Malte, da se učijo od kolegov v Nemčiji, na Nizozemskem in v Belgiji. Na koncu bo projekt TBrainBoost ustvaril resničnost, v kateri bodo znanstveniki/raziskovalci z vseh področij intuitivno delili znanje, izkušnje in veščine, krepili svoje osebne profile, delovali v korist starajoče se družbe in spodbujali razvoj gospodarstev vseh sodelujočih.

Uroš Marušič

GUIDELINES FOR AUTHORS

1. **Aim and scope of the journal:**
   Annales Kinesiologiae is an international interdisciplinary journal covering kinesiology and its related areas. It combines fields and topics directed towards the study and research of human movement, physical activity, exercise and sport in the context of human life style and influences of specific environments. The journal publishes original scientific articles, review articles, technical notes and reports.

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j) References

The journal uses the Harvard reference system (Publication Manual of the American Psychological Association, 6th ed., 2010), see also: https://www.apastyle.org). The list of references should only include work cited in the main text and being published or accepted for publication. Personal communications and unpublished works should only be mentioned in the text. References should be complete and contain up to seven authors. If the author is unknown, start with the title of the work. If you are citing work that is in print but has not yet been published, state all the data and instead of the publication year write „in print".

Reference list entries should be alphabetized by the last name of the first author of each work. Titles of references written in languages other than English should be additionally translated into English and enclosed within square brackets. Full titles of journals are required (no abbreviations).

Where available, DOI numbers should be provided in the form of a resolvable URL https://doi.org/10.1037/rmh0000008.

Examples of reference citation in the text

<u>One author</u>: This research spans many disciplines (Enoka, 1994) or Enoka (1994) had concluded...

<u>Two authors</u>: This result was later contradicted (Greene & Roberts, 2005) or Greene and Roberts (2005) pointed out...

<u>Three to six authors</u>:
a) first citation: Šimunič, Pišot and Rittweger (2009) had found... or (Šimunič, Pišot & Rittweger, 2009)
b) Second citation: Šimunič et al. (2009) or (Šimunič et al., 2009)

<u>Seven or more authors</u>:
Only the first author is cited: Di Prampero et al. (2008) or (Di Prampero et al., 2008).

Several authors for the same statement with separation by using a semicolon: (Biolo et al., 2008; Plazar & Pišot, 2009)

***Examples of reference list**:*
The style of referencing should follow the examples below:

<u>Books</u>
Latash, M. L. (2008). Neurophysiologic basis of movement. Campaign (USA): Human Kinetic.

<u>Journal articles</u>
Marušič, U., Meeusen, R., Pišot, R., & Kavcic, V. (2014). The brain in micro- and hypergravity : the effects of changing gravity on the brain electrocortical activity. European journal of sport science, 14(8), 813–822. https://doi.org/10.1080/17461391.2014.908959

Šimunič, B., Koren, K., Rittweger, J., Lazzer, S., Reggiani, C., Rejc, E., … Degens, H. (2019). Tensiomyography detects early hallmarks of bed-rest-induced atrophy before changes in muscle architecture. Journal of applied physiology, 126(4), 815–822. https://doi.org/10.1152/japplphysiol.00880.2018

Book chapters

Šimunič, B., Pišot, R., Mekjavić, I. B., Kounalakis, S. N. & Eiken, O. (2008). Orthostatic intolerance after microgravity exposures. In R. Pišot, I. B. Mekjavić, & B. Šimunič (Eds.), The effects of simulated weightlessness on the human organism (pp. 71–78). Koper: University of Primorska, Scientific and research centre of Koper, Publishing house Annales.

Rossi, T., & Cassidy, T. (in press). Teachers' knowledge and knowledgeable teachers in physical education. In C. Hardy, & M. Mawer (Eds.), Learning and teaching in physical education. London (UK): Falmer Press.

Conference proceeding contributions

Volmut, T., Dolenc, P., Šetina, T., Pišot, R. & Šimunič, B. (2008). Objectively measures physical activity in girls and boys before and after long summer vacations. In V. Štemberger, R. Pišot, & K. Rupret (Eds.) Proceedings of 5th International Symposium A Child in Motion "The physical education related to the qualitative education" (pp. 496–501). Koper: University of Primorska, Faculty of Education Koper, Science and research centre of Koper; Ljubljana: University of Ljubljana, Faculty of Education.

Škof, B., Cecić Erpić, S., Zabukovec, V., & Boben, D. (2002). Pupils' attitudes toward endurance sports activities. In D. Prot, & F. Prot (Eds.), Kinesiology – new perspectives, 3rd International scientific conference (pp. 137–140), Opatija: University of Zagreb, Faculty of Kinesiology.

Data set references

Omejc, N., Peskar, M., & Marušič, U. (2022). Dataset of the visual EEG oddball paradigm with young and older age group (Vrsion v0) [Data set]. Zenodo. https://doi.org/10.5281/zenodo.7495536

k) Supplementary materials

Authors are requested to publish the data (input data, results, tabular data, etc.) resulting from the research and used or generated in the preparation of the article published in Annales Kinesiologiae in a recognised online repository and to cite this publication in the reference list.

When publishing the data in the repository, it must be stated that the data has been (or will be) published in the article. If the data is used elsewhere, the article must also be properly cited.

4. Manuscript submission

The article should be submitted via online Open Journal Systems application, which is open source journal management and publishing software at https://ojs.zrs-kp.si/index.php/AK/about/submissions. All the communication process with authors proceeds via Open Journal System and e-mail.

5. For additional information regarding article publication, please do not hesitate to contact the secretary of Annales Kinesiologiae.

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