KINESIOLOGIA SLOVENICA

SCIENTIFIC JOURNAL ON SPORT

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Kinesiologia Slovenica (KinSI)

Kinesiologia Slovenica (KinSI) is an international forum for scholarly reports on kinesiology, broadly defined. The journal publishes empirical and theoretical contributions related to the science of physical activity, human movement, exercise, and sport. It is aimed at enhancing the knowledge (theoretical and practical) in these fields. Manuscripts which deal with high quality research and comprehensive research reviews will be considered for publication. The journal is open to the use of diverse methodological approaches.

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EDITORS FOREWORD

Dear readers,

We are pleased to present the second issue of volume 31 of Kinesiologia Slovenica. This issue features a diverse collection of sixteen scientific papers, reflecting the breadth and depth of contemporary kinesiology and sport science research.

The topics covered several thematic areas, including motor abilities and competitive anxiety, aquatic movement competencies, neuromuscular adaptations to training, perceptual-cognitive strategies in futsal, exercise motivation among older adults, and resistance training effects on muscle hypertrophy. Other contributions explore body image perfectionism, biomechanical assessments, gait speed and frailty, sleep and focus in elite athletes, load monitoring in martial arts, and early childhood physical education. The issue concludes with articles examining rhythmic gymnastics training structure and the biochemical responses to anaerobic exercise.

This issue also marks a significant milestone – it is the final issue issued by the current editorial board. As editors, we would like to express our sincere gratitude to all authors, reviewers, and readers for their continued support, contributions, and trust. We also extend our heartfelt thanks to the Faculty of Sport at University of Ljubljana for its longstanding institutional backing.

We are proud that under our leadership, Kinesiologia Slovenica achieved several major milestones: the journal received its first official Impact Factor, articles were assigned DOI numbers, and the journal was successfully indexed in the Scopus database. These accomplishments reflect the journal's growing scientific influence and international reputation.

With kind regards,

Dr. Vedrana Sember & Dr. Saša Đurić

PREDGOVOR

Dragi bralci,

z veseljem vam predstavljava drugo številko revije Kinesiologia Slovenica v letu 2025. Tokratna številka vključuje sedemnajst znanstvenih prispevkov, ki odražajo raznolikost in globino sodobnih raziskav na področju kineziologije in znanosti v športu.

Prispevki pokrivajo različna tematska področja, med drugim gibalne sposobnosti, tekmovalno tesnobo, kompetence gibanja v vodi, nevromišične prilagoditve na trening, zaznavno-kognitivne strategije v futsalu, motivacijo za vadbo pri starejših, ter učinke vadbe za moč na mišično hipertrofijo. Ostali prispevki obravnavajo perfekcionizem glede telesnega videza, biomehanske analize, povezave med hitrostjo hoje in starostno krhkostjo, spanec in zbranost pri vrhunskih športnikih, spremljanje obremenitev v borilnih športih ter športno vzgojo v zgodnjem otroštvu. Številko zaokrožujejo članki o strukturi treninga ritmične gimnastike in biokemičnih odzivih na anaerobni trening.

Ta številka predstavlja tudi posebno prelomnico – zadnja je, ki jo izdaja trenutni uredniški odbor. Urednika se iskreno zahvaljujeva vsem avtorjem, recenzentom in bralcem za zaupanje, podporo in sodelovanje skozi leta našega delovanja. Prav tako se toplo zahvaljujeva Fakulteti za Šport Univerze v Ljubljani za dolgotrajno institucionalno podporo.

Ponosna sva, da je revija pod najinim vodstvom dosegla pomembne mejnike: pridobila je prvi uradni faktor vpliva v bazi WoS, člankom smo tudi za nazaj dodelili DOI številke, revija pa je bila uspešno vključena v podatkovno bazo Scopus. Ti dosežki potrjujejo vse večjo znanstveno prepoznavnost in mednarodni ugled revije.

Lepo pozdravljava,
Vedrana Sember in Saša Đurić

Srboljub Žunić [1]
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DOES COMPETITIVE ANXIETY MEDIATE THE RELATIONSHIP BETWEEN MOTOR ABILITIES AND ENTRANCE EXAM PERFORMANCE?

ALI TEKMOVALNA TESNOBA VPLIVA NA ODNOS MED GIBALNIMI SPOSOBNOSTMI IN USPEŠNOSTJO NA SPREJEMNEM IZPITU?

ABSTRACT

Achieving competitive success in sports often requires navigating high-stress, anxiety-inducing situations. While motor abilities are fundamental for athletic performance, psychological factors such as anxiety also significantly impact competitive outcomes. This study explores the mediating role of competitive state anxiety components (cognitive and somatic) in the relationship between motor abilities and success on the entrance exam for the Faculty of Sport and Physical Education, a high-stakes, anxiety-provoking event. We hypothesized that motor abilities would be positively correlated with performance, with cognitive and somatic anxiety mediating this relationship. The sample consisted of 100 candidates (59 males) who underwent a five-week preparation program and completed a range of motor ability tests, as well as the Competitive State Anxiety Inventory-2. Results revealed a moderate negative correlation between competitive anxiety and performance, with cognitive anxiety partially mediating the relationship between motor abilities and success, while somatic anxiety showed no significant mediating effect. These findings contribute to a deeper understanding of the psychological mechanisms linking motor skills and performance in competitive environments. We suggest that psychological interventions focusing on reducing cognitive anxiety may improve performance in high-pressure situations, emphasizing the importance of mental preparation in sports. Further research is necessary to explore these effects in real-world competitive contexts and investigate additional factors, such as athletes' perception of anxiety as facilitative or debilitative.

Keywords: Psychological preparation, Performance, Mediation, Cognitive, Selection

IZVLEČEK

Doseganje tekmovalnih uspehov v športu pogosto zahteva spopadanje z visoko stopnjo stresa in tesnobe. Čeprav so gibalne sposobnosti temeljne za športno uspešnost, psihološki dejavniki, kot je tesnoba, prav tako pomembno vplivajo na tekmovalne rezultate. Ta študija preučuje posredniško vlogo komponent tekmovalne tesnobe (kognitivne in somatske) v odnosu med gibalnimi sposobnostmi in uspešnostjo na sprejemnem izpitu na Fakulteti za šport in športno vzgojo, ki predstavlja dogodek z visokimi vložki in velikim izzivom za tesnobo. Hipoteza je bila, da so gibalne sposobnosti pozitivno povezane z uspešnostjo, pri čemer kognitivna in somatska tesnoba vplivata na ta odnos. Vzorec je zajemal 100 kandidatov (59 moških), ki so opravili pettedenski pripravljalni program ter vrsto testov gibalnih sposobnosti in izpolnili vprašalnik Competitive State Anxiety Inventory-2. Rezultati so pokazali zmerno negativno korelacijo med tekmovalno tesnobo in uspešnostjo, pri čemer je kognitivna tesnoba delno vplivala na odnos med gibalnimi sposobnostmi in uspehom, medtem ko somatska tesnoba ni imela pomembnega posredniškega učinka. Ti izsledki prispevajo k boljšemu razumevanju psiholoških mehanizmov, ki povezujejo gibalne spretnosti in uspešnost v tekmovalnih okoljih. Predlagamo, da bi psihološke intervencije, osredotočene na zmanjševanje kognitivne tesnobe, lahko izboljšale uspešnost v situacijah z visokim pritiskom, kar poudarja pomen psihološke priprave v športu. Za nadaljnje razumevanje teh učinkov v resničnih tekmovalnih okoliščinah in raziskovanje dodatnih dejavnikov, kot je dojemanje tesnobe kot spodbudne ali zaviralne, pa je potrebnih več raziskav.

Ključne besede: Psihološka priprava, nastop, meditacija, kognitivno, selekcija

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INTRODUCTION

Achieving competitive results, as the ultimate goal of sports activity, occurs in situations that are filled with stressors and accompanied by intense emotions. Competitive performance is primarily determined by motor abilities and sports skills, but it is also influenced by various psychological characteristics such as anxiety. Psychological factors become especially significant in sports situations that are perceived as important and uncertain (Weinberg & Gould, 2007).

Motor abilities, including agility, speed, and cardiovascular endurance, significantly impacts athletic performance. These components vary among athletes in different sports, suggesting the need for sport-specific fitness training to enhance performance (Reza et al., 2024). Motor abilities such as explosive strength, repetitive strength, speed, and flexibility have a statistically significant effect on performance in athletic disciplines like running, long jump, and shot put (Pavlovic, 2017). The study by de Quel et al. (2020) found that agility, upper- and lower-body muscle power, and general fitness significantly differentiated elite from sub-elite female junior karate athletes. Binary logistic-regression models demonstrated that assessing these fitness attributes in junior categories has predictive value for future competitive success, highlighting the importance of muscle power and agility as key indicators for coaches. However, some other studies on team sports showed no or a selective association between physical fitness and sport performance. For example, a study by Ibáñez et al. (2023) on a sample of women basketball players found a relationship between physical fitness and technical-tactical contributions, which varied across different times of the season. Physical fitness predicted competition performance only for centers and forwards at specific stages, and distinct physical-physiological profiles were identified, linking playing positions, performance ratings, and physical attributes.

In addition to motor abilities, various psychological factors can also influence athletes' performance in competitive situations. One of the most significant is the state anxiety provoked by competitive stressors and influenced by factors such as the importance of the competition and the uncertainty of the outcome (Weinberg & Gould, 2007). Classical theories (Martens, Vealey, & Burton, 1990) of competitive anxiety emphasize its multidimensional nature, distinguishing between two components: cognitive (e.g. negative expectations about one's performance, concerns about potential failure, anticipation of negative feedback and somatic (e.g. increased heart rate, rapid breathing, sweaty palms, muscle tension) anxiety.

A large body of research focused on the relationship between competitive anxiety and sports performance. A meta-analytical study encompassing 48 investigations examined the relationship between athletes' cognitive anxiety and their sports performance (Woodman & Hardy, 2003). Significant but small effects of both concepts on sports performance (cognitive anxiety: $r = -0.10$) were obtained. A similar pattern of results was observed in another meta-analytical study, which explored the influence of somatic anxiety and cognitive anxiety (measured using the Competitive State Anxiety Inventory – CSAI 2) on sports performance (Craft, et al., 2003), where anxiety had a small but significant impact on sports performance (somatic anxiety: $r = -0.09$, cognitive anxiety: $r = -0.13$). On the other hand, a meta-analytic study by Kleine (1990) found somewhat stronger effects of these anxiety components, measured using the CSAI-2 questionnaire, on sports performance (somatic anxiety: $r = -0.30$, cognitive anxiety: $r = -0.16$).

This study examines if competitive state anxiety components mediate the relationship between motor abilities and success in the entrance exam at the Faculty of Sport and Physical Education. The entrance exam at the Faculty of Sport and Physical Education is based on demonstrating a wide range of motor abilities and skills and includes candidates who have been involved in sports for many years. Considering that admission to the faculty depends on the achieved result in comparison to other candidates, the entrance exam takes on the characteristics of a sports competition, which is highly important and uncertain for candidates and has the potential to provoke anxiety. Supporting this, research findings have shown that taking an entrance exam for different faculties represents a highly motivating and highly stressful situation for candidates (Arce-Medina & Flores-Allier, 2012).

Numerous studies have examined the effects of motor abilities and competitive anxiety on sports performance separately, but little attention has been given to their combined effects. This study aims to explore the mediating role of competitive anxiety components in the relationship between motor abilities and success on entrance exam for the Faculty of Sport and Physical Education. We hypothesize that higher motor ability scores will be associated with higher entrance exam performance, with this effect being partially mediated by competitive anxiety components. The findings will contribute to a better understanding of the psychological mechanisms that link motor abilities and success in anxiety provoking sport situations.

METHODS

Participants

The sample included 100 participants, candidates for admission to the Faculty of Sport and Physical Education (59 males), with an average age of 19.01 years (SD = 0.41) and an average sports experience of 9.28 years (SD = 3.54). All participants underwent a five-week preparation program for the entrance exam, which included 15 sessions aimed at increasing aerobic endurance and 15 sessions for each of the obstacle courses that are an integral part of the entrance exam. The study was conducted in accordance with the Declaration of Helsinki and all participants signed informed consent approved by the Institutional Review Board (Approval No. 02 25/24-02).

Instruments and measures

Motor test battery

The motor test battery assessed speed, explosive power, agility, maximal power, flexibility, and aerobic endurance. Prior to testing, all participants underwent a standardized warm-up, which included light jogging, dynamic stretching, and flexibility exercises. The warm-up consisted of 5 minutes of moderate-intensity running followed by upper-body dynamic stretches. Specific warm-up exercises targeted the upper body, shoulder girdle, trunk, back, and legs to prepare for the motor tests. After the dynamic warm-up, participants performed static stretching for all major muscle groups, guided by a qualified instructor, lasting up to 10 minutes.

Speed (10-meter Flying Start Sprint Test)

Speed was assessed using the 10-meter flying start sprint test. Participants started sprinting at the signal from the test operator and sprinted between two lines positioned 10 meters apart. Timing was recorded using the Microgate system (Microgate, Bolzano, Italy), with photoelectric sensors marking the start and finish lines. Each participant performed the test twice with a 5-minute rest between trials, and the best result was used for analysis. Time was recorded with a precision of 0.4ms.

Explosive Power (10-meter Sprint Test)

Explosive power was evaluated using the 10-meter sprint test from a stationary start behind the starting line. Participants started from a static position and sprinted between two lines separated by 10 meters, equipped with photoelectric sensors (Microgate, Bolzano, Italy). Each participant

performed the test twice with a 5-minute rest between trials. The best result was used for statistical analysis, recorded with a precision of 0.1 seconds.

Agility (T-Test)

Agility was assessed using the T-Test, where participants ran between four cones (A, B, C, D) arranged in a T-shaped configuration. The total running distance was 40 meters, starting and ending at cone A. Timing was recorded using the Microgate photoelectric cells system (Microgate, Bolzano, Italy). Participants started from cone A, ran forward 10 meters to cone B, sidestepped 5 meters to cone C, sidestepped 10 meters to cone D, returned 5 meters to cone B, and ran backward 10 meters to cone A. Each participant performed one practice trial followed by two timed trials, with the best result used for analysis. The researchers started the stopwatch at the command "go" and stopped it as the participant crossed the plane of the finish line. The time taken to complete each trial was recorded in seconds. Participants were disqualified if they failed to follow the course instructions, did not reach the finish line or complete the course, displaced any cones, failed to keep their trunk and feet facing forward throughout the test, or crossed their legs more than once during sidestepping. Unsuccessful trials were assigned a score of 0.

Maximal Power (Countermovement Jump Test)

Maximal power was measured using the countermovement jump (CMJ) test. Participants performed a vertical jump starting from an upright position between two sensors using the Optojump photoelectric cells system (Microgate, Bolzano, Italy). On the command "go", participants performed a rapid downward squat followed by an explosive vertical jump, utilizing arm swings. During the jump, participants maximally extended all joints and landed as close as possible to the take-off point. Two trials were performed with a 10-second rest between attempts, and the highest jump height, recorded in centimeters (cm), was used for analysis. In the "Maximal Power (Countermovement Jump Test)" section, instead of "upon the test operator's signal," it would be more precise to use "on the command 'go'."

Flexibility (Sit-and-Reach Test)

Flexibility was assessed using the sit-and-reach test. The equipment included a wooden sit-and-reach box measuring 45 cm in length, 35 cm in width, and 32 cm in height. The top surface of the box extended 15 cm beyond the footrest and featured a scale ranging from 0 to 50 cm with a sliding ruler. Participants sat with their feet flat against the footrest, legs extended, and knees

stabilized by the researcher to prevent bending. They reached forward, pushing the sliding ruler as far as possible. The farthest distance achieved was recorded in centimeters (cm).

Aerobic Endurance (Cooper's 2400-meter Test)

Aerobic endurance was evaluated using Cooper's 2400-meter test on a 1200-meter outdoor track with clearly marked distances every 100 meters. Participants completed two laps (2400 meters) in the shortest time possible. Testing was conducted in groups of 10 following a 30-minute warm-up that included jogging, dynamic and static stretching. Performance times were measured using a stopwatch.

Anxiety

The Competitive State Anxiety Inventory-2 (CSAI-2; Martens et al., 1990) was used to assess anxiety level immediately before the entrance exam. The inventory consists of 27 items, divided into three subscales: Cognitive Anxiety, Somatic Anxiety and Self-confidence (9 items each). For the purposes of this study, scales measuring cognitive and somatic anxiety were used. Cognitive Anxiety refers to the mental aspect of anxiety, such as worry or negative thoughts about performance. Somatic Anxiety refers to the physical symptoms of anxiety, such as increased heart rate, sweating, or muscle tension. Participants rate each item on a 4-point Likert scale ranging from 1 (not at all) to 4 (very much so). The score is calculated as the average of the responses to the items belonging to the corresponding subscale, and a higher score indicates a greater expression of a certain subdimension.

Entrance exam

The entrance exam consists of three obstacle courses that assess the candidates' skills and abilities.

Swimming obstacle course

The swimming obstacle course used in the entrance exam for the Faculty of Sport and Physical Education, assessed candidates' aquatic motor skills, breath control, and swimming proficiency in a 50-meter pool with a depth of 2 meters. The course was divided into three sections, requiring candidates to complete five sequential tasks. They began with a water entry from a starting block or pool edge, followed by underwater swimming for 10 meters (females) or 12 meters (males). In the second section, they swam 38 meters (females) or 36 meters (males) on the surface using any stroke, then performed a deep dive to the pool bottom. In the final section,

candidates retrieved a object weighing up to 4 kg from a depth of 2 meters and placed it on the finish line to complete the course.

Ball-handling obstacle course

The ball-handling obstacle course assessed candidates' coordination, dexterity, and motor control with various types of balls, including handballs, basketballs, volleyballs, and footballs. The course consisted of multiple tasks, whose exact sequence was unknown to candidates in advance, requiring them to execute ball bouncing, passing, catching, dribbling, throwing, shooting, rolling, and maneuvering. Tasks included wall rebounding with controlled receptions, dribbling through obstacles, performing rotational and acrobatic movements while handling the ball, passing against a wall with directional changes, goal shooting, and precise ball control using hands and feet. Candidates had to complete the tasks efficiently within a time limit, demonstrating speed, precision, and adaptability in handling different balls under dynamic conditions.

General motor skills obstacle course

The general motor skills obstacle course assessed candidates' strength, agility, coordination, balance, and flexibility through a variety of gymnastic and athletic tasks. The course included balancing on beams, vaulting over apparatuses (horse, box), climbing ropes and bars, crawling through obstacles, performing rolls and somersaults, jumping over hurdles, maneuvering through agility drills, and handling small equipment such as hoops, sticks, and balls. Tasks required running, jumping, vaulting, rolling, crawling, climbing, and coordination-based exercises that tested body control, spatial awareness, and adaptability. Candidates had to complete the course efficiently within a time limit, demonstrating precision, speed, and fluidity of movement across different apparatuses and movement challenges.

The results of all obstacle courses were measured in time units (seconds), where lower values indicate better performance. To compute the overall score for the entrance exam, Z-scores were calculated for each obstacle course, and the average performance score on the entrance exam was subsequently derived from these values.

Procedure

Motor ability testing was conducted five days before the entrance exam, with each candidate undergoing a 20-minute assessment. Before testing, all participants completed a mandatory warm-up consisting of 5 minutes of light-intensity running, 5 minutes of mobility exercises,

and 5 minutes of full-body stretching. Each candidate then performed each test twice, with the better result used for analysis. The state anxiety test was administered individually, 5 minutes before the obstacle course assessment, and took approximately 5 minutes to complete.

Statistical analysis

First, descriptive statistics, including mean, standard deviation, skewness, and kurtosis were calculated for all variables in the study. To examine the underlying factor structure of the six motor ability variables, a Principal Component Analysis (PCA) with direct oblimin rotation was conducted. Next, Pearson's correlation analysis was performed to select variables for mediation analyses. Mediation analysis was conducted following Baron and Kenny's (1986) four-step regression approach. To statistically confirm mediation, the Sobel test was performed. All statistical analyses were conducted using the Statistical Package for the Social Sciences (SPSS, Version 25; IBM Corp., Armonk, NY, USA).

RESULTS

Descriptive statistics for variables related to competitive anxiety and motor skills are presented in Table 1. The results indicate that respondents exhibit a moderate level of competitive anxiety, as well as self-confidence. Additionally, the skewness and kurtosis values suggest that the data meet the assumptions required for parametric statistical analyses (Byrne, 2010; Hair et al., 2010).

Table 1. Descriptive statistics for the competitive anxiety variables and motor abilities variables.

	Min	*Max*	*M*	*SD*	*Skew (SE)*	*Kurt (SE)*
Cognitive anxiety	1.00	4.00	2.02	0.65	0.41 (0.24)	-0.03 (0.48)
Somatic anxiety	1.11	3.89	2.05	0.58	0.83 (0.24)	0.50 (0.48)
Speed (s)	1.13	2.05	1.40	0.13	1.16 (0.24)	4.55 (0.48)
Explosive power (s)	1.66	2.40	1.89	0.14	0.63 (0.24)	0.68 (0.48)
Agility (s)	9.65	14.40	11.53	1.00	0.59 (0.24)	0.18 (0.48)
Maximal power (cm)	22.4	64.6	39.16	7.21	0.31 (0.24)	0.65 (0.48)
Flexibility (cm)	5.0	45.0	27.91	8.27	-0.61 (0.24)	0.09 (0.48)
Aerobic endurance (s)	503	980	660.66	85.47	0.58 (0.24)	1.39 (0.48)

Notes. Min – minimum, Max – maximum, M – mean, Sd – standard deviation, Skew – skewness, Kurt – kurtosis, SE – standard error

Factor analysis

A Principal Component Analysis (PCA) with direct oblimin rotation was conducted on six motor abilities variables to explore the underlying factor structure. The Kaiser-Meyer-Olkin (KMO) measure verified the sampling adequacy for the analysis, with a value of 0.81, indicating that the data was suitable for factor analysis. Additionally, Bartlett's Test of Sphericity was significant ($\chi^2(12) = 217.71$, $p < 0.001$), supporting the factorability of the correlation matrix.

An initial analysis revealed that two factors had eigenvalues greater than 1, explaining 68.41% of the total variance. Specifically, Factor 1 accounted for 51.44% and Factor 2 for 16.96% of the variance. The scree plot further confirmed the two-factor solution. The first factor included variables such as explosive strength, speed, maximal strength, aerobic endurance, and agility and was named the general motor factor, while the second factor included only flexibility (Table 2). The factor scores were saved as variables and used in further analyses.

Table 2. Pattern and structure matrix for motor abilities (principal components analysis with oblimin rotation).

	Pattern matrix		Structure matrix	
	1	2	1	2
Speed	0.856		0.860	
Explosive power	0.902		0.901	
Agility	0.563		0.570	
Maximal power	-0.795		-0.793	
Flexibility	0.983		0.983	
Aerobic endurance	0.769		0.759	

Correlations between state anxiety variables, general motor factor, flexibility and entrance exam score are given in Table 3. As expected, the highest positive correlation was obtained between the general motor factor and entrance exam score. Further, cognitive and somatic anxiety are in a negative relationship with entrance exam score (considering that a lower score on entrance exam indicates better achievement) and in positive relationship with self-confidence.

Table 3. Correlations between state anxiety variables, general motor factor, flexibility and entrance exam score (Pearson r).

	CA	SA	GMF	FL	EE
CA	1				
SA	.651**	1			
GMF	.371**	.363**	1		
Fl	-0.148	-0.059	0.000	1	
EE	.446**	.350**	.700**	-0.092	1

Notes. CA – cognitive anxiety, SA – somatic anxiety, GMF – general motor factor, Fl – flexibility, EE – entrance exam score

Mediation

To determine mediating role of anxiety components in the relationship between general motor factor and entrance exam score mediation analysis was conducted, separately for cognitive anxiety and somatic anxiety.

Cognitive anxiety. In Step 1 of the mediation model, the regression of the General Motor Factor on Entrance Exam Score, ignoring the mediator, was significant ($b = 0.50$, $t = 9.69$, $p < 0.01$). Step 2 indicated that the regression of the General Motor Factor on the mediator, Cognitive Anxiety, was also significant ($b = 0.24$, $t = 3.95$, $p < 0.01$). In Step 3, the mediation analysis showed that the mediator (Cognitive Anxiety), when controlling for the General Motor Factor, was significant ($b = 0.24$, $t = 2.88$, $p < 0.01$). Step 4 revealed that the General Motor Factor, when controlling for the mediator (Cognitive Anxiety), remained a significant predictor of Entrance Exam Score ($b = 0.44$, $t = 8.26$, $p < 0.01$). The significance of the mediating effect (indirect effect) was confirmed using Sobel's Z test, with a significant result ($z = 2.33$, $p < 0.05$). The mediation analysis partitioned the total effect of the General Motor Factor on Entrance Exam Score ($c = 0.495$) into a direct effect ($c' = 0.439$) and a mediated effect ($ab = 0.057$). Although the mediation through Cognitive Anxiety was statistically significant, it explained only a small proportion of the total effect of the General Motor Factor on Entrance Exam Score (Figure 1).
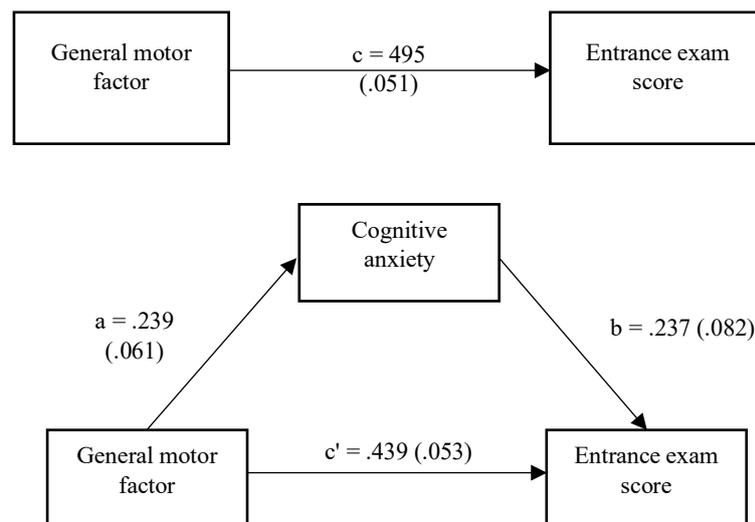
Figure 1. Mediation model for cognitive anxiety.

Somatic anxiety. In Step 1 of the mediation model, the regression of the General Motor Factor on Entrance Exam Score, without considering the mediator, was significant (b = 0.50, t = 9.69, p < 0.01). Step 2 showed that the regression of the General Motor Factor on the mediator, somatic anxiety, was also significant (b = -0.22, t = -3.88, p < 0.01). Step 3 showed that somatic anxiety remained significant when controlling for the General Motor Factor (b = -0.22, t = -3.88, p < 0.01). In Step 4, the analysis revealed that the General Motor Factor, when controlling for the mediator (somatic anxiety), was still a significant predictor of Entrance Exam Score (b = 0.47, t = 8.63, p < 0.01). However, the Sobel Z-test for the mediating effect (z = 1.09, p > 0.05) was not significant. This suggests that somatic anxiety does not significantly mediate the relationship between the General Motor Factor and Entrance Exam Score (Figure 2).
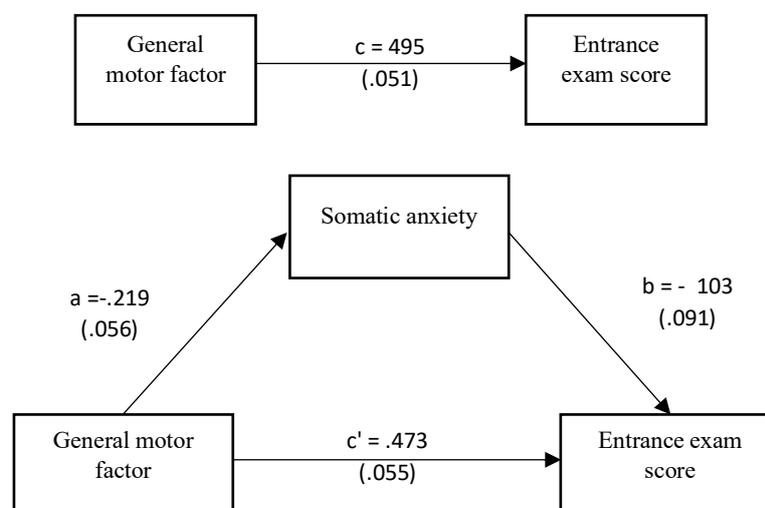
Figure 2. Mediation model for somatic anxiety.

DISCUSSION

Understanding the determinants that influence performance in competitive situations, as well as their interrelationships, is of great theoretical and practical significance for both sports professionals and athletes. The aim of this study was to examine the mediating role of competitive state anxiety components in the relationship between motor abilities and success in a highly competitive and anxiety-inducing entrance exam for the Faculty of Sport and Physical Education.

Since the entrance exam assesses a broad spectrum of motor abilities and skills, participants were assessed on the following motor abilities: speed, explosive power, agility, maximal power, flexibility, and aerobic endurance. Principal Component Analysis revealed that flexibility emerged as a distinct factor, while the remaining motor abilities grouped into a general motor factor. As expected, correlation analysis showed a strong association between success on the entrance exam and the general motor factor, but no significant relationship with flexibility. Given these findings, only the general motor factor was included in the further analysis.

As expected, the results confirmed a negative correlation between candidates' performance on the entrance exam and competitive anxiety. Specifically, the correlation between performance and cognitive anxiety was -0.45, while the correlation between performance and somatic anxiety was -0.35, both of which, according to Cohen (2013), correspond to a moderate effect size. These findings align with previous research and meta-analytic evidence, which consistently report a low-to-moderate negative association between performance and competitive anxiety. Moreover, the evidence suggests that cognitive anxiety exhibits a stronger relationship with performance outcomes than somatic anxiety (Craft et al., 2003; Kleine, 1990; Woodman & Hardy, 2001).

Since motor abilities are a strong predictor of performance in competitive settings, a key objective of this study was to examine whether this influence is direct or mediated by competitive anxiety. Mediation analysis revealed that cognitive anxiety partially mediated the relationship between motor abilities and performance, whereas no significant mediating effect was found for somatic anxiety. These findings suggest that while motor abilities primarily exert a direct effect on candidates' performance on the entrance exam, they also contribute indirectly through their impact on cognitive anxiety.

Numerous studies and theoretical models suggest that cognitive and somatic anxiety influence sports performance through distinct mechanisms. Regarding cognitive anxiety, researchers

propose a negative linear relationship, indicating that higher levels of cognitive anxiety are associated with poorer performance in competitive situations (Martens et al., 1990), which has been confirmed by various studies (Filaire et al., 2009; Terry et al.,1996). This effect is primarily explained by reduced cognitive capacity, including impaired attention and working memory, which limits the processing of relevant information. This occurs due to an excessive preoccupation with self-evaluation and concerns about performance outcomes (Wilson, Vine, & Wood, 2009; Weinberg & Gould, 2023). Beyond these established mechanisms, our findings suggest that an individual's perception of their motor abilities may heighten cognitive anxiety, thereby contributing to poorer performance.

According to dominant theoretical models, the relationship between somatic anxiety and sports performance follows an inverted U-shaped pattern. This means that an optimal level of somatic anxiety is necessary for peak performance, while both excessively low and excessively high levels can negatively impact results (Martens et al., 1990). Theoretical assumptions indicate that somatic anxiety, through the activation of physiological arousal (i.e., the sympathetic nervous system), can directly impair fundamental motor abilities, primarily movement coordination (Weinberg & Gould, 2023). However, our study did not provide evidence that somatic anxiety serves as a mediator in the relationship between motor abilities and success on the entrance exam for the Faculty of Sport and Physical Education. A possible explanation for these findings can be found in the temporal dynamics of cognitive and somatic anxiety during sports competitions (Martens et al., 1990). Specifically, while somatic anxiety tends to decrease rapidly from the beginning to the end of a competition, cognitive anxiety exhibits a more variable trajectory and has the potential to persist throughout the performance. In other words, even if candidates experience high levels of somatic anxiety at the start, it tends to decline over the course of the competition, reducing its capacity to mediate the relationship between motor abilities and performance outcomes. Moreover, considering that candidates complete multiple performance tasks (polygons) within the same day, they develop a certain level of habituation to the triggers of somatic anxiety, further diminishing its mediating role in this relationship.

Study limitations and future research

The present study examined candidates undergoing the entrance exam for the Faculty of Sport and Physical Education, an assessment designed to evaluate extensive prior sports experience and a high level of motor proficiency. While the selection process closely mirrors competitive performance demands, a critical question remains regarding the generalizability of these

findings to real-world competitive sports contexts. These results offer valuable insights into the mechanisms through which anxiety states influence performance in high-stakes, uncertain competitive situations. However, for a more comprehensive validation, future research should examine these effects in athlete populations engaged in actual competitive environments. Moreover, meta-analytic evidence suggests that the anxiety-performance relationship is influenced by multiple factors, such as gender, competition level, and sport type. Consequently, the moderating effects observed in this study should be further tested while accounting for these contextual variables. Furthermore, research has shown that the impact of competitive anxiety varies depending on whether athletes perceive it as facilitative or debilitative (e.g., Butt, Weinberg, & Horn, 2003; Jones & Swain, 1992). This distinction represents another crucial factor that should be incorporated into future studies to refine the understanding of anxiety's role in sports performance.

CONCLUSION

This study demonstrated that, beyond their direct impact, motor abilities also partially contribute to the development of the cognitive component of competitive anxiety, which in turn affects performance. However, somatic anxiety did not show a similar mediating effect. One possible explanation is that the perceived level of one's motor abilities influences self-doubt regarding one's competence to successfully perform in a critical and uncertain competitive setting, (such as completing the entrance exam obstacle course), which ultimately impairs performance. Although the mediating effect of cognitive anxiety is not large, it may be crucial in high-stakes sports competitions where many athletes possess similar levels of motor abilities, making psychological factors a key determinant of success.

Based on these findings, psychological preparation for high-stakes competitions should include reframing techniques designed to achieve two key objectives. First, they should help athletes detach from self-evaluations of their motor abilities at a given moment and instead focus on achieving their optimal performance. Second, they should encourage a performance-oriented mindset rather than an outcome-driven one, thereby reducing the pressure associated with an absolute need to win.

Declaration of Conflicting Interests

The authors have no conflicts of interest to declare.

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VALIDATION OF NEWLY CONSTRUCTED QUESTIONNAIRE FOR WATER MOVEMENT COMPETENCIES

VALIDACIJA NOVO OBLIKOVANEGA VPRAŠALNIKA ZA KOMPETENCE GIBANJA V VODI

ABSTRACT

The aim of this study was to construct and validate a questionnaire for assessing movement competences in water. Water competences encompass all forms of movement in water that contribute to drowning prevention and are closely linked to understanding water safety, as well as behaviors and attitudes that ensure safety in aquatic environments. Properly defining these competences can contribute to greater public awareness of the importance of early swimming education and the acquisition of key skills necessary for safe movement in water. The study involved 684 students from the University of Zagreb, including 344 male and 340 female participants. For the purpose of the research, a 22-item questionnaire was developed to assess the importance of various aspects of water competences. Data analysis confirmed satisfactory internal consistency of the questionnaire, with Cronbach's alpha coefficient of $\alpha \geq 0.7$. The highest average score was obtained for statement Q12, which emphasizes the importance of breathing, breath control, and managing shortness of breath as key components of movement competences in water (M=4.63). Based on the results, it can be concluded that the developed questionnaire represents a valuable tool for assessing water competences, demonstrating acceptable validity and reliability. Raising awareness of the importance of swimming skills is essential not only for individual safety in water but also for enabling enjoyment in activities that the aquatic environment offers. Early education and systematic development of movement skills in water can have a significant impact on reducing the risk of drowning and promoting safe behavior in aquatic settings.

Keywords: teaching; swimming; students; assessment

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IZVLEČEK

Cilj te študije je bil oblikovati in validirati vprašalnik za ocenjevanje kompetenc gibanja v vodi. Vodne kompetence zajemajo vse oblike gibanja v vodi, ki prispevajo k preprečevanju utapljanja ter so tesno povezane z razumevanjem vodne varnosti, vedenjem in odnosi, ki zagotavljajo varnost v vodnem okolju. Ustrezna opredelitev teh kompetenc lahko prispeva k večji ozaveščenosti javnosti o pomenu zgodnjega učenja plavanja in pridobivanja ključnih veščin, potrebnih za varno gibanje v vodi. V raziskavi je sodelovalo 684 študentov Univerze v Zagrebu, od tega 344 moških in 340 žensk. Za potrebe raziskave je bil razvit vprašalnik z 22 postavkami, namenjen ocenjevanju pomena različnih vidikov vodnih kompetenc. Analiza podatkov je potrdila zadovoljivo notranjo skladnost vprašalnika, pri čemer je bil Cronbachov alfa koeficient $\alpha \geq 0.7$. Najvišjo povprečno oceno je dobila trditev Q12, ki poudarja pomen dihanja, nadzora diha in obvladovanja kratke sape kot ključnih sestavin kompetenc gibanja v vodi (M = 4,63). Na podlagi rezultatov lahko sklepamo, da razviti vprašalnik predstavlja dragoceno orodje za ocenjevanje vodnih kompetenc, saj izkazuje sprejemljivo veljavnost in zanesljivost. Ozaveščanje o pomenu plavalnih veščin je bistveno ne le za individualno varnost v vodi, temveč tudi za uživanje v aktivnostih, ki jih ponuja vodno okolje. Zgodnje učenje in sistematičen razvoj gibalnih veščin v vodi lahko pomembno vplivata na zmanjšanje tveganja za utapitev ter spodbujanje varnega vedenja v vodnih okoljih.

Ključne besede: poučevanje, plavanje, študenti, ocenjevanje

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INTRODUCTION

Competences can be defined as common knowledge, abilities, skills associated with a high effect at work (Schippmann et al., 2000). When it comes to defining motor competences, it can be defined as the mastery of physical skills and movement patterns (Castelli & Valley, 2007). Swimming is a physical activity that have many health benefits across all ages and can be used in recreation, therapy as well in sports performance. Recent research showed that motor competence can differentiate children's swimming ability (Gllareva et al., 2020). By conducting research on water competences, most authors try to find out what are the key elements for achieving the necessary competences. Insufficiently acquired swimming skills, i.e. inadequate knowledge about the risks of swimming, is a risk in itself. Therefore, proper education and methods of evaluating that knowledge are important, in order to prevent possible risks in terms of the safe use of swimming as knowledge and applied practical skills. Water competences can be defined as the sum of all movements in the water that help prevent drowning (Moran et al., 2012). It is related to knowledge about water safety as well as attitudes and behaviors that will facilitate safety in and around the water. Defining waters competences in this way aims to raise the awareness of the population and point out that swimming lessons should be started at an early stage of childhood. The ability to swim is promoted and presented as a necessary component of adequate movement in water, but with the understanding that the ability to swim alone is often not enough to prevent drowning (Brenner et al., 2006). Encouraged by this, most of the studies that today deal with the management of this technique seek to discover and present the basic and most important competences of movement in water.

Experts strive to raise the level of awareness and knowledge of the population about the importance of swimming competences in the modern way of life in order to prevent non-essential outcomes when in the water. The more pronounced and highly adopted competence of swimming plays a protective role in the case of drowning, and therefore differences in swimming competency in the aquatic surface can explain why the risk of drowning in some individuals is much more pronounced than in the rest of the population (Brenner et al., 2006; Kjendlie et al., 2013; Stallman et al., 2017). The aim of most research papers on this topic is to present, describe and provide the population with scientifically substantiated facts about how much physical, cognitive and affective competences can contribute to the ability to move in an aquatic surface in the most efficient way. Taking all the risks and benefits that characterize swimming, experts seek to highlight the scientifically proven facts and figures obtained by research not only on young people, but also on people of middle and older age, and to raise

awareness of the importance of introducing swimming programs not only in primary education and high school but also beyond.

The foundations of water safety education are based on a clear definition of the water competencies that a person must possess. Today, it is recommended to replace expressions such as swimming ability with the term swimming competence (Moran et al., 2012; Brenner et al., 2006; Kjendlie et al., 2013; Stallman et al., 2017). Swimming ability exceeds both ability and skill, as skills can be modified or learned, while ability is resistant to change (Langendorfer, 2011). Research shows that swimming ability alone is often not enough to prevent drowning, highlighting the importance of awareness of water competencies (Stallman et al., 2008; Olstad et al., 2021; Peden & McGee, 2003; Stanley & Moran, 2017; Moran & Stanley, 2006; Junge et al., 2010; Brenner et al., 2003; Brenner et al., 2009). According to a report by the World Health Organization (WHO) about 360.000 people drown every year, more than half of them are as young as 25 years old (World Health Organization [WHO], 2014). Drowning is one of the leading causes of mortality among children and adolescents worldwide. The WHO states that it is the most common cause of death for children aged 5 to 14 years. In the European Union and the United States, it is the second most common cause of death for children aged 0 to 19 years (Bierens, 2006; Ferenčić et al., 2018). Assessing swimming skills is crucial for drowning prevention, the development of motor skills in water, increasing self-confidence in water, and raising awareness about safety. Swimming competencies should include self-rescue skills and the ability to save others. Research shows that many individuals believe they possess swimming skills, while they are unable to swim safely (Moran et al., 2012). This highlights the need for an objective assessment of swimming skills to identify at-risk individuals in a timely manner and provide appropriate education. Developing water skills can significantly impact self-confidence and the tendency to participate in water activities, contributing to a positive attitude toward physical activity (Sporiš et al., 2011). Swimming skill assessment also plays a key role in water safety education (Stallman et al., 2017). Most research relies on self-assessment due to difficulties in measuring actual competencies (Mickalide, 1997; Nelson, 1996; Robertson, 1992; Watson et al., 2003; Morgan et al., 2012).

Swimming education is thought to be one of the most important interventions to prevent the consequences of drowning. Among young population that lost their lives in the water, approximately 10% lived in high-income countries where learning to swim through various schools or organizations offering swimming lessons (Rejman et al., 2020). Children who have undergone training at an early age will not have a fear of water, and will adopt other swimming

skills much sooner than other children, will learn quickly about certain motor skills, will have greater self-confidence when moving in the water media, better ability to concentrate, quick reaction times and will become independent more quickly. When children overcome their fears of water through various games and methods in a very short time, they will achieve significant progress compared to other children (Amelia, 2012). The aim of this research was to construct and validate the questionnaire for the assessment movement competences in the water.

METHODS

Participants

The participants were 684 students of University of Zagreb. This research involved 346 male participants and 340 female subjects. All the participants voluntarily agreed to complete the questionnaire, and were guaranteed anonymity of the answer, as well as being thanked for participating in the same. Moreover, the number of the ethical approval from the Faculty of Kinesiology, Zagreb, Croatia, was XXIa-8501.

Measuring procedure

The data collection protocol entailed group surveying, i.e. surveying a larger number of participants. All participants answered questions relating to facts with which they were previously informed. Before completing the questionnaire, the participants were introduced with the aims of the research, and accordingly they were further encouraged to cooperate and give honest answers. In the first part of the questionnaire, the purpose of the research and reasons for conducting the research was clear to the subjects.

Design of the questionnaire

For the purposes of this research questionnaire a measuring instrument was used, specifically a questionnaire on the importance of water movement competences. The procedure of the survey method of the participants collected information, data, attitudes, and thoughts on the subject matter of the research itself. The questionnaire included the written collection of data and information on attitudes and opinions in a representative sample of participants. The questionnaire consisted of 22 statements obtained by mapping the research regarding the competences of movement in the water. The opinion of the subjects was assessed by using the Likert's scale of agreement or disagreement. The potential answers for each question was

evaluated as follows: Score 5 (I fully agree), Score 4 (I generally agree), Score 3 (I neither agree nor disagree), Score 2 (I generally disagree), Score 1 (I completely disagree).

Statistical analysis

The measuring data was processed using the STATISTICA 13.0 statistic package (StatSoft, Inc., Tulsa, OK, USA). In all variables the basic descriptive parameters were calculated, and the normality of the distribution was assessed trough the Kolmogorov-Smirnov test. In order to determine the exact object of measurement to be tested by a specific measuring instrument, to the extent to which each of its factors conditions the variability of the results obtained, it was necessary to carry out an exploratory and contemplative factor analysis. The exploratory (EKS) and confirmatory (KON) factor analysis was carried out with the help of psych packages, in the RStudio software (version 2022.07.0.548, Spotted Wakerobin, Boston, MA) and was used for the extraction of factors in a constructed questionnaire examining subjects' opinion on the importance of movement competencies in water. First, the data was analyzed in order to meet multivariate assumptions (normality, linearity, homogeneity and homoskedasticity). The internal consistency method established the reliability of each questionnaire question. The internal consistency was measured through the Pearson correlation coefficient.

RESULTS

Descriptive parameters from the 22 questions were presented in Table 1. It can be seen that Q16 and Q18 have the lowest values. Also, the statement Q12 (breathing, shortness of breath, and breathing control are important components of the competences of movement in the water and the statement) showed the highest values. To examine the internal consistency of the water movement competence questionnaire, all subjects were tested together by calculating the average inter-item correlations and Cronbach's alpha coefficients. The results show acceptable internal consistency $\alpha \geq 0.7$. The Cronbach's alpha coefficient, calculated based on standardized results, is 0.757, while the basic value is 0.726. The questionnaire consists of a total of 22 items.

Table 1. Descriptive indicators of each survey questionnaire question.

QUESTIONS	N	Mean	SD
Q1. The concept of water movement competence is more comprehensive than swimming competence.	684	3.80	0.966
Q2. Moving in the water as a basic movement like walking is something that is not taught but is a part of the development.	684	3.14	1.180
Q3. From the perspective of the competence of movement in the water, all aspects of movement should be covered (forward, backward, sideways, below the surface of the water).	684	4.44	0.681
Q4. The concept of being able to move in the water or master movements in the water is more important than just the correct performance of the swimming movement.	684	3.60	1.003
Q5. Water movement competences are only part of water safety and must be part of the knowledge and attitudes of all programs (courses).	684	4.04	0.811
Q6. Moving underwater should be as pleasant and efficient as moving on the surface.	684	3.80	1.088
Q7. Movement on the back should be as comfortable and effective as movement on the chest.	684	3.85	1.085
Q8. It does not matter "how far you can swim, it is how you swim".	684	3.79	1.059
Q9. Water movement competences are of great importance in the modern way of life.	684	3.67	0.971
Q10. A range of movements should be developed in all directions and in all ways.	684	3.99	0.864
Q11. Learning movement in all it's forms (along the sagittal, transverse and longitudinal axis of the body) can save a life in a situation of drowning.	684	4.42	0.749
Q12. Breathing, breath retention and breathing control are important components of water movement competences.	684	4.63	0.642
Q13. Eye-opening (looking on the water) is of great importance for navigating the space medium of water.	684	4.13	0.939
Q14. A swimmer is a person who has well developed competences of movement in the water, i.e. in the water. That is capable of coping with unexpected and involuntary submerging.	684	4.28	0.834
Q15. Knowing how to move in water means to perform a set of competences of movement in the water.	684	4.11	0.783
Q16. Swimming is considered only a matter of preforming the swimming movement "correctly".	684	2.81	1.044
Q17. From a perspective of competences of movement in water, swimming should not be a shift from position A to position B.	684	3.14	0.920
Q18. For knowledge of swimming, it is not necessary to swim a certain meter (25m, 50m..).	684	2.65	1.295
Q19. For swimming knowledge, it is necessary to have well-developed competences of movement in the water.	684	4.08	0.808
Q20. Education for water safety must strive to make teaching as realistic and authentic as possible.	684	4.14	0.753
Q21. It is of great importance that during primary education the competences of movement in the water are checked in all students of primary schools in the Republic of Croatia.	684	4.35	0.782
Q22. In the modern way of life, it is essential to give each person the opportunity to learn how to move in the water.	684	4.48	0.768

Legend: Q-question; N-number of participants; SD-standard deviation.

After the collected data presented in the previous table and statistical analysis of the questionnaire on the competences of movement in the water, the internal consistency of all the above claims was observed in the study. It is also important to state that the higher correlation value represents both greater and stronger consistency. All claims were divided into three subgroups depending on the values of the new Pearson correlation coefficient.

Questions Q2, Q16, Q17 and Q19 show very little internal consistency given that their Pearson correlation coefficient range from 0,187 to 0,285. Statistical analysis showed that all these coefficients are statistically significant with the value of $p \leq 0,01$. Moreover, questions Q1, Q4,

Q6, Q8, Q10 show a small internal consistency because there the Pearson correlation coefficient ranges from 0,33 to 0,446. Also, statistical analysis found all these coefficients are statistically significant with the value of $p \leq 0,01$. The rest of the statements showed medium internal consistency because their Pearson correlation coefficient range from 0,454 to 0,498.

An exploratory and affirmative factor analysis was further made with the aim of verifying the validity of the assumed theoretical model of the conducted questionnaire, and it was found that all the multivariate assumptions were satisfied, by the axis of homoskedasticity. Twelve participants were excluded from the analysis based on the assumed criterion, which implied an unaffected response to five or more claims. With Mahalanbis distance, 29 multivariate outliers were identified, which were removed from further analysis. The Bartlett test showed correlation adequacy, $X2$ (300) = 2483.55 p < .001 and the Kaiser-Meyer-Olkinov (KMO) sampling adequacy test, measure of sampling adequacy (MSA) = 0.83.

Table 2. Results for the internal consistency.

Questions	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Cronbach's Alpha if Item Deleted
Q 1.	81.55	57.024	0.214	0.722
Q 2.	82.21	57.559	0.119	0.733
Q 3.	80.91	56.705	0.381	0.711
Q 4.	81.75	56.843	0.213	0.722
Q 5.	81.31	55.829	0.378	0.709
Q 6.	81.55	54.796	0.316	0.713
Q 7.	81.50	54.031	0.377	0.707
Q 8.	81.56	55.357	0.292	0.715
Q 9.	81.68	56.129	0.275	0.716
Q 10.	81.36	55.961	0.338	0.712
Q 11.	80.93	56.218	0.382	0.710
Q 12.	80.72	57.010	0.377	0.712
Q 13.	81.22	55.854	0.309	0.714
Q 14.	81.07	55.745	0.372	0.709
Q 15.	81.24	55.654	0.412	0.707
Q 16.	82.54	58.665	0.083	0.733
Q 17.	82.20	57.823	0.172	0.724
Q 18.	82.70	58.970	0.021	0.746
Q 19.	81.27	55.973	0.369	0.710
Q 20.	81.21	56.141	0.387	0.709
Q 21.	81.00	55.606	0.417	0.707
Q 22.	80.87	56.357	0.358	0.711

Parallel analysis and scree plot suggested two factors, which corroborates the original theoretical model. The maximum probability estimate was tested by direct round rotation due to the expected correlation of factors. After testing all the questions, 2, 16, 17 and 18 were

omitted from the analysis, due to very low factor saturations. After that, another 2-factor model was tested, and factor loads are presented in the following table (Table 3).

Table 3. Representation of factor loads.

Questions	Factor 1	Factor 2
1	0.38	-0.13
3	0.46	0.03
4	0.28	-0.05
5	0.55	-0.06
2	0.37	0.13
10	0.62	0
11	0.58	-0.03
12	0.38	-0.01
13	0.42	0.06
14	0.53	-0.02
15	0.49	0
19	0.47	0.06
20	0.54	0.07
21	0.49	0.03
22	0.55	-0.06
6	-0.04	0.71
7	0.06	0.69
8	0.09	0.28
9	0.13	0.26
16	0.38	-0.13
17	0.46	0.03
18	0.28	-0.05

This model has achieved a simple structure with the load on each statement solely on one factor. Also, the model had a good fit: the value of the root mean square error of approximation (RMSEA) indicated a great fit at .06, 90% collective intelligence - CI [.05-.06]. Also, the value of root mean square of residuals (RMSR) indicated a great fit (.05), while comparative fit index - CFI (.87) and Tucker–Lewis index - TLI (.83) values indicated that this model could be further improved.

The multiple R^2 between the factor and the estimated values of the result factor, which can be viewed as a regression model predicting the estimated factor result, was 0.82 and 0.72, for factors 1 and 2. The average results for each factor were as follows: Factor 1, M=4.19 (SD=0.40) and Factor 2, M=3.79 (SD=0.68).

The internal consistency (reliability) of the scale was satisfactory. Also, the average correlation between statements was 0.19, indicating that there is a satisfactory correlation between the items, but not too high, as this could indicate the simultaneous construct of certain issues. The internal consistency of the sub scale (factor) was .79 and .58 for factors 1 and 2. The relatively low reliability of the second sub-scale is expected, due to the relatively small number of items (four items).

DISCUSSION

The aim of this study was to construct and validate a questionnaire for assessing motor competencies in water by collecting important information from previous research. In the current study, an attempt was made to construct and validate a measuring instrument-survey questionnaire for assessing the attitude of competences of movement in water through twenty-two statements obtained by mapping scientific research in this field. After analyzing the obtained results, the statements were divided into three subgroups depending on the values of their Pearson correlation coefficients. The obtained value for Cronbach's alfa was 0.7, from which we conclude that the internal consistency of statements in the questionnaire is acceptable. A high value of Cronbach's Alpha indicates that the items in the test are likely highly related. However, this value is also sensitive to the number of items in the test: a larger number of items generally results in a higher Cronbach's Alpha, while a smaller number of items may lead to a lower value. Additionally, a very high Cronbach's Alpha may suggest that some items are redundant. The results of this research provide new insights into the key factors influencing the perception of water movement competencies and comfort during water movement. Two factors identified in this study – the importance of water movement competencies (Factor 1) and comfort during water movement (Factor 2) – highlight different aspects of the development of water competencies, and the new findings from these factors significantly contribute to the understanding of how to develop safety and efficiency in the water.

Factor 1, which includes thirteen statements related to the perception of the importance of water movement competencies, reveals a high level of awareness among respondents about the necessity of developing water competencies for water safety. The participants recognized that water movement competencies are not only crucial for swimming but also play a key role in accident prevention, such as drowning. Statements such as "competencies for water movement are just a part of 'water safety'" and "learning to move in all its forms can save a life in a drowning situation" confirm that water movement competencies must be an integral part of the educational curriculum, starting from the earliest age (Wiesner, 2008; Moran et al., 2012). These results also support previous recommendations that self-awareness about one's own skills and the assessment of water safety play a key role in preventing accidents, especially among youth (Moran et al., 2012). Considering that many people consider themselves good swimmers, despite the inability to swim even 25 meters, the study shows that self-assessment of competencies is not always aligned with actual abilities, which can lead to unjustified confidence in risky conditions (Stanley & Moran, 2017). These findings suggest that

educational programs should focus on developing a realistic assessment of one's own skills, highlighting the importance of water safety and preventive measures (Stallman et al., 2017).

Factor 2 refers to the perception of comfort during movement in water, which includes the respondents' sensitivity to the difference between moving on the surface and underwater. Statements such as "movement underwater should be just as comfortable and efficient as movement on the surface" and "backstroke should be just as comfortable and efficient as breaststroke" indicate an increasing awareness of the importance of physical comfort in aquatic activities. Since comfort is linked to lower levels of stress and greater confidence in one's abilities (Olstad et al., 2021), this study suggests that educational programs should consider how subjective experiences of comfort can affect long-term outcomes in swimming education and water safety.As highlighted in earlier studies, changes in swimming conditions, such as transitioning from calm to choppy water, swimming in water of different temperatures, or even swimming in clothing instead of swimwear, can significantly reduce swimming efficiency and cause insecurity among swimmers (Tipton et al., 1999; Kjendlie et al., 2013). Therefore, it is important to emphasize that comfort is not only physical but also psychological – participants who feel comfortable in the water are more likely to develop correct swimming techniques, reduce fear, and increase their safety in aquatic conditions (Sporiš et al., 2011). These results support the importance of developing competencies that encompass all aspects – cognitive, affective, and psychomotor – to achieve long-term water safety (Stallman et al., 2017; Rejman et al., 2020). Recent studies show that the use of goggles and snorkels improves the skills of young non-swimmers with a fear of water, such as water entry, back gliding, and front swimming (Misimi et al., 2022). On the other hand, a study on non-swimmers without a fear of water did not show a significant difference in most skills, except for the bubble-blowing skill, where participants with goggles showed smaller improvements (Misimi et al., 2023).

Water competencies, according to the research, involve both cognitive and psychomotor skills that enable effective coping with challenges in the water. These competencies relate to the ability to recognize risks, manage emotions, control physical stress, and react to changing conditions, such as water temperature, waves, clothing, or even dangers like electrical currents (Rejman et al., 2020). In this context, it is important that educational curricula emphasize the development of these competencies to reduce the risk of drowning, as even good swimmers may not always be able to save themselves in unfamiliar conditions (Moran et al., 2012; Tipton et al., 1999). Additionally, it is crucial that the assessment of one's abilities is based on actual skills and experience, not subjective evaluation. To achieve effective education, it is necessary

to promote the development of realistic self-assessment in terms of one's skills in the water, which is essential for reducing the risk of accidents (Rejman et al., 2020). Using exploratory and confirmatory factor analysis, the study confirmed the validity of the theoretical model of the questionnaire. Although all multivariate conditions were met, except for homoscedasticity, the results indicate that the respondents' answers were largely shaped by their previous experiences and attitudes toward water safety. Respondents who had personal experiences with drowning or had witnessed such situations showed a greater awareness of the importance of water movement competencies, supporting the findings of other studies (Stallman et al., 2008).

Additionally, it is important to note that all participants in this study were students from the University of Zagreb, who had not undergone systematic water safety education within their educational curricula. This fact suggests the need for the implementation of programs that would educate students on the importance of water competencies and water safety. In light of this, the results of the research support the recommendation that water safety education should be included in educational programs from an early age to reduce the risk of accidents and increase overall safety (Moran & Stanley, 2006; Brenner et al., 2009). The findings of this study underline the importance of integrating water safety education into curricula across all stages of education, starting at a young age, to ensure that individuals develop the necessary competencies to function safely in aquatic environments. This research contributes to the growing body of evidence that highlights the need for comprehensive water safety education and the development of water competencies as a critical element in drowning prevention (Sporiš et al., 2011; Wiesner, 2008).

CONCLUSION

Based on the results obtained, the main findings indicate that the questionnaire can be presented as a valuable tool for assessing motor competencies in water, showing acceptable validity and reliability, and providing a valid examination that reflects self-rescue skills. This is based on the content analysis of water skills deemed important for drowning prevention, as well as the proper selection of program content in teaching non-swimmers. A high level of awareness of the importance of swimming competencies enables safe movement in the environment of the water, but also to enjoy the activities that the aquatic medium provides. Therefore, such information should be part of the school program and various educational programs. This, as well as the influence of the public media, would certainly contribute to greater awareness of the

population and thus to greater prevention of undesirable outcomes when doing activities in the water.

Declaration of Competing Interest

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ACUTE EFFECTS OF FAST ECCENTRIC CONTRACTIONS WITH DIFFERENT LOAD ON THE POSTACTIVATION POTENTIATION

AKUTNI UČINKI HITRIH EKSCENTRIČNIH KONTRAKCIJ Z RAZLIČNO OBREMENITVIJO NA POSTAKTIVACIJSKO POTENCIRANJE

ABSTRACT

Background: This study aimed to investigate the acute effects of fast eccentric contractions with different load on the postactivation potentiation (PAP). Methods: Potentiation was performed using 3 sets of 3 repetitions with dynamic contractions (EC90%) at 90% of one repetition maximum (1RM), fast eccentric contractions at 60% (ECC60%), and 40% (ECC40%) 1RM on a sample of 20 students. The procedure was carried out in four sessions with a 7-day rest between sessions. Anthropometric measurements and 1RM assessment using the barbell squat on the Smith machine were conducted in the first session. Acute PAP effects were assessed based on kinematic parameters (h - maximal jump height) using pretest and posttest Countermovement Jump (CMJ) tests in the second, third, and fourth sessions. The rest period between the potentiation stimulus and CMJ was 6 minutes for all conditions. Results: Repeated measures ANOVA showed significant differences in jump height after all three types of potentiation ($p < .001$). Bonferroni post-hoc analysis revealed significant differences between EC90% (2.81 ± 1.08 cm) and ECC60% (2.45 ± 0.8 cm) potentiation ($p < .005$). Additionally, jump height after EC90% and ECC60% was significantly higher compared to ECC40% (1 ± 0.3 cm). Conclusions: The results suggest that dynamic loads of 90% 1RM, along with 60% and 40% via fast eccentric contractions, can be used for acute increases in CMJ height after 6 minutes of rest. Furthermore, potentiation with fast eccentric contractions and moderate load shows similar effects on CMJ height as dynamic submaximal loads, a valuable finding for strength and conditioning coaches.

Keywords: PAP, fast eccentric contraction, explosive strength, CMJ, OptoGait

IZVLEČEK

Ozadje: Namen te študije je bil preučiti akutne učinke hitrih ekscentričnih kontrakcij z različnimi obremenitvami na postaktivacijsko potenciranje (PAP). Metode: Potenciranje je bilo izvedeno s 3 serijami po 3 ponovitve z dinamičnimi kontrakcijami (EC90%) pri 90 % enega maksimalnega ponavljanja (1RM), hitrimi ekscentričnimi kontrakcijami pri 60 % (ECC60%) in 40 % (ECC40%) 1RM na vzorcu 20 študentov. Postopek je bil izveden v štirih sejah s 7-dnevnim premorom med njimi. V prvi seji so bile opravljene antropometrične meritve in ocena 1RM pri počepu s palico na Smithovi napravi. Akutni učinki PAP so bili ocenjeni na podlagi kinematičnih parametrov (h – maksimalna višina skoka) s predtestnimi in potestnimi testi skoka z uporabo protokola Countermovement Jump (CMJ) v drugi, tretji in četrti seji. Odmor med potencirajočim dražljajem in CMJ je bil za vse pogoje 6 minut. Rezultati: Ponovljena analiza variance (ANOVA) je pokazala statistično značilne razlike v višini skoka po vseh treh vrstah potenciranja ($p < .001$). Bonferronijeva post-hoc analiza je razkrila pomembne razlike med potenciranjem EC90% (2.81 ± 1.08 cm) in ECC60% (2.45 ± 0.8 cm) ($p < .005$). Poleg tega je bila višina skoka po EC90% in ECC60% značilno višja v primerjavi z ECC40% (1 ± 0.3 cm). Zaključki: Rezultati kažejo, da lahko dinamične obremenitve pri 90 % 1RM ter hitre ekscentrične kontrakcije pri 60 % in 40 % 1RM povzročijo akutno povečanje višine CMJ po 6-minutnem odmoru. Nadalje je potenciranje s hitrimi ekscentričnimi kontrakcijami in zmerno obremenitvijo pokazalo podobne učinke na višino CMJ kot dinamične submaksimalne obremenitve, kar je dragocena ugotovitev za trenerje moči in kondicije.

Ključne besede: PAP, hitra ekscentrična kontrakcija, eksplozivna moč, CMJ, OptoGait

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INTRODUCTION

Post-Activation Potentiation (PAP) is defined as a physiological phenomenon that leads to an acute increase in muscle force as a result of its prior activation (Borba et al., 2017; Dello, Martone, & Padulo, 2016). Prior activation, or the previous potentiation stimulus, is achived by performing an exercise with a load that is biomechanically identical or similar to the main movement executed afterward, but without the load (Seitz & Haff, 2016). Thus, the essence of PAP lies in the effect of heavier loads that cause a high level of neural stimulation, resulting in the recruitment of more motor units and a higher frequency of neural impulses (Blazevich & Babault, 2019). These positive physiological effects on the neuromuscular system, triggered by the previous potentiation, typically last acutely for 8 - 12 minutes (Kilduff et al., 2007). Despite numerous studies investigating the occurrence and effects of PAP, the exact physiological mechanisms have not yet been fully clarified (De Hoyo et al., 2015; Blazevich & Babault, 2019). The scientific community has proposed two main mechanisms: 1) phosphorylation of regulatory light chains of myosin, which makes actin and myosin sensitive to calcium released from the sarcoplasmic reticulum during subsequent muscle contractions (Tilin & Bishop, 2009; Bauer et al., 2019); and 2) Increased synaptic excitation of higher-order motor units, i.e., increased postsynaptic potentiation and subsequent increase in muscle force generation based on enhanced recruitment of fast motor units (Xenofondos et al., 2010) In addition to these two mechanisms, there are indications that PAP also contributes to changes in the pennation angle (Tilin & Bishop, 2009. The assumption is that after applying the potentiation exercise, the pennation angle of the muscle fibers decreases, which consequently results in greater force transmission through the tendon and ultimately to the bone.

Research has shown that PAP can be induced by various methods, including maximal voluntary isometric contractions, dynamic, concentric, and eccentric contractions, as well as post-tetanic contractions induced by the use of electrical stimulation on the muscle (Sale, 2002). Numerous studies have investigated the effect of submaximal loads (80-90% 1RM) through dynamic contractions on PAP (Wilson et al., 2013). The results have shown that performing squats (90% of 1RM) x 4 repetitions with dynamic (eccentric-concentric) muscle contractions has positive effects on Countermovement Jump (CMJ) height after a 3-minute rest (Bauer et al., 2019). A significant mean increase in CMJ height of 1.7 cm was also observed in a sample of 12 active athletes who performed squats at 85% 1RM x 3 repetitions (Evetovich, Conley, & McCawley, 2015). Furthermore, an increase in CMJ height of 1-3% was recorded in athletes after performing the last squat at 90% of 1RM with a 5-minute rest, while the effects were absent in

recreational athletes (Chiu et al., 2003). However, the results of one meta-analysis showed that 104 (58.1%) out of 179 studies that used 80-90% 1RM loads had positive effects on PAP (Dobbs, Tolusso, Fedewa, & Esco, 2019). This suggests that the effects of submaximal dynamic loads may have limited application, which (Suchomel et al., 2019) attributed to significant mechanical and metabolic load. In contrast, eccentric contractions allow for the development of greater force with lower energy expenditure, which may represent an alternative strategy for inducing PAP with potentially less fatigue (Beato, Stiff, & Coratella, 2021).

Inducing PAP through eccentric muscle contractions can be performed in several ways, including supramaximal loads (i.e., Eccentric Overload) (Wagle et al., 2017), isoinertial machines (i.e., Flywheel) (Beato et al., 2021), depth jumps (Bridgeman et al., 2017), expanders or elastic bands (Aboodarda et al., 2013), adjusting external loads during the exercise by a coach or assistant (i.e., Accentuated Eccentric Load - AEL) (Tseng et al., 2021; Ditch, 2024), and releasing the load at the end of the eccentric phase of the landing (Sheppard et al., 2008).

The accentuation of the eccentric phase through AEL as a method has been examined in several studies, with varying loads and application modalities showing different effects on jump height. The optimal load for increasing jump height in trained athletes has been identified as 20% of body mass (BM) during depth jumps, with a significant effect observed after a two-minute recovery period (Bridgeman et al., 2017). Similar positive effects were recorded in young athletes after jumps with an additional load of 15% BM (Lloyd et al., 2021), as well as with the application of elastic resistance at 30% BM (Aboodarda et al., 2013). Additionally, CMJ with extra loading in the eccentric phase (20% and 40% BM) did not significantly enhance jump height but contributed to greater power output (Godwin et al., 2021). In contrast, applying a 10 kg load, which was released after the eccentric phase of the jump, led to a significant increase in jump height (Sheppard et al., 2008). An increasing number of studies are examining the use of flywheel inertial devices as an eccentric potentiation method. This modality has demonstrated effectiveness in enhancing jump height (Cormier et al., 2021), with protocols involving half-squats under moderate and high loads leading to significant improvements (Beato et al., 2021; Keijzer et al., 2020). However, only few studies have analyzed isolated eccentric contractions in the context of potentiation. While a half-squat with 85% 1RM in the eccentric phase alone did not significantly affect CMJ performance after a 2-minute recovery (Kannas et al., 2024), a 70% 1RM load induced a positive PAP effect after 3 minutes (Bogdanis et al., 2014). These findings highlight the importance of optimizing load, recovery duration, and eccentric phase velocity for effective PAP induction. Despite numerous studies on PAP,

the optimal methods and loads for maximizing the effects of this phenomenon are still not fully understood, particularly in the context of eccentric contractions of varying intensities and speeds. Considering this, the aim of this study was to examine the acute effects of fast eccentric contraction with different loads on PAP represented by the CMJ height. It was hypothesized that (1) moderate (ECC60%) and light (ECC40%) loads with fast eccentric contractions would lead to an acute increase in CMJ height, and (2) submaximal dynamic (EC90%) loads would have a greater acute effect on CMJ height compared to moderate ECC60% and light ECC40% loads with fast eccentric contractions.

METHODS

Participants

The sample consisted of 20 male students, from University of Banja Luka. The main characteristics were age = 21.4 ± 0.6 yrs, body mass = 88.8 ± 8.4 kg, height = 184.5 ± 5.4 cm, and body fat percentage: $16.3 \pm 3.4\%$). The inclusion criteria for participation in the testing were: participants in normal health status, regularly involved in minimum two trainings with weights per week, free of muscle injuries in the last 6 months prior to testing, and with at least three years of experience in strength training with weights. All participants were informed about the potential risks and benefits of the testing and provided written consent for voluntary participation in the study. All procedures were conducted in accordance with the Helsinki Declaration (Williams, 2008). The ethical aproval for this study was approved by the Ethics Committee of the Faculty of Physical Education and Sport, University of Banja Luka (11.1/989/24).

Study design

The study had a pre-experimental design (one-group pretest-posttest). All measurements were conducted across 4 separate sessions with a 7-day break between each session (Figure 1). Anthropometric measurements and 1RM assessment in the barbell squat on the Smith machine were performed during the first session. The assessment of the acute effects of 3 different types of potentiation was carried out in the second, third, and fourth sessions. In the second session, a load of 90% of 1RM was used through dynamic (eccentric-concentric) contractions. In the third and fourth sessions, loads of 60 and 40% of 1RM were applied through fast eccentric contractions, respectively.
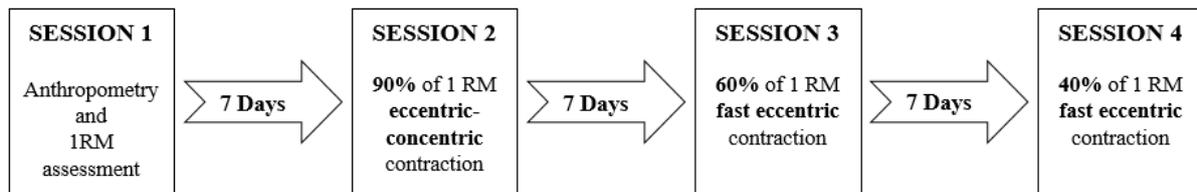
Figure 1. Study design.

Study procedures

All testing sessions were conducted at the Sports Institute, in the biomechanics laboratory of the Faculty of Physical Education and Sport, University of Banja Luka, in the morning (between 9:00 and 11:00 AM), to minimize variations in the participants circadian rhythms. In the first session, after familiarizing the participants with the experimental protocol, their body height was taken using stadiometer (SECA 206, Germany) with an accuracy of 0.1 cm and body composition using bioelectrical impedance (Tanita BC-418MA, Tokyo, Japan). At the beginning of each session, a standard warm-up protocol was carried out, consisting of 10 minutes of cycling on an ergometer (Monark, Sweden) at a constant load (1 W*kg of body weight). Immediately following the cycling, participants performed calistenics and mobility exercises and dynamic stretching for 6 minutes. Before the actual test protocols, participants performed 2 progressive warm up sets of 4 repetitions using the Smith machine with 40 and 60 kg (about 30% and 40% of 1RM), with a 3-minute rest between sets.

Assesment of 1RM

The 1RM assessment in the back squat was conducted under laboratory conditions on a modified Smith machine, specifically designed for this study. The Smith machine had standard dimensions and was equipped with four ball bearings, which reduced the friction coefficient to a negligible level. The average 1RM value was 148.4 ± 20.4 kg. The squat was performed with feet positioned parallel, slightly wider than hip-width, and to a depth of 90° in the knee joint. The knee joint angle of 90° was measured using the SG12F goniometer (Leica Vetronix, Germany), while the squat depth was individually controlled using a specially designed stopper placed behind the participant during the exercise (Figure 2). Participants performed a total of 12 repetitions with 5 different loads: 50, 60, 70, and 80% × 3 repetitions, and 90% × 1 repetition, based on the self-reported 1RM provided by each participant before testing. Participants were required to perform each repetition at the maximum possible speed in the concentric phase of the movement, while the researcher provided additional verbal motivation. Linear encoder

(Hontko HPSM1, New Taipei City 23545, Taiwan) was attached to the barbell, recording the displacement velocity of the barbell at sampling frequency of 1000 Hz. The vertical displacement of the bar and the load was recorded using a custom-written computer program (National Instruments LabVIEW, 2010, Austin, TX, USA), which low-pass filtered the signal using a recursive Butterworth filter with a cutoff frequency of 10 Hz. The derivation of data from the signal allowed for the calculation of the average velocity (Vmean), which, along with the load variable (kg), was used to obtain the load-velocity (L-V) profile. L-V profiles were assessed based on the calculated individual linear regressions using L and Vmean data at 5 different load magnitudes. Further, based on the multiple-point method and the recommended minimal velocity threshold (MVT) for the loaded back squat exercise, according to García-Ramos et al. (2023)**,** the 1RM was estimated for each participant.

Figure 2. The Smith machine used for testing and potentiation

PAP assesment

The assessment of the effects of different types of potentiation on PAP was conducted during the second, third, and fourth sessions based on the pre- to posttest changes in maximum jump height of CMJ. The CMJ test is widely used in sports science and practice to assess explosive strength and the functional capabilities of the lower limb muscles, demonstrating a high level

of validity and reliability (Marković et al., 2004). Jump height was measured using an infrared system OptoGait (Microgate, Bolzano, Italy) following a standard manufacturer's protocol (Microgate S.R.L., 2023). OptoGait is an advanced system for analyzing gait, running, and jumping biomechanics, utilizing optical sensors to precisely measure various kinetic parameters. The reliability of this system has been confirmed in multiple scientific studies (Lee et al., 2014; Gomez, Vallejo & Losa-Iglesias, 2016).

The pre-experimental procedure is shown in (Figure 3). In second, third, and fourth testing session, participants performed an initial CMJ test consisting of 3 repetitions, with the best result used for further analysis. Then, after a 3-minute rest, potentiation was attempted by 3 reps of back squat at 90% of 1RM through a dynamic contraction in the second session, and fast eccentric contractions at 60% and 40% of 1RM in third and fourth session, respectively. Following potentiation, a 6-minute passive rest period was implemented, after which the post-test CMJ was conducted with 3 repetitions, again selecting the best result for further analysis. The potentiation treatment procedure was repeated in 3 sets with 3-minute rest intervals between sets. Potentiation through fast eccentric contractions was performed by instructing participants to descend rapidly through the eccentric phase of the movement until reaching a 90° knee joint angle. After each repetition, two assistants lifted the load to an initial standing position.
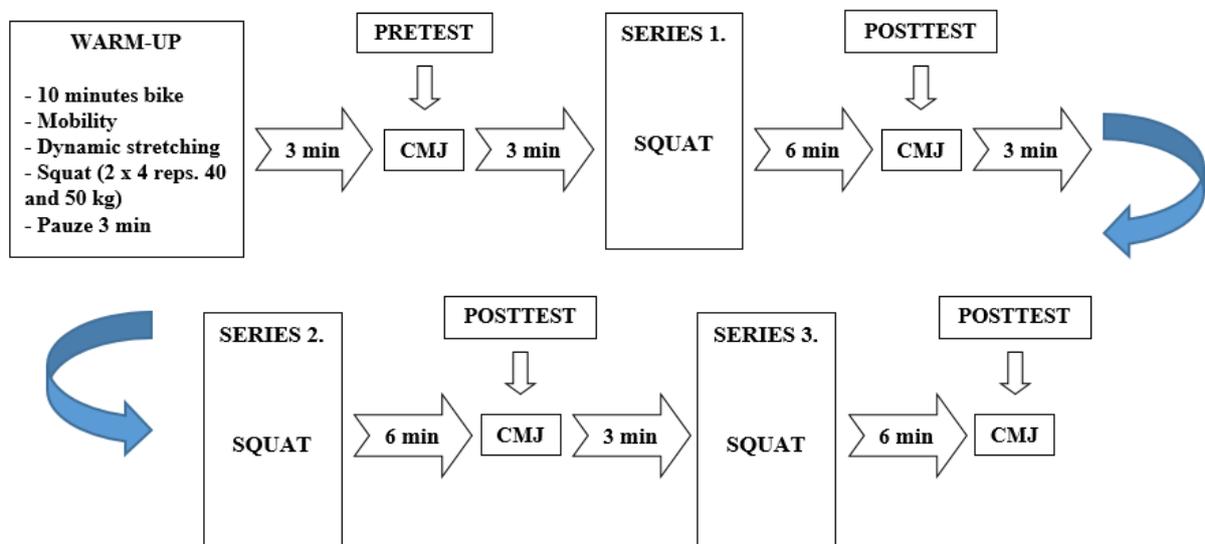
Figure 3. Schematic representation of the experimental procedure

Statistical analysis

All statistical analyses were conducted using JASP statistical software (version 0.18.3, Amsterdam, Netherlands). Descriptive data are presented as mean and standard deviation. The normality of data distribution was assessed using the Shapiro–Wilk test, and all variables were normally distributed. The effect of potentiation on jump height (i.e., PAP) was determined using a repeated-measures analysis of variance (ANOVA) with Bonferroni correction. The level of statistical significance was set at p < 0.05. Differences in the effects of various types of potentiation on the acute changes in CMJ height were analyzed using the Student's t-test for dependent samples. Effect sizes (ES) were represented by eta squared (η^2), where $\eta^2 = 0.01$–0.05 indicated a small effect, $\eta^2 = 0.06$–0.13 a medium effect, and $\eta^2 > 0.14$ a large effect. Additionally, the partial effect size was reported using Cohen's d, which was interpreted as trivial (<0.2), small (0.2–0.5), moderate (0.5–0.8), large (0.8–1.2), and very large (>1.2) (Sullivan & Feinn, 2012).

RESULTS

All three types of potentiation resulted in a statistically significant increase in CMJ height: EC90% ($F = 33.27$, $p < 0.001$, $\eta^2 = 0.63$), ECC60% ($F = 16.53$, $p < 0.001$, $\eta^2 = 0.46$), and ECC40% ($F = 4.99$, $p < 0.05$, $\eta^2 = 0.20$) (Table 1). Since the ANOVA results showed a violation of sphericity in the Mauchly test ($p < 0.05$) for ECC60% and ECC40%, the Greenhouse-Geisser correction was applied to minimize the likelihood of a Type I error. Post-hoc analysis revealed that the EC90% load (mean = 131.6 ± 17.2 kg) and ECC60% (mean = 88.7 ± 11.8 kg) had a statistically significant effect on vertical jump height after all three series. The average jump height after potentiation at EC90% increased by 2.81 ± 1.08 cm, representing a 7.3% improvement. (Figure 3). After analyzing the individual sets, the average increases in jump height were 1.5, 1.8 cm with a small effect size, and 2.6 cm with a moderate effect size, corresponding to 3.8%, 4.6%, and 6.6% in the first, second, and third sets, respectively. Furthermore, the average jump heights after the third set differ significantly compared to the jump heights after the first ($p = 0.002$) and second sets ($p = 0.038$), while there is no significant difference between the first and second sets.

Similar to EC90%, after potentiation with moderate load using fast eccentric contraction (ECC60%), significant differences were observed after all three series, $p < 0.001$, but with a small effect size. The average increase in CMJ height was 2.45 ± 0.8 cm, which is 6.8%, while

the increases after the individual sets were 1.2, 1.6 and 1.9 cm, corresponding to 3%, 4%, and 4.7% after the first, second, and third sets, respectively (Figure 3). Jump height results between the series were not significantly different.

In comparison to the previous two potentiations, the low load, ECC40% (mean = 60.1 ± 10 kg) using fast eccentric contraction had the smallest effect on average jump height, 1 ± 0.3 cm, or 2.5%. Furthermore, ECC40% did not have a significant effect on CMJ height after the first two sets. After the third set, jump height was significantly higher, but with a small effect size compared to the pretest, 0.8 cm or 2% (Figure 3). Moreover, the average jump height did not significantly differ between the sets.

Table 1. Descriptive statistics and within-group differences at pretest and posttest.

Potentiation	Pretest CMJ		Series	Posttest CMJ		t	d
	Mean	Std. Dev.		Mean	Std. Dev.		
EC90%	39.6	4.6	PSTS1	41.1	5.0	5.96	0.29 ***
			PSTS2	41.4	4.8	6.60	0.35 ***
			PSTS3	42.2	5.1	8.26	0.51 ***
ECC60%	40.1	4.2	PSTS1	41.3	4.0	6.23	0.28 ***
			PSTS2	41.7	4.5	6.23	0.37 ***
			PSTS3	42.0	4.5	5.81	0.44 ***
ECC40%	40.2	4.2	PSTS1	40.4	4.4	0.86	0.04
			PSTS2	40.3	4.4	0.59	0.03
			PSTS3	41.0	4.3	5.90	0.17 ***

Notes. EC90% - eccentric-concentric contraction with 90% 1RM, ECC60% - fast eccentric contraction with 60% 1RM, ECC40% - fast eccentric contraction with 40% 1RM, PSTS1 - posttest series 1, PSTS2 - posttest series 2, PSTS3 - posttest series 3.t - obtained t-value; d - Cohen's effect size, *** Significant at $p < 0.001$.

The results showed that all analyzed differences, pretest and the highest jump heights in the posttest (Δ), significantly differ (Table 3). A moderate effect was observed when comparing (ΔEC90%) and (ΔECC60%), 0.36 cm, with a statistical significance of $p = 0.015$. The analysis of the differences between the changes in jump height (ΔEC90%) and (ΔECC40%), 1.81 cm, revealed a significant difference with an effect size d (95% CI: 1.23 - 2.78). Additionally, the effect of ECC60% is significantly greater on average jump height compared to ECC40%, 1.45 cm, with an effect size of d (95% CI: 1.31 - 2.92) (Figure 4).
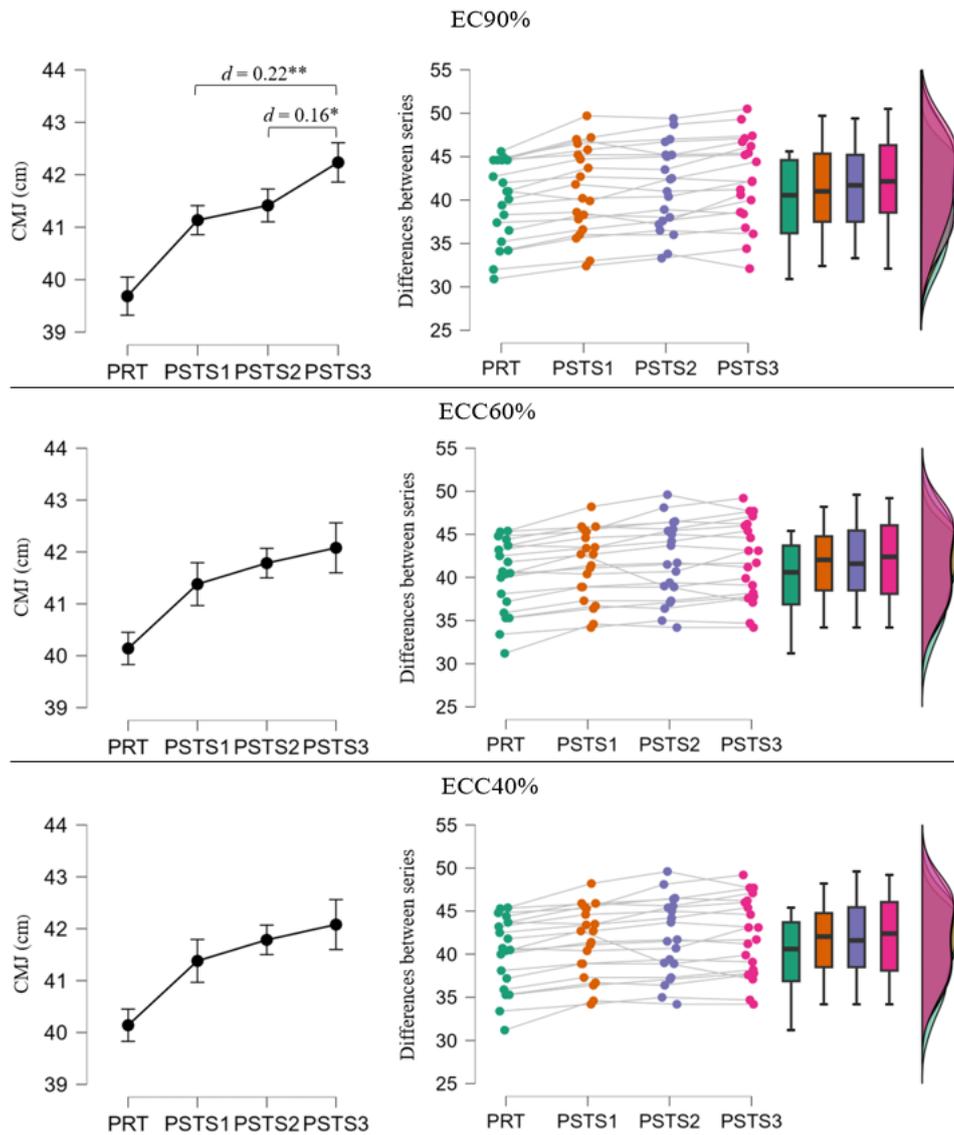
Figure 3. Differences between pretest and posttest across three series after applying three types of potentiation. Legends: PRT – pretest, PSTS1 - posttest series 1, PSTS2 - posttest series 2, PSTS3 - posttest series 3, d - Cohen's effect size, ** Significant at p < 0.01, * Significant at p < 0.05.

Table 2. Between-type differences in potentiation at the pretest and posttest.

Potentiation		t-test	p	Cohen's d
Δ EC90%	Δ ECC60%	2.68	<0.05*	Moderate
Δ EC90%	Δ ECC40%	9.02	<.001***	Very large
Δ ECC60%	Δ ECC40%	9.51	<.001***	Very large

Notes. ΔEC90% - differences between pretest and posttest, ΔECC60% - differences between pretest and posttest, ΔECC40% - differences between pretest and posttest, t - obtained t value, *** Significant at p < 0.001.

A difference of 0.36 cm was observed when comparing (ΔEC90%) and (ΔECC60%), accompanied by a moderate effect size. Data indicates that in most cases, higher CMJ values were achieved following the EC90% protocol compared to ECC60%, suggesting a more pronounced potentiation effect at submaximal intensity (Figure 4). All participants achieved significantly greater jump heights following ECC90% potentiation compared to ECC40%, where recorded changes were mostly minimal or close to zero, as confirmed by the observed difference of 1.81 cm in CMJ height increase, accompanied by a very large effect size. CMJ height was significantly higher after ECC60% potentiation compared to ECC40%. All subjects demonstrated an average increase of 1.45 cm in CMJ height after ECC60%, corroborating individual differences illustrated with an exceptionally large effect size (Figure 4).
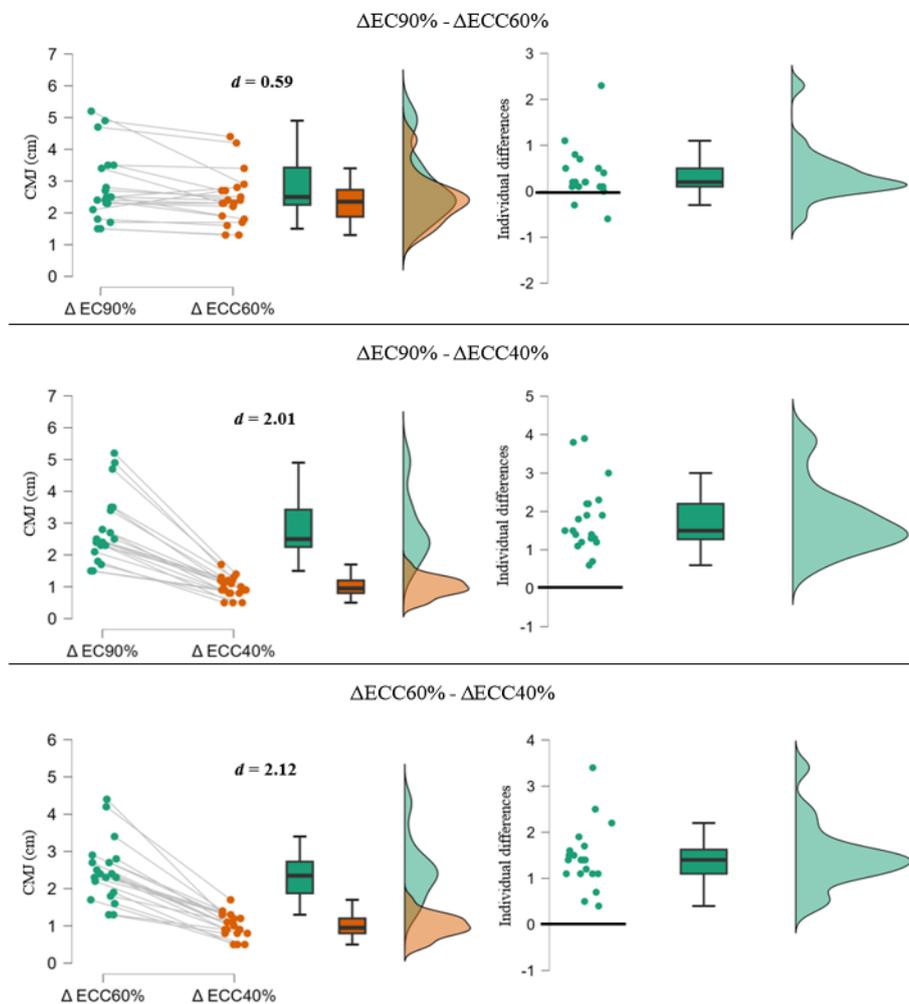
Figure 4. Differences between the acute effects of 3 types of potentiation on CMJ height
Legend: ΔEC90% - differences between pretest and posttest, ΔECC60% - differences between pretest and posttest, ΔECC40% - differences between pretest and posttest, d - Cohen's effect size.

DISCUSSION

This study was designed to examine the effects of 3 different types of potentiation on the acute effects of CMJ height in students. Assumption was that: (1) moderate (ECC60%) and light (ECC40%) loads with fast eccentric contractions would lead to an acute increase in CMJ height, and (2) submaximal dynamic (EC90%) loads would have a greater acute effect on CMJ height compared to moderate ECC60% and light ECC40% loads with fast eccentric contractions. The results showed that all three loads significantly affected vertical jump height, with the greatest effect observed after the application of EC90%, with an average jump height increase of 2.81 $\pm$ 1.08 cm. The potentiation with ECC60% showed a significantly smaller acute effect on the increase in CMJ, 2.45 $\pm$ 0.8 cm, compared to EC90%, but significantly greater than the jump height after ECC40%, 1 $\pm$ 0.3 cm. In this regard, the hypotheses of this study were confirmed.

The average increase of 7.3% after potentiation with EC90% and a 6-minute rest suggests that this modality has the potential to acutely and significantly increase vertical jump height. The serial increases of 3.8%, 4.6%, and 6.6% after the first, second, and third sets, respectively, suggest that at least 3 sets of potentiation are needed to optimally induce PAP. These findings are consistent with the results of previous studies (Evetovich, Conley & McCawley, 2015; Bauer et al., 2019; Dobbs, Tolusso, Fedewa & Esco, 2019). Dynamic contractions with submaximal loads, such as 90% of 1RM, activate large motor units, and thus a large percentage of fast-twitch type II fibers, which are crucial for generating high force. Furthermore, generating high force during the potentiation exercise significantly influences the display of explosive strength in subsequent conversion exercises (Seitz et al., 2016). Therefore, previous research, which is supported by the results of this study, has shown that dynamic contractions with submaximal loads lead to an acute increase in CMJ height, and thus have acute effects on PAP (Tillin & Bishop, 2019).

A similar effect was observed after the application of potentiation with fast eccentric contractions and a 60% 1RM load, ECC60%, while the effect after the application of ECC40% was the smallest, but still practically significant. After potentiation with ECC60%, the average vertical jump height increased by 6.8%, which, compared to the jump height after potentiation with EC90%, is not a large practical difference, but still statistically significant. The average CMJ height after potentiation with ECC40% was 2.5% higher. Although these values are the lowest compared to the average jump heights after the previous two potentiations, EC90% and ECC60%, they still represent a significant practical acute increase. The serial increase in

average vertical jump height after potentiation with ECC60% was lower than after EC90%, with increases of 3%, 4%, and 4.7% after the first, second, and third sets, respectively. interestingly, potentiation with ECC40% had an acute effect on increasing the average CMJ height only after the third set, by 2%.

According to our knowledge, this study represents the first investigation into the acute effects of fast eccentric contractions with moderate and low loads on post-activation potentiation (PAP) using this specific methodological potentiation framework. Although direct comparisons with previous research are challenging due to methodological differences, the observed PAP effects align with previous findings in the context of accentuated eccentric loading (AEL). Furthermore, the findings of this study confirm prior research on AEL potentiation, which has shown that PAP responses are load-dependent, although the results vary depending on the methodological implementation. While (Bridgeman et al., 2017) reported optimal improvements in countermovement jump (CMJ) with loads of 20% body mass (BM) during drop jumps, our results, using percentages of maximal load in a fast eccentric regime, suggest alternative relationships between potentiation and acute effects. The absence of effects in the early sets with ECC40% aligns with the findings of (Aboodarde et al., 2014), where loads of 20–30% BM improved kinetic force parameters but did not lead to an increase in jump height. However, potentiation in the third set with ECC40% is consistent with the results of (Popp Marin et al., 2021) on submaximal loading using resistance bands, potentially indicating a delayed manifestation of PAP effects when potentiation occurs at lower intensities. Discrepancies with (Godwin et al., 2021), who reported an increase in power without an improvement in jump height using eccentric phases with dumbbells, may be due to the 6-minute pause between load application and the subsequent vertical jump. The progressive improvement in vertical jump height across three sets following the intervention with ECC90% and ECC60% suggests cumulative neurophysiological adaptations, potentially through enhanced heavy myosin chain kinetics (Walker et al., 2016) and increased sensitivity of actin-myosin cross-bridges (Tillin & Bishop, 2019). Furthermore, this 6-minute rest period appears to reflect both the potentiation of neurophysiological excitability (Seitz & Haff, 2016) and the mechanisms of elastic energy storage (Kubo et al., 2002), with the third set achieving optimal temporal summation of these effects after potentiation with EC90% and ECC60%. However, the reduced response following potentiation with ECC40% in the initial sets indicates that there are load levels optimal for mechanical stimulation, where lower intensities may not have sufficiently activated high-threshold motor units or generated adequate tendon recoil forces (Bridgeman et

al., 2017; Lloyd et al., 2021). These findings indicate a key interdependence between load magnitude, rest intervals, and movement patterns in the process of optimizing PAP through fast eccentric contractions.

Limitations

The sample size could have been larger and varied in terms of fitness levels, which would have allowed for the assessment of acute effects of different types of potentiation on CMJ height across more time frames, and after varying durations of rest periods. This might have revealed potentially greater effects of light loads after shorter rest periods than the 6 minutes used in this study. Including female participants could also highlight potential differences in response to all three types of potentiation. Additionally, using force platforms, as the gold standard for testing vertical jumps, would certainly have generated more variables for analysis and evaluation of acute PAP effects. Increasing the number of series could also be considered for further research.

CONCLUSION

Moderate load potentiation through fast eccentric contraction (ECC60%) can be effectively used for the acute increase in CMJ height. Furthermore, ECC60% induces similar acute effects on PAP as submaximal load through dynamic contraction (EC90%) during the back squat after a 6 minutes rest. However, it is important to highlight that PAP can also be triggered by applying potentiation with a small load through fast eccentric contraction (ECC40%). Although the subsequent increase in jump height was the smallest compared to the previous two types of potentiation, it is still practically significant. A 6-minute rest period between the potentiation exercise and CMJ can be considered optimal for achieving acute PAP effects after potentiation with EC90% and ECC60%. The increase in effect in later series suggests that multiple series may contribute to improving jump height. Given that this is the first study to investigate the acute effects of fast eccentric contractions with moderate and small loads on PAP in such a methodological framework of potentiation, further research is needed to confirm and expand these findings.

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THE LEVEL OF INFORMATIONAL DEPENDENCE BETWEEN GAZE BEHAVIORS IN DECISION-MAKING ON SHOOTING THROUGHOUT A FUTSAL GAME

RAVEN INFORMACIJSKE ODVISNOSTI MED VEDENJEM POGLEDA PRI ODLOČANJU O STRELJANJU V IGRI FUTSALA

ABSTRACT

Purpose: This study investigated whether gaze fixation behaviors during shooting situations influence subsequent visual behaviors throughout a futsal game. *Methods:* A total of thirty shots from seven futsal players who wore an unobtrusive eye tracking device during matches of futsal were analyzed using the Kinovea software. The visual information were analyzed from the moment a teammate passed the ball to the shooter (initial moment) until the moment the shot was performed (final moment). The analyses employed normalized mutual information (NMI). *Results:* The results showed that the NMI values were close to zero, suggesting minimal dependence between gaze fixation behaviors in consecutive shots. *Discussion and Conclusions*: These findings indicate significant variability in players' gaze fixation behaviors during shooting situations, which may reflect their adaptive responses to the game's dynamic conditions. The identification of multiple gaze fixation patterns among players suggests that different strategies may be employed to optimize performance in response to varying game contexts, offering new insights into the role of visual information in futsal.

Keywords: eye tracking, adaptive behaviors, normalized mutual information, team sports, futsal

IZVLEČEK

Namen: Ta študija je preučevala ali vedenje fiksiranja pogleda med situacijami streljanja vpliva na poznejše vizualno vedenje skozi igro futsala. *Metode*: S programsko opremo Kinovea je bilo analiziranih skupno trideset strelov sedmih igralcev futsala, ki so med tekmami futsala nosili nemotečo napravo za sledenje očem. Vizualne informacije so bile analizirane od trenutka, ko je soigralec podal žogo strelcu (začetni trenutek) do trenutka, ko je bil izveden udarec (končni trenutek). Analize so uporabile normalizirano medsebojno informacijo (NMI). *Rezultati*: Rezultati so pokazali, da so bile vrednosti NMI blizu nič, kar kaže na minimalno odvisnost med vedenjem fiksiranja pogleda v zaporednih posnetkih. *Razprava in zaključki*: Te ugotovitve kažejo na veliko variabilnost v vedenju igralcev pri fiksiranju pogleda med situacijami streljanja, kar lahko odraža njihove prilagodljive odzive na dinamične pogoje igre. Identifikacija več vzorcev fiksiranja pogleda med igralci nakazuje, da se lahko uporabijo različne strategije za optimizacijo uspešnosti kot odgovor na različne kontekste igre, kar ponuja nov vpogled v vlogo vizualnih informacij v futsalu.

Ključne besede: sledenje očem, prilagodljiva vedenja, normalizirane medsebojne informacije, ekipni športi, futsal

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INTRODUCTION

Over the past few decades, players' decision-making ability has increasingly been considered as *sine qua non* for success in team sport (Araújo et al., 2006; Causer & Williams, 2013; Hastie, 2001; Raab et al., 2019; Ripoll, 1994; Tenenbaum et al., 1993; Williams & Jackson, 2019). This is because team sport match unfold as a process of continuous emergence of situations involving several possibilities for action. For example, when receiving the ball, a futsal player can make the decision to perform a pass, a dribble, a shot or drive. Still, each of these decisions comprises several alternatives such as how, where, and/or when to perform it. In such sports, players simultaneously make decisions to cooperate with each other by performing motor skills with and without the ball to, as a team, oppose the other team (Corrêa et al., 2012a; Davids et al., 2005; McGarry, 2009). Considering the natural dependence between context and actions for success, the ongoing interactions in team sports must be considered as an informational source for decision-making in team sports.

Based on this, researchers have developed a body of studies to understand how information on players' interactions (i.e., interpersonal coordination) constrains players' decision-makings (Denardi et al., 2016; Passos et al., 2013, 2016; Vilar et al., 2013). The main assumption here is that players make decision based on perceived properties of interpersonal coordination (e.g., area, angle, distance, and velocity). For instance, regarding the team sport of futsal studies have pointed out that players make decision based on (i) angles involving the passer, receiver and their markers for passing direction and velocity (Corrêa et al., 2012a, 2014a; Silva et al., 2017); (ii) distance between the passer and the defenders, and between the two closest defenders for passing moment (Corrêa et al., 2020a; Travassos et al., 2012a); (iii) distance between the marker and the passer (pressure) and the line of the ball (Travassos et al., 2012a) as well as on the changing the defensive area for ball interception (Corrêa et al., 2014b; Travassos et al., 2011, 2012b); (iv) variability of the passing and shooting angles for dribbling (Corrêa et al., 2016); (v) spatiotemporal information about the closest defender and the goalkeeper for shooting (Vilar et al., 2012a); and (vi) distance to the goal and ball line to anticipate the shot (Vilar et al., 2012b).

These findings have provided important insights on how interpersonal coordination information constrains decision-making in futsal. Following this line of thinking, further studies investigated how futsal players behave visually with such informational variables in the shooting situation (Corrêa et al., 2020b; Oliveira et al., 2023). These studies have demonstrated

that (i) the longer the time of ball possession, the greater the variability in visual search because futsal players look for an optimal value of angular interpersonal coordination (Corrêa et al., 2020b); (ii) futsal players vary their gazes among the nearest defender, goalkeeper, court floor, and ball, the latter two being used as an anchor point and postural and accuracy controls, respectively (Oliveira et al., 2023).

Despite the cumulative knowledge gathered through these studies, it is important to note that the nature of a team sports match must be further incorporated in the analyses and interpretation of decision-making studies. These previous studies were analyzed by grouping shots (e.g., averaging) independent of their temporal aspects. This disregards the fact that the shots occur within a sequence of events that comprise the futsal game. However, the game unfolds as a non-autonomous coupled dynamic system; that is, a system that has time-dependent changes depending on the status of both teams operating (e.g., while one attacks, the other defends; further attacks do not lead to the same responses) (Corrêa et al., 2012b). Furthermore, the fact that teams influence each other, but without absolute correspondence between their actions, makes the changes a non-linear process (Clavijo et al., 2022).

Therefore, the current study sought to extend previous findings by exploring how futsal players use the visual information for decision-making on shootings throughout the game. Our question was given the game is a dynamic system, would previous gaze behaviors in shooting situations influence subsequent gaze behaviors throughout the game? Would there be patterns of visual information used in shooting situations throughout the game? To answer these questions, data from gaze behavior (fixation and its duration) of shooting situations over futsal games were analyzed complementarily by methods of mutual information (e.g., Williams, 1997) and clustering (e.g., Schöllhorn et al., 2013). While the first allows accessing the amount of information that one variable contains about another in different points over time, the second allows the use of similarity (or distance) measures to form clusters between the visual behavior patterns throughout the game.

METHODS

Participants

They were seven amateur players with normal visual acuity (average age of 18.85 ± 1.66 years), who voluntarily played competitive matches of futsal wearing an unobtrusive eye tracking

device. The volunteers were also identified by the coach as those players with the greatest tendency to perform shots. Participation required the volunteers' written consent, and the experimental protocol was given ethical approval by the local Institutional Review Board.

Procedures

An Eye Tracking System (TOBII PRO, Danderyd, Sweden) was utilized by one player from each team in each half of the game. This apparatus allows capturing the corneal and pupil behavior, thereby enabling inferences about gaze fixation and its duration (Duchowski, 2007; Holmqvist & Anderson, 2017). The visual information from the TOBII PRO eye-tracking videos were analyzed through the KINOVEA software 8.27 (http://www.kinovea.org), from the moment a teammate passed the ball to the shooter (initial moment) until the moment the shot was performed (final moment). It ranged from 0.36 to 5.28 seconds. The inter-rater reliability was verified through re-analyze five minutes of the game by another researcher ($r = 0.94$, $p < 0.01$).

Data analyses

30 shots were collected. However, one player performed no shots, two players performed only one shot, and one player performed only two shots. Therefore, to meet the objective of the present study, the analyzed sample comprised data from 26 shots performed by 3 players.

For the first analysis, data were analyzed using the mutual information method (see Williams, 1997 for a tutorial). This is a measure that quantifies the extent to which one variable reduces the uncertainty (a measure of information in Information Theory terms). It can also be employed to assess the information that a given point in time "carries" to another (Cover & Thomas, 1991; Williams, 1997). This measure ranges from zero, indicating the absence of a relationship between two time points, to infinite (only depending on the total entropy of the system).

To conduct this analysis, the gaze fixation durations over each shooting were divided into quartiles (Altman & Bland, 1994) as follows: player A [first quartile (Q1), from 40 to 80 ms; second quartile (Q2), from 81 to 200 ms; third quartile (Q3), from 202 to 420 ms; fourth quartile (Q4), from 425 and 3160 ms]; player B [Q1, from 40 to 70 ms; Q2, from 72 to 160 ms; Q3, from 170 to 450 ms; Q4, from 460 to 1600 ms]; player C [Q1, from 40 to 130 ms; Q2 from 135 to 300 ms; Q3, from 303 to 770 ms; Q4 from 780 to 2560 ms]. The data were organized based on transition probabilities within each shot. For instance, the interest area of gaze fixation and its quartile of time were combined into a single variable. For instance, during a shot, a player

may have focused on the ball with a fixation time in quartile 3 (Q3), on the ground with a fixation time in quartile 2 (Q2), on the opposing goalkeeper with a fixation time in quartile 1 (Q1), and again on the ball with a fixation time in quartile 4 (Q4). These data represented the following gaze behaviors: transition probability of the state "ball-quartile3" for the state "ground-quartile2" and transition probability of the state "opposing goalkeeper-quartile1" for the state "ball-quartile4", respectively. A mathematical entropy function was used to quantify the randomness associated with the probabilities of a player select the "ball-quartile3" option, and then the "ground-quartile2", "opposing goalkeeper-quartile3", and finally the "ball-quartile4" options (for instance, see Lai et al., 2005, 2008).Thus, this meant that the first state, for example, "ball-quartile", was considered the variable X in the equations, and the second state, "teammate-quartile3", was considered the variable Y in the equations. This logic was applied throughout all gaze fixations of all kicks that resulted in time terms $t + t1$. The marginal probabilities were then employed to calculate the entropies of each variable I (X) and II (Y) using Shannon's entropy formula (Shannon & Weaver, 1949) (equations 1 and 2).

Equation 1:

$$H_X = -\sum_{i=1}^{N_s} P(x_i) \log_2 P(x_i)$$

where H_X is the entropy of the random variable x. It represents the average amount of information (or uncertainty) generated by each value of x; N_s is the total number of possible states or distinct values that x can assume. $\sum_{i=1}^{N_s}$ is the summation that iterates over all N_s possible values of the variable x; $P(x_i)$ is the probability of the i-th value x_i of the random variable x; $\log_2 P(x_i)$ is the logarithm, base 2, of the probability $P(x_i)$. The use of a logarithm with base 2 measures the amount of information in bits; the negative sign $(-)$ ensures that entropy is always positive, since $P(x_i)\log_2 P(x_i)$ is negative when $P(x_i)$ lies in the interval $(0,1)$.

Equation 2:

$$H_Y = -\sum_{j=1}^{N_s} P(y_j) \log_2 P(y_j)$$

where H_y is the entropy of the random variable x. It represents the average amount of information (or uncertainty) generated by each value of y; N_s is the total number of possible states or distinct values that x can assume; $\sum_{i=1}^{N_s}$ is the summation that iterates over all N_s

possible values of the variable x; $P(y_i)$ is the probability of the i-th value y_i of the random variable y; $\log_2 P(y_i)$ is the logarithm, base 2, of the probability $P(y_i)$. The use of a logarithm with base 2 measures the amount of information in bits, the negative sign ($-$) ensures that entropy is always positive, since $P(y_i)\log_2 P(y_i)$ is negative when $P(y_i)$ lies in the interval $(0,1)$.

Subsequently, the joint probability matrix, represented by $P(x_i, y_j)$, was calculated to demonstrate the influence of the relationship between variables on the occurrence probabilities of different event combinations. Additionally, the conditional probability matrix, represented by $P(y_j \mid x_i)$, was calculated, providing the probabilities of an event occurring given another event. The conditional entropy of variable Y given the specific value or event of variable X, or $H_{Y \mid X}$, was calculated. The mutual information was then determined according to equations 3 and 4.

Equation 3:

$$H_{Y|X} = -\sum_{i=1}^{N_s}\sum_{j=1}^{N_s} P(x_i)P(y_i|x_i) \log_2 P(y_j|x_i)$$

where $H_{y|x}$ is the conditional entropy of y given x. It represents the average amount of uncertainty (or information) about the variable y when the variable x is known; $P(y_j|x_i)$ is the conditional probability of y_j given x_i. In other words, it is the probability that $y = y_j$, given that $X = x_i$. $\sum_{i=1}^{N_s}\sum_{j=1}^{N_s}$. These are the two summations that iterate over the possible values of x and y. The first summation iterates over all possible values of x (from $i = 1$ to N_s, where N_s is the total number of possible states or values that X can assume). The second summation iterates over all possible values of y (from $j = 1$ to N_s). $\log_2 P(y_j|x_i)$: The logarithm with base 2 of the conditional probability $P(y_j|x_i)$. This logarithm measures the amount of information (in bits) associated with the probability $P(y_j|x_i)$. The negative sign ($-$) at the beginning of the equation ensures that the entropy is always positive.

Equation 4:

$$I_{Y;X} = H_Y - H_{Y|X}.$$

where $I_{y|x}$ is the mutual information between y and x. It quantifies the amount of information that the variable x provides about y; H_Y is the Entropy of y. It represents the amount of uncertainty (or information) about the variable y without any additional knowledge of x; $H_{y|x}$ is

the conditional entropy of y given x. It represents the amount of uncertainty about y when the variable x is known.

Given the upper limit of mutual information is contingent on the entropy of the variable, comparisons between samples are rendered challenging (Fedorowich et al., 2015; Johansen et al., 2013; Madeleine et al., 2011). To address this, a normalized version of mutual information (NMI) was implemented and defined as follows:

Equation 5:

$$NMI = \frac{I_{y;x}}{H(x) * H(y)}$$

where NMI is the Normalized Mutual Information. This is a normalized version of the mutual information between two variables y and x; $I_{y;x}$ is the Mutual Information between y and x. This measures the amount of information that x provides about y (or vice versa); H(x) is Entropy of x; and H(y) is Entropy of Y.

This normalization resulted in NMI values ranging from 0 to 1. The value of 0 meant no dependence between variables. On the other hand, the value of 1 indicated complete dependence among them (Johansen et al., 2013; Kawczyński et al., 2015; Madeleine et al., 2011). All mutual information analyses were conducted using R software version 4.2.0.

RESULTS

Regarding the descriptive trends of visual behaviors, the results showed that the main areas of interest for gaze fixation were the goalkeeper, a teammate, an opponent, the court floor, and the ball. It was found that, while players A and C fixed their gaze on the ball, the opponent, and the court floor, player B, in addition to these items, fixed his gaze on the opposing goalkeeper and his teammate. Table 1 shows the ball was the item most focused on during the shots, especially those performed by players A and B. It can also be observed that the court floor was the focus of fixations, but in a smaller amount than the ball. It is interesting to note that player B's shots were those with the greatest amount of fixation focuses. In relation to the gaze fixation time, Table 1 shows the ball was the item with the longest fixation time. Some highlights can be observed in shots 2 and 3 by player C and shot 4 by player B, in which the court floor had the longest fixation time.

Table 1. Relative frequency (%) and average duration (ms) of gaze fixation on each interest area (goalkeeper, teammate, opponent, court floor, and ball).

Player	Goalkeeper		Teammate		Opponent		Court floor		Ball	
	Freq. (%)	Time (ms)	Freq. (%)	Time (ms)	Freq. (%)	Time (ms)	Freq. (%)	Time (ms)	Freq. (%)	Time (ms)
A	-	-	-	-	0,52	40	8,9	170	90,58	461,33
B	2,07	120	3,63	96	11,05	320	9,15	163,08	74,09	536,25
C	-	-	-	-	0,58	80	26,51	283,08	72,91	843,33

The values of NMI analysis are presented in the Figure 1. It shows that Players A, B, and C exhibited 0.26, 0.13, and 0.20 of NMI.
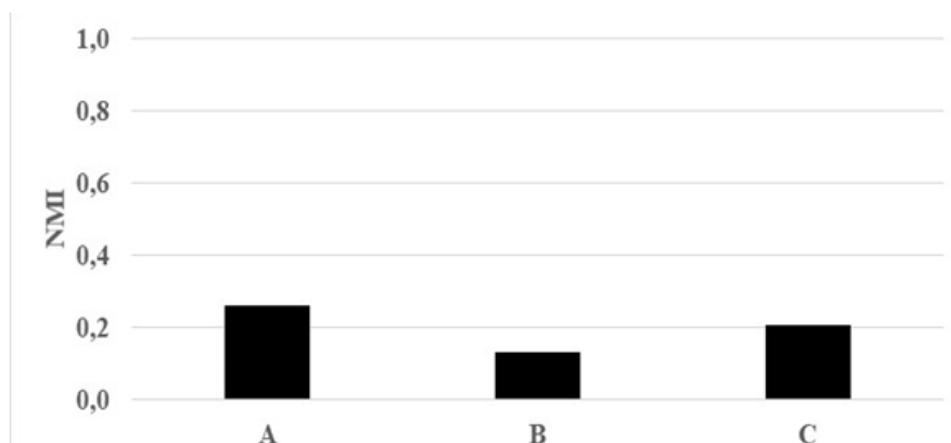
Figure 1. Normalized mutual information (NMI) for Players A, B, and C's gaze behaviors.

DISCUSSION

This study investigated whether previous gaze behaviors in shooting situations would influence subsequent gaze behaviors throughout the game. The main results indicated that normalized mutual information obtained values close to zero.

Although normalized mutual information has been utilized in many studies in recent years (e.g., Fedorowich et al., 2015; Johansen et al., 2013; Kawczyński et al., 2015; Kristiansen et al., 2023; Lai et al., 2008; Madeleine et al., 2011, 2016; Murakami & Yamada, 2022), none of them investigated the shooting in futsal. Regarding this motor skill, our results indicated that there

was almost no dependence from the previous gaze behaviors on the subsequent ones, that is, what and how players focused on at time x reflected very little on what they focused on at time $x + 1$ (Williams, 1997).

This derisory informational dependence can be explained by considering the futsal teams as hierarchical adaptive systems (e.g. see Corrêa et al. 2021). Hierarchical systems like futsal can comprise two main levels: (1) the inferior one is known as microstructure; it refers to the players individual behaviors; and (2) the superior level, called macrostructure, is the result of the interaction between players: the team. Generally, in team sports macrostructure is defined by the tactics adopted by the team. For instance, a given futsal team may decide to play in a diamond formation (1-2-1) (i.e., one player in the defense, two players laterally in midfield, and one attacking player up front). The hierarchy here consists of macrostructure defining the roles of the players for the emergence of the diamond. However, the individual behaviors (e.g., what and how they will do to perform their roles) will be constrained by the game circumstances (e.g., the actions of the opponents). This is why the way that players interact is less variable than their individual behaviors. That is, as a hierarchical systems the futsal teams show regularity and spatiotemporal pattern at the macroscopic level, and irregularity in behaviors at the microscopic level (Clavijo et al., 2022; Reis & Corrêa, 2021).

Furthermore, as previously described, the game of futsal unfolds because of the simultaneous work of opposition in which one team acts to take advantage of the other. For example, while the attacking team acts to generate uncertainty for the defending team, the latter works to obtain information from the opponent (to reduce uncertainty) and use it to recover the ball possession. This process of reducing/increasing uncertainty may generate different degrees of perturbation between the teams. From a hierarchical systems point of view, in this case the teams may deal with perturbation by adapting themselves in two main ways. First, the team might alter their microstructure – modify parameters of one or another player (e.g., running faster or slower, or playing more wide or tight). In this case, there is maintenance of macrostructure because players can run faster or slower with the team playing in a diamond formation. It is this type of adaptation that characterizes the regularity of a team throughout the game (McGarry, 2013; McGarry & Franks, 1996; McGarry et al., 1999, 2002). Second, reorganizing their macrostructure by adopting a new organization (Tani et al., 2014). For example, faced with a perturbation, a team could change the pattern of interaction between players so that the team changes the playing system from a diamond to a square (i.e., from 1-2-1 to 2-2) (Corrêa et al., 2012b).

Based on the foregoing, the weak dependence between the gaze fixation behaviors in the shots throughout the game may have occurred because the shooting situations demanded different macrostructures. To put it another way, the perturbations generated by the defensive team throughout the game may have required a new organization of the attack for the performance of each shot. For this reason, there was a very weak relationship between gaze behaviors.

Obviously, this does not mean that the whole game developed based on the emergence of novelty/creativity, as we only analyzed the shooting. Furthermore, relatively few occurrences (probabilities) of the gaze fixation focus were noted during shots, with three occurrences for two players and five for one player. In them, the occurrence of ball fixation was greater than other areas of interest, which may indicate that this variable has a dominant influence or that other variables do not have much influence on it. This may also explain the weak dependence found. In other words, most of the data were related to the ball, and there was little variation or influence from other variables, therefore, the observation of the ball brought very little additional information about the other variables (Kvålseth, 2017).

The fact that the ball was the most focused item and had the longest fixation duration can be due its central role in the game and in shootings (Jerome et al., 2024, Oliveira, 2023). Players direct their gaze to the ball to ensure accuracy in its contact with the foot (Dörge et al., 2002; Shan & Zhang, 2011). In addition, focusing on the ball during the kick makes it easier for players to regulate the postural and biomechanical adjustments necessary for effective kick performance (Dörge et al., 2002; Shan & Shang, 2011). Another explanation is that the gaze fixation on the ball may have been used as a pivot or visual anchor. Visual anchoring refers to the fixation of the gaze on a specific point on the court so that constant saccadic changes are not necessary to monitor the positioning of other players (Vater et al., 2019). On the other hand, the visual pivot involves the visual exploration of the environment around this anchor point, allowing the player to select the next fixation on a peripheral information source (Vater et al., 2019). Therefore, the gaze fixation on the ball during shots may have been functional for players to simultaneously monitor different sources of information (Oliveira et al., 2023; Ryu et al., 2013).

CONCLUSION

In summary, the results of this study allow us to conclude there was little informational dependence between gaze behavior patterns throughout the game because they occur in a non-

sequential order of structural and parametric adaptations. One could argue that the small number of players and shots could be considered a limitation of this study. However, it is important to consider that this reflects the nature of the game. For example, there is no guarantee that a player will perform many shots in over the game. Our study provides insights for new considerations on gaze behavior in sport contexts, going beyond the "aggregate" behavior (averages) of previous studies. Despite the advances and limitations, as part of the scientific enterprise these findings need to be replicated, including in relation to other futsal motor skills, in order to guarantee them the consistency necessary for generalization and transformation into knowledge for the practice of futsal.

Declaration of Conflicting Interests

No potential conflict of interest was reported by the authors.

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PRESERVING HEALTH: THE MAIN MOTIVE FOR EXERCISING IN THE SENIOR EXERCISE PARK FOR A NURSING HOME RESIDENTS

OHRANJANJE ZDRAVJA: GLAVNI MOTIV ZA VADBO V SENIOR VADBENEM PARKU STANOVALCEV DOMA STAREJŠIH OBČANOV

ABSTRACT

Introduction: The aim of this study was to evaluate the motives and attitudes of the Nursing Home residents for exercising in Senior Exercise Park (SEP). **Methods:** Fifty volunteers (79.3 ± 8.4 years; 80% women; 50% exercising in SEP) were interviewed. Beside the descriptive statistics, a one-sample t-test and a chi-square test were used. **Results:** The results showed that physical activity (PA) performed by the respondents in the past was not significantly (p>0.05) related to their engagement in the SEP. More than a half of those who had been exercising in the SEP were exercising five or more times per week, which was also significantly (p<0.05) more frequent than the recommended three times per week. The majority of those who exercised in the SEP spent up to 30 minutes for each exercise session. The most frequent motives for exercising in the SEP were medical/health factors, challenge/benefit and curiosity. Among the reasons why some Nursing Home residents had not engaged in the SEP exercise, the most frequently mentioned were health problems, physical difficulties and lack of interest. The main benefit of the SEP exercise was the ability to perform everyday tasks much easier, feeling better and being in a better mood. **Discussion and Conclusions:** Installation of SEPs in the Nursing Homes is reasonable and could represent an important home's achievement, as it can significantly contribute to the increase in PA of its residents. Moreover, it can also have an indirect positive effect on their health and overall home's atmosphere.

Keywords: elderly, physical activity, outdoor exercise, motives, attitudes

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IZVLEČEK

Uvod: Cilj raziskave je bil ugotoviti motive in stališča stanovalcev doma starejših za vadbo v Senior vadbenem Parku (SVP). **Metode:** V raziskavi je prostovoljno sodelovalo 50 stanovalcev Doma starejših občanov Šiška v Ljubljani (79,3 ± 8,4 let; 80,0% žensk), od katerih je 25 vadilo v SVP, 25 pa ne. Poleg opisne statistike, sta bila uporabljena tudi t-test za en vzorec glede na fiksno vrednost in hi-kvadrat test. **Rezultati:** Telesna aktivnost, ki so jo anketiranci izvajali v preteklosti ni bila značilno povezana (p>0,05) z njihovo vadbo v SVP. Več kot polovica vadečih je v SVP vadila pet- in večkrat tedensko, kar je bilo tudi značilno (p<0,05) pogosteje od splošno priporočene 3-krat tedenske vadbe. Pri tem je večina za izvedbo posamezne vadbene enote porabila do 30 minut. Najpogostejši motivacijski dejavniki za vključevanje v SVP so bili zdravstveni dejavniki, izziv in korist ter radovednost. Med razlogi, zaradi katerih se nekateri stanovalci doma niso vključili v vadbo, so bile najpogosteje omenjene zdravstvene težave in telesna/gibalna oviranost ter nezainteresiranost za vadbo. Pri analizi stališč do vadbe v SVP se je pokazalo, da se med vsemi oblikami vadbe, ki se v domu izvajajo, vadeči poleg hoje in sprehodov najpogosteje odločajo za vadbo v SVP. Slednja jim koristi predvsem zato, ker lahko veliko lažje opravljajo vsakdanja opravila, se bolje počutijo in so bolje razpoloženi. **Diskusija in zaključek:** Postavitev SVP v domovih za starejše občane je vsekakor smotrna in predstavlja pomembno pridobitev, saj lahko bistveno prispeva k dvigu telesne aktivnosti njenih stanovalcev ter posredno pozitivno vpliva na njihovo zdravje in vzdušje v domu.

Ključne besede: starostniki, telesna aktivnost, vadba na prostem, motivi, stališča

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INTRODUCTION

The global demographic landscape is undergoing a pronounced shift due to accelerated population aging. Between 1980 and 2020, global life expectancy increased from 62 to 73 years, a trend observable in both high-income and low- to middle-income countries (Akhtar, 2023). This demographic transition is anticipated to continue, with the global population projected to surpass 9 billion by 2050, accompanied by a substantial rise in the proportion of older individuals (Smith et al., 2024). Population aging poses considerable challenges to healthcare systems worldwide, as older adults typically exhibit elevated protein requirements and heightened susceptibility to acute health crises, including the COVID-19 pandemic (Lopreite et al., 2023). In parallel, the need for geriatric dental care is expanding, reflecting the growing prevalence of age-related oral health issues (Calabrese & Rawal, 2023). Moreover, social isolation and loneliness among individuals aged 50 years and older are projected to increase markedly, with estimates rising from 104.9 million in 1990 to 333.5 million by 2050 (Newmyer et al., 2022). These demographic dynamics underscore the urgency for targeted policy reforms aimed at ensuring the sustainability and resilience of healthcare infrastructures and social support systems tailored to the needs of aging populations. For this reason, care for older adults is also growing at one time with the awareness of the positive effects of active ageing. In Slovenia, there is still 4% of older people with severe unmet needs of care (Hlebec, Srakar and Majcen, 2016). Adequately planned and regular physical activity (PA) is one of the rare "medicines", known from the antiquity, without adverse side effects (Berryman, 2010; Tipton, 2014; Strojnik, 2017; Thompson, Sallis, Joy, Jaworski, Stuhr and Tilk, 2020). It is also an effective tool for preventing or reducing the age-related decrease in functional capacity as well as it contributes to a greater independency and higher quality of life of older adults (Chodzko-Zajko et al., 2009).

Regular engagement in physical activity is associated with a wide range of health benefits, including a reduced risk of cardiovascular diseases, various forms of cancer, and all-cause mortality (Garcia et al., 2023). In addition to its physical health advantages, physical activity has been shown to exert positive effects on mental health by alleviating symptoms of depression, stress, and anxiety (Giandonato, Tringali and Thoms, 2021). Current guidelines issued by the World Health Organization recommend that adults engage in 150 to 300 minutes of moderate-intensity or 75 to 150 minutes of vigorous-intensity aerobic physical activity per week to achieve optimal health outcomes (Kunutsor, Jae and Laukkanen, 2022). Notably, emerging evidence suggests that individuals following a "weekend warrior" pattern –

concentrating physical activity into one or two sessions per week – may derive health benefits comparable to those who engage in more frequent exercise routines (Kunutsor, Jae and Laukkanen, 2022). Physical activity also plays a critical role in the prevention and management of non-alcoholic fatty liver disease, with guidelines recommending a minimum of 150 minutes of moderate or 75 minutes of vigorous activity on a weekly basis (Stine et al., 2023). Furthermore, the built environment is increasingly recognized as a key determinant in facilitating or hindering population-level physical activity, with features such as walkability, green spaces, and access to recreational facilities being particularly influential (Laddu, Paluch and LaMonte, 2021). Despite the well-documented health benefits, global adherence to physical activity guidelines remains insufficient (Rodrigues et al., 2023a). In response, numerous national and international public health strategies have been developed to promote physical activity across all segments of the population, recognizing its central role in the prevention of chronic diseases and the promotion of overall public health (Katzmarzyk et al., 2023).

The overall evidence for adults aged 65+ years demonstrates that, compared to less physically active individuals, older adults who are more active have lower rates of all-cause mortality, coronary heart disease, high blood pressure, stroke, type 2 diabetes, colon cancer, breast cancer and have a higher level of cardiorespiratory, muscular fitness and overall physical function, healthier body mass and body composition as well as reduced incidence of falls and fall-related injuries (Pantelić, Kostić, Djurašković, Uzunović, Milanović and Trajković, 2013; WHO, 2017; Thompson, Sallis, Joy, Jaworski, Stuhr and Tilk, 2020). Health problems on the other hand can highly endanger one's quality of life, which is strongly represented by the category of independence (Kavčič, Hrast and Hlebec, 2012).

The awareness of the positive effects of PA itself is not enough to make people become more active. Many reasons and motives could lead a person to physical inactivity. Motivation and appropriate provisions are important on the way from the awareness to the realization of goals and our involvement in PA as well as for its continuation. Organizers and promoters of PA are aware of the importance and impact that the outdoor exercise, attractive and safe equipment and adapted infrastructure have on motivation, even for older adults. For this reason, the popularity of the so-called Senior Exercise Parks (SEP) or Outdoor Fitness Parks for older adults is increasing. Senior Exercise Park or Outdoor Fitness Park is a general name for outdoor exercise stations that are adapted to the special and individual needs, abilities and performance of older adults and/or frail people (Strojnik, 2007). They allow maintaining or improving strength, flexibility and balance as well as gross and fine coordination and mobility. SEP could

also be a place where older adults could socialize and actively spend their free time on fresh air (Strojnik, 2007).

Recent research on outdoor fitness parks specifically designed for older adults indicates promising outcomes in promoting physical activity, enhancing functional capacity, and improving overall well-being. Empirical evidence suggests that age-friendly exercise equipment installed in public parks can effectively encourage older adults to frequent these spaces and participate in physical exercise (Levinger et al., 2025). Furthermore, structured intervention programs conducted in such environments have demonstrated significant improvements in physical function, quality of life, and mental health parameters among older populations (Levinger et al., 2020; Ng et al., 2023). Park design features, including expansive natural areas and the availability of outdoor fitness equipment, have been positively correlated with higher levels of physical activity in older adults (Zhai et al., 2020). Nevertheless, findings across studies are not entirely consistent; for example, one investigation reported no significant improvements in functional fitness among already active seniors (Liu et al., 2020). Despite these mixed results, the existing body of evidence supports the feasibility and safety of outdoor fitness parks as a public health intervention aimed at fostering physical activity and social engagement in aging populations. However, further longitudinal research is warranted to evaluate their long-term efficacy and broader health impacts (Ng et al., 2023; Levinger et al., 2022).

Even if the understanding of the motivational factors affecting PA of older adults is a prerequisite for any effective exercise program design/prescription, until recently there were just a few studies on this field (Paxton, Browning and O'Connell, 1997; Baranowski, Anderson and Carmack, 1998; Kolt, Driver and Giles, 2004; Paudel et al., 2024; Rodrigues et al., 2023b; Tsai et al., 2022). According to Kolt, Driver and Giles (2004), who did the first deeper study on the subject, there are six motivational factors: social, fitness, recognition, challenge/benefit, medical and involvement. The predominant reasons reported by older adults who were regular exercisers related to health, fitness, enjoyment of the activity, and relaxation, all of which were rated as very important by more than half of the sample. The findings of this study have provided further evidence of health, fitness, and enjoyment as reasons important to older adults for participating in exercise and sport. The study also identified several differences in participation motives based on gender, age, occupation, and education level among older adults.

However, the open question is, if the motivational factors are the same for those older adults who live in homes for seniors. Considering that these people are less independent and probably have more accompanying health problems in comparison to those living in their own homes, the involvement in PA could have greater limitations. On the other hand, the activities in the homes for seniors could perhaps be better organized, managed and more accessible. If we compare studies from the field (Cohen-Mansfield, Marx and Guralnik, 2003; Jiménez-Beatty Navarro, Graupera Sanz, del Castillo, Izquierdo and Rodríguez, 2007; Myiake and Rodgers, 2008; Moschny, Platen, Klassen-Mielke, Trampish and Hinrichs, 2011) it could be noticed that there are similarities between the two groups of older adults only in the reasons for non-inclusion in PA.

Thus, it was the aim of this study to find out, which are the motives that encourage or stimulate some of the Nursing Home residents to exercise in the SEP and why some others do not engage in it. It was also verified if PA habits in the past have any influence on SEP practice. Finally, we wanted to know how popular and useful is exercising in the SEP in comparison to other Nursing Home physical or other activities. These findings can be used in developing relevant exercise and physical activity programs for the growing population of older adults.

METHODS

Participants

Fifty residents (N=50) of the Ljubljana Šiška Nursing Home (40 women and 10 men, age 79.3 ± 8.4 years) voluntarily participated in the study, which was conducted according to the ethical principles of the Helsinki-Tokyo Declaration. All participants were acquainted with aims of the study and have signed a written informed consent. They were divided in two groups: the Exercising Group (EG – exercising in the SEP) and the Control Group (CG – not exercising in the SEP). In the EG there were 22 women and 3 men (age 79.3 ± 8.9 years) and in the CG there were 18 women and 7 men (age 79.4 ± 8.0 years). The educational structure of the groups is shown in Figure 1.
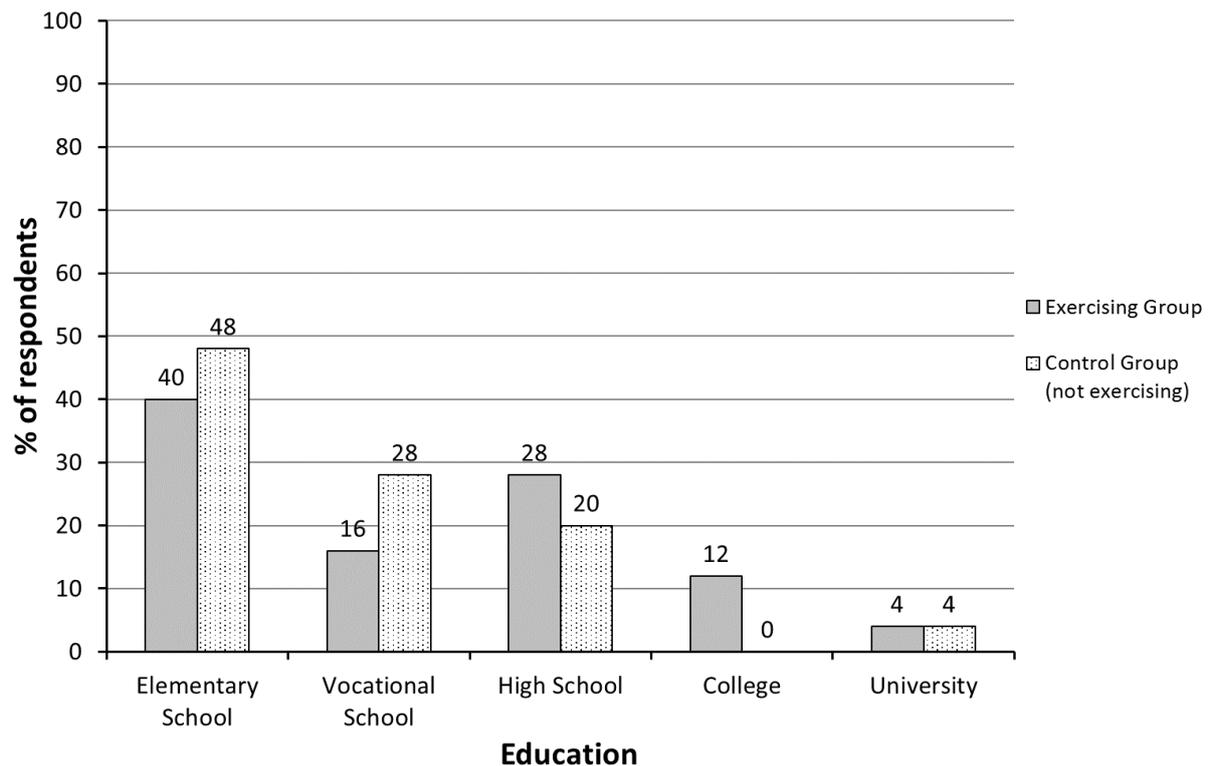
Figure 1. Educational structure of the sample (grey bars – Exercising Group; white dotted bars – Control Group (not exercising)). The overall proportion of respondents with completed Primary School was 44.0% (N = 22), Vocational School 22.0% (N = 11), High School 24.0% (N = 12), College 6.0% (N = 3) and University 4.0% (N = 2).

Data Acquisition and Equipment

To achieve the objectives of the study, a questionnaire specifically designed for this purpose was used. It was divided into four sections with open and closed type of questions: i) General information about the respondent, ii) Motives and motivation for engaging in the SEP practice, iii) Frequency, regularity and graduation of practice in the SEP and iv) Attitudes towards the SEP exercise. The survey was conducted with each resident individually at the Nursing Home. The interviewer asked questions and also wrote the answers into the survey form. In this way it has decreased the possibility of misunderstanding the questions, because the interviewer has further explained misapprehensions. Simultaneously, it has decreased the possibility of the occurrence of errors in entering answers.

Data Analysis

The data were processed with the statistical package IBM SPSS Statistics 19.0 for Windows (IBM Corporation, New York, U.S.A.). In addition to the basic descriptive statistics with frequency distributions, One-Sample T-test and Pearson's Chi-Square test were used to analyse whether the respondents of the Exercising group practiced significantly more or less than the recommended exercise frequency of at least three times per week and to determine if PA or sports training and exercise habits in the past (in early life) had any influence on today's PA in the SEP, respectively. Statistical significance was accepted at the p-level < 0.05 (two-tailed).

RESULTS

The most common motivational factors for engaging and practicing in SEP were health factors, factors of challenge, benefit and curiosity. Reasons why some Nursing Home residents did not exercise in the SEP were health problems and physical difficulties as well as lack of interest for exercise. For details see Gerževič and Gerževič (2014).

Analysis of the Influence of Physical Activities in the Past on Exercise in the SEP

Results of the Pearson's chi-square test did not show significant influence or relationship between PA or sports training and exercise habits in the past and today's participation and exercise in the SEP ($\chi^2 = 0$, df = 1, p > 0.05).

Among all respondents there were 44.0% (N = 22) physically active people in the past (in their younger age). Half of them (N = 11) were regularly as well as occasionally active (Figure 2), while 18.0% (N = 9) of all respondents were engaged in competitive sport (regular trainings in clubs and participation in competitions).

The proportion of those who exercised in the SEP (EG) and had been regularly physically active in the past was 16.0% (N = 4), those who were occasionally active was 28.0% (N = 7) and those who were not physically active at all was 56.0% (N = 14) – Figure 2.

The proportion of respondents who had not exercised in the SEP (CG) and had been regularly physically active in the past was 28.0% (N = 7), occasionally active 16.0% (N = 4) and those who were not physically active at all also 56.0% (N = 14) – Figure 2.

Have you been physically active or practiced any sports in the past?
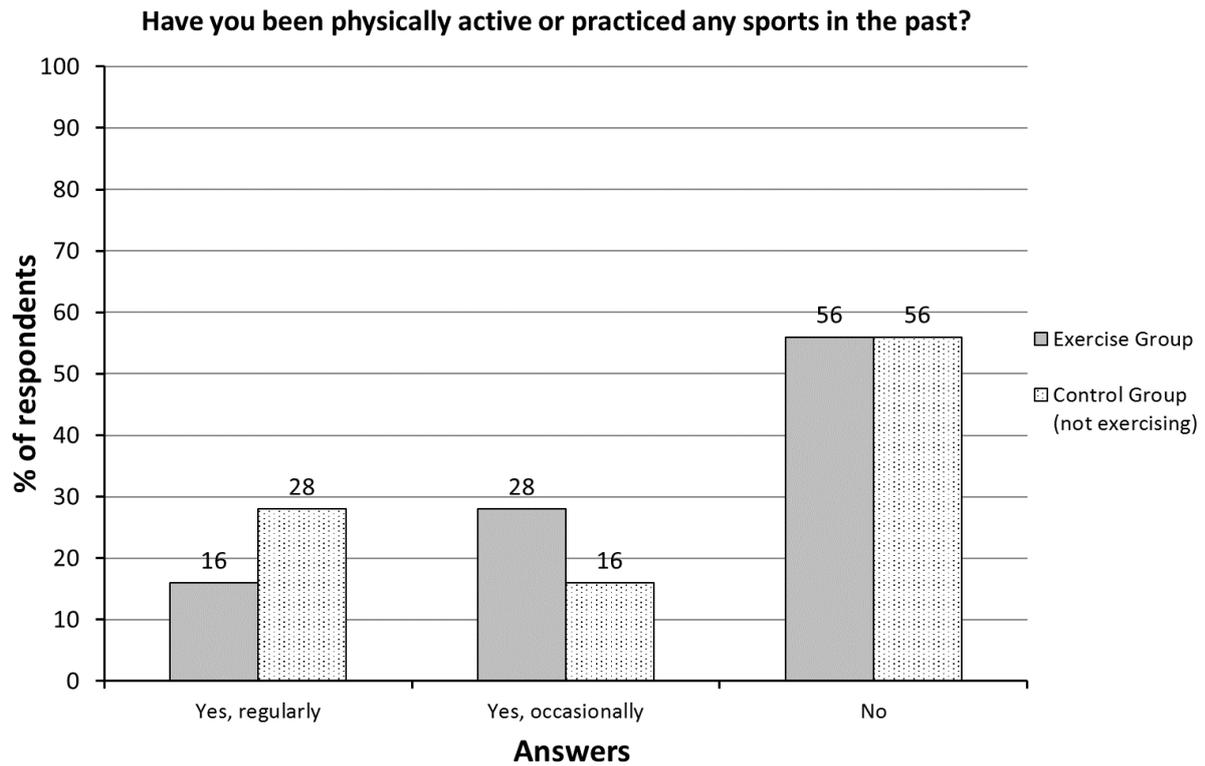
Figure 2. The proportion of respondents who had been regularly, occasionally or had not been physically active in the past.

The majority of respondents (72%, N = 18) were self-motivated. Therapists encouraged 16% (N = 4) of respondents to exercise in the SEP, while 8% (N = 2) were motivated by relatives, and cohabitants motivated only 4% (N = 1) of the respondents (Figure 3).
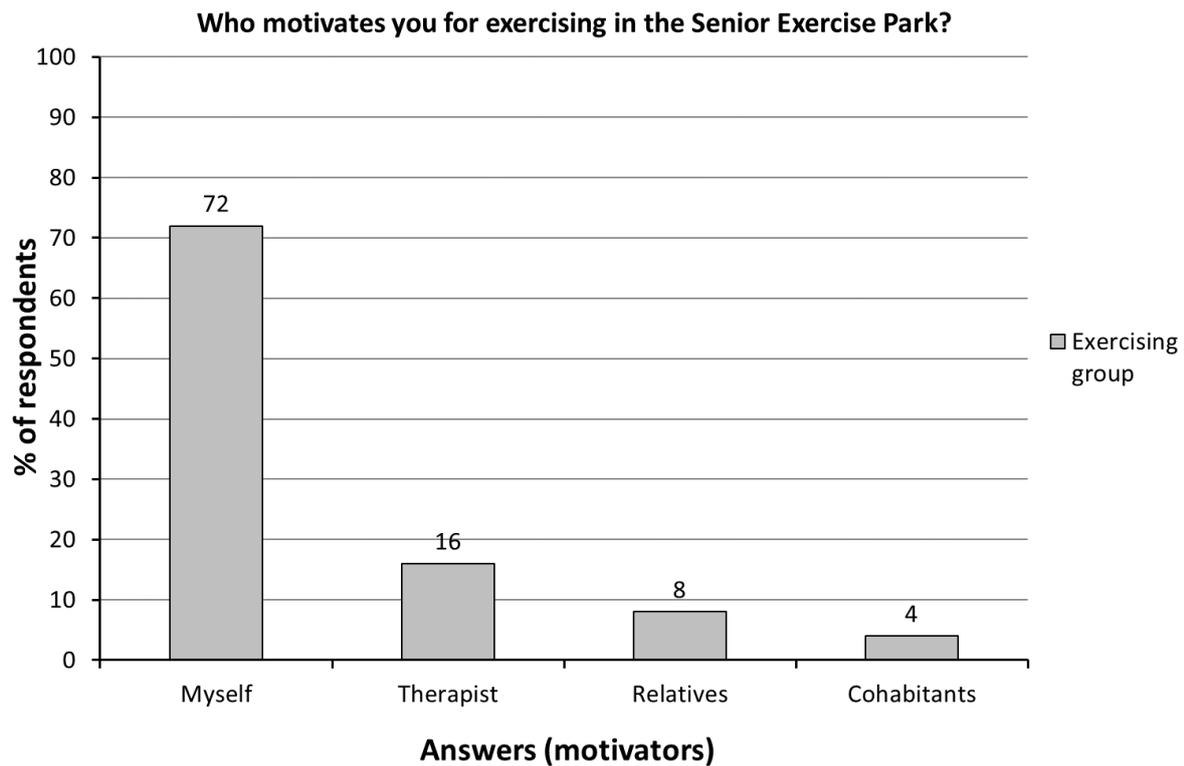
Figure 3. Frequency distribution (% of respondents) of the motivators for exercising in the Senior Exercise Park.

Analysis of the Frequency and Duration of Exercising in the SEP

The majority of respondents (56%, N = 14) practiced five and more times a week in the SEP (Figure 4). Using one-sample t-test it was analysed whether respondents of the Exercising group were practicing significantly more frequently than the general recommendation by the American College of Sports Medicine (Chodzko-Zajko et al., 2009) and U.S. Department of Health and Human Services (2018) of at least three times per week of moderate to vigorous PA and at least two times per week for muscle-strengthening activities. The results confirmed a significantly higher (p = 0.001) frequency of exercise for the Exercising group (EG).
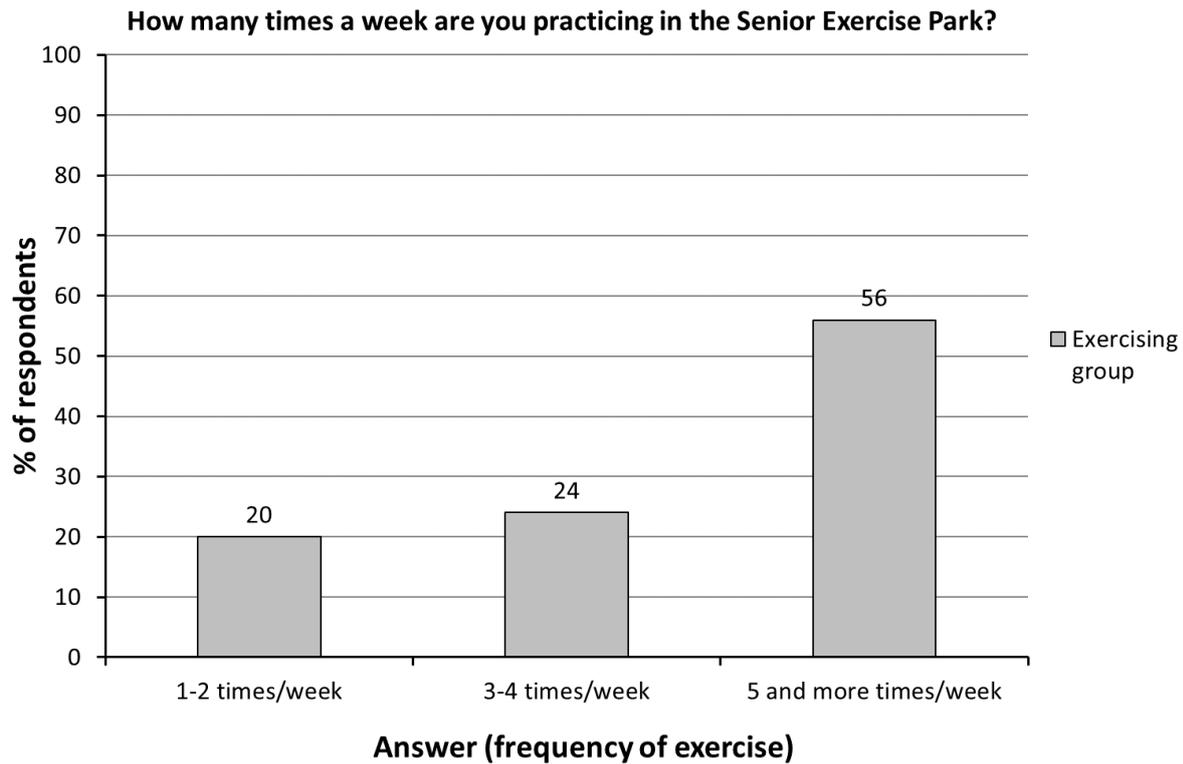
Figure 4. Frequency distribution (% of respondents) of weekly frequency of exercise in the Senior Exercise Park.

From the responses to the question on how long do you usually exercise in the Senior Exercise Park (open type question), which were post-hoc classified in three classes (as shown in Figure 5), we can see that the majority of respondents (64%, N = 16) spend 16 to 30 minutes for a single session in the SEP. They are followed by those who spend up to 15 minutes/session (20%, N = 5), and finally those who spend 31 to 45 minutes/session for training (16%, N = 4). Participants reported that they more easily perform everyday tasks, feel better and are in a better mood when exercising in the SEP (see Gerževič and Gerževič, 2014).

How long do you usually exercise in the Senior Exercise Park lasts?
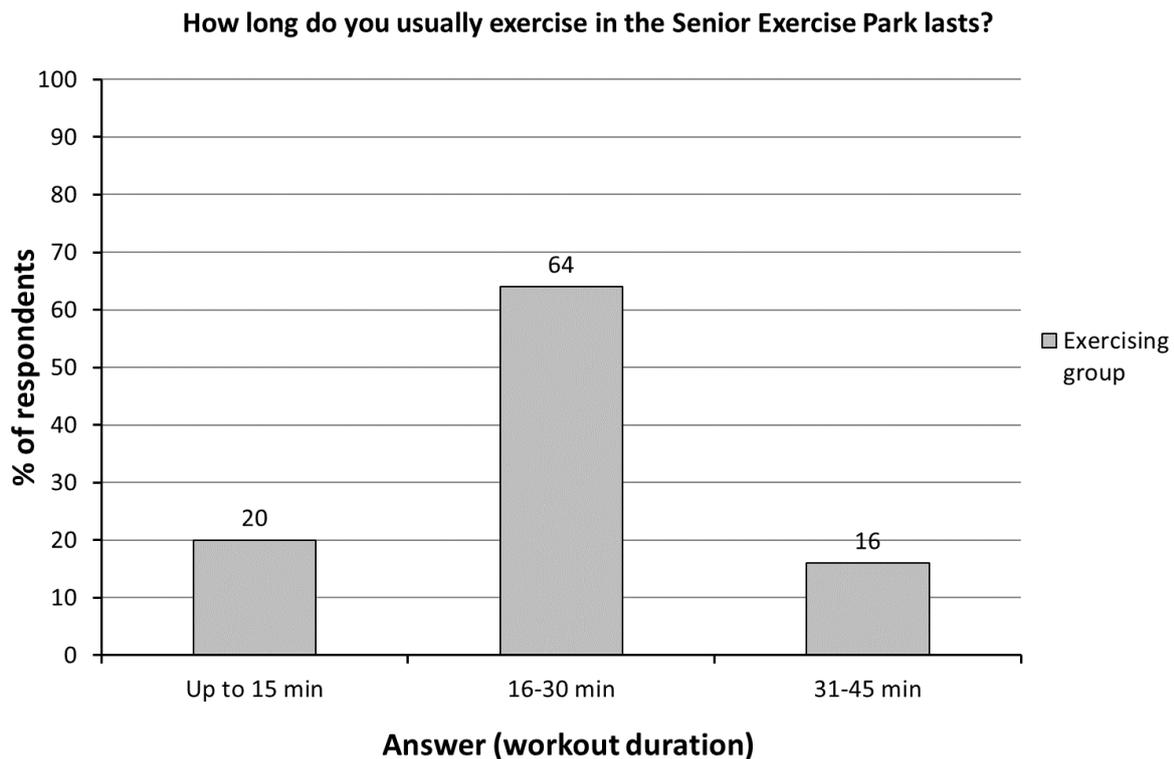
Figure 5. Frequency distribution (% of respondents) of the time usually spent for one workout by a person who exercises in the Senior Exercise Park.

According to the respondents it turned out that the most appropriate parts of the day to exercise in the SEP were early morning (28%, N = 7) and before noon (60%, N = 15). Reasons why early morning or before noon is the best time to exercise were: i) at that time individuals have most free time (24%, N = 6), ii) they are well rested, motivated and able to exercise (20%, N = 5), iii) it is not hot outside (16%, N = 4), iv) they consequently feel better during the rest of the day (12%, N = 3), v) for socializing purposes (8%, N = 2) and vi) because they are assisted by a therapist (4%, N = 1).

Analysis of Attitudes Toward Exercise and Tools in the SEP

The results showed that 96.0% of respondents who exercise in the SEP are also involved in other forms of exercise, therapy or physical activity, such as morning exercise, physiotherapy, occupational therapy, fingers stretching, stationary cycling, fitness devices, and bowling (Figure 6).
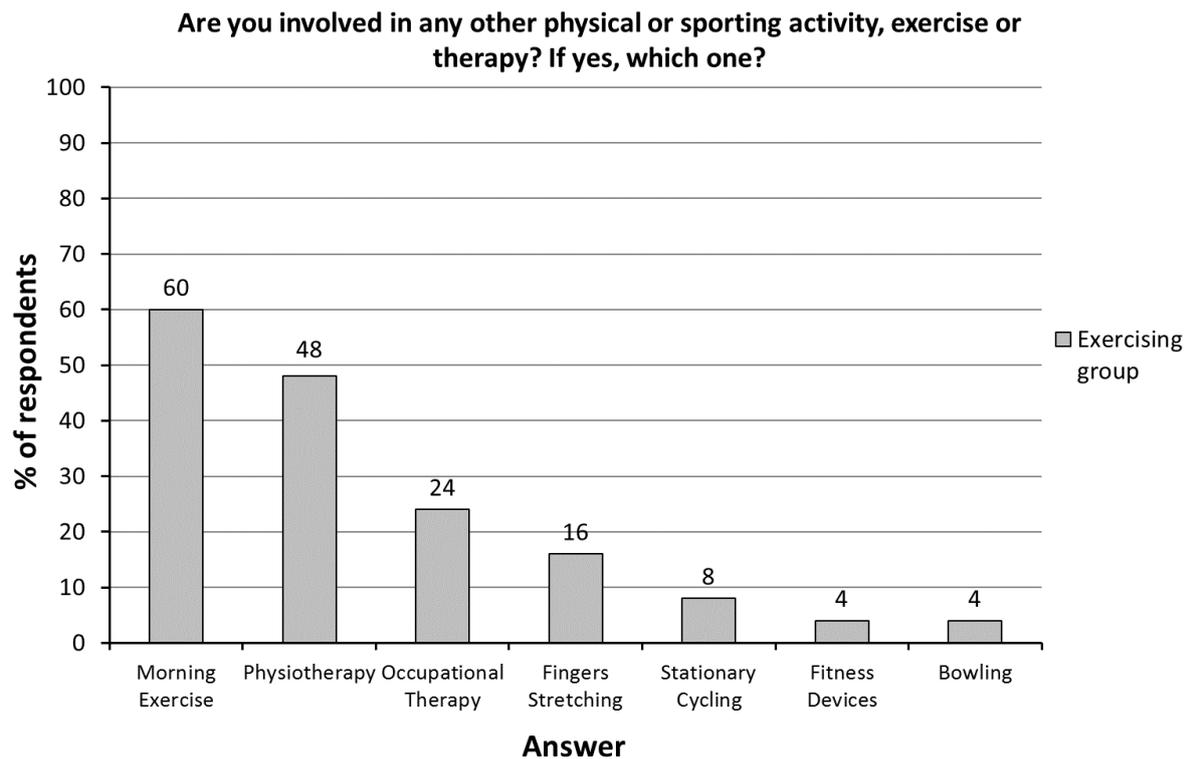
Figure 6. Other forms of exercise, which involve individuals who exercise in the Senior Exercise Park.

It was also found out that individuals who exercise in the Senior Exercise Park prefer the layout of exercise stations in the outdoor environment (68%, N = 17) and the ability to adapt the workout to their abilities and skills (56%, N = 14).

Further, for the vast majority of individuals who exercise in the SEP (72%, N = 18), the instructions were clear enough, illustrative and understandable, although 16% (N = 4) of them did not read the instructions. Almost all individuals who exercise in the SEP (96%, N = 24) feel safe during the workout.

DISCUSSION

Awareness of the importance and positive effects of PA in the older age, in spite of everything, is growing (Jiménez-Beatty Navarro, Graupera Sanz, del Castillo, Izquierdo and Rodríguez, 2007; Huang and Wu., 2024). The year 2012 was especially important, since it was marked as the "European Year for Active Ageing and Solidarity between Generations." Since then, new approaches have been increasingly sought for in order to encourage older adults for PA, for

which it is necessary to know what the most motivates them. According to Jiménez-Beatty Navarro, Graupera Sanz, del Castillo, Izquierdo and Rodríguez (2007), physical health is the highest rated factor among 630 older adult participants aged 65–94. Compared to the study of Kolt, Driver and Giles (2004), the results of the present research vary considerably by frequency or importance. Undoubtedly, this is the result of the fact that we only considered those older adults who live in Nursing Homes. It is also understandable that older adults valuated the social factors, motor competence and recognizability with the highest scores (Kolt, Driver and Giles, 2004). These people are relatively healthy, and independent, they live in their own households. Since they do not have to take particular care about their health, they decide for PA for other motives. Their priority is to spend their free time actively and they connect this with socializing with friends and meeting new people, maintaining or improving their skills or motor competences, vitality and health. They want to be noticed, recognized and important. Typically, in studies of motivational factors for the integration of older people in PA (Kolt, Driver and Giles, 2004; Jiménez-Beatty Navarro, Graupera Sanz, del Castillo, Izquierdo and Rodríguez, 2007; Rodrigues et al., 2023b), the factor of curiosity does not occur, presumably because it deals with PA which are already known to the participants.

On the other hand, the reasons why some Nursing Home residents did not exercise mostly included health problems and physical/motor disability (52.0%) and the lack of interest for exercise (44.0%). This can be explained by the fact that older adults in Nursing Homes are a very specific population, especially because they are partially independent or even dependent on others, and they also have health problems. The lack of interest is most likely the consequence of the lack of motivation. Studies which examine the reasons (motives) for inclusion or non-inclusion in PA (Baranowski, Anderson and Carmack, 1998; Alexandris, Barkoukis, Tsorbatzoudis and Grouios, 2003; Kolt, Driver and Giles, 2004; Lees, Clarkr, Nigg and Newman, 2005; Jiménez-Beatty Navarro, Graupera Sanz, del Castillo, Izquierdo and Rodríguez, 2007; Moschny, Platen, Klassen-Mielke, Trampish and Hinrichs, 2011; Huang et al., 2020; Rodrigues et al., 2023b), commonly deal with older adults, who are more or less independent and living in their own households, therefore, it is difficult to completely compare them with those who live in Nursing Homes.

Despite that the mentioned studies conclude, similarly to our study, that health problems (Baranowski, Anderson and Carmack, 1998; Moschny, Platen, Klassen-Mielke, Trampish and Hinrichs, 2011) and the lack of motivation or the lack of interest for PA (Alexandris, Barkoukis, Tsorbatzoudis and Grouios, 2003; Lees, Clarkr, Nigg and Newman, 2005; Myiake and Rodgers,

2009; Moschny, Platen, Klassen-Mielke, Trampish and Hinrichs, 2011), are the most frequently detected limits for inclusion of older adults in PA, including the fear of falls (Lees, Clarkr, Nigg and Newman, 2005; Myiake and Rodgers, 2009), the lack of company (Moschny, Platen, Klassen-Mielke, Trampish and Hinrichs, 2011), the lack of time and fatigue (Baranowski, Anderson and Carmack, 1998). The lack of interest and motivation, the fear of injury and accessibility represent the greatest obstacles for the inclusion in PA of older adults living in their own households, which suggests that the reasons for the non-inclusion in PA are similar for both groups of older adults (Myiake and Rodgers, 2009; Zhou et al., 2024).

The majority of the individuals who exercise in the SEP are quite self-motivated for exercise in the SEP (72.0%) or even more than therapists (16.0%), relatives (8.0%) or roommates (4,0%) would motivate them. Self-motivation is actually the key factor for inclusion in PA and ultimately for well-being (Myiake and Rodgers, 2009; O'Neil-Pirozzi et al., 2022).

A recent study (Parra-Rizo et al, 2022) has shown that the mentioned barriers for involvement in PA (restrictions due to health, illness or injury, fear of injury, lack of time, energy, motivation, skills/abilities or knowledge, remoteness, inaccessibility, high price) and self-perceived health status ("your health status is in general excellent/very good/good/satisfactory/poor") are not the main reasons for non-inclusion in PA. It turned out that chronic health problems (vision problems, heart diseases, obstructive pulmonary disease, diabetes, osteoporosis, consequences of neurological damage (stroke), motor difficulties) are the major indicator (predictor) of non-inclusion in PA.

Given the high percentage of the factor of curiosity among the motives for engaging in a workout in the SEP, one should not overlook the fact that the introduction of innovation is actually very important in encouraging older people to exercise. We can imagine that life in a Nursing Home eventually become quite ordinary, and this is why the changes that could diversify daily routine are very welcome. Curiosity is important because it arouses interest inside the individual and in the best case attracts them to such an extent, that they make the first step and approach things, which are usually the hardest.

The move from the interest to the actual exercise, which with time develops into a pleasure and regularity, is not a big one. Therefore, the providers of PA, therapists and entertainers at Nursing Homes as well as in other organizations and in various forms of organized exercise for older adults, take into account this aspect and from time to time introduce some novelties in activities.

Above all, as was found by Pinheiro and collegues (2022), the planning of PA should focus on satisfying the health needs of older adults.

Gerontologists would agree that psycho-physical condition of older adults strongly depends on the identity crisis that emerges when entering early old age. Therefore, people should be prepared well for this period already when they are middle-aged. PA in the form of aerobic and resistance exercise leading to a high level of cardio-respiratory fitness represents a strong non-pharmacological preventive tool against the reduction of cognitive functions and neuro-degenerative diseases in older adults (Bherer, Erickson and Liu-Ambrose, 2013; Hökelmann, Rehfeld, Dordevič, Gujar, Henrichs and Partie, 2015; Vints et al., 2024). The effects are even greater if we use body-mind meditative exercises, such as Tai Chi (Bherer, Erickson and Liu-Ambrose, 2013; Sun, Kanagawa, Sasaki, Ooki, Xu and Wang, 2015) or even dancing and video dancing (Hökelmann, Rehfeld, Dordevič, Gujar, Henrichs and Partie, 2015; Hamacher, Hamacher, Rehfeld, Hökelmann and Schega, 2015; Kattenstroth, Kalisch, Holt, Tegenthoff and Denise, 2013; Pichierri, Murer and de Bruin, 2012; Rodrigues-Krause et al., 2016; Lu et al., 2024; Hewston et al., 2021) and/or the so-called motor-cognitive exercise (Geržević, Dobnik and Pišot, 2014), which represents the simultaneous combination of the motor task with additional cognitive task.

Limitations and Future Research Directions

The article has certain acknowledgeable limitations and offers some directions for future research. However, this study presents certain limitations, and we must be cautious with our observations.

The study was conducted in only one nursing home with a relatively small sample of 50 participants. This limits the generalizability of the findings to other nursing homes and populations. The results may not be representative of the broader population of nursing home residents, as the experiences and attitudes in one home might differ from those in others.

The study relied on interviews and self-reported data, which can be subject to biases and inaccuracies. Participants may have overestimated or underestimated their exercise frequency or motivations. Thus, this study provides a direction for future research to explore our results in more detail.

CONCLUSION

The purpose of this paper was to examine the views of the residents of the Šiška Nursing Home to exercising in the SEP. The results have shown that PA, which was carried out by the respondents in the past was not significantly associated with their inclusion in exercising in the SEP. The fact that a large proportion of residents of the home, which in the past had not been physically active, were exercising in the SEP, represents a major success for the home.

The most common motivational factors were: health factors, factors of challenge, benefit and curiosity. The latter has proven as an important reason for engaging in exercise and indicates the advisability of integration of innovation in residential activities. On the other hand, the most common reasons why some Nursing Home residents did not exercise in the SEP were health problems and physical/motor difficulties and the lack of interest for exercise.

It was also found out that to a large extent the individuals who exercise in the SEP are more self-motivated than motivated by therapists, relatives or roommates. With regard to the frequency of exercise, the results have shown that more than half of the individuals who exercise in the SEP, exercise five times and more a week, which was also significantly more frequent as the general recommendation of at least three per week. Therefore, the majority of respondents of the Exercise group spent up to 30 minutes for the execution of each exercise session, which may also be regarded as a great success of the Nursing Home in question.

When analysing the consideration of exercising in the SEP, the results have shown that home residents who were walking a lot, most usually also decided for exercising in the SEP, which again points to the advisability of installing the SEP in the home. This further emphasizes the fact that individuals benefit from exercising in the SEP, because they perform daily chores much more easily, they feel better and are in a better mood.

Finally, the majority like exercising in the SEP mainly due to the installation of exercise stations in the outdoor environment and the options of customizing the workout to their skills and abilities. According to the obtained results, the relatively small sample of respondents and the implementation of the survey in only one Nursing Home it would be recommend to carry out the research in other homes with the SEP, and further examine other types of PA, which is carried out by those who do not practice in the SEP. Thus, we could generalize the results for the majority of older people living in Nursing Homes.

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HYPERTROPHIC RESPONSE OF LOWER EXTREMITY MUSCLES TO DIFFERENT RESISTANCE TRAINING INTENSITIES: A META-ANALYSIS AND META-REGRESSION

HIPERTROFIČNI ODGOVOR MIŠIC SPODNJIH OKONČIN NA RAZLIČNE INTENZITETE TRENINGA ZA MOČ: META-ANALIZA IN META-REGRESIJA

ABSTRACT

This study evaluates the effectiveness of different resistance training intensities (high, moderate, and low) on quadriceps femoris muscle hypertrophy in healthy adults. A literature search was conducted in January 2023 using multiple databases, including Web of Science, SPORTDiscus, Embase, and PubMed. The methodological quality of the studies was assessed using the TESTEX scale. A total of 22 studies with 519 participants were included in this meta-analysis. Statistical analysis, performed using ReviewManager 5.2, showed that all resistance training intensities led to hypertrophy in the quadriceps femoris muscle compared to control or pre-test values. High-intensity training resulted in a muscle thickness increase of 2.3 mm (95% CI: 2.21-2.38), moderate-intensity training led to an increase of 1.88 mm (95% CI: 1.74-2.02), and low-intensity training showed an increase of 10.92 mm (95% CI: 10.77-11.08), all with p<.001. Meta-regression analysis revealed a significant relationship between training intensity and hypertrophy in the vastus intermedius ($\beta=0.01$, p=0.05, $R^2=0.56$) and vastus lateralis ($\beta=0.01$, p=0.007, $R^2=0.34$). However, no significant effect was found for the rectus femoris ($\beta=0.03$, p=0.417, $R^2=0.04$) or vastus medialis ($\beta=0.003$, p=0.895, $R^2=0.002$). In conclusion, resistance training at different intensities promotes hypertrophy across all quadriceps muscles, with variations depending on the specific muscle group. Meta-regression suggests that every 10% increase in training intensity corresponds to a 0.1 mm increase in vastus intermedius hypertrophy. No significant effect of training intensity was observed for the vastus lateralis, vastus medialis, or rectus femoris muscles.

Keywords: Muscle hypertrophy, quadriceps femoris, knee extensors, muscle thickness

IZVLEČEK

Ta študija ocenjuje učinkovitost različnih intenzitet vadbe za moč (visoka, zmerna in nizka) na hipertrofijo mišične skupine kvadriceos femoris pri zdravih odraslih. Iskanje literature je bilo izvedeno januarja 2023 z uporabo več podatkovnih baz, vključno z Web of Science, SPORTDiscus, Embase in PubMed. Metodološka kakovost študij je bila ocenjena s pomočjo lestvice TESTEX. V to metaanalizo je bilo vključenih skupno 22 študij s 519 udeleženci. Statistična analiza, izvedena z uporabo programa ReviewManager 5.2, je pokazala, da so vse intenzitete vadbe za moč povzročile hipertrofijo mišice kvadriceps femoris v primerjavi s kontrolnimi ali predtestnimi vrednostmi. Visoko-intenzivni trening je povzročil povečanje debeline mišice za 2,3 mm (95% CI: 2,21–2,38), zmerno-intenzivni trening je privedel do povečanja za 1,88 mm (95CI: 1,74–2,02), nizko-intenzivni trening pa je pokazal povečanje za 10,92 mm (95 % CI: 10,77–11,08), vse z p<.001. Meta-regresijska analiza je pokazala pomembno povezavo med intenziteto treninga in hipertrofijo mišice vastus intermedius ($\beta=0,01$, p=0,05, $R^2 = 0,56$) ter vastus lateralis ($\beta = 0,01$, p = 0,007, $R^2 = 0,34$). Vendar pa ni bilo ugotovljenega pomembnega vpliva na mišici rectus femoris ($\beta=0,03$, p=0,417, $R^2=0,04$) in vastus medialis ($\beta=0,003$, p=0,895, $R^2=0,002$). Zaključno lahko rečemo da vadba za moč pri različnih intenzitetah spodbuja hipertrofijo vseh mišic kvadriceps, pri čemer obstajajo razlike glede na posamezno mišično skupino. Meta-regresijska analiza nakazuje da vsakih 10 % povečanja intenzitete vadbe ustreza 0,1 mm povečanju hipertrofije mišice vastus intermedius. Vendar pa ni bilo ugotovljenega pomembnega vpliva intenzitete vadbe na mišice vastus lateralis, vastus medialis in rectus femoris.

Ključne besede: Mišična hipertrofija, kvadriceps femoris, iztegovalke kolena, debelina mišice

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INTRODUCTION

Resistance training is a suggested form of exercise since it can enhance the ability to accomplish everyday tasks improve overall health and well-being indicators, including physical independence and decreased risk of all-cause death, and also increase sportive performance in the athletic population. Muscle hypertrophy is one of the primary responses seen with resistance training with chronic exposure (Brad Schoenfeld & Grgic, 2018). As a result of muscle hypertrophy and an increase in myofibrils, the principal alteration entails a rise in the cross-sectional area of the total muscle and specific muscle fibers. Early in the resistance exercise process, satellite cells become activated; their growth and fusion with preexisting fibers are crucial for the hypertrophic response. Additional potential architectural modifications in quadriceps muscles involve hyperplasia, modifications to muscle design, myofilament thickness, connective tissue composition, and tendon and connective tissue structure (Folland & Williams, 2007).

In addition, many internal and external factors are also influential in muscle hypertrophy. Exercise characteristics like frequency, intensity, time/duration, and type are examples of various external factors, called the FITT principle (Campbell et al., 2019). However, there are multiple studies on the effect of resistance training intensity (Borde, 2015; Fry, 2004; Brad Schoenfeld, Grgic, Ogborn, & Krieger, 2017), frequency (Borde, 2015; Polito, Papst, & Farinatti, 2021; Brad Schoenfeld, Grgic, & Krieger, 2019), number of sets (Borde, 2015; Krieger, 2009), repetition (Hackett, Ghayomzadeh, Farrell, Davies, & Sabag, 2022; Nicholson, Ispoglou, & Bissas, 2016; Brad Schoenfeld, Peterson, Ogborn, Contreras, & Sonmez, 2015), and type (Henselmans & Schoenfeld, 2014; Roig et al., 2009; Brad Schoenfeld, Ogborn, Vigotsky, Franchi, & Krieger, 2017) on muscle hypertrophy. One of the most crucial variables is exercise intensity since high-intensity exercises, particularly in elderly and very young individuals, may lead to adverse outcomes like higher injury risk and psychological burden and lower training motivation. Therefore, if lowering exercise intensity will not reduce hypertrophic responses, which some studies suggest, engaging in low-intensity resistance training can be preferable.

High-intensity resistance training ($\geq$ 70% of 1 repetition maximum (RM)) has been promoted for many years as the primary method for promoting improvements in muscular hypertrophy. Recent findings, however, have questioned this concept in terms of hypertrophy, with multiple studies revealing equivalent increases in muscle hypertrophy across low ($\leq$ 50% of 1RM) and

high ($\geq$ 75% of 1RM) resistance training loads (Brad Schoenfeld et al., 2015). In contrast, the optimal resistance intensity regarding the quadriceps muscle group hypertrophic adaptations remains uncertain. Though in healthy people, high (Brigatto et al., 2022; Csapo & Alegre, 2016; Brad Schoenfeld, Contreras, et al., 2019) and low (Correa et al., 2012; Brad Schoenfeld et al., 2015) intensity resistance exercises were demonstrated to improve muscle mass for quadriceps femoris, and other studies highlighted no intensity-based differences (Amirthalingam et al., 2017; Carvalho et al., 2022; Correa et al., 2012; Mitchell et al., 2012; Brad Schoenfeld, Grgic, et al., 2017). Therefore, this study searches for the answer to the question, "what is the net range of intensity of resistance training one provides to increase quadriceps femoris muscle hypertrophy?". It has not been directly examined in the literature separately for each muscle in the quadriceps femoris muscle in healthy adults.

METHODS

Registration

The study was registered before the literature search in Open Science Framework (OSF) (https://doi.org/10.17605/OSF.IO/UWYSA), and it adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) standards (Liberati, Tetzlaff, & Altman, 2009).

Sources of Data And Search Strategy

Seven electronic databases (Web of Science, SPORTDiscus, Embase, PubMed, Google Scholar), ClinicalTrials website (https://clinicaltrials.gov/), and grey literature database (https://opengrey.eu/) were scanned with ("Resistance training" OR "Strength training") AND ("Muscle hypertrophy" OR "Muscle thickness") keywords till January 2023. All randomized or non-randomized experimental studies are included. During the literature search, hand searching was performed by going to the reference's reference and looking for relevant systematic reviews simultaneously.

Inclusion and Exclusion Criteria

The inclusion criteria were; (i) studies examining the effect of resistance training on muscle hypertrophy, (ii) studies in lower extremity muscle thickness is measured by ultrasonography, (iii) studies in which the measurements of muscle hypertrophy are clearly stated, (iv) studies with healthy individuals without chronic disease or disability, (v) had a minimum duration of 4

weeks, (vi) carried out training to muscle failure, (vii) open access and randomized or non-randomized human trials were included. The exclusion criteria were; (i) studies that do not include resistance or strength exercises, (ii) studies in which measurements such as muscle volume and circumference (not taken by ultrasonography; since ultrasonography is accepted as the gold standard in determining muscle thickness (hypertrophy) in various studies (Amirthalingam et al., 2017; Brad Schoenfeld, Contreras, et al., 2019; Brad Schoenfeld et al., 2015). For this reason, studies conducted with this method have been preferred.), (iii) studies that include measurements other than the muscles in the lower extremity, (iv) studies that include individuals with chronic diseases or rats and not open access were excluded.

Data Extraction

From each trial, two authors independently retrieved descriptive and result data. These obtained data were as follows: author and year of studies, design, samples, resistance exercise protocols (intensity (% 1RM) and total sets (number of sets * repetitions) of exercises), duration of the study, hypertrophy area, and results. In addition, the raw mean and standard deviation of post-training muscular hypertrophy measurements and the number of participants were extracted. If data is given graphically, WebPlotDigitizer (https://automeris.io/WebPlotDigitizer/) was used to interpret data that could only be presented visually. The data was then imported into the meta-analysis tool from the excel file.

Evaluation Of Methodological Quality

A new proven method for evaluating the quality of the study and report in exercise training research, the "*Tool for the assEssment of Study qualiTy and reporting in EXercise*" (TESTEX) Scale, is used to determine the risk of bias in this study. This scale considers eligibility and allocation concealment and includes 12 criterion evaluations with a maximum score of 15. In exercise training research, subsequent blinding of participants and researchers is rarely possible and only affects quality assessment (Smart et al., 2015). Answers to every item on the TESTEX scala are "yes" or "no," with "yes" being connected with a point and "no" being related to a score if criteria are not satisfied. Studies are categorized as having "excellent quality" (12–15 points), "good quality" (9–11 points), "fair quality" (6–8 points), or "poor quality" (6 points) based on the summary scores (Nunes et al., 2021). Additionally, two researchers (C.D.E and Y.B) will independently assess the methodological quality.

Statistical Analysis

For continuous data, meta-analyses were done using the post-intervention lower extremity muscle thickness measurements' raw mean value and standard deviation measurements for effect size calculation. The effect sizes were evaluated as "small" (≤ 0.2), "moderate" (0.21-0.5), "large" (0.51-0.8), and "very large" (>0.8) (Cohen, 1992). A random effect model was used for all analyses. Meta-analysis was conducted for each result with RevMan 5.2 toll for lower extremity (Vastus Lateralis, Medialis, Intermedius, and Rectus Femoris) muscles. The I^2 test was used to determine the degree of heterogeneity (Sutton & Higgins, 2008). TESTEX scale was used to detect the quality of the studies (Smart et al., 2015). Additionally, the relationship between resistance training intensity and change in quadriceps femoris muscle thickness was explored by conducting a meta-regression analysis with MedCalc (MedCalc software, version 16.1; MedCalc, Ostend, Belgium) program. For that, muscle thickness (mm) was the primary moderator as a continuous variable for meta-regression analysis. Ninety-five percent confidence intervals were employed, and the significance level was 5%.

RESULTS

Selection of Studies

All of the studies that were considered reported comparing the effects of various resistance exercise intensities (low, moderate, high) on the development of muscular hypertrophy in the lower extremity in healthy adults. As a result of the literature review, a total of 607 studies were reached via various databases. Following the elimination of duplicate studies, 81 were kept for screening. Twenty-two of them were evaluated for eligibility, while 59 were eliminated. In total, 22 studies were evaluated (Figure 1).

Characteristics of The Included Studies

The total number of articles found was based on the type of analyzed variables: Eighteen articles for the RF, 20 for the VL, 9 for the VM, and 7 for the VI muscles. Twenty-two trials included 519 healthy participants in the existing meta-analysis. Every study had between 15 (Gonzalez et al., 2017; Ikezoe, Kobayashi, Nakamura, & Ichihashi, 2020) and 58 individuals (Correa et al., 2012). The duration of resistance training varies between 5 and 16 weeks, and the most common application period is eight weeks. Additionally, there are eight studies for high-intensity ($\geq 80\%$ of 1 RM) resistance training, 11 for moderate-intensity (60-79% of 1 RM)

resistance training, and 6 for low-intensity (30-59 % of 1 RM) resistance training. The most commonly studied resistance training intensity is moderate (60-79%) (Carvalho et al., 2022).

Categorization of Research

Two researchers (C.D.E and Y.B) independently focused on studies. They recorded data relating to the following variables into a worksheet: year of study, author, design, participant group, the protocol of resistance exercises (determined as regions of maximal repetitions or by a percentage of the 1RM test), muscle area, TESTEX scores of studies and results. Resistance exercise loads are classified into three categories according to the latest meta-analysis (Carvalho et al., 2022): low (30-59 % of 1 RM or 16-35 RM), moderate (60-79% of 1 RM or 8-12 RM), and high (≥ 80 % of 1 RM or ≤ 7 RM). The table containing the studies accessed and categorized as a result of the literature review is as follows (Table 1).
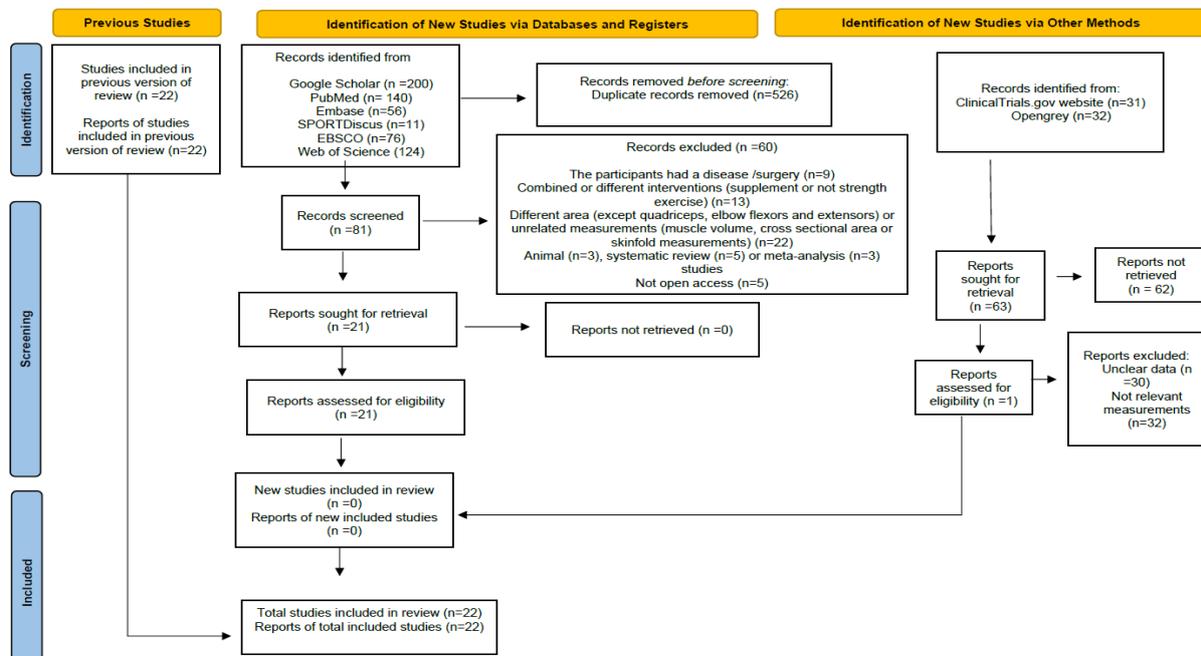
Figure 1. Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) Flow Chart of Study Selection Process (Page et al., 2021).

Table 1. All Included Papers' Methodological Features and Outcomes

Author, year	Design	Sample	Resistance exercise protocol	Duration	Muscle area	Results
Carvalho et al. (2020) **TESTEX: 10	Randomized parallel group Repeated measures	26 resistance-trained men	3-week 4 sets *1-3 RM with 3 min rest and 5-week 4 sets * 8-12 RM back squat and leg press training	8 weeks (2d/w)	VL	Resistance exercise protocol induced more significant muscle growth in VL (p <0.05) in 3 weeks.
Alkan (2019) **TESTEX: 10**	Pre-post	20 young individuals Experiment-1: 20 Experiment-2: 20	3-4 sets*10 repetitions (80-100 % 1RM) **Experiment-1:** Resisted leg raise and knee extension **Experiment-2:** Resisted knee flexion	8 weeks (3d/w)	VI RF	After an 8-week training period, both groups had increased muscle thickness (p <0.05).
Santos, Valamatos, Mil-Homens, and Armada-da-Silva (2018) **TESTEX: 11**	RCT	28 young male adults Experiment-1: 9 (Focused on eccentric exercise) Experiment-2: 11 (Focused on concentric exercise) Control: 8 (no exercise)	**Experiment:** First 3 weeks 5 sets * 6 repetitions with 60°s^{-1} angular velocity. The number of contraction sets conducted at 60°s^{-1} reduced to only 2 during the next 12 weeks, but extra sets were performed at 90°s^{-1} (weeks 4-6), 120°s^{-1} (weeks 7-9), 150 °s^{-1} (weeks 10-12), and 180 °s^{-1} (weeks 13-15). isokinetic knee flexion and extension training	15 weeks (3d/w)	VL VI VM RF	All QF muscle thickness increased with strength exercise (p <0.05) except VL muscle.
Ikezoe et al. (2020) **TESTEX: 10**	Pre-post	15 healthy men Experiment-1: 7 Experiment-2: 8	**Experiment-1**: 12 sets * 8 repetitions (30% 1RM) with 90 s rest **Experiment-2**: 3 sets * 8 repetitions (80% 1RM) with 90 s rest concentric and eccentric contractions in biodex dynamometer	8 weeks (3d/w)	RF	The 8-week resistance training increased by 11.3% and 20.4% RF muscle thickness for both training conditions (p <0.01).
Müller et al. (2020) **TESTEX: 10**	Pre-post	35 older men Experiment-1: 18 Experiment-2: 17	**Experiment-1**: 2-4 sets * 6-15 repetitions (65-80% 1RM) **Experiment-2**: 3-4 sets * 6-8 repetitions (40-60 %1 RM) bilateral leg press and bilateral knee extension exercises-	16 weeks (2d/w)	VL VM RF	Significant increases (p <0.05) were observed in QF muscle thickness in both groups with no differences between groups.

Table 1. Continued

Boone, Stout, Beyer, Fukuda, and Hoffman (2015) **TESTEX: 10**	RCT	18 untrained young men Experiment: 9 Control: 9 (no exercise)	3 sets * 8-10 repetitions (80% 1RM) leg press and leg extension training	4 weeks (3d/w)	RF VL	Resistance training resulted in significant increases in RF ($p <0.001$) and VL ($p <0.001$) muscle thickness.
*Cadore et al. (2014) **TESTEX: 11**	Pre-post	22 healthy individual (F: 14 M:8) Experiment-1: 11 Focused on eccentric exercise Experiment-2: 11 Focused on concentric exercise	2-5 sets * 8-12 repetitions- isokinetic exercise with $60°s^{-1}$ angular velocity.	6 weeks (2d/w)	VL	Both groups exhibited increased VL muscle thickness ($p <0.05$).
*Yoshiko and Watanabe (2021) **TESTEX: 11**	Pre-post	16 healthy older (F:13 M:3) Experiment-1: 8 Experiment-2: 8	**Experiment-1:** 4 sets * 35 RM weight-bearing deep squat exercise **Experiment-2:** 4 sets * 35 RM weight-bearing shallow squat exercise	12 weeks (3d/w)	VL VI RF	No significant change was observed for QF muscle thickness in both groups.
*Zaras et al. (2020) **TESTEX: 10**	Pre-post	16 healthy male Experiment-1: 8 Experiment-2: 8	**Experiment-1:** 4 sets * 6 repetitions (85 % 1RM) leg press exercise with 3 min rest **Experiment-2:**4 sets * 6 repetitions (85 % 1RM) leg press exercise with 3 min rest +20 s inter-repetition rest period between single repetitions.	7 weeks (2d/w)	VL VI	Following resistance training, the thickness of the VL muscle increased dramatically over time ($p = 0.043$).
*Nakamura et al. (2021) **TESTEX: 10**	Pre-post	16 healthy young men Experiment-1: 8 Experiment-2: 8	**Experiment-1:** 3 sets * 10 RM parallel squat exercise with 3 min rest **Experiment-2:** Static stretching exercises	5 weeks (2d/w)	VL VI VM RF	QF muscle thickness increased in both groups, but no significant difference was observed.

Table 1. Continued

Karsten, Fu, Larumbe-Zabala, Seijo, and Naclerio (2021) **TESTEX: 11**	Pre-post	18 resistance-trained men Experiment-1: 9 Experiment-2: 9	Chest and bench press, deadlift, lateral pull down, dumbell fly, barbell lying arm extension, barbell shoulder press, reverse grip bent-over row exercises **Experiment-1:** 4 sets * 10 repetitions (75 % 1RM) with 2 min rest **Experiment-2:** 8 sets * 5 repetitions (75 % 1RM) with 1 min rest	6 weeks (2d/w)	VM	The VM muscle thickness increased (+3.28 ±2.32 mm) only significantly (p <0.05) in the experiment-1 group.
Korkmaz (2018) **TESTEX: 11**	Pre-post-randomised	23 footballer Experiment-1: 12 Experiment-2: 11	**Experiment-1:** 4 sets * 8-12 repetition (80% 1RM) knee extension exercise with 2 min rest **Experiment-2:** 4 sets * 8-12 repetition (80% 1RM) knee extension exercise with 2 min rest and blood flow restriction	6 weeks (2d/w)	VL RF	Blood flow restricted training provides better benefits than traditional strength training to improve muscular hypertrophy.
Pinto et al. (2014) **TESTEX: 10**	RCT	36 sedentary elderly women Experiment: 19 Control: 17 (no exercise)	2-3 sets * 12-15 RM knee flexion, leg press and knee extension exercises	6 weeks (2d/w)	VL VI VM RF	All measurements of the QF muscle thickness (vastus lateralis, medialis, intermedius, and rectus femoris) showed a significant increase only in the experiment group (p ≤0.05).
Correa et al. (2012) **TESTEX: 10	RCT	58 healthy older woman Experiment:41 Control:17 (no exercise)	**First period (6 weeks)** 2-3 sets * 12-20 RM **Second period (6 weeks)** 3-4 sets * 8-12 RM leg press, knee extension and flexion exercises with 2 min rest	12 weeks (2d/w)	VL VM RF	After 6 weeks of resistance training, a significant increase occurred in QF muscle thickness (p <0.05).
Usui, Maeo, Tayashiki, Nakatani, and Kanehisa (2015) **TESTEX: 11**	Pre-post	16 healthy young men Experiment-1: 9 Experiment-2: 7	**Experiment-1:** 3 sets * 10 repetitions (50% 1RM) parallel squat training 3 s lowering and 3 s lifting without a pause phase **Experiment-2:** 3 sets * 10 repetitions (50% 1RM) parallel squat training 1 s lowering and 1 s lifting with 1 s pause phase	8 weeks (3d/w)	VL VI VM RF	In experiment-1 group, RF muscle thickness increased at +10% (p=0.026). No changes were observed experiment -2 group.

Table 1. Continued

Brad Schoenfeld and Grgic (2018) **TESTEX: 10**	Pre-post	30 male volunteers Experiment-1: 15 Experiment-2: 15	4 sets * 8-12 RM standing barbell curl and the machine leg extension with 2 min rest. Experiment-1: focused on contracting the target muscle during training Experiment-2: focused on the outcome of the lift	8 weeks (3d/w)	VL RF	RF and VL muscle thickness showed small and insignificant effect sizes favoring experiment 1 and 2 groups (p=0.418 and p=0.999, respectively).
Gonzalez et al. (2017) **TESTEX: 11**	Pre-post RCT	15 resistance trained men	4 sets * 10 RM bench press, barbell back squat and deadlift training with 2 min rest	8 weeks (3d/w)	VL RF	Significant improvements occurred with resistance training for all muscle thickness measurements (p <0.05)
Zaroni et al. (2018) **TESTEX: 10**	Pre-post RCT	18 healthy men Experiment-1: 9 (training a muscle group 5 days per week) Experiment-2: 9 (training a muscle group 1 day per week)	**Experiment:** 3 sets * 10-12 RM bench press, hack squat, deadlift, machine lat pull down, biceps curl, nosebreaker, dumbbell hammer curl, leg press, parallel back squat, cable triceps	8 weeks (TOTAL routine training a muscle group 5 days per week)	VL	Total routine strength training significantly increases in VL muscle (p <0.05).
***Nogueira et al. (2009)** **TESTEX: 11**	Pre-post	20 healthy older men Experiment-1: 9 Experiment-2: 11	**Experiment-1**: 3 sets * 8 repetitions (40-60 % 1RM) knee and elbow flexion/extension, leg and chess press exercise with 90 s rest interval **Experiment-2:** Power exercises	10 weeks (2d/w)	RF	RF muscle thickness increased solely in power training (p <0.05).
***Evangelista et al. (2019)** **TESTEX: 12**	Pre-post	29 sedentary healthy adults Experiment-1: 17 Experiment-2:12	**Experiment-1:** 4 sets * 8-12 RM bench press, knee flexion and extension, arm curl, seated row exercises with 90 s rest interval **Experiment-2:** 4 sets * 8-12 RM bench press, knee flexion and extension, arm curl, seated row exercises with 90 s rest interval + streching exercises	8 weeks (2d/w)	RF VL	RF muscle thickness increased (p ≤0.0001) in both groups.

Table 1. Continued

Brad Schoenfeld et al. (2016) **TESTEX: 10**	Pre-post	23 young resistance-trained men Experiment-1: 12 Experiment-2: 11	Experiment-1: 3 sets * 8-12 RM flat barbell press, plate-loaded leg press, plate-loaded seated cable row, barbell back squat exercise with 1 min rest Experiment-2: 3 sets * 8-12 RM flat barbell press, plate-loaded leg press, plate-loaded seated cable row, barbell back squat exercise with 3 min rest	8 weeks (3 times per day)	VL	Long interval resting group significantly increased QF muscle thickness from baseline to post by 5.4% and 7% (p <0.01).
Bartolomei et al. (2021) **TESTEX: 12**	Pre-post	21 resistance-trained men Experiment-1: 10 Experiment-2: 11	5 sets* 6 RM deep squat, leg curl and extension, lunges, triceps extension, bench press, front raises exercises with 2 min rest. **Experiment-1:** Focusing on all muscle group **Experiment-2:** Focusing on one muscle group	10 weeks (4d/w)	VL	In experiment-2 group, changes in VL muscle thickness were substantially larger (p=0.037) than in experiment-1 group.

Abbreviations: d/ w: days a week, QF: Quadriceps femoris, RCT: Randomised Controlled Trial, RDB: Randomise Double Blind, RF: Rectus Femoris, RM: Repetition Maximum, VI: Vastus Intermedius, VL: Vastus Lateralis, VM: Vastus Medialis
*: Only the results of rresistance exercises from two different exercises or practices were evaluated.   **: Only the measurements of the relevant weeks were evaluated.

Evaluation of Quality

The average score on the TESTEX scale was 10,6. Three studies (Bartolomei et al., 2021; Evangelista et al., 2019; Pinto et al., 2014) were classified as excellent, and 19 studies (Alkan, 2019; Boone et al., 2015; Cadore et al., 2014; Carvalho et al., 2020; Correa et al., 2012; Gonzalez et al., 2017; Ikezoe et al., 2020; Karsten et al., 2021; Korkmaz, 2018; Müller et al., 2020; Nakamura et al., 2021; Nogueira et al., 2009; Santos et al., 2018; Brad Schoenfeld & Grgic, 2018; Brad Schoenfeld et al., 2016; Usui et al., 2015; Yoshiko & Watanabe, 2021; Zaras et al., 2020; Zaroni et al., 2018) had good quality. None of the evaluated studies were assessed for their fair or poor methodological quality. The findings of the quality evaluation are shown (Table 2).

Table 2. TESTEX Scala (Overall TESTEX score out of 15 points)

Study	Eligibility criteria specified	Randomly allocated participants	Allocation concealed	Groups similar at baseline	Assessors blinded	Outcome measure assessed more than %85 of participants*	Intention to treat analysis	Reporting of between group statistical comparison	Point measures and measures variability reported #	Activity monitoring in control group	Relative exercise intensity review	Exercise volume and energy expenditure	Overall TESTEX score
Alkan, 2019	YES	YES	YES	YES	NO	2	NO	YES	2	YES	NO	YES	10
Karsten et al., 2021	YES	YES	YES	YES	NO	2	NO	YES	2	NO	YES	YES	11
Pinto et al., 2014	YES	YES	YES	YES	NO	2	NO	YES	2	YES	YES	YES	12
Schoenfeld et al.,2018	YES	YES	NO	YES	NO	2	NO	YES	2	YES	NO	YES	10
Correa et al., 2012	YES	YES	NO	YES	NO	2	NO	YES	2	NO	YES	YES	10
Evangelista et al., 2019	YES	YES	YES	YES	NO	2	NO	YES	2	YES	YES	YES	12
Bartolomei et al., 2021	YES	YES	YES	YES	NO	2	NO	YES	2	YES	YES	YES	12
Zaras et al., 2020	YES	NO	NO	YES	NO	2	NO	YES	2	YES	YES	YES	10
Cadore et al., 2014	YES	YES	NO	YES	NO	2	NO	YES	2	YES	YES	YES	11
Usui et al., 2015	YES	YES	NO	YES	NO	2	NO	YES	2	YES	YES	YES	11
Nogueira et al., 2009	YES	YES	NO	YES	NO	2	NO	YES	2	YES	YES	YES	11
Santos et al., 2018	YES	YES	NO	YES	NO	2	NO	YES	2	YES	YES	YES	11
Gonzalez et al., 2017	YES	YES	NO	YES	NO	2	NO	YES	2	YES	YES	YES	11
Zaroni et al., 2018	YES	YES	NO	YES	NO	2	NO	YES	2	NO	YES	YES	10
Schoenfeld et al., 2016	YES	YES	NO	YES	NO	2	NO	YES	2	NO	YES	YES	10
Carvalho et al., 2020	YES	YES	NO	YES	NO	2	NO	YES	2	NO	YES	YES	10
Ikezoe et al., 2020	YES	YES	NO	YES	NO	2	NO	YES	2	NO	YES	YES	10
Müller et al., 2020	YES	YES	NO	YES	NO	2	NO	YES	2	NO	YES	YES	10
Nakamura et al., 2021	YES	YES	NO	YES	NO	2	NO	YES	2	NO	YES	YES	10
Boone et al., 2015	YES	YES	NO	YES	NO	2	NO	YES	2	NO	YES	YES	10
Korkmaz, 2018	YES	YES	NO	YES	NO	2	NO	YES	2	YES	YES	YES	11
Yoshiko & Watanabe, 2021	YES	YES	NO	YES	NO	2	NO	YES	2	YES	YES	YES	11
Mean Score													10.59

Notes. *: Three points possible - 1 point if adherence is greater than 85%, 1 point if adverse events are reported, 1 point if exercise attendance is reported. #: Two points possible - 1 point if primary outcome is reported, 1 point if all other results are reported.

Resistance Training's Impact on Muscular Hypertrophy

Based on the random effects model, high, moderate, and low-intensity resistance training significantly increased quadriceps muscle hypertrophy compared to the control or pre-test group (Table 3).

Table 3. The effect of resistance exercise intensities on muscle hypertrophy (meta-analyses results).

Subgroups	ES (%95 CI)	p-value	Heterogeneity (I^2)	Weight
High Intensity Resistance Training				
VL	2.45 [2.26, 2.64]	$p<.001$	96%	20.3%
VM	0.70 [0.27, 1.13]	$p = .001$	Not applicable	4.1%
VI	0.62 [0.46, 0.78]	$p < .001$	99%	30.0%
RF	3.48 [3.35, 3.60]	$p < .001$	99%	45.6%
Total	2.30 [2.21, 2.38]	$p < .001$	99%	100%
Moderate Intensity Resistance Training				
VL	2.45 [2.27, 2.63]	$p < .001$	85%	60.0%
VM	2.01 [0.84, 3.19]	$p = .0008$	0%	1.4%
VI	0.57 [-1.01, 2.14]	$p = .0048$	85%	0.8%
RF	0.99 [0.76, 1.22]	$p < .001$	55%	37.8%
Total	1.88 [1.74, 2.02]	$p < .001$	87%	100%
Low Intensity Resistance Training				
VL	14.21 [13.87, 14.56]	$p <.001$	99%	20.3%
VM	2.46 [0.66, 4.26]	$p = .007$	0%	0.8%
VI	15.59 [15.25, 15.93]	$p < .001$	72%	21.0%
RF	8.19 [7.98, 8.39]	$p < .001$	100%	57.9%
Total	10.92 [10.77, 11.08]	$p < .001$	100%	100.0%

Data demonstrated are presented as a standardized ES estimate (signifying the raw mean difference between experiment and pre or control groups) with 95% CI and p-value. Positive ES values favor resistance training performed in experiment groups.

According to Table 3, high-intensity resistance training had a significantly increasing effect (p<.001) on quadriceps femoris muscle hypertrophy [Raw mean difference (RMD)= 2.30; confidence interval (CI) 95%: [2.21, 2.38]] with 99 % heterogeneity ratio compared to control/pre-test group. Moderate-intensity resistance training had a significantly increasing effect (p<.001) on quadriceps muscles hypertrophy [Raw Mean difference (RMD) =1.88; confidence interval (CI) 95%: [1.74 – 2.02]] with 87% heterogeneity ratio compared to control or pre-test group. Low-intensity resistance training had a significantly increasing effect (p<.001) on quadriceps muscles hypertrophy [Raw mean difference (RMD) =10.92; confidence interval (CI) 95%: [10.77 – 11.08)]] with 100% heterogeneity ratio compared to control or pre-test group. Shortly, resistance training is effective on the quadriceps muscles hypertrophy.

Meta-Regression Analysis

Meta-regressions to examine the relationship between muscle thickness and resistance training intensity were carried out to recognize the sources of heterogeneity because they were statistically significant (p<.001) and had a large amount of unexplained heterogeneity. The dose-response relationship between resistance training intensity (% of 1RM) and change in quadriceps femoris muscle thickness (mm) is shown with scatter plots. The 95% confidence intervals are represented by dotted lines (Figures 2. and 3.). According to meta regression, it was determined that there was a non-significant direct relationship between resistance training intensity (% of 1RM) and change in RF (β=0.03; $p = 0.417$; $R^2 = 0.04$) and VM muscle thickness ($\beta = 0.003$; $p = 0.895$; $R^2 = 0.002$). It was also determined that there was a significant direct relationship between resistance training intensity and change in VI (β=0.01; $p = 0.05$; $R^2 = 0.56$) and VL muscle thickness ($\beta = 0.01$; $p = 0.007$; $R^2 = 0.34$).
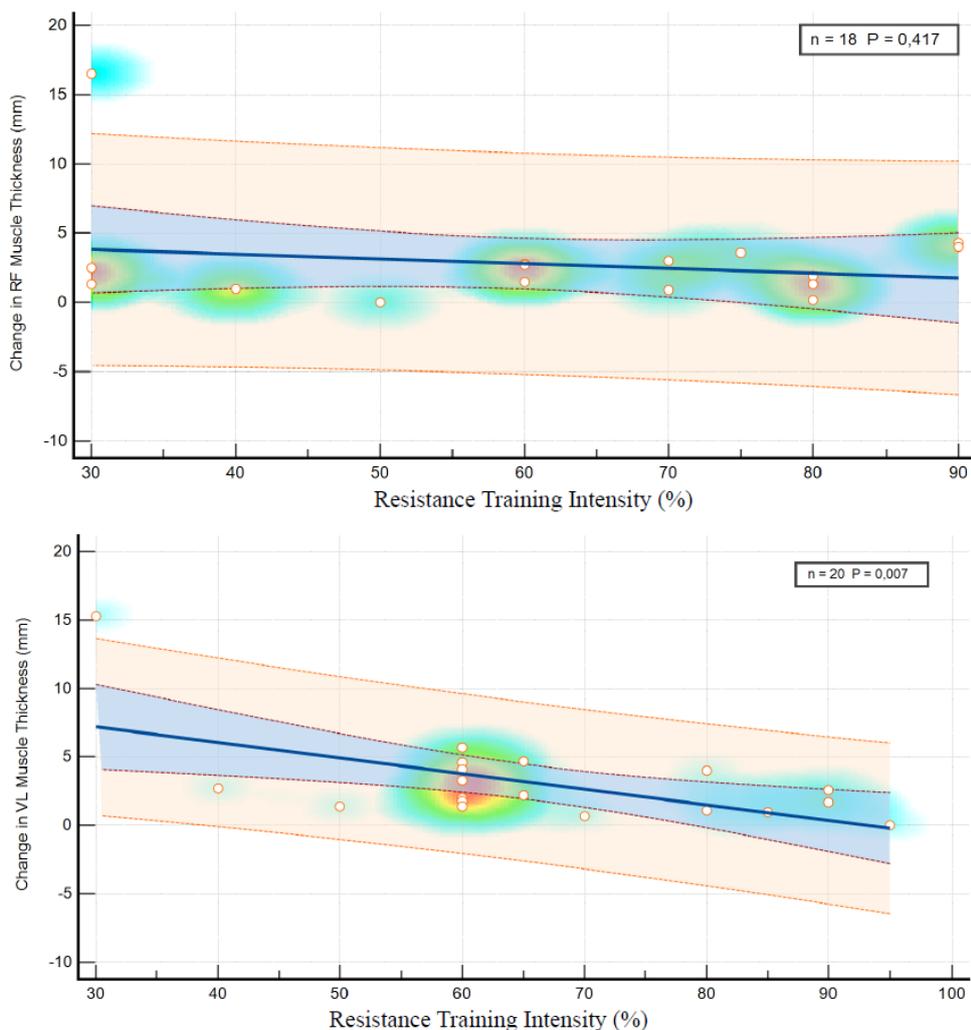
Figure 2. Scatter Plots of RF and VL Muscles
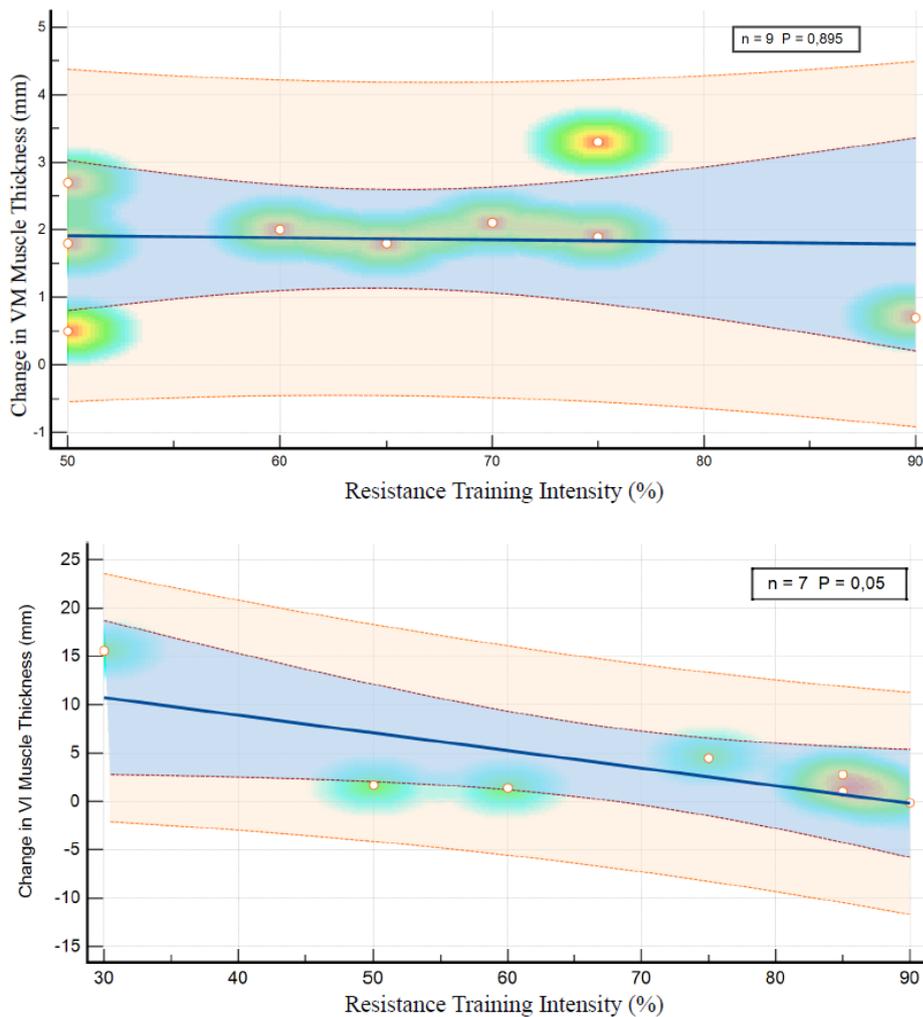
Figure 3. Scatter Plots of VM and VI Muscles

Based on the scatter plots, when resistance exercise intensity increases by 10%, RF muscle thickness increases by 0.3 mm, and VM muscle thickness increases by 0.03 mm. When resistance exercise intensity increases by 10%, VI and VL muscle thickness increases by 0.1 mm. While the increase in RF and VM muscle thicknesses is not statistically significant, the rise in VI and VL is statistically significant ($p = 0.417$, $p = 0.89$, $p = 0.05$, $p = 0.007$, respectively).

Additionally, R^2 values indicate that the relationship between resistance training intensity and changes in RF, VM, and VL muscle thickness is insufficient except for the change in VI muscle thickness ($R^2 = 56\%$).

DISCUSSION

This study searches for the answer to the question, "What is the net range of intensity of resistance training one provides to increase quadriceps muscle hypertrophy?". To the best of the authors' knowledge, there is no study in which the hypertrophic effects of resistance exercises are evaluated separately for each muscle in the quadriceps femoris. The main finding of this study is that resistance exercises, at all intensities (high-moderate-low), significantly enhance quadriceps femoris muscle size. Further, a significant direct relationship between resistance training intensity and change in VI and VL in which as intensity increases by 10%, muscle thickness increases by 0.1 mm.

Given that it has been proven that resistance training's acute and chronic effects diminish with time, it is necessary to manipulate resistance training components, including "intensity," for consistent strength and morphological changes (Borde et al., 2015). Based on the results of this meta-analysis, athletes and coaches can maintain resistance exercise intensity in any range from low (30% of 1RM) to high (80% of 1RM) for various purposes at different periods of the training period without affecting the hypertrophic adaptation magnitude of quadriceps femoris. Parallel to this, in the meta-analysis by Carvalho et al. (2022), even when volume load is equalized across conditions, muscle hypertrophy is identical regardless of the level of resistance intensity from 30% to 80% of 1RM. Another meta-analysis, which examined the effects of high and low-intensity resistance exercises on muscle hypertrophy, determined no difference between the intensities (Brad Schoenfeld, Grgic, et al., 2017). Furthermore, according to these conclusions from three meta-analyses, one can perform resistance training with lower intensities (30-59% of 1RM), in turn, enlarge the training volume loads (Morton et al., 2019). The evidence suggests a dose-response relationship between training volume load and hypertrophic adaptations, therefore this might affect on changes in muscle size (Lasevicius et al., 2022). In other meta-analysis studies, dose response analysis was not evaluated. However, in this study, dose response connection was applied to investigate how resistance training intensity change would affect the hypertrophic response. Determining at what intensity there is significant hypertrophy may be useful to inform practitioners. On the other hand, it was proposed by three studies that higher training intensities induce greater increases in muscle fiber cross sectional area of vastus lateralis in "*untrained*" individuals (Campos et al., 2002; Holm et al., 2008; Schuenke et al., 2012). Supporting our and the other two meta-analyses abovementioned, Brad Schoenfeld et al. (2015) demonstrated that both low and high resistance intensities, even when training load volume equated, induce a similar increase in muscle size

after 8 weeks of resistance training in "*resistance trained*" men. It can be speculated that the resistance training experience may determine the size of hypertrophic adaptation depending on the intensity of resistance training, at least in the first few months. Even though low-volume, high-intensity resistance training is demonstrably beneficial to promoting muscle growth, the high intensities (80% 1RM) employed may be challenging for untrained individuals or remote training programs with limited access to equipment. In individuals with less resistance exercise experience, relatively greater volumes of lower intensity resistance training may be a more viable choice (Fyfe, Hamilton, & Daly, 2021). It could be the most effective approach to keep an elevated resistance intensity for the first several months and gradually reduce it. Lastly, it should be remembered that the "repetition to failure" regimen has been demonstrated as a key component for low intensity resistance training to be as effective as high loads for muscle growth (Lasevicius et al., 2022; Lim et al., 2019).

The consensus is that an intensity of more than $\geq 60\%$ of 1 RM is required to produce meaningful improvements in muscle size using conventional resistance training techniques. Nevertheless, there is mounting evidence that low-intensity resistance exercise, also using various techniques, can significantly improve muscle hypertrophy, often comparable to typical high-intensity exercise (B. J. Schoenfeld, 2013). In response to resistance training, three central components have been postulated to drive hypertrophic alterations: muscle damage, mechanical tension, and metabolic stress (B. J. Schoenfeld, 2010). Resistance training-related mechanical tension compromises the skeletal muscle's stability by prompting myofibers and satellite cells to respond mechanically and chemically (Toigo & Boutellier, 2006). Motor unit activation frequency, which determines both the intensity and length of excitation coupling, is thought to transmit signals for a variety of downstream pathways, including CaMKII (upregulates muscle atrophy) and CAMKIV (promotes mitochondrial biogenesis) (Chin, 2005). Conversely, it has been demonstrated that higher-intensity resistance training can regulate the acute secretion of growth hormone, particularly in routines meant to increase metabolic stress (Hoffman et al., 2003). Similarly, it has been suggested that glycolytic activity may elevate the acidic environment, accelerate muscle damage, and further stimulate sympathetic nerve function, resulting in a higher adaptation for muscle hypertrophy (Buresh, Berg, & French, 2009). On the other hand, it has also been hypothesized that the mechanisms of exercise-induced muscle growth are entirely intrinsic and unaffected by temporary changes in circulating hormones (West, Burd, Staples, & Phillips, 2010).

Another main finding is that as the intensity of resistance exercise increases, there is no significant increase in RF and VM muscle thicknesses; in contrast, a significant increase is observed in VI and VL muscle thicknesses. Since there is no meta-analysis where the hypertrophic response of four muscle heads (VL, RF, VM, and VI) to resistance training is investigated, it is impossible to make a direct comparison. More recently, the literature has offered contradictory findings about resistance training "intensity" and increases in VL-VI muscle size. Several researchers have seen larger gains in muscle growth with increasing intensity (Campos et al., 2002; Holm et al., 2008; Schuenke et al., 2012), whereas others revealed no statistically significant difference between low and high intensity (Tanimoto et al., 2008). A potential limitation in most of this research is that training volume differed between groups. When volume equated, all intensities (40%, 60% and %80 of 1RM) were found to enhance VL cross-sectional area similarly (Lasevicius et al., 2018; Brad Schoenfeld et al., 2015). For this reason, the result of this meta-analysis is that the muscle thickness in VL and VI increases in an intensity-dependent manner, which may be caused by the "volume" of resistance training. Moreover, the fact that almost all studies in this meta-analysis employed "closed chain" exercises, which predominantly leads to hypertrophy of vastus muscles (Ema, Sakaguchi, Akagi, & Kawakami, 2016), may have contributed to the failure of RF to respond even when "intensity" rises.

VL, RF, VM, and VI are the four muscle heads that make up the quadriceps femoris. The surface head VL is located outside the thigh. RF is positioned in the center of the anterior side of the thigh, while VM is on the side. VI is positioned at the interior of the thigh because it is above the femur and beneath the three surface heads (Pasta, Nanni, Molini, & Bianchi, 2010). Physiological cross-sectional area (PCSA), the biggest cross-sectional area point of a pennate muscle perpendicular to its muscle fibers, volume, muscle length, fascicle length, and fascicle pennation angle are all distinctive architectural characteristics of each head (Lieber, 2002). Because of its location, the VL head of the quadriceps is the most investigated. It has been used as a substitute for the entire quadriceps muscle to assess muscle size, electromyographic activity, metabolic characteristics, and muscle fiber composition, whether for clinical or sports purposes (Coratella et al., 2020; El-Ansary et al., 2021; Methenitis et al., 2016). According to a recent current experimental study, the best substitutes for the entire resistance training-induced hypertrophy of the quadriceps appear to be VL and VI (Spiliopoulou et al., 2022). VL and VI could offer accurate data on whole quadriceps muscle hypertrophic response lower-body resistance training when ultrasonography is employed. In the current study, the best

hypertrophic result against the increase in density was seen in VL and VI, which is attributed to the broader presence of PCSA. In addition, when the types of exercises performed based on the studies included in the analysis are examined, it is observed that the resistance exercises performed on the lower extremities are primarily aimed at the VL and VI muscles. The lack of training of the RF and VM muscles in exercise applications and the smaller PCSA will make it difficult to observe a hypertrophic effect on these muscles. Especially in recent years, the increase in the risk of lower extremity injuries in sportive activities and competitions has increased the number of studies on this subject. It has been suggested that the most critical issue that increases this risk is due to the power imbalance in the hamstring/quadriceps ratios (Cheung, Smith, & Wong, 2012; Padasala, Joksimovic, Bruno, Melino, & Manzi, 2020; Yoo, 2016). To minimize the risk of injury, the focus should be on hypertrophy of all quadriceps muscles. Based on the current results of the meta-analysis, special programs should be applied mainly for RF and VM muscles in lower extremity resistance exercise applications with lower intensities ($\leq 80\%$ of 1RM).

CONCLUSION

This meta-analysis indicated that resistance training had a significantly increasing effect on quadriceps femoris muscle hypertrophy. Meta-regression analysis identified a substantial relationship between resistance training intensity and change in VI and VL muscle thickness and a non-significant direct link between resistance training intensity and change in RF and VM muscle thickness.

It can be said that the increase in VI muscle hypertrophy is dependent on the resistance training intensity based on its R^2 value. Conversely, resistance training intensity is less likely to explain VL, VM, and RF muscle hypertrophy. By this perspective, analyses using multiple covariates such as frequency, type, time or total protein intake status, and type of sets (interset/drop set) in line with the FITT principle can be done in future studies. In addition, it was determined that the number of studies on VI and VM muscle hypertrophy was low. Therefore, future studies can focus on filling this gap in the literature. These results point to a potential advantage of including a wide range of loading values in a hypertrophy-focused exercise for quadriceps femoris muscles.

Consequently, the meta-analysis results determined that the resistance training intensity gave similar results in the hypertrophy of the quadriceps femoris muscle. However, since the

percentage of muscle hypertrophy explained by exercise intensity is high (R^2=56%), every 10% increase in resistance exercise provides a hypertrophic response of 0.1 mm in the VI muscle.

This study is vital in performing muscle-specific strengthening exercises and detecting the intensity of a significant hypertrophy point. In addition, there will be benefits such as providing information to practitioners on this subject and indicating to researchers at what point there needs to be more literature.

LIMITATIONS

This meta-analysis has several limitations. Hypertrophic adaptations to resistance training are influenced by multiple variables beyond training intensity, including movement tempo, exercise execution tempo, repetition cadence, and eccentric-concentric loading patterns. However, due to the heterogeneity of training protocols across the included studies and incomplete reporting of these parameters, their independent effects on muscle hypertrophy could not be systematically analyzed.

Moreover, factors such as total training volume, rest intervals, training experience of participants, and neuromuscular adaptations may have contributed to variability in hypertrophic responses. The lack of uniformity in measurement techniques (e.g., ultrasound vs. MRI) and differences in anatomical sites used for assessing muscle thickness could also introduce methodological inconsistencies. Additionally, variations in participant characteristics such as age, sex, baseline strength levels, and genetic predispositions may have influenced the results, limiting the generalizability of the findings.

Future research should aim to standardize resistance training protocols, ensuring consistent reporting of movement tempo, contraction phases, and repetition cadences. Additionally, studies employing advanced imaging techniques with strict methodological controls are needed to isolate the effects of specific training variables on quadriceps hypertrophy.

PRACTICAL APPLICATIONS

- This study searches for the answer to the question, "What is the net range of intensity of resistance training one provides to increase quadriceps muscle hypertrophy?".
- Starting from here, this study aims to detect the effectiveness of different resistance training intensities (high, moderate, and low) for quadriceps femoris muscle group hypertrophic response in healthy adults.

- The meta-analysis results detected that the different resistance training intensities gave similar results in the hypertrophy of the quadriceps femoris muscle.

- The meta-regression analysis showed that for every 10% greater difference in resistance exercise intensity, the hypertrophic response in the VI muscle was determined to be 0.1 mm greater significantly. However, no significant hypertrophic response was observed for VL, VM, and RF muscles.

- This study may be helpful in performing muscle-specific strengthening exercises and detecting the intensity of a significant hypertrophy point for practitioners on this subject and athletes who want to track muscle hypertrophy.

Declaration of Conflicting Interests

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RELIABILITY OF TWO-DIMENSIONAL KINEMATIC ASSESSMENT OF SINGLE-LEG LANDING, COUNTERMOVEMENT JUMP, AND BROAD JUMP TECHNIQUES AMONG ELITE HANDBALL PLAYERS

ZANESLJIVOST DVODIMENZIONALNE KINEMATIČNE ANALIZE TEHNIČNE IZVEDBE ENONOŽNEGA PRISTANKA, SKOKA Z NASPROTNIM GIBANJEM IN SKOKA V DALJINO PRI VRHUNSKIH ROKOMETAŠIH

ABSTRACT

The aims of this study were: a) to assess the intra-session reliability of two-dimensional kinematic variables related to the knee, hip, and trunk joints, and b) to compare the results between subjectively and objectively identified key movement positions in single-leg countermovement jumps (SLCMJ), broad jumps (SLBJ), and drop landings. Eighty elite handball players (mean age 21.8 years; weight 92.0 kg; height 1.9 m) participated in the study. Three repetitions of each test, using both the dominant and non-dominant legs, were video recorded from lateral and frontal planes. Kinematic analysis was performed manually using Kinovea software. Inclinations of the shin, thigh, pelvis, and trunk (absolute variables) were calculated based on anatomical landmarks, along with joint angles (relative variables). Key movement positions were identified subjectively by expert assessment and objectively by the time point of the highest vertical ground reaction force for each task. The results indicated moderate-excellent reliability for drop landing test ($ICC_{2.1}$ = 0.54-0.99), moderate-good reliability ($ICC_{2.1}$ = 0.51-0.83) for SLCMJ, and poor-moderate reliability for SLBJ in both the push off ($ICC_{2.1}$ = 0.01-0.81) and landing phases ($ICC_{2.1}$ = 0.10-0.86). Significant differences were found between the results from subjective and objective key movement position identification ($p < 0.05$). Based on the results, we recommend conducting at least three test repetitions and averaging the outcomes to ensure reliability when performing manual 2D kinematic analysis with manual marker placement, as well as maintaining consistency in the criteria used to determine key movement positions for variable extraction.

Keywords: jump performance, stability, validity, reproducibility, consistency

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IZVLEČEK

Glavna cilja naše raziskave sta bila: a) oceniti znotrajobiskovno zanesljivost izračunanih naklonov telesnih segmentov in kotov v sklepih z dvodimenzionalno (2D) kinematično analizo in b) primerjati rezultate omenjenih spremenljivk med subjektivno in objektivno določenima ključnima gibalnima položajema pri enonožnem skoku z nasprotnim gibanjem (SLCMJ), skoku v daljino (SLBJ) in pristanku. V raziskavi je sodelovalo osemdeset vrhunskih rokometašev (povprečna starost 21,8 let; teža 92,0 kg; višina 1,9 m). Izvedli so tri ponovitve vsakega testa z dominantno in nedominantno nogo. Testi so bili posneti v bočni in čelni ravnini, kinematična analiza posnetkov pa je bila izvedena z uporabo programske opreme Kinovea. Izračunane so bile naslednje spremenljivke: nagib goleni, stegna, medenice in trupa (absolutne spremenljivke) ter koti v sklepih med segmenti (relativne spremenljivke). Ključni gibalni položaji za izračun spremenljivk so bili določeni subjektivno na podlagi ocene merilca in objektivno glede na trenutek največje sile na podlago. Rezultati so pokazali zmerno-odlično zanesljivost spremenljivk pri testu pristanka ($ICC_{2.1}$ = 0,54–0,99), zmerno-dobro zanesljivost ($ICC_{2.1}$ = 0,51–0,83) pri SLCMJ ter slabo-zmerno zanesljivost pri SLBJ, tako v fazi odriva ($ICC_{2.1}$ = 0,01–0,81) kot v fazi pristanka ($ICC_{2.1}$ = 0,10–0,86). Ugotovljene so bile razlike v rezultatih med subjektivnim in objektivnim kriterijem določitve ključnega gibalnega položaja za analizo ($p < 0.05$). Na podlagi rezultatov za zagotovitev zadovoljive zanesljivosti priporočamo analizo vsaj treh skokov in konsistentno uporabo enega kriterija pri določitvi ključnega gibalnega položaja za izračun spremenljivk.

Ključne besede: uspešnost skoka, stabilnost, veljavnost, ponovljivost, konsistentnost

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INTRODUCTION

Jumping and landing tasks are valuable diagnostic tools in sports performance and injury prevention (Bishop et al., 2022). These movements assess key aspects of athletic ability, such as neuromuscular performance in the lower limbs (kinetics), while also evaluating movement strategies (kinematics) (Kotsifaki et al., 2020). By analyzing jump and landing mechanics, coaches and sports scientists can identify movement inefficiencies or asymmetries that may increase the risk of injury, particularly in the lower extremities.

However, there is still limited knowledge about easy-to-use video assessment methods that can provide objective kinetic and kinematic data, offering greater validity than qualitative assessments. Since torque is a product of muscle force and its lever arm, which changes with joint angles, the spatial orientation and movement of body segments directly affect the magnitude of jump impulse and, consequently, the jump outcome (Cushion et al., 2022; Floría et al., 2016; Kotsifaki et al., 2020; Macedo Alfano Moura & Alves Okazaki, 2022). Furthermore, poor technical execution in jumps or landings can result in reduced force production and inefficient transfer through the kinetic chain, leading to suboptimal force distribution on soft tissues and joint structures. This increases the risk of both chronic and acute injuries (Bakker et al., 2016; De Bleecker et al., 2020; Moore, 2016; Mousavi et al., 2020; Pedley et al., 2020). Thus, jump performance depends not only on muscle strength and power but also on the technical execution of the movement (Chapman & Sanderson, 1990; Dowling & Vamos, 1993). Therefore, integrating kinematic with kinetic variables to assess an athlete's condition from both a performance and injury risk perspective should be an essential component of sports diagnostics (Floría et al., 2016; Kotsifaki et al., 2020; Saito et al., 2022).

While three-dimensional (3D) motion analysis is considered the gold standard for measuring movement kinematics—using high-frequency cameras, retroreflective markers, and specialized software (Alt Murphy et al., 2018) — its application in clinical settings is limited due to high costs and time-consuming data capture (Mousavi et al., 2020). An alternative is two-dimensional (2D) kinematic analysis, which is more affordable, easier to use, and compatible with free software. Previous studies have demonstrated that 2D kinematic analysis is a reliable and valid method compared to 3D (Della Villa et al., 2022; Ortiz et al., 2016; Ramirez et al., 2018). Moreover, the reliability of 2D kinematic variables in the sagittal and frontal planes has been confirmed for running and direction change analyses, showing good intra- and interrater reliability (Maykut et al., 2015).

Nonetheless, there is a lack of research on the reliability of 2D kinematic variables particularly in single-leg jumping and landing, which are common movement strategies in sports and a frequent focus in sports diagnostics. Understanding the technical execution during critical movement phases (i.e., key positions, KP) is crucial, as imbalances in force production and transfer through the kinetic chain can lead to inefficient movement patterns and injuries (Moore, 2016; Mousavi et al., 2020). Analysis of the force-time curve during a countermovement jump shows that the center of mass (COM) reaches its lowest point at peak ground reaction force (GRF) time point (McMahon et al., 2018). At this time point, the knee often displays a marked dynamic valgus position (Barfod et al., 2019; Hewett et al., 2005; Hewett & Myer, 2011; McLean et al., 2005), a factor associated with an elevated risk of both acute and chronic knee injuries. These include injuries to the anterior cruciate ligament (ACL) and medial collateral ligament (MCL), as well as conditions like anterior knee pain and patellofemoral pain (Bakker et al., 2016; Vosoughi et al., 2021), which are common in handball due to repeated single-leg jumping and landing tasks.

The challenge with 2D kinematic analysis lies in ensuring its reliability and validity when assessing dynamic, multi-planar body movements. Therefore, the primary aim of this study was to determine whether 2D kinematic variables related to the knee, hip, and trunk joints during single-leg countermovement jumps (SLCMJ), single-leg drop (SLD) landings, and the push off and landing phases of single-leg broad jumps (SLBJ) can be reliably assessed through manual marker identification in video recordings from the frontal and sagittal planes. Additionally, we aimed to examine the differences between the variables extracted from subjectively and objectively identified key movement positions. We hypothesized that the reliability of the kinematic variables would be excellent ($ICC_{2.1} > 0.9$), regardless of leg dominance (dominant or non-dominant), criteria used (objective or subjective key movement position identification), and the specific test performed (CMJ, SLBJ, or SLD). Furthermore, we expected no significant differences in kinematic variables between subjective and objective key position identification, thus confirming the validity of subjective criteria for determining key movement position in 2D kinematic analysis.

METHODS

Study design and participants

This was a cross-sectional study conducted in a single visit, with the total duration of approximately 45 minutes. Eighty elite team handball players from the first national Slovenian league, each with at least 10 years of training experience, were recruited. The participants were (average [SD]) 21.8 (3.9) years old, 1.90 (0.06) m tall and weighed 92.0 (9.6) kg. All players were actively engaged in regular handball training, practicing at least five times per week at their clubs over the previous five years.

Inclusion criteria required participants to be free from musculoskeletal injuries or pain syndromes within the last year, as well as any medical conditions that could be aggravated by the testing procedures. Participants were instructed to avoid strenuous activity for two days prior to testing. Before data collection, they were fully informed about the study protocol and signed an informed consent form. They wore only tight-fitting shorts (mid-thigh length), low-ankle socks, and low-ankle training shoes of their choice to minimize any influence on the testing process. Since the testing procedures were routinely performed as part of their physical preparation in regular training, no additional familiarization session was necessary. The experimental procedures were reviewed and approved by the University of Ljubljana, Faculty of Sport Ethics Committee (reference number: 14:2023) and adhered to the tenets of the Oviedo Convention and Declaration of Helsinki.

Testing procedures

Before testing, participants completed a warm-up protocol consisting of 10 minutes of light running, followed by 5 minutes of dynamic stretching and 5 minutes of dynamic strength exercises that simulated the testing drills (lunges and jumps), led by a qualified member of the research team. After the warm-up, we attached black and white markers (unfilled circles with a 25-millimeter outer diameter and a 2-millimeter inner diameter) to nineteen anatomical points, following established procedures in the literature (Puig-Diví et al., 2019). Markers were placed on the sternum, the midpoint of the thigh (measured halfway between the midpoint of the patella and the anterior superior iliac spine using a measuring tape), the center of the patella, and the center of the ankle joint in the frontal plane. An additional telescopic marker was positioned as an extension of the great trochanter, five centimeters laterally from the body. In the sagittal plane, markers were placed at the center of the deltoid muscle, on the great trochanter, lateral

epicondyles, and lateral malleoli (see Figures 1 and 2). Marker placements were determined through palpation.

Participants were instructed to perform SLCMJs, SLBJs, and SLD landing tests. Each participant completed three repetitions of each test. Detailed information on how the dominant leg was determined is provided in the individual test descriptions. The sequence of tests (SLBJ, SLCMJ, and SLD landing) and the order of leg use were randomized to minimize systematic errors due to fatigue. All jumps and landings were performed on a parquet floor.

Single leg countermovement jump test

Following the procedures outlined by Šarabon et al. (2020), participants performed the jumps while standing on one leg on a bilateral force plate (model 9260AA6, Kistler, Winterthur, Switzerland). They were instructed to lower themselves as quickly as possible from a single-leg standing position into a half-squat (see Figures 1 and 2) and then jump as high as they could. A jump was deemed invalid and required repetition if the participant landed on both feet, touched the ground with any part of their body other than the jumping foot, lost balance after landing, or moved their arms away from their hips. In general, maximum four repetitions were conducted. The dominant leg was determined post hoc as the leg with which the participant achieved the higher jump. Jump height was quantified using the impulse-momentum method in MARS software (Measurement, Analysis and Reporting Software, S2P, Ljubljana, Slovenia).

Single leg drop landing test

Participants were instructed to assume a single-leg stance on a platform elevated 0.3 m above the ground. Following the procedures detailed by Saito et al. (2022), upon hearing the signal "ready," participants placed their hands on their hips, looked forward, and extended the leg they would land on. When the signal "hop" was given, participants dropped down from the platform and landed on a force plate (model 9260AA6, Kistler, Winterthur, Switzerland). They were required to achieve a balanced position and maintain it for five seconds (see Figures 1 and 2). The task was considered invalid and required repetition if the participant was unable to hold the balanced position for at least five seconds, landed on both feet, touched the ground with any part of their body other than the landing foot, lost balance after landing, or moved their arms away from their hips. In general, three to maximum five repetitions were conducted. The dominant leg was determined post hoc based on the vertical dynamic postural stability index (DPSI) at landing, which was measured using the force plates and analyzed with MARS

software (Measurement, Analysis and Reporting Software, S2P, Ljubljana, Slovenia), following the equations presented by Wikstrom & Borsa (2005).

Single leg broad jump test

The test was conducted in a standardized space designated for post-hoc video analysis. A rectangle measuring 3.2 m by 1.7 m was marked on the floor using 0.05 m thick adhesive tape. Following the procedures outlined by Dobbs et al. (2015), participants began in a standing position on their take-off foot at the center of the shorter edge of the marked area. They were instructed to push off with the intent of jumping as far as possible, landing on the same leg and maintaining the position for an additional two seconds (the broad jump analysis is presented in Supplementary Material C, available at: https://osf.io/r4fxv/?view_only=130a038442344c f28e2d8e9591bcfa7a). The dominant leg was determined post hoc as the leg that achieved the greater distance. The task was deemed invalid and required repetition if the participant landed on both feet, touched the ground with any part of their body other than the jumping foot, lost balance after landing, or moved their arms away from their hips. In general, three to maximum five repetitions were conducted.

Video recording and data processing

The technical execution of the movement was recorded with two Panasonic DMC-FZ200 cameras (Panasonic Corporation, Kadoma, Osaka, Japan) at a capture frequency of 100 Hz. All push offs and landings were captured in both the frontal and sagittal planes for the dominant and non-dominant legs. The cameras were positioned at one m height, three meters sagittal or frontal relative to the participants. Video recordings were imported to and analyzed with Kinovea software (Version 0.9.5, Kinovea Open-Source Project, www.kinovea.org). The reliability and validity of the software for obtaining kinematic parameters have been previously verified (Puig-Diví et al., 2019).

Before analysis, video recordings of the SLCMJ and SLD landing tests were calibrated in 2D space using the 0.3 m high vertical edge of the wooden box as a reference object, which was placed 0.05 m behind the force plates. For the SLBJ push off phase and landing phase, video recordings were calibrated using a marked rectangle on the floor. Specifically, the longer 3.2 m edge of the rectangle was used as a horizontal reference for sagittal plane analysis, while the shorter 1.7 m edge was used for frontal plane analysis.

Time synchronization

Before conducting the 2D kinematic analyses, video recordings of the SLCMJ and SLBJ push off phases were time-synchronized with the vertical component of the GRF data in MARS software (Measurement, Analysis and Reporting Software, S2P, Ljubljana, Slovenia). The start of the unloading phase for the SLCMJ was synchronized with the video recording when the downward movement of the marker placed over the greater trochanter was visually observed.For the SLD landing and SLBJ landing phases, synchronization occurred between the point at which the vertical component of the ground reaction force signal reached 20 N and the visually observed first contact of the foot with the force plate. The initiation of the downward movement and the first foot contact were identified through visual inspection of the video, with a precision of 0.01 seconds for all assessments.

Absolute and relative kinematic variables calculation

The markers were zoomed-in to the maximum extent and precisely marked using a computer mouse. After this we extracted the coordinates of the placed markers (x, y). We exported the coordinated to Excel (Microsoft Office Excel 2019, Microsoft, Washington, USA) and calculated the kinematic variables as follows. Body segments were firstly defined as a line between two markers (x_1, y_1 and x_2, y_2; sagittal: shin, femur, trunk, and frontal: shin, femur, hip and trunk).

Then, slope (k) for each segment was calculated as the ratio of the x change to the y change. Absolute kinematic variables represented the inclination of body segment relative to vertical or horizontal planes (Minosse et al., 2022). Deviations from vertical line in degrees were calculated for each segment in both planes following the equation:

$$90° \text{ - arctan(k)} \times \frac{180}{\pi},$$

and, only for hip angle in the frontal plane the deviation of the pelvis line from the horizontal plane was calculated with the equation:

$$\text{arctan (k)} \times \frac{180}{\pi}.$$

Moreover, the relative kinematic variables represented joint angles, calculated between two adjacent body segments, following the equation:

$$\text{arctan} \left| \frac{k_2 - k_1}{1 + k_1 \times k^2} \right| \times \frac{180}{\pi}$$

Schematic illustrations of the absolute and relative kinematic variables are presented in Figures 1 and 2. Finally, the amplitudes of the countermovement during the SLCMJ and SLBJ push off phases were calculated as the change in the vertical position (y) of the greater trochanter between the single-leg standing position and the KP time points. Additionally, the amplitude of the vertical position change of the greater trochanter during SLD landing and the SLBJ landing phase was calculated between the first contact of the foot with the force plate and the KP time points. The time points were determined using synchronized video recordings and force plate data, with visual inspection of the video conducted at a precision of 0.01 seconds.

Key position determination based on subjective and objective criteria

We performed all analyses at a crucial time point of the movement, referred to as the KP, using two criteria for KP identification: objective (OBJ) and subjective (SUB). This was done separately for the SLCMJ, SLD landing, SLBJ push off and landing phase.

For the *OBJ analysis* of the SLCMJ and SLBJ push off, the KP was defined as the moment at the end of the eccentric phase of the jump. This is based on the understanding that the COM reaches its lowest vertical position when the GRF is at its peak (McMahon et al., 2018). This moment is also associated with the most pronounced dynamic knee valgus position (Barfod et al., 2019; Hewett et al., 2005; Hewett & Myer, 2011; McLean et al., 2005), which has been linked to an increased risk of both acute and chronic knee injuries, such as anterior cruciate ligament (ACL) and medial collateral ligament (MCL) injuries, as well as anterior knee and patellofemoral pain (Bakker et al., 2016; Vosoughi et al., 2021). Similarly, during single-leg landings, the dynamic knee valgus position is most prominent at the peak GRF time point (Heebner et al., 2017; Saito et al., 2022). Therefore, for the OBJ analysis of the landing and SLBJ landing tests, the KP was determined at the time of peak vertical GRF during the SLD landing test. The "Stopwatch" module in Kinovea software was utilized to track the time from the initiation of the movement (time normalized with force plates) to the KP.

For the *SUB criteria*, the KP for all tests was consistently defined as the moment when the greater trochanter reached its lowest vertical position, determined through expert visual inspection of the video, at a precision of 0.01 seconds for all analyses.
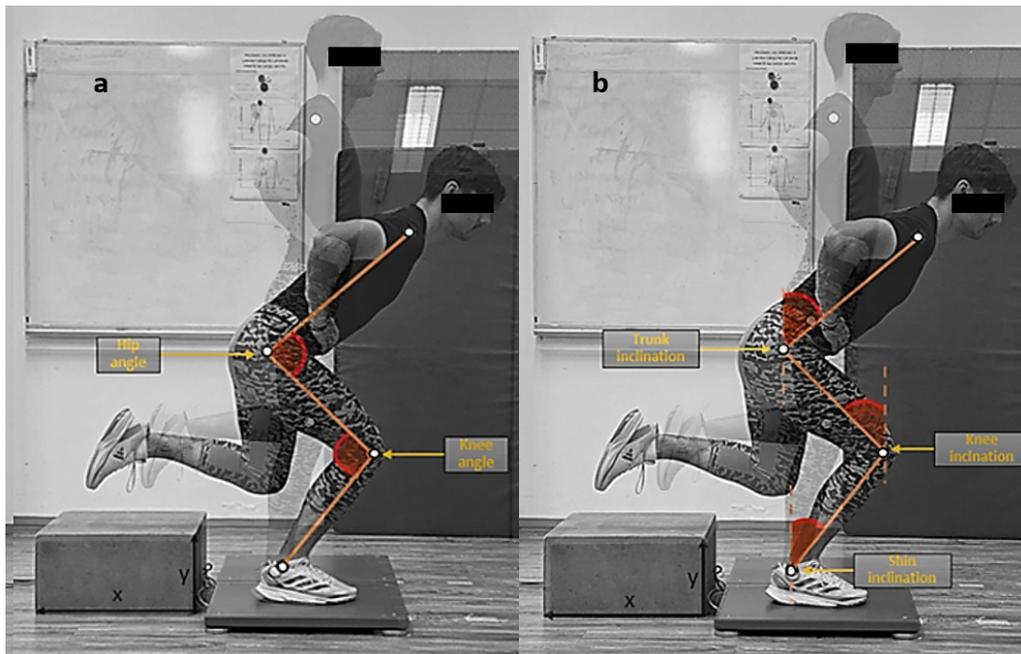
Figure 1. Presentation of (a) relative and (b) absolute kinematic variables in the sagittal plane.
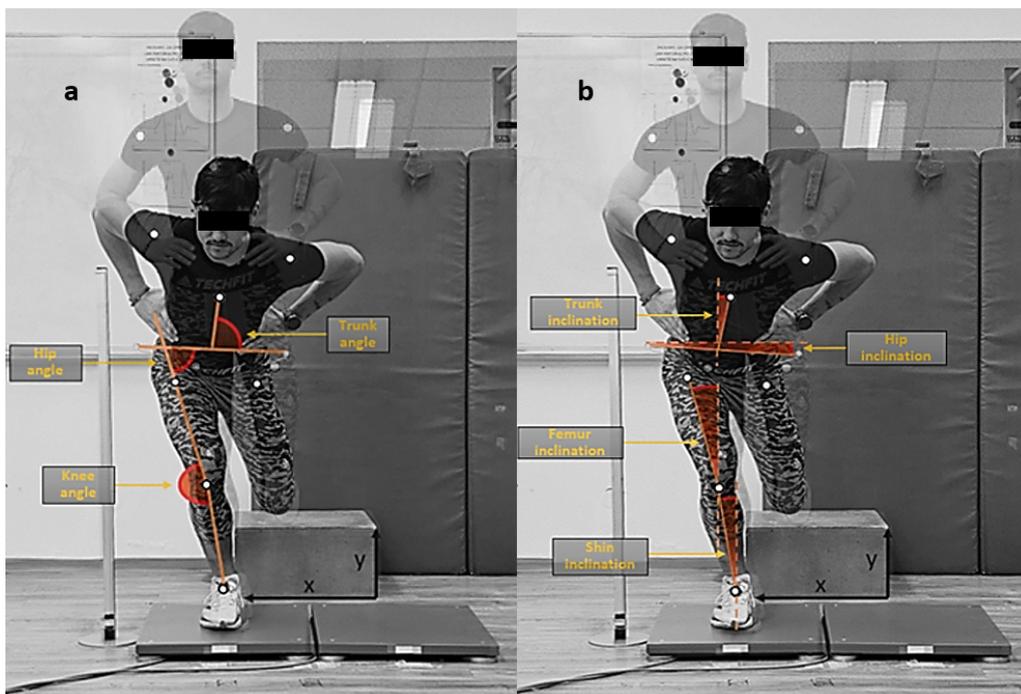
Figure 2. Presentation of (a) relative and (b) absolute kinematic variables in the frontal plane.

Statistical analyses

The obtained kinematic variables were reported as averages and standard deviations (SD). Before analysis, the normality of the data distributions for all variables was verified using the Shapiro-Wilk test (all $p \geq 0.195$). Intra-session reliability across the three repetitions was

calculated using the intraclass correlation coefficient ($ICC_{2.1}$) with 95% confidence intervals (CI) — which served as a main statistical outcome variable in our study. According to the latest guidelines, $ICC_{2.1}$ values were interpreted as follows: values < 0.50 indicate poor reliability, $0.50 \leq ICC_{2.1} < 0.75$ indicate moderate reliability, $0.75 \leq ICC_{2.1} < 0.90$ indicate good reliability, and $ICC_{2.1} > 0.90$ indicate excellent reliability (Koo & Li, 2016).

Absolute reliability was assessed using the coefficient of variance (CV), with values $\leq 10\%$ considered acceptable (Cormack et al., 2008). Additionally, the standard error of measurement (SEM) was calculated using the formula $SEM = SD \cdot \sqrt{(1 - ICC_{2.1})}$, where SD refers to the pooled standard deviation of the three repetitions (Dvir, 2015). The statistical significance of differences between the three repetitions was analyzed using a repeated measures one-way analysis of variance (ANOVA).

The differences between the results of SUB and OBJ KP identification were compared with paired samples t-test. To determine the effect size of the test statistic, we used Cohen's coefficient d according to the author's criteria (Cohen, 1988.). A value of 0.2 indicates a weak; 0.5 medium; and 0.8 or higher a strong connection. Pearsons's correlation coefficient (r) was additionally calculated between the results of both criteria. The interpretation of the results was as follows: using the following criteria: 0.0 indicates no correlation; 0.1–0.29 small; 0.3–0.49 medium; 0.5–0.69 large; 0.7–0.89 very large, and 0.9–1 perfect correlation (Akoglu, 2018).

Statistical analyses were performed in the RStudio: Integrated Development Environment for R (v4.3.3.; Posit team [2024], Boston, MA; http://www.posit.co/, accessed in April 2024), while figures were generated using the GraphPad Prism (v8, GraphPad, San Diego, California, United States). The cut-off for statistical significance was set at $p < 0.05$.

RESULTS

Figure 3 illustrates the $ICC_{2.1}$ results for kinematic variables, presented separately by variable conditions. $ICC_{2.1}$ values ranged from 0.01, observed in the "SLBJ push off with dominant leg trunk inclination variable at OBJ identification of KP for analysis in the frontal plane" to 1.00 in "SLD landing with non-dominant leg hip inclination variable at OBJ identification of KP for analysis in the frontal plane."

CV values ranged from 1.1% to 84.0% in "SLD landing with dominant leg knee angle variable at OBJ identification of KP for analysis in the frontal plane" and "SLBJ push off with non-

dominant leg shin inclination variable at OBJ identification of KP for analysis in the frontal plane," respectfully. SEM values ranged from 1.45° to 12.14° in "SLD landing with dominant leg shin inclination variable at OBJ identification of KP for analysis in the frontal plane" and " SLBJ push off with non-dominant leg trunk angle variable at OBJ identification of KP for analysis in the frontal plane," respectfully. Notably, ANOVA revealed statistically significant differences between the three repetitions in 39 out of 192 variables (Supplementary Material A, available at: https://osf.io/r4fxv/?view_only=130a038442344cf28e2d8e9591bcfa7a).
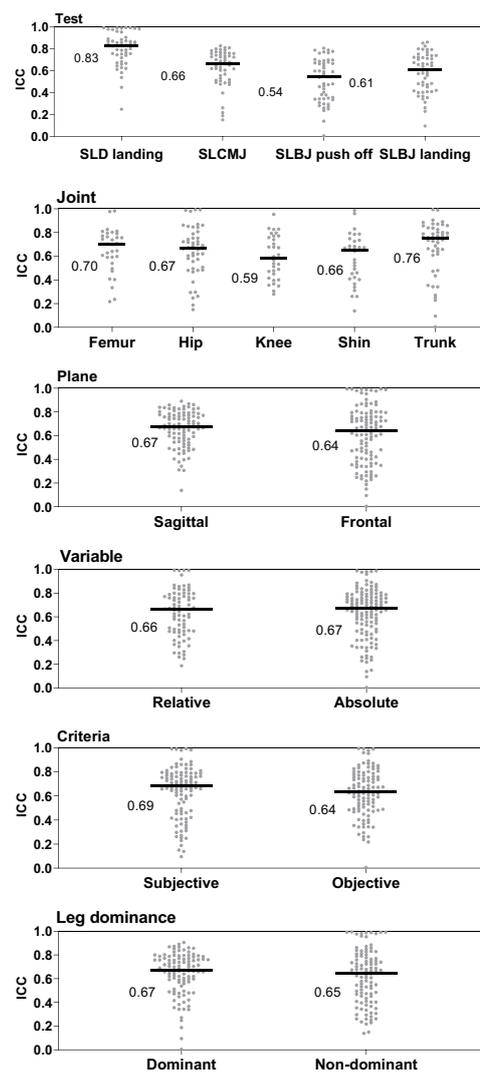
Notes: ICC – Intraclass Correlation Coefficient type 2.1; SLD – single-leg drop; SLCMJ – single-leg countermovement jump; SLBJ – single-leg broad jump. Values represent the median ICC across all variables. Each dot represents the ICC result for a specific variable. All of the tables can be found in Supplementary material A (https://osf.io/r4fxv/?view_only=7e98cc72d56b49ed976a841c350349b0)

Figure 3. Summary of intraclass correlation coefficient results for kinematic variables, presented separately by variable conditions.

Figure 4 illustrates Cohen's d results for differences between kinematic variables calculated based on OBJ and SUB KP identification criteria for SLCMJ, SLD landing, SLBJ push off, and landing phase. T-test results revealed statistically significant difference between the criteria in 70 out of 96 variables. The magnitudes of difference ranged from -3.08 to 3.19 for "SLBJ push off with dominant leg femur inclination variable in the frontal plane" and "SLD landing with non-dominant leg femur inclination variable in the saggital plane", respectively. The results were statistically significantly correlated in 96% of the cases (92/96 variables). The correlation coefficient ranged from -0.34 observed in "SLD landing with non-dominant leg knee angle variable in the frontal plane" to 0.99 in "SLBJ landing with dominant leg hip inclination variable in the frontal plane" (Supplementary Material B, available at: https://osf.io/r4fxv/?view_only=130a038442344cf28e2d8e9591bcfa7a).
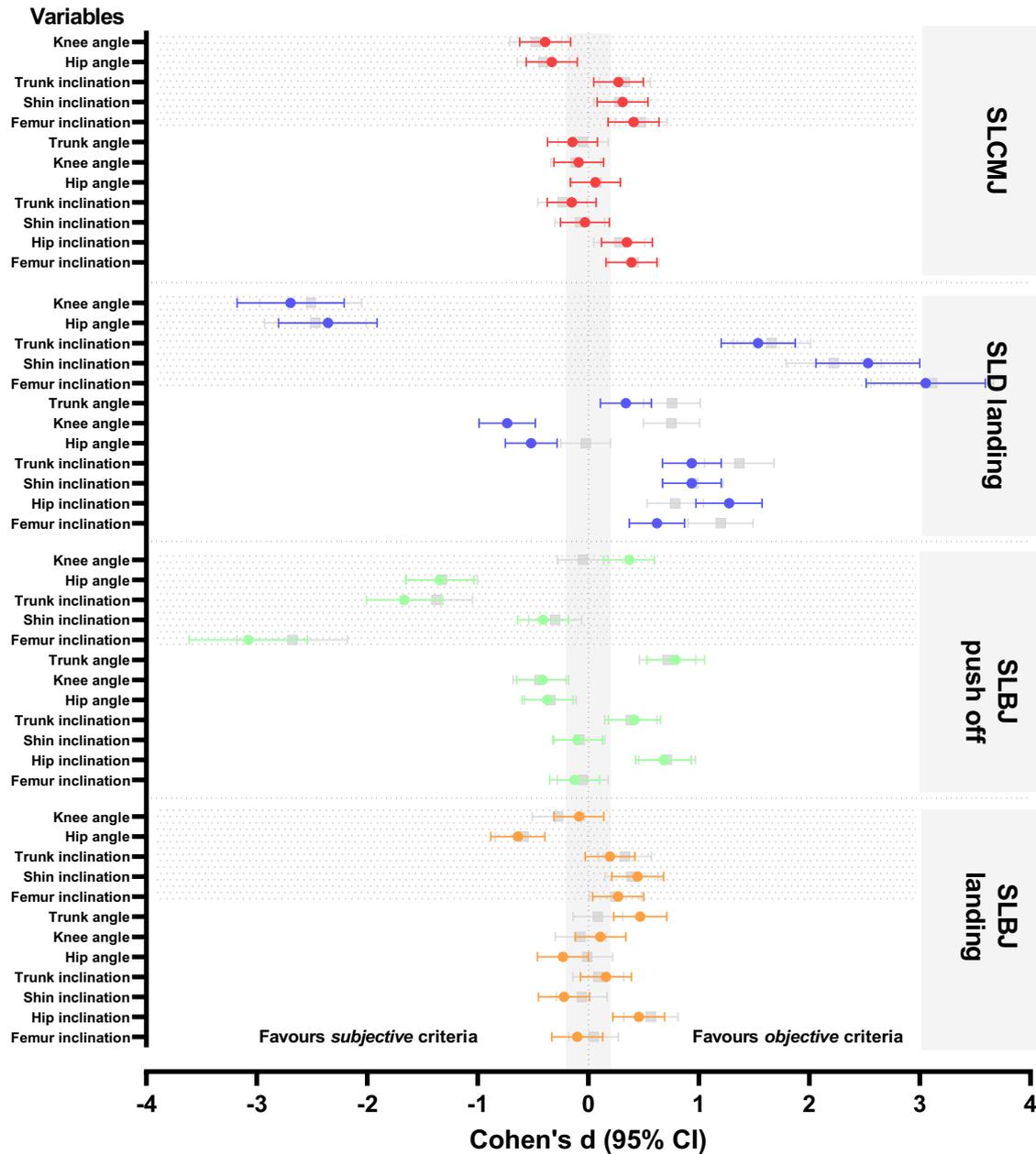
Notes: SLD – single-leg drop; SLCMJ – single-leg countermovement jump; SLBJ – single-leg broad jump. Cohen's d effect sizes are presented with 95% confidence intervals (CIs) for the dominant leg (filled circles) and the non-dominant leg (transparent gray squares behind the circles). The shaded area over the first five variables of each test represents sagittal plane variables, while the unshaded area represents frontal plane variables. Variables labeled "angle" indicate relative measurements, and those labeled "inclination" represent absolute measurements. Negative values indicate that higher variable values were found when calculated based on subjective key position identification criteria. Full results, including means, standard deviations, paired-samples t-test statistics, mean differences, Pearson correlations, typical errors, and Cohen's d statistics, can be found in Supplementary Materials A and B at https://osf.io/r4fxv/?view_only=130a038442344cf28e2d8e9591bcfa7a.

Figure 4. Summary of Cohen's d results for differences in kinematic variables calculated based on objective and subjective key position identification criteria.

DISCUSSION

2D kinematic analysis is a commonly used method in sports practice for evaluating the technical execution of movement. However, there is limited research confirming the reliability of this method when applied to SLCMJs, SLBJs, and SLD landing tasks. Therefore, the aim of our study was to assess the reliability of variables obtained through a simplified method of 2D kinematic analysis in the frontal and sagittal planes during these sport-specific movements. Additionally, we aimed to compare results between subjectively and objectively identified KPs for analysis. The findings did not support our first hypothesis, which assumed excellent reliability across all obtained variables. The highest reliability of kinematic variables, as measured by the $ICC_{2.1}$, was found for the SLD landing test, regardless of leg dominance, KP identification criteria, or plane of analysis (sagittal or frontal). In contrast, the SLBJ test exhibited poor to moderate reliability for both the push off and landing phases. Furthermore, we found that the results for kinematic variables differed when calculated at the time point identified subjectively as the peak GRF condition compared to the actual peak GRF. Consequently, our second hypothesis—supporting the validity of SUB criteria for determining KP in 2D kinematic analysis—must be rejected. Possible reasons for the results are emphasized in the future text.

The reliability results for the SLD landing test from our study are presented in Supplementary Material A, Tables 2 and 3, available at https://osf.io/r4fxv/?view _only=130a038442344cf28e2d8e9591bcfa7a. Good to excellent reliability was reported across all kinematic variables ($ICC_{2.1} > 0.75$), with CV indicating acceptable reliability throughout (CV < 10%). Good-excellent reliability of the kinematic variables can be attributed to several factors. The sample consisted of professional handball players who, through extensive training, had likely become familiar with and mastered the technical execution of single-leg landings. Additionally, the test is easier to perform from a coordination standpoint compared to other tests in this study, as it only requires force absorption during landing rather than body propulsion, ultimately contributing to the better reliability of the obtained variables. Previous research has reported similar findings, specifically demonstrating good to excellent reliability for the knee valgus variable (Munro et al., 2017; Peebles et al., 2021). To the authors's knowledge this was the first study examining movement technique in SLD landing. Studies using bilateral landings show comparable results, with trunk inclination in the frontal plane achieving excellent reliability for both the dominant ($ICC_{2.1} = 0.98$) and the non-dominant legs

($ICC_{2.1} = 0.99$) (Dingenen et al., 2014). Literature indicates that knee and hip flexion in the sagittal plane are typically evaluated at maximum knee flexion (Belyea et al., 2015; Robles-Palazón et al., 2021). Previous studies have reported good to excellent reliability for knee angle ($ICC_{2.1} = 0.73$–0.92) and for hip angle ($ICC_{2.1} = 0.80$–0.97) during the landing phase of a bilateral drop jump for the dominant leg (Belyea et al., 2015; Robles-Palazón et al., 2021). However, our study found moderate to good reliability for knee and hip flexion in the sagittal plane for the dominant leg. We believe that this discrepancy may be attributed to the unilateral instead of bilateral landings; while bilateral landing likely provides greater stability, which can reduce variability in performance and lower dependence on lower extremity strength. In addition, comparisons between subjectively and objectively derived kinematic variables showed statistically significant differences and moderate to strong correlations for all variables, except one (*SLD landing test: hip angle with non-dominant leg in the frontal plane*), in both the frontal and sagittal planes (Supplementary Material B, Table 2 available at: https://osf.io/r4fxv/?view_only=130a038442344cf28e2d8e9591bcfa7a). These findings suggest that the SUB assessment of the KP in the SLD landing test may not be accurate, possibly because the peak GRF occurs before the lowest point of the COM. This misalignment may be related to the activation of inhibitory neural mechanisms in the leg muscles during landing, where high forces trigger a reduction in force generation (Aagaard et al., 2000). This effect might be particularly pronounced in single-leg actions, where impact forces per leg are high.

The reliability results of SLCMJ kinematic variables are presented in Supplementary Material A, Table 4 and 5, available at: https://osf.io/r4fxv/?view_only=130a038442344cf28e2d8e9591bcfa7a. Our study demonstrates moderate reliability ($ICC_{2.1} = 0.50$–0.75) for kinematic variables in the SLCMJ, irrespective of the criteria, leg, or plane of motion. Additionally, the kinematic variables exhibited acceptable CV values (CV < 10%), indicating consistent measurement precision. To the author's knowledge, only one study (Miller & Callister, 2009) has examined the reliability of 2D kinematic variables in SLCMJ, finding moderate reliability for knee valgus using both relative (tibia-femur angle) and absolute (femur inclination from vertical axis) kinematic measures. Their findings align with ours, while we also found moderate reliability for knee valgus (knee angle and femur inclination) for the dominant leg. There is a lack of studies investigating the reliability of other variables obtained using the 2D kinematic analysis method. Focusing solely on variables in the frontal plane and at a specific joint (e.g., knee valgus) underestimates the intersegmental coordination required for complex, multi-segmental movements like jumping (Kiefer et al., 2013; Nagelli et al.,

2018). Knee valgus is not only a result of poor knee control but can also be a consequence of poor control and function of interdependent segments (trunk-hip-knee-ankle). Therefore, for causal relationships in injury analysis and physical performance, it is necessary to consider variables in both the frontal and sagittal planes and across multiple segments. Thus, our simplified 2D kinematic analysis method represents a stepping stone for further research in the field of 2D kinematic analysis. Furthermore, statistically significant differences were found between subjectively and objectively derived kinematic variables (Supplementary material B: Table 3 available at: https://osf.io/r4fxv/?view_only=130a038442344cf28e2d8e9591bcfa7a) for all variables in the sagittal plane and in 5 out of 14 variables in the frontal plane. This discrepancy in the results may be attributed to the movement patterns employed by the subjects. It is not necessarily the case that the peak GRF occurs at the lowest point of the movement amplitude. This discrepancy could be attributed to insufficient strength or an excessively deep descent, where the energy generated during the eccentric phase is not efficiently transferred to the concentric phase of the movement (Kennedy & Drake, 2018).

In the analysis of the SLBJ, the push off and landing phases were examined separately. The push off phase is presented in Supplementary material A: Tables 6 and 7 (available at: https://osf.io/r4fxv/?view_only=130a038442344cf28e2d8e9591bcfa7a), where poor to good reliability was observed for the kinematic variables, irrespective of the criteria, leg dominance or plane of analysis ($ICC_{2.1}$ = 0.05–0.81). Similar results were found for SLBJ landing, presented in Supplementary material A: Table 8 and 9 (available at: https://osf.io/r4fxv/?view_only=130a038442344cf28e2d8e9591bcfa7a). We report poor to good reliability for SLBJ landing kinematic variables, irrespective of the criteria, leg dominance or plane of analysis ($ICC_{2.1}$ = 0.09–0.86). Notably, the coefficient of variation indicated that acceptable reliability was achieved across all relative kinematic variables (i.e., angle variables) during the SLBJ push off and landing phases (CV < 10%). In contrast, the absolute kinematic variables (i.e., inclination variables) during the SLBJ push off and landing phases mostly demonstrated higher CV values, indicating unacceptable reliability (CV = 3.7%–84.0%). The literature lacks studies evaluating the reliability of 2D kinematic variables in the SLBJ, particularly given the increased complexity of the task, which is associated with greater variability in movement execution, especially in individuals not trained in the technical aspects of the task. The SLBJ requires the individual to shift their center of gravity forward through eccentric-concentric contractions and to jump as far as possible, resulting in the expression of both horizontal and vertical GRF vectors. Furthermore, it could be that the subjects in our

sample were not accustomed to such movements in their training regime. Given the complexity of the movement and the reliability results obtained in our kinematic variables, it can be concluded that for more complex movements such as the SLBJ, averaging more than three test repetitions is necessary, along with the implementation of an appropriate learning phase for jump technique. In the case of SLBJ push off and landing, mostly all of the kinematic variables showed statistically significant differences and moderate to strong correlations (Supplementary material B: Table 4 and 5 available at: https://osf.io/r4fxv/?view_only=130a03844 2344cf28e2d8e9591bcfa7a). The results could be due to the time-synchronization, which was applied to SLBJ push off and landing with SLCMJ and SLD landing GRF signal data, respectfully. These results suggest that the discrepancies in reliability may stem from the challenges associated with accurately aligning kinematic data with force plate signals, leading to inconsistencies in the measurement of SLBJ kinematic variables.

Strengths and limitations

One of the strengths of this study is its comprehensive analysis, which evaluated multiple joint angles and inclinations in both the sagittal and frontal planes through the SLCMJ, SLBJ push off and landing phases, as well as the SLD landing test. Additionally, the KP were determined using both SUB and OBJ criteria. Taken together, these approaches enabled a thorough assessment of the kinematic variables using this simplified 2D kinematic analysis method. Additionally, the study included a relatively high sample size of participants, which enhances the reliability and generalizability of the findings. Furthermore, the inclusion of elite handball players as participants ensures that the results are highly relevant to performance analysis and training optimization in high-level athletes. This focus on an elite population provides valuable insights into the movement patterns of players at the top of their sport.

Nonetheless, this study has certain limitations. Errors in identifying the KP can occur with both the OBJ and SUB criteria. In our analysis, we determined the KP based on the duration of the eccentric phase of the countermovement. It is possible that using the duration of the concentric phase instead could have yielded different results. Additionally, the duration of the landing and the countermovement in the SLCMJ and SLD landing test, respectively, was used to objectively determine the KP for analyzing the SLBJ push off and landing phases. This may have resulted in lower reliability compared to the other tests in the study. Finally, manually marking the markers in Kinovea was time-consuming and might be less accurate than using marker "tracing". These limitations suggest that the results should be interpreted with caution, as

variations in methodology could influence the findings. Further research is needed to explore alternative methods for determining the KP and their impact on the reliability of the analysis.

CONCLUSION

Based on our findings, we recommend analyzing at least three test repetitions and averaging the results to obtain reliable outcomes when performing 2D kinematic analysis with manual marker placement for single-leg jumping and landing techniques. Additionally, it is important to note that statistically significant differences exist between the SUB and OBJ identification of key movement positions during the analysis. This underscores the need for consistency in the criteria used to determine key movement positions for variable extraction. Sports practitioners should be aware of these limitations and apply additional caution and critical judgment when reading, analyzing, and interpreting the data in the future.

Declaration of Conflicting Interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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THE MEDIATING ROLE OF PHYSICAL APPEARANCE PERFECTIONISM IN DETERMINING THE CAUSAL RELATIONSHIP BETWEEN PERCEIVED PRESSURES AND PERCEPTION OF APPEARANCE

POSREDNIŠKA VLOGA PERFEKCIONIZMA GLEDE TELESNEGA VIDEZA PRI DOLOČANJU VZROČNE POVEZAVE MED ZAZNANIMI PRITISKI IN DOJEMANJEM VIDEZA

ABSTRACT

This study aimed to examine how perceived pressures impact the perception of appearance, with physical appearance perfectionism acting as a mediator. A total of 310 adults (Mage = 30.69, SD = 10.3 years), including 150 women and 160 men aged 18-60 years, participated in this cross-sectional study. The path analysis was conducted to test the mediating role of physical appearance perfectionism in the relationship between the perception of appearance and perceived pressures related to appearance. We modeled the influence of perceived pressures related to appearance on the perception of appearance through worry about imperfection regarding their physical appearance. The resulting model achieved an excellent fit. The full mediating effect of the worry about imperfection in predicting the perception of appearance with perceived pressures was significant ($p < .001$). Perceived pressure from peers/significant others and the media positively and significantly predicted the worry about imperfection (path coefficient = 0.277, $p < .007$; path coefficient = 0.163, $p < .00$, respectively). The worry about imperfection significantly contributes to the negative perception of appearance (path coefficient = -0.38, $p < .001$). As a result, worry about imperfection regarding physical appearance was determined as a mediator between perceived pressures related to physical appearance and perception of appearance.

Keywords: Perceived pressure of peers/significant others, perceived media pressure, physical appearance perfectionism, perception of appearance

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IZVLEČEK

Namen te študije je bil preučiti, kako zaznani pritiski vplivajo na dojemanje videza, pri čemer perfekcionizem glede telesnega videza deluje kot mediator. V presečni študiji je sodelovalo 310 odraslih (povprečna starost = 30,69 let, SD = 10,3 let), med njimi 150 žensk in 160 moških, starih med 18 in 60 let. Za preverjanje mediacijske vloge perfekcionizma glede telesnega videza v odnosu med dojemanjem videza in zaznanimi pritiski, povezanimi z videzom, je bila uporabljena analiza poti. Modelirali smo vpliv zaznanih pritiskov, povezanih z videzom, na dojemanje videza prek skrbi zaradi nepopolnosti glede telesnega videza. Dobljeni model se je odlično prilegal podatkom. Popolna mediacijska vloga skrbi zaradi nepopolnosti pri napovedovanju dojemanja videza ob prisotnosti zaznanih pritiskov je bila statistično značilna (p < 0,001). Zaznani pritiski s strani vrstnikov/pomembnih drugih in medijev so pozitivno in statistično značilno napovedovali skrb zaradi nepopolnosti (koeficient poti = 0,277, p < 0,007; koeficient poti = 0,163, p < 0,00). Skrb zaradi nepopolnosti pomembno prispeva k negativnemu dojemanju videza (koeficient poti = -0,38, p < 0,001). Skrb zaradi nepopolnosti glede telesnega videza je tako opredeljena kot mediator med zaznanimi pritiski, povezanimi s telesnim videzom, in dojemanjem videza.

Ključne besede: zaznani pritiski vrstnikov/pomembnih oseb, zaznani medijski pritiski, perfekcionizem glede telesnega videza, dojemanje videza

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INTRODUCTION

Physical standards associated with appearances, such as beauty and body shape are accepted by society as indicators of psychological and physical health (Ahmadpanah et al., 2019). For example, the risk of diabetes has been associated with a high hip-to-waist ratio, while a low hip-to-waist ratio is considered to be one of the universal beauty standards (Singh, 2002). Some of the universal beauty standards might change according to culture (Xu et al., 2010). However, today highly developed technological opportunities and the media have allowed individuals to connect with people with similar views around the world. Meeting certain appearance standards in society has been associated with for example successful romantic relationships, good health conditions, better social integration, and higher academic success, and the desire to reach these standards might add pressure on individuals (Gordon et al., 2013). Besides these, appearance is one of the main factors for participation in physical activity which is considered very important for a healthy lifestyle (Vani et al., 2021).

Body image is a complex construct that includes perceptions, attitudes, and behaviors related to one's physical appearance (Smolak, 2006). Body image was also defined as a multidimensional concept that is influenced by genetic and non-shared environment, and relatively independent of BMI (Wade et al., 2003). People who have a positive body image are more likely to have healthy eating habits and an active lifestyle by practicing yoga and exercises to maintain their body conditions (Gillen, 2015). On the other hand, a negative body image is associated with negative thoughts about the body, beliefs, emotions, and unhealthy habits such as excessive exercise (Vani et al., 2021). Those thoughts can be affected by the clear or hidden messages regarding appearance ideals by society and the media. When the individuals' body mismatched with their ideal body perception, body dissatisfaction occurs, and individuals may compare their bodies with pictures provided by the media (Pritchard & Cramblitt, 2015). In fact, males have reported that they feel pressured to be muscular from different socio-cultural sources and females have reported that they feel pressure to be thin from media sources (Xu et al., 2010). Having anxiety about one's weight or body shape might cause eating disorders which are one of the most common psychological reasons for death (Girard et al., 2018). Additionally, pressure set by adult relatives and media sources may reinforce some body-changing behaviors for both genders (Xu et al., 2010). In other words, the internalization of unattainable appearance ideals by individuals might cause body dissatisfaction which is a risk factor for unhealthy weight-controlling methods such as overloaded diets and eating disorders (Schaefer et al., 2017).

In the Tripartite Influence Model, body image and eating disorders were assumed to be affected by two main factors, which are the internalization of thinness ideals and social comparisons of appearance, especially from parents, peers, and the media (Hardit & Hannum, 2012). These relationships have been supported by several studies (Keery et al., 2004; Shroff & Thompson, 2006). Individuals may be exposed to these unattainable ideals at every stage of their life. For example, the examination using anthropometric measurements on the Barbie dolls, which are very popular among children, has shown that the body shape of the Barbie is unhealthy, and 1 in 100.000 women can have that body, and 1 in 50 men have the body of the Ken doll (McCreary & Sasse, 2000). Furthermore, advertisements, banners, and posters, for example, often feature muscular men and thin women. Such behaviors with the excessive desire to reach these thin and muscular figures have been found associated with depression (McCreary & Sasse, 2000). In this context, ideals and pressures set by socio-cultural structures might play a role in body-changing behaviors and have a strong influence on an individual's perception of their bodies (Xu et al., 2010).

The appearance standards set by society may be accepted as the perfect appearance by individuals and they may have perfectionist tendencies toward their physical appearance (Stoeber & Stoeber, 2009). Furthermore, these individuals want to be accepted and confirmed by their significant others for their personal and social image (Hill et al., 2004). Regarding these issues, Yang and Stoeber (2012) introduced the concept of physical appearance perfectionism and developed the Physical Appearance Perfectionism Scale. One of the subscales 'hopes for perfection', which has shown a positive correlation with the indicators of a positive body image of an individual, involves the behaviors that set challenging standards and self-evaluation through criticism. This may help the individuals to improve themselves continuously. On the other hand, the other subscale 'worry about imperfection', which has shown negative associations with indicators of a positive body image, involves an individual's desire to reach high standards and may cause depression by social anxiety due to the fear of negative criticism from other people when they are unable to reach these high standards (Yang and Stoeber, 2012). Such individuals need the approval of others to feel good about themselves and it is important to be considered 'perfect' by others. This may cause the individuals to easily internalize physical appearance and be affected by social and environmental pressures (Grammas & Schwartz, 2009; Stoeber & Stoeber, 2009). Therefore, there may be a relationship between socio-cultural pressures and appearance perfectionism. In fact, in their study, Grammas and Schwartz (2009) reported that internalized societal messages and socially prescribed

perfectionism, which is defined as following certain standards for the individual and meeting expectations that are set by significant other people, presumes muscle dissatisfaction.

Studies in the literature show that sociocultural pressures that support the appearance standards of society can affect the body image negatively which leads to many unhealthy behaviors (Girard et al., 2018). Individuals are exposed to these pressures daily. To these authors' knowledge, there are limited studies examining relationships between sociocultural pressures and body image by focusing on the mediators of these relationships. In the present study, we thought that worry about the imperfection dimension of physical appearance perfectionism may have a significant role in these relationships as a mediator. In this manner, this study extends previous body image and sociocultural pressures research by additionally investigating physical appearance perfectionism. Moreover, this study critically engages with the Tripartite Influence Model by proposing physical appearance perfectionism as a key psychological mechanism linking perceived social pressures to appearance perception. While Tripartite Influence Model highlights internalization and appearance comparison as primary pathways, the model proposed in this study suggest that perfectionism may serve as an additional mediator. Furthermore, examining Tripartite Influence Model among gender balanced adult sample would broaden the applicability of model beyond adolescent and female-dominated perspectives. In addition, revealing the relationships between sociocultural pressures and body image, and understanding the mechanisms and reasons behind the relationships can contribute to developing strategies to deal with these unhealthy behaviors and create prevention programs. In this context, this study aimed to investigate the mediating effect of worry about the imperfection in the relationship between family, media, peers/significant others pressure, and perceived appearance. To this end, the following hypotheses were established:

H1: Family pressure would affect worry about imperfection positively.

H2: Peers/significant others' pressure would affect worry about the imperfection positively.

H3: Media pressure would affect worry about imperfection positively.

H4: Worry about imperfection would affect perceived appearance negatively.

H5: Worry about imperfection would be a mediator in the relationship between family pressure and perceived appearance.

H6: Worry about imperfection would be a mediator in the relationship between peers/significant others' pressure and perceived appearance.

H7: Worry about imperfection would be a mediator in the relationship between Media pressure and perceived appearance.

The hypothesized model is illustrated in Figure 1.
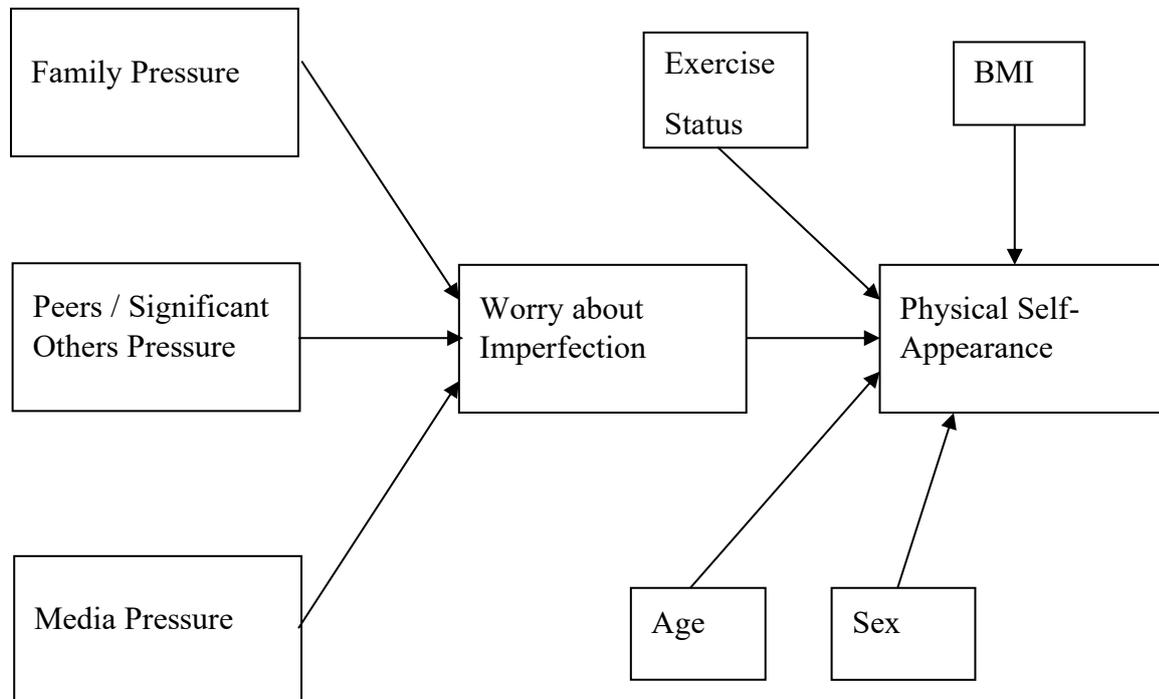
Figure 1. Hypothesized model

METHODS

Participants

Participants were 160 females and 150 males (Mage= 30.69, SD= 10.3 years) in this convenience-sampled study. It was determined through demographic information sheets that 147 participants (%47) practiced physical activity regularly and the mean body mass index (BMI) was 23.7 (SD= 3.6) for all participants. In Structural Equation Modeling (SEM) studies, one of the suggestions is that there should be ten participants for each parameter to determine the sample size correctly (Worthington and Whittaker, 2006). The sample size in this study is higher than the number of samples obtained by this formula. All the participants have signed the consent forms.

Instruments

Demographic Information Sheets

It contains information on the age, sex, height, weight, and exercise status (regular participant/ non-participant) of the participants.

The Sociocultural Attitudes Towards Appearance Questionnaire (SATAQ-4R)

SATAQ-4R was developed by Schaefer et al. (2015). It contains thirty-one items and seven subscales: Internalization-Thin/Low Body Fat, Internalization-Muscular, Internalization-General Attractiveness, Pressures-Family, Pressures-Media, Pressures-Peers, Pressures-Significant Others. Each item was evaluated on a 5-point Likert scale ranging from 'agree' to 'disagree'. SATAQ-4R was adapted to Turkish on female samples by Cihan et al. (2016). "Pressure-Peers" and "Pressure-Significant Others" factors in the original form were loaded onto a single factor in the Turkish female sample. This factor was labeled Pressures-Peers/Significant Others in the Turkish version of the SATAQ-4R (Cihan et al., 2016). We have conducted confirmatory factor analysis (CFA) to check the construct validity of the SATAQ-4R for the current sample because of having male participants. CFA revealed acceptable and good fit index values for males (χ^2/df = 2.30, CFI = 0.94, TLI = 0.93, GFI = 0.97, and IFI = 0.94) and for females (χ^2/df = 2.03, CFI = 0.996 TLI = 0.995, GFI = 0.992, and IFI = 0.996) in the present study. To measure socio-cultural pressures; "Pressures-Family" subscale (5 items, e.g., 'I feel pressure from family members to look thinner'), "Pressures-Media" subscale (4 items, e.g., 'I feel pressure from the media to improve my appearance'), and "Pressures-Peers/Significant Others" subscale (7 items, e.g., 'My peers encourage me to get thinner.') were used in this study. The Cronbach's alpha values were found 0.87 for females and males in Pressures-Family subscale, 0.97 for females and 0.94 for males in Pressures-Media subscale, and 0.89 for females and 0.93 for males in Pressures-Peers/Significant Others subscale in the sample of this study.

The Physical Appearance Perfectionism Scale (PAPS)

PAPS was developed by Yang and Stoeber (2012) and adapted to Turkish by Kolsallayan and Kazak (2021). It contains twelve items and two subscales: Worry about imperfection (7 items) and Hope for perfection (5 items). Each item was evaluated on a 5-point Likert scale ranging from 'disagree (1)' to 'definitely agree (5)'. The total score calculation was not performed in this tool. To evaluate how much an individual is worrying about their appearance, only the

Worry about imperfection subscale (e.g., 'I wish I could completely change my appearance') was used in this study, and the Cronbach's alpha coefficient for the present sample was 0.93.

The Physical Self-Description Questionnaire (PSDQ)

 PSDQ was developed by Marsh et al. (1994) and adapted to Turkish by Marsh et al. (2002). It contains seventy items and eleven subscales: Strength, Body Fat, Activity, Endurance/Fitness, Sports Competence, Coordination, Health, Appearance, Flexibility, Global Physical Self-concept, and Global Esteem. Each item was evaluated on a 6-point true-false response scale. To measure an individual's perception of their appearance, the Appearance subscale (6 items, e.g., 'I am attractive for my age) was used in this study. The internal consistency coefficient of the Appearance subscale was .89 for the current sample.

Procedure

The protocol of the study was approved by the Hacettepe University Ethics Commission (Number: E-35853172-900-00001636010). First, consent forms and information about the research were sent to the participants by Google Forms via WhatsApp or e-mail. If the participants signed the consent form, the second page was opened where the information on how to fill out the questionnaires, demographic information sheets, and measurement tools was written. It was observed that filling out the forms takes 15-20 minutes in total.

Data Analysis

Statistical analyzes were performed by using IBM, SPSS 23.0, and R Project for Statistical Computing Program version 4.0.0. Descriptive statistics were presented as mean and standard deviation, minimum and maximum values for continuous variables, and frequency and percentage for categorical variables. Kolmogorov-Smirnov test was performed to assess the normality distribution of the continuous variables, and all distributions were non-normal ($p<0.05$). In order to demonstrate the reliability of the measures, Cronbach's alpha coefficient was calculated, and confirmatory factor analysis (CFA) was performed to test the construct validity of the SATAQ-4R scale (see Instruments). Before the path analyses, bivariate analyses were performed between the dependent and independent variables. The Mann Whitney-U test was performed to examine differences in dependent variables in terms of sex and the status of exercise (regular participant/ non-participant). Kruskal Wallis was conducted to determine BMI group (Underweight/Normal/Overweight/Obese) differences on the dependent variables.

Spearman rank correlation coefficient (rho) was performed to assess the correlation between continuous variables.

The path model was constructed using the "Lavaan" package in R Project for Statistical Computing program to examine the associations between family, peer/significant others, and media pressures sub-dimensions of SATAQ, worry about the imperfection sub-dimension of PAPS, and Perceived Appearance sub-dimension of PSDQ. Covariates such as sex, BMI, age, and exercise status were also included in the model to obtain adjusted parameter estimates. These covariates have a direct impact on the perceived appearance and are allowed to correlate with each other. Dummy coding was applied for the covariates, sex (1:Female, 0:Male), and exercise status (1: regular exercise participant, 0: non-participant). Mediation effects were tested via the Sobel test. Since the normality assumption did not hold, parameter estimates were obtained by the unweighted least-squares (ULS) method. The robustness of the parameter estimates was evaluated by calculating confidence intervals through a 5000-sample bootstrap procedure. To further validate the hypothesized mediation model, alternative models were compared to determine the directional robustness of the relationships. Based on the structure of the hypothesized model, the 15 free parameters included: 8 direct regression paths (from three types of sociocultural pressure to the mediator, and from the mediator and covariates to the outcome), 4 variance terms (including residual variances and latent variable variances), 2 intercepts, and 1 residual covariance between variables. With a total sample size of 310 participants, the model meets the recommended participant-to-parameter ratio of at least 10:1 (Kline, 2023), indicating adequate statistical power for the path analysis conducted. The overall fit of the model was assessed by Chi-square/degrees of freedom ($\chi2/sd$), Root Mean Square Error of Approximation (RMSEA), Comparative Fit Index (CFI), Goodness of Fit Index (GFI), and NFI (Normed Fit Index) and Standardized Root Mean Square Residual (SRMR) fit measures.

RESULTS

The group differences across family, peer/significant others, and media pressures sub-dimensions of the SATAQ, Worry about the Imperfection sub-dimension of the PAPS, and Appearance sub-dimension of the PSDQ were assessed by Mann Whitney-U and Kruskal Wallis tests. Mann Whitney-U test results indicated significant sex differences in family and media pressure subdimensions of the SATAQ, $p < 0.05$. Mean scores of these subdimensions showed that female participants perceived more pressure than male participants. Moreover, there were also significant exercise status group differences in peer/significant others and media pressure of the SATAQ, worry about imperfection, and the perceived appearance. ($p < 0.05$, $p < 0.001$, see Table 1). Accordingly, regular exercise participants perceived less pressure and higher perceived appearance compared to non-participants.

Table 1. Mann Whitney-U test results across sex and exercise status groups.

Dependent Variables	Sex					Exercise Status				
	Female		Male		p-values	Participant		Non-Participant		p-values
	Median (IQR)	M (SD)	Median (IQR)	M (SD)		Median IQR	M (SD)	Median IQR	M (SD)	
Family Pressure	1.5 (1-2.5)	1.94 (1.09)	1.25 (1-2)	1.68 (0.94)	**0.033***	1.25 (1-2.25)	1.72 (1.00)	1.5 (1-2.5)	1.89 (1.05)	0.128
Peer/significant others' pressure	1.25 (1-2)	1.65 (0.83)	1.25 (1-2)	1.67 (0.89)	0.623	1 (1-2)	1.54 (0.77)	1.5 (1-2.25)	1.77 (0.91)	**0.001****
Media Pressure	3.0 (1-4)	2.80 (1.51)	1.37 (1-2.75)	1.89 (1.09)	**<0.001****	1.50 (1-3)	2.09 (1.28)	2.75 (1-4)	2.61 (1.46)	**0.002****
Worry about Imperfection	1.71 (1-2.28)	1.81 (0.83)	1.57 (1-2)	1.64 (0.70)	0.086	1.57 (0.85-2)	1.55 (0.68)	1.71 (1.28-2.28)	1.88 (0.82)	**<0.001****
Perceived Appearance	4.83 (4-5.33)	4.63 (0.94)	4.66 (4.16-5.16)	4.58 (0.76)	0.237	4.83 (4.33-5.33)	4.79 (0.81)	4.66 (3.83-5)	4.45 (0.87)	**<0.001**

*Notes. IQR: Interquartile range, M: Mean, SD: Standard deviation *p < 0.05, **p < 0.001*

Table 2. Kruskal-Wallis test results across BMI groups.

Dependent Variables	Underweight		Normal		Overweight		Obese		p-values
	Median (IQR)	M (SD)	Median (IQR)	M (SD)	Median (IQR)	M (SD)	Median (IQR)	M (SD)	
Family Pressure	1 (1-1.75)[a]	1.35 (0.52)	1.25 (1-2)[a]	1.69 (0.94)	2 (1-2.75)[b]	2.12 (1.16)	2.5 (2-3.5)[b]	2.65 (1.29)	**<0.001**
Peer/significant others pressure	1 (1-1.25)[a]	1.30 (0.61)	1 (1-2)[a]	1.54 (0.72)	1.75 (1-2.75)[b]	1.93 (1.01)	2.5 (1.25-3.25)[b]	2.39 (1.10)	**<0.001**
Media Pressure	2.75 (1-4)	2.62 (1.43)	2 (1-4)	2.43 (1.45)	1.5 (1-3)	2.01 (1.22)	2.5 (1-4)	2.63 (1.39)	0.079
Worry about Imperfection	1.57 (0.89-2)	1.68 (0.80)	1.71(1.14-2.14)	1.74 (0.74)	1.57 (1-2.14)	1.60 (0.70)	2 (1.42-3.28)	2.23 (1.09)	0.105
Perceived Appearance	5.16 (4.5-5.45)	4.90 (0.74)	4.66 (4-5.16)	4.55 (0.89)	4.66 (4-5.33)	4.59 (0.83)	4.83 (4-5.33)	4.48 (0.92)	0.102

Notes. IQR: Interquartile range, M: Mean, SD: Standard deviation

[a,b] *There is no difference between the BMI groups with the same superscript value.*

Kruskal Wallis test results indicated statistically significant differences among BMI groups on pressures from family and peer/significant others subdimensions of the SATAQ and worry about imperfection ($p < 0.05$, as shown in Table 2). Follow-up pairwise comparisons indicated that underweight individuals perceived significantly different family and peer/significant others pressure than overweight and obese individuals. Underweight individuals perceived less pressure than those in the other BMI groups. Similarly, normal-weight individuals also perceived significantly less family and peer/significant others pressure compared to overweight and obese individuals. Regarding the worry about imperfection subscale, obese individuals reported significantly higher scores than all other groups.

The correlations between family, peer/significant others, and media pressures sub-dimensions of the SATAQ, Worry about the Imperfection sub-dimension of the PAPS, and Appearance sub-dimension of the PSDQ were assessed by Spearman rank correlation coefficient. According to the results, "worry about imperfection" was moderately and positively correlated with "media pressure" ($r=0.420$, $p < 0.001$). Moreover, there was also a weak and significantly positive correlation between "worry about imperfection" and "family pressure" ($r=0.241$, $p < 0.001$) and "peers/significant others pressure" ($r=0.348$, $p < 0.001$). There was a weak negative correlation between perceived appearance and "Worry about imperfection" ($r=-0.353$, $p < 0.001$), and "peers/significant others pressure" ($r=-0.166$, $p < 0.05$).

The path analysis was performed and the estimated path coefficients with both p-values and their associated standard errors with bootstrapped confidence intervals and the results of hypotheses 1-4 are displayed in Table 3. According to Table 3, hypothesis 1 which claims that family pressure positively affects worry about the imperfection was rejected ($\beta = -0.0004$, $p = 0.083$). The path from peers/significant others' pressure to worry about the imperfection was positive and significant ($\beta = 0.277$, $p = 0.006$). Therefore hypothesis 2 was supported. Media pressure had a positive, significant effect on worry about the imperfection ($\beta = 0.163$, $p = 0.029$) and this result supports hypothesis 3. Finally, worry about imperfection was negatively associated with perceived appearance, therefore hypothesis 4 was supported.

To assess the sensitivity of the parameter estimates, confidence intervals based on 5000 bootstrap samples were examined. The results were considered robust when the bootstrapped confidence intervals did not include zero. In this context, the confidence interval for Hypothesis 1 included zero, and the associated p-value was not statistically significant. This combination suggested a lack of statistical stability, as non-significant p-values and confidence intervals that

included zero indicated weak or unreliable effects. In contrast, the confidence intervals for Hypotheses 2 and 3 did not include zero and were supported by statistically significant p-values. These findings indicated that the corresponding relationships were statistically significant, consistent, and reliable.

Table 3. Path Analysis Results.

Path	Standardized Path Coefficients	SE	p	Results	BBC 95% CI	
					LL	UL
H1: Family pressure → Worry about the imperfection	-0.0004	0.083	0.996	Not Supported	-0.190	0.189
H2: Peers/significant others pressure → Worry about the imperfection	0.277	0.101	0.006	Supported	0.085	0.542
H3: Media pressure → Worry about the imperfection	-0.386	0.109	<0.001	Supported	0.137	0.443
H4: Worry about the imperfection → Physical self-appearance	-0.386	0.109	<0.001	Supported	-0.481	-0.222

Notes. Model adjusted for age, sex, BMI, and exercise status. SE: Standard error; BBC 95% CI: Bootstrapped bias corrected for 5000 samples; LL: Lower limit; UL: Upper limit

The mediating effect of worry about the imperfection was tested via the Sobel test and the results were given in Table 4. As shown in Table 4, the indirect effect of peers/significant others' pressure on perceived appearance and media pressure on perceived appearance was found significant and the fully mediated effect of worry about the imperfection was supported. However, the mediating effect of worry about imperfection on the relationship between family pressure and perceived appearance was insignificant.

To evaluate the sensitivity and robustness of the mediation effects, parameter estimates were assessed using 5000 bootstrap samples with bias-corrected confidence intervals. As shown in the Table 4, the indirect effect for hypothesis 5 was not statistically significant, as the bootstrapped confidence interval includes zero (LL = -0.067, UL = 0.067), and the p-value was non-significant (p = 0.996). This indicates a lack of statistical stability and suggests that the indirect effect is not supported. In contrast, the mediation effects for hypothesis H6 and hypothesis H7 were statistically significant. For both paths, the bootstrapped 95% confidence intervals did not include zero (H6: [-0.200; -0.021]; H7: [-0.170; -0.034], and the p-values were below the threshold (H6: p = 0.021; H7: p = 0.003). These findings suggest that the indirect effects are statistically stable, consistent, and supported by the data.

Table 4. Mediation Analysis Results.

Path	Standardized Path Coefficients	SE	p	Results	BBC 95% CI	
					LL	UL
H5: Family pressure → Worry about the imperfection → Physical self-appearance	0.0001	0.083	0.996	Not Supported	-0.067	0.067
H6: Peers/significant others pressure → Worry about the imperfection → Physical self-appearance	-0.107	0.046	0.021	Supported	-0.200	-0.021
H7: Media pressure → Worry about the imperfection→ Physical self-appearance	-0.063	0.021	0.003	Supported	-0.170	-0.034

Notes. Model adjusted for age, sex, BMI, and exercise status. SE: Standard error; BBC 95% CI: Bootstrapped bias corrected for 5000 samples; LL: Lower limit; UL: Upper limit

The fit indices were obtained to assess the overall fit of the hypothesized mediation model. The value of χ^2/sd was found to be 0.9801, indicating that the model fit is good (recommended range: 1-3). The RMSEA value was 0.000, suggesting an excellent fit (recommended cut-off: <0.05). GFI was obtained as 1.000, which shows that the model has a very good degree of fitness (recommended cut-off: >0.95). Additionally, NFI = 0.957, CFI =1.000 and SRMR = 0.043(<0.05=very good) all meet the commonly accepted thresholds for a very good model fit (recommended cut-off value for NFI and CFI: >0.95; SRMR <0.05). According to these results, the model demonstrates very good fitness (Tabachnik & Fidell, 2018).

Although the current study utilized a cross-sectional design, which limits the ability to draw definitive causal inferences, especially in the context of mediation analysis, several steps were taken to enhance the robustness of the findings. First, the path model was constructed based on established theoretical frameworks and prior empirical findings. Second, covariates such as sex, age, BMI, and exercise status were included to account for potential confounding influences. Third, alternative model comparisons were conducted to evaluate the stability and directionality of the hypothesized mediation model. Specifically, a reverse mediation model was tested in which the direction of influence between the mediator and the outcome variable In addition, a reduced model excluding covariates was analyzed to examine the robustness of the structural relationships in the absence of control variables was reversed (i.e., physical self-apperance → worry about imperfection → family pressure).

In model comparison, lower AIC value indicates a better-fitting model. Results indicated that the hypothesized mediation model provided a better overall fit compared to the alternative specifications. Specifically, the hypothesized model yielded the lowest Akaike Information Criterion (AIC = 1398.6) value, compared to the reverse mediation model (AIC = 1454.5) and the reduced model without covariates (AIC = 1399.1). These alternative model analyses provide further evidence supporting the robustness and theoretical validity of the hypothesized model, despite the inherent limitations of a cross-sectional design.

DISCUSSION

The aim of this research was to examine the mediating effect of worry about the imperfection in the relationship between family, media, peers/significant others pressure, and perceived appearance. Prior studies have noted the importance of how individuals perceive their appearance for various health behaviors such as eating healthy, exercise thoughts, and mental health (Robertson et al., 2021). In addition, sociocultural pressure was demonstrated to be associated with body image dissatisfaction in various cultures (Frederick et al., 2016; Sundgot-Borgen et al., 2021). Physical appearance perfectionism also includes an individual's desire to reach high standards with their appearance, and cultural norms are highly influential on ideal appearance (Stoeber & Stoeber, 2009). The results of this study indicated that peers' and significant others' and media pressures were significantly associated with the worry about imperfection, and worry about imperfection was significantly and inversely associated with perceived appearance. Moreover, the mediation analyses in the path model indicated the mediating effect of worry about imperfection between sociocultural pressures (peers/ significant others and media) and perceived appearance. The findings of this study support Hardit and Hannum's (2012) Tripartite Influence Model's suggestion on how family, peers, significant others, and media may cause body dissatisfaction, and were also used as the basis for explaining the mediating effect of worry about imperfection between sociocultural pressures and perceived appearance.

The tripartite influence model of body image is a theoretical approach that focuses on the direct effects of family, peer, media, and sociocultural appearance standards as possible leading factors for body dissatisfaction (Shroff & Thompson, 2006). According to the Tripartite Influence Model, ideal internalization and social comparisons are two processes that have been used to explain negative body image as a result of ideal body imagery exposure to peers, parents, and media pressure (Keery et al., 2004). Moreover, Vani et al. (2021) indicated that

these mechanisms are not distinct and can function mutually as the socially prescribed appearance ideals internalize by using social comparison, and socially constructed pressure on body image is also associated with perfectionism concerns about physical appearance (Williams, 2009). The path model in the present study largely supported the Tripartite Influence Model by demonstrating that perceived pressures from peers/significant others and media significantly contribute to worry about imperfection, which in turn negatively influences perceived appearance. Specifically, the results supported hypotheses H6 and H7, revealing that worry about imperfection acts as a mediating mechanism through which sociocultural pressures influence individuals' perceptions of their appearance. Similar with prior research (Keery et al., 2004; Shroff & Thompson, 2006), these results confirm that peers and media are salient social agents in the formation of body-related concerns. Previous studies have also highlighted that exposure to idealized body standards via media and social reinforcement from peers such as appearance-related conversations, teasing may contribute to body dissatisfaction (Roberts et al., 2022).

The mediating effect of worry about imperfection on the association between media pressure and perceived appearance can be explained by how society's ideal body standards are depicted in mass and social media. According to the Tripartite Influence Model, one of the most impactful sociocultural factors on body dissatisfaction and eating disorder is media which might include the internalization of media images and information provided by the media related to appearance messages and norms (Shroff & Thompson, 2006). Developing technological opportunities and the quickly rising popularity of social media have allowed people to see more body images through computers and mobile applications and media highlighted as the most powerful sociocultural transmitter of beauty ideals (Groez et al., 2002). Moreover, Gillen and Lefkowitz (2009) highlighted media as transmitting more negative messages compared to family, peers, and school. As a result of this mass ideal body image transmission, social media use, and body image disturbance was found to be related (Saiphoo & Vahedi, 2019). The media and the social media platforms such as Facebook, Instagram, etc. provided a basis for both propagating unrealistic and idealized appearance ideals by using filters to enhance the images (Simon et al., 2022). There were similar findings in the literature as Simon et al. (2022) indicated that physical appearance perfectionism specifically worries about imperfectionmediates the relationship between social media platform addiction and body esteem. On the other hand, Xu et al. (2010) found that media positively contributed to body-related concerns; the negative association observed in the present study suggests that some

individuals may engage in critical evaluation or rejection of idealized media portrayals, potentially mitigating its effects on perfectionistic concerns. This highlights the complexity of media influence and suggests that individual differences, such as media literacy or coping strategies, may moderate its impact on body-related perfectionism. Furthermore, the source of the underlying cause of the pressure was highlighted as sociocultural sources, and the difference between Chinese and Turkish culture was also important on conflicting results (Xu et al., 2010). Finally, considering that participants of this study were adults, who may have more developed media literacy skills compared to younger populations, may dismiss or critically evaluate media images, reducing their perfectionistic concerns.

Another impactful sociocultural factor on body dissatisfaction in Tripartite Influence Model is peers, and the indirect effect of peers/significant others' pressure on perceived appearance was found to be significant and the fully mediated effect of worry about the imperfection in this study. Other studies have also reported peer pressure to be an important and negative variable in body image (Tsang, 2017). More specifically, Jankauskiene and Baceviciene (2021) demonstrated that the relationship between peers' pressure and appearance evaluation was significant, and mediated by the internalization of ideal things/low body fat among Lithenuean young adults. Similarly, significant associations of pressure family/peers muscularity with the internalization of thin/low body fat and internalization of muscular/athletic body were mediated by the appearance comparison among young French men (Girard et al., 2018). In our study, the same relationship was mediated by the worry about imperfection which individual's desire to reach high standards, and fear of negative criticism from other people when they are unable to reach the aimed standard. As peers may be seen as more attainable and having similar lifestyles and resources, engaging in peer appearance comparison might be more common for some adults (Fardouly & Vartanian, 2015). Hence, peers' appearance, information related to ideal physical appearance provided by the peers, or social norms in peer-group might cause pressure on adults, and this pressure might be associated with the fear of not reaching ideal body standards, in turn, low physical self-appearance perception. It is also important to note that peer and social media influence should be considered together because social media users generally follow their friends and see their posts constantly. Tiggemann et al. (2018) discussed that investment in likes was related to appearance comparison and facial dissatisfaction among young women.

Surprisingly, neither the direct effect of family pressure on worry about the imperfection nor the relationship between family pressure and perceived appearance mediated by worry about the imperfection were not significant in our study. This result contrasts with the Tripartite

Influence Model, which traditionally posits that parents play a key role in shaping body image concerns, particularly through direct and indirect mechanisms (Keery et al., 2004; Shroff & Thompson, 2006). This result might be associated with the worry about imperfection subscales' theoretical framework which indicates negative outcomes related to physical appearance. Family is generally highlighted as a transmitter of positive and healthful messages in the context of body and appearance (Gillen & Lefkowitz, 2009). On the other hand, family pressure can have a significant impact on the development of physical appearance perfectionism in individuals (Shroff & Thompson, 2006). However, studies indicate the significant role of family on physical appearance and perfectionism perceptions among adolescents. For example, Rodgers et al. (2009) indicated that parental pressure was a significant predictor of body dissatisfaction among adolescents. Moreover, there are a limited number of studies conducted with adult samples. To illustrate, similar to adolescents, Nikodijevic et al. (2015) reported family pressure as a significant predictor of body dissatisfaction, disordered eating behaviors, and low self-esteem in adult women.

While significant parental influence has been well-documented in adolescent populations (Rodgers et al., 2009; Shroff & Thompson, 2006), the lack of significance in the present study suggests that family pressure may become less relevant in shaping body-related perfectionism and appearance perception in adulthood. According to these studies, family pressure can manifest in various ways, such as comments about weight or appearance, pressure to conform to certain beauty standards, and criticism of one's appearance in adolescents and adult women. However, in our study, these associations were insignificant possibly due to the composition of the sample which includes adults and males. A possible explanation for these results may be associated with the age group of the study sample. The composition of the sample group is comprised of adult individuals and the notion that individuals are more influenced by their peers compared to their family during adulthood, while the influence of the family weakens with age. As individuals age, the number of resources they use to form their self-perceptions gradually decreases, and in adulthood, it is observed that these resources become significantly limited (Weiss & Amarose, 2005). This might be due to the accumulation of wealth of experiences and knowledge that shape their self-perceptions. These experiences may become more familiar and predictable in adulthood, leading to a narrower range of sources to draw upon for self-perception (Lachman, 2006). Another possible explanation for the non-significant effect of family pressure is that as individuals age, they gain independence from parental influence, relying more on peer networks, romantic partners, and media exposure for body-related

feedback (Oudekerk et al., 2015). To illustrate, adult body image concerns are more strongly shaped by social comparison among peers and romantic partners rather than by parental attitudes (Tylka, 2011). Thus, social networks tend to become smaller in terms of forming self-perception, and this reduction in social interactions limits the diversity of perspectives and feedback that individuals receive about themselves from others (Carstensen et al., 2003). As a result, as people transition into adulthood, parental involvement in shaping body image concerns diminishes, while peer and media influences become more dominant, reinforcing the idea that body-related perceptions are increasingly shaped by external social comparisons rather than familial expectations.

CONCLUSION

To conclude, in this study, The Tripartite Influence Model was replicated to examine its relationship with perceived appearance mediated by the physical appearance perfectionism in Turkish adults. The media and peers'/significant others' pressure were found to be significantly associated with perceived appearance mediated by worry about imperfection. The worry about imperfection was defined as an individual's desire to reach high standards and was found to be in relationship with body image disturbances regarding appearance and body shape may cause depression by social anxiety due to the fear of negative criticism from other people (Yang & Stoeber, 2012). Thus, individuals might tend to internalize the critiques or compare themselves with their family members, friends, or media and social media figures.

There were several limitations of the present study. First of all, this study was limited to the pressure aspect of the Tripartite Influence Model, worry about the imperfection subscale of the physical appearance perfectionism and the perceived appearance of the physical self-concept. Secondly, the questionnaire utilized two distinct subscales: Worry About Imperfection and Hope for Perfection. However, the 'Hope for Perfection' subscale wasnt included in the the analysis, as the primary focus was on examining the impact of perceived social pressures on individuals' perceptions of their appearance. Given that social pressure is theoretically conceptualized as a negative influence, often linked to body dissatisfaction, perfectionistic tendencies, and self-criticism, the researchers aimed to maintain a consistent negative framework throughout the study. Moreover, the cross-sectional design prevents the establishment of causal relationships between perceived social pressures, worry about imperfection, and perceived appearance. Although the Tripartite Influence Model provides a

theoretical foundation for directional hypotheses, longitudinal or experimental research would be necessary to confirm whether social pressures directly lead to perfectionistic concerns and negative appearance perception, rather than these variables being bidirectionally or interactively related. The study relies on self-report measures, which are inherently subject to biases such as social desirability effects and retrospective distortions. Given that body image and perfectionism-related concerns are sensitive topics, participants may have underreported or overreported their experiences to align with socially acceptable norms. Another limitation of the study was the convenient sampling method which limit the generalizability of the study. Finally, data were collected during the COVID-19 pandemic, which affected daily physical activity, exercise, and eating behavior as well as work routines (Robinson et al., 2021).

Despite the limitations of the current study, this study contributes to existing knowledge of the causal relationship between perceived pressures on appearance and perceived appearance by providing mediating effects of worrying about imperfection. The findings suggest that peers/ significant others and media pressures are significantly associated with worry about imperfection, and that worry about imperfection is significantly and inversely associated with perceived appearance. Based on these findings interventions should focus on developing media literacy programs, policies to regulate advertising, and peer support. Educating individuals about the influence of media on body image and providing strategies for developing healthy media consumption habits can contribute to reducing the negative impact of media pressure on physical appearance perfectionism. Secondly, developing policies to regulate mass and social media content promoting unrealistic beauty standards can help reduce pressure on physical appearance perfectionism. Encouraging supportive relationships and reducing negative peer pressure through the promotion of positive self-talk, empathy, and appreciation of diversity can help individuals develop a positive body image and diminish worry about imperfection. Lastly, intervention protocols may also include providing counseling and therapy services that address the underlying causes of worry about imperfection such as peers, significant others, and media pressures that can help individuals develop healthy attitudes toward their appearance.

Declaration of Conflicting Interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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EFFECTS OF UPPER EXTREMITY FATIGUE ON SHOOTING ACCURACY, KINEMATICS, AND MUSCLE ACTIVATION IN BASKETBALL PLAYERS

UČINKI UTRUJENOSTI ZGORNJIH OKONČIN NA NATANČNOST META, KINEMATIKO IN AKTIVACIJO MIŠIC PRI KOŠARKARJIH

ABSTRACT

Fatigue is a critical determinant of sports performance, often impairing athletic precision and efficiency. This study investigated the effects of upper extremity fatigue on shooting accuracy, kinematics, and muscle activity in adolescent basketball players. Twelve participants (age: 15 ± 1.1 yrs; sports experience: 6 ± 2.7 yrs) performed free throws under pre- and post-fatigue conditions. Fatigue was induced through a structured protocol utilizing a graphical user interface to monitor exertion levels. Shooting accuracy was qualitatively assessed based on predefined shot outcome categories. Kinematic variables, joint angles, joint angular velocities, and ball trajectory parameters were analyzed alongside muscle activation of key upper extremity muscles. Post-fatigue analysis revealed a significant decrease in elbow angular velocity (−5.08%, p = 0.041, effect size = 0.59), indicating impaired joint coordination. Additionally, palmaris longus muscle activation declined (−4.68%, p = 0.028, effect size = 0.63), suggesting reduced wrist stability and grip control. Furthermore, shooting accuracy deteriorated, with a significant increase in the frequency of 'Airball' (p < 0.05) and 'Short or uncontrolled shot did not score' (p < 0.05) outcomes. However, no significant differences were observed in the 'Balanced and controlled shot, but did not score' and 'Successful shot' categories. These findings highlight the negative impact of fatigue on neuromuscular control and biomechanics, underscoring the importance of fatigue management strategies in basketball training to maintain shooting efficiency.

Keywords: basketball, electromyography, muscular fatigue, motion analysis, triceps brachii, free throw

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IZVLEČEK

Utrujenost je ključen dejavnik športne uspešnosti, saj pogosto zmanjšuje natančnost in učinkovitost športnika. Ta študija je preučevala vplive utrujenosti zgornjih okončin na natančnost meta, kinematiko in mišično aktivnost pri mladostnikih košarkarjih. Dvanajst udeležencev (starost: 15 ± 1,1 let; športne izkušnje: 6 ± 2,7 let) je izvajalo proste mete v pogojih pred in po utrujenosti. Utrujenost je bila povzročena s strukturiranim protokolom, ki je z grafičnim vmesnikom omogočal spremljanje ravni napora. Natančnost meta je bila kvalitativno ocenjena na podlagi vnaprej določenih kategorij izida meta. Kinematične spremenljivke, kot so koti v sklepih, kotne hitrosti sklepov in parametri trajektorije žoge, so bili analizirani skupaj z aktivacijo ključnih mišic zgornjih okončin. Analiza po utrujenosti je pokazala pomembno zmanjšanje kotne hitrosti v komolcu (−5,08 %, p = 0,041, velikost učinka = 0,59), kar kaže na oslabljeno koordinacijo sklepa. Poleg tega se je zmanjšala aktivacija mišice palmaris longus (−4,68 %, p = 0,028, velikost učinka = 0,63), kar nakazuje zmanjšano stabilnost zapestja in nadzor prijema. Natančnost meta se je poslabšala, s pomembnim povečanjem pogostosti izidov »Airball« (p < 0,05) in »Prekratek ali nenadzorovan met, ki ni zadel« (p < 0,05). V kategorijah »Uravnotežen in nadzorovan met, ki ni zadel« ter »Uspešen met« ni bilo zaznanih pomembnih razlik. Ti izsledki poudarjajo negativen vpliv utrujenosti na nevromišični nadzor in biomehaniko ter izpostavljajo pomen strategij za obvladovanje utrujenosti v košarkarskem treningu za ohranjanje učinkovitosti metov.

Ključne besede: košarka, elektromiografija, mišična utrujenost, analiza gibanja, triceps brachii, prosti met

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INTRODUCTION

Muscle fatigue is defined as a reduction in force production following repeated or sustained contractions (Gandevia, 2001). In basketball, fatigue plays a crucial role in determining key skills such as coordination, strength, velocity, and shooting accuracy, all of which are essential for optimal performance (Ali et al., 2015; Kellis et al., 2006; Marcolin et al., 2018; Rashid et al., 2020; Slawinski et al., 2015). Among these skills, free throw (FT) shooting holds particular importance, as its accuracy often determines the outcome of games (Miller & Bartlett, 1993). Understanding the impact of fatigue on shooting performance is crucial for enhancing basketball performance and minimizing injury risk (Zhao, 2025).

Previous studies highlighted the detrimental effects of fatigue on basketball performance (Li, Li, et al., 2021). For instance, upper extremity fatigue has been shown to significantly impair shooting accuracy in basketball, particularly when induced by high-intensity exercises targeting the shoulder or elbow extensors during FTs, as well as two-point and three-point shots (Chen et al., 2005; Rashid et al., 2020). Additionally, fatigue impairs kinematic parameters critical to shooting mechanics, such as joint angular velocity and ball release speed (Erculj & Supej, 2009; Li, Knjaz, et al., 2021). For example, a study demonstrated that basketball-induced fatigue adversely affects three-point shooting accuracy by delaying shot execution, reducing optimal ball trajectory, and decreasing shot success (Bourdas et al., 2024). These findings underscore the need for effective fatigue management strategies to help athletes maintain biomechanical efficiency and shooting accuracy during gameplay.

Muscle activity, as assessed through surface electromyography (EMG), provides further insight into the neuromuscular effects of fatigue (Yasar et al., 2024). Previous research has demonstrated that fatigue can alter EMG signals, reflecting diminished force production and neuromuscular efficiency (Ghasemi et al., 2012; Rashid et al., 2020). For example, a study indicated that basketball-specific fatigue significantly reduces EMG activation in the deltoid anterior muscle during a three-point jump shot (Peterca & Dolenec, 2019). Another study found that in basketball players, an isometric submaximal triceps brachii fatigue protocol led to an increase in RMS values and a decrease in frequency values in MVIC measurements taken before and after fatigue (Rashid et al., 2020).

However, there is limited evidence on how specific muscles involved in basketball shooting, such as the triceps brachii and palmaris longus, respond to fatigue, especially during FT shooting in young basketball players. This study aims to address this gap by investigating the

effects of upper extremity fatigue on free-throw accuracy, kinematic parameters, and the muscle activity of the triceps brachii and palmaris longus in adolescent basketball players. These muscles play critical roles in arm extension, torque control, and stability during shooting (Pakosz et al., 2021; Salonikidis et al., 2021). While FT shooting requires coordination across the entire kinetic chain, the release phase of the movement is primarily dependent on upper limb muscles. In particular, the triceps brachii is essential for elbow extension and force application during the shot (Mir et al., 2025). For this reason, the present study concentrated on inducing localized fatigue in the triceps brachii to examine its specific impact on shooting performance. We hypothesize that fatigue in these muscles will disrupt shooting mechanics and accuracy, providing further evidence for the necessity of targeted training interventions to mitigate fatigue's impact on basketball performance.

METHODS

Participants

Twelve right-handed elite male adolescent basketball players participated in this study (mean ± SD: age: 15 ± 1.1 years; height: 182.7 ± 9.3 cm; weight: 68.5 ± 9.8 kg; body mass index: 20 ± 2.3 kg/m²). Participants had an average of 6 ± 2.7 years of sports experience, engaged in training five times per week, and actively competed in the U15–U16 local league. Only healthy athletes without any chronic pain or injury history were included in the study. Participants were instructed to complete their meals at least two hours before testing and to refrain from caffeine consumption. The study received ethical approval from the Sakarya University of Applied Sciences Rectorate Ethics Committee (Approval no: E-26428519-044-37254). Informed consent was obtained from the participants' families prior to data collection.

Procedure

Testing was conducted individually for each participant over approximately 45 minutes. Each participant completed an 11–12 minute warm-up supervised by a strength and conditioning coach. The protocol included 5 minutes of jogging followed by 6–7 minutes of basketball-specific exercises (half-court dribbling, jump shots, layups, and FTs). After warm-up, markers were placed on key joints and surface electrodes were applied to specific muscle groups for data collection. Participants were then instructed to shoot 10 FTs, during which kinematic and EMG data were recorded simultaneously. Shooting accuracy was also assessed. Subsequently, the Maximum Voluntary Isometric Contraction (MVIC) force of the triceps brachii was measured using a load cell (Baykon BT604, 200 kg). Following the fatigue protocol,

participants performed another set of 10 FTs using the same protocol as the pre-fatigue measurements. The study design is illustrated in Figure 1.
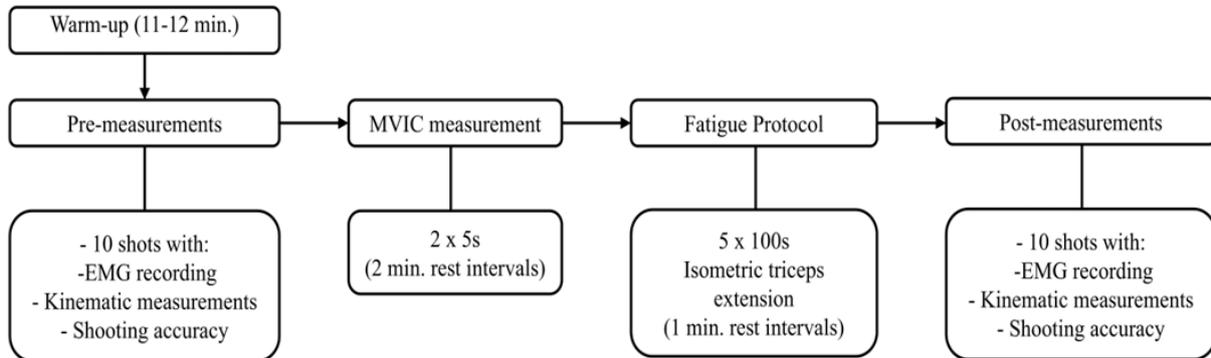
Figure 1. Study design.

MVIC measurements

For the triceps brachii muscle MVIC measurement, participants positioned themselves with their backs against a wall to ensure stability and minimize extraneous movements. The assessment was conducted with participants pulling the load cell downward while maintaining a standardized posture: elbow flexed at 90°, shoulder internally rotated at 45°, and wrist in a neutral position (Konrad, 2005). The load cell was fixed at chest level, and adjusted according to each athlete's height for consistency. Each participant performed two trials, each lasting 5 seconds, with 2-minute intervals between trials to ensure maximal force exertion. A graphical user interface (GUI), developed in MATLAB R2021a, was used to provide real-time visual feedback. The GUI displayed an indicator and a countdown timer, enabling participants to follow the measurement protocol precisely (Figure 2).

Figure 2. MATLAB Graphical User Interface.

Fatigue protocol

A fatigue protocol targeting the triceps brachii was chosen in this study because this muscle plays a key role in basketball shooting by enabling elbow extension—the final and critical movement during ball release. This action is particularly important in free throws, where precision and control are essential. Given that shooting involves coordinated shoulder elevation and elbow extension, understanding the impact of triceps fatigue is crucial for designing training strategies to improve shooting consistency and performance (Mir et al., 2025). The fatigue protocol required participants to maintain the same body position as in the MVIC measurement while performing isometric triceps extensions on the load cell at chest level, with a neutral wrist, 90° elbow flexion, and 45° shoulder internal rotation. The protocol consisted of five sets of 100-second triceps extensions at 40% ±10% of their MVIC (Rashid et al., 2020) with 2–3 minutes of rest between trials to minimize additional fatigue. The protocol was terminated when MVIC force dropped below 30% of its initial value, as monitored in real-time via the GUI.

Shooting accuracy assessment

Shooting accuracy was evaluated qualitatively based on four predefined categories (Table 1). It was divided into these categories to move beyond a simple successful/missed classification and to capture the qualitative characteristics of each attempt, such as control, balance, and shot trajectory (Ozdalyan et al., 2022). This approach allows for a more detailed analysis of shooting

performance, particularly when examining the effects of fatigue. An Airball refers to a shot that completely misses both the rim and the backboard. A Short or Uncontrolled Shot (did not score) is an unsuccessful attempt that is visibly off-target, typically falling short or lacking control, and may hit only the backboard or barely graze the rim. A Balanced and Controlled Shot (did not score) is a missed shot that demonstrates proper balance, form, and trajectory, indicating sound shooting mechanics. A Successful Shot is a made basket, regardless of whether it passes cleanly through the hoop or makes contact with the rim. Each participant completed 20 total shots (10 pre-fatigue and 10 post-fatigue), and shooting accuracy was calculated as a percentage for each category. Each participant completed 20 total shots (10 pre-fatigue and 10 post-fatigue), and accuracy was calculated as a percentage for each category.

Table 1. Qualitative evaluation of shooting accuracy.

Scores	Categories
0	Airball
1	Short or uncontrolled shot (did not score)
2	Balanced and controlled shot (did not score)
3	Successful shot

Kinematic measurements

Kinematic data were collected using a high-speed camera (iPhone 13 Pro) operating at 240 frames per second (FPS).This method has been widely adopted in sports biomechanics research and has shown acceptable levels of validity and reliability for capturing joint angles and angular velocities during dynamic movements (Erculj & Supej, 2009). To track joint positions, reflective markers were placed on key anatomical landmarks: the wrist (ulnar styloid process), elbow (lateral epicondyle), shoulder (acromion), hip (greater trochanter), knee (lateral femoral epicondyle), ankle (lateral malleolus), and the base of the fifth metatarsal. A 135 cm calibration stick was used for two-dimensional spatial calibration. Video recordings were analyzed using Tracker Video Analysis Tool version 6.1, an open-source software commonly utilized in sports biomechanics (Brown, 2008; Wee & Lee, 2012). The extracted parameters included joint angles (°), joint angular velocities (°/s), ball velocity components (cm/s), ball release height (cm), and ball release angle (°) (see Table 2).

Table 2. Parameters of kinematic for pre- and post-fatigue.

Parameters
Joint Angles (°) at ball release (Ankle, Knee, Hip, Shoulder, Elbow)
Joint Angular velocities (°/s) at ball release (Ankle, Knee, Hip, Shoulder, Elbow)
Ball velocity (cm/s) at ball release x-axis (Vx) and y-axis (Vy)
Ball release height (cm)
Ball release angle (°)

Electromyography (EMG) measurements

Muscle activity was assessed using the Delsys Trigno Wireless EMG system (Natick, MA, USA) (Figure 3) a well-validated and widely used tool in biomechanical and neuromuscular research (Jayaraman et al., 2024). Electrodes were placed on the palmaris longus and the lateral and medial heads of the triceps brachii, following the SENIAM guidelines (Hermens et al., 2000). Skin preparation included shaving (if necessary) and cleaning with gel. EMG data were collected at a sampling rate of 1259 Hz. Signals were filtered with a 20–450 Hz bandwidth filter, and root mean square (RMS) values were calculated using MATLAB R2021a. EMG responses were recorded for each FT pre- and post-fatigue.

Statistical analysis

Data analysis was conducted using SPSS v24.0. The Shapiro-Wilk test was performed to assess the normality of the data. Since the data did not follow a normal distribution, the Wilcoxon Signed-Rank Test was used to evaluate differences between pre- and post-fatigue conditions for kinematic and EMG variables. To determine the effect size (r) for the kinematic and EMG parameters, the formula $r = Z / \sqrt{N}$ was applied. Effect sizes were interpreted based on Cohen's (1988) classification, where small effects were defined as ($0.10 \leq r < 0.30$), medium effects as ($0.30 \leq r < 0.50$), and large effects as ($r \geq 0.50$) (Cohen, 1988). Lastly, the shooting accuracy percentage was analyzed using the Wilcoxon Signed-Rank Test. All results are reported as the median and interquartile range (IQR: 25th–75th percentile), with statistical significance set at $p < 0.05$.

RESULTS

The results in Table 3 indicate that fatigue did not significantly affect joint angles (°) (ankle, knee, hip, shoulder, and elbow) during shooting, as all comparisons remained non-significant

(p > 0.05). Joint angular velocity (°/s) showed mixed responses to fatigue. While ankle, knee, hip, and shoulder angular velocities remained unchanged (p > 0.05), elbow angular velocity significantly decreased (p = 0.041, effect size = 0.59), suggesting a large effect of fatigue. Regarding ball kinematics, ball velocity (cm/s) in the x-axis (Vx) and y-axis (Vy) and ball release height (cm) did not change significantly. However, the ball release angle showed a moderate effect size (effect size = 0.52) despite not reaching statistical significance (p = 0.071), indicating a possible impact of fatigue on shooting mechanics. Muscle activation analysis revealed no significant changes in triceps brachii (medial and lateral heads) (mV) EMG activity (p > 0.05), suggesting that triceps function remained stable. However, palmaris longus (mV) EMG amplitude significantly decreased (p = 0.028, effect size = 0.63), indicating a notable decline in wrist stability and grip control due to fatigue.

Table 3. Kinematic and electromyographic parameters pre and post fatigue.

Parameters	Percentiles		Z	p	Effect size
	Pre-fatigue Median (25th - 75th)	Post-fatigue Median (25th - 75th)			
Ankle Angle (°)	123.1 (116.7 - 134.8)	125.5 (117.7 - 133.2)	-0.235	0.814	0.07
Knee Angle (°)	164.8 (156.6 - 169.2)	164.3 (157.7 - 171.3)	-0.471	0.638	0.14
Hip Angle (°)	171.9 (165.8 - 175.8)	173.5 (171.7 - 174.7)	-1.218	0.223	0.35
Shoulder Angle (°)	105.4 (97.8 - 109.2)	106.4 (93.8 - 108.9)	-0.133	0.894	0.04
Elbow Angle (°)	110.5 (105.3 - 113.9)	111.6 (101.3 - 117.9)	-0.314	0.754	0.09
Ankle Angular Velocity (°/s)	194.5 (117.8 - 235.7)	196.1 (125.7 - 231.6)	-0.471	0.638	0.14
Knee Angular Velocity (°/s)	112.6 (92.0 - 138.3)	123.4 (106.6 - 142.3)	-1.452	0.147	0.42
Hip Angular Velocity (°/s)	69.9 (39.5 - 108.1)	78.4 (56.3 - 97.8)	-0.392	0.695	0.11
Shoulder Angular Velocity (°/s)	273.6 (247.7 - 385.7)	280.8 (231.6 - 441.0)	-0.549	0.583	0.16
Elbow Angular Velocity (°/s)	806.6 (712.1 - 890.0)	765.6 (683.0 - 853.1)	-2.04	*0.041**	0.59
Ball Velocity Vx (cm/s)	329.2 (308.8 - 357.2)	330.0 (306.8 - 359.8)	-0.471	0.638	0.14
Ball Velocity Vy (cm/s)	474.2 (432.0 - 492.9)	465.7 (445.5 - 492.4)	-0.392	0.695	0.11
Ball release height (cm)	235.1 (224.7 - 242.7)	236.2 (228.0 - 243.5)	-1.245	0.213	0.36
Ball release angle (°)	44.0 (41.5 - 47.6)	42.1 (40.4 - 46.1)	-1.804	0.071	0.52
Triceps Medial (mV)	0.17835 (0.11653 - 0.28105)	0.16035 (0.13843 - 0.21225)	-0.863	0.388	0.25
Triceps Lateral (mV)	0.10820 (0.06768 - 0.13425)	0.09970 (0.06688 - 0.12880)	-1.098	0.272	0.32
Palmaris Longus (mV)	0.09825 (0.07623 - 0.16633)	0.09365 (0.05160 - 0.12608)	-2.197	*0.028**	0.63

* p < 0.05

The analysis in Table 4 revealed a significant difference in the 'Airball' (p = 0.041) and 'Short or uncontrolled shot did not score' (p = 0.023) categories between pre- and post-fatigue conditions (p < 0.05). However, no significant differences were observed in the 'Balanced and

controlled shot, but did not score' and 'Successful shot' categories (p > 0.05). These findings indicate that fatigue negatively impacts uncontrolled and inaccurate shooting outcomes but does not significantly influence the execution of balanced or successful shots.

Table 4. Comparison of shooting accuracy.

Category	Percentiles		Z	p
	Pre-fatigue Median (25th - 75th)	Post-fatigue Median (25th - 75th)		
Airball	0.00 (0.00-0.00)	0.00 (0.00-17.50)	-2.041	0.041*
Short or uncontrolled shot (did not score)	10.00 (0.00-27.50)	30.00 (20.00-47.50)	-2.270	0.023*
Balanced and controlled shot (did not score)	35.00 (10.00-40.00)	20.00 (10.00-30.00)	-1.223	0.221
Successful shoot	50.00 (32.50-77.50)	35.00 (22.50-57.50)	-1.393	0.164

Notes. * p < 0.05

DISCUSSION

This study investigated the effects of upper extremity fatigue on FT shooting accuracy, kinematic variables, and muscle activation in adolescent basketball players. The findings indicate that fatigue selectively impacted elbow angular velocity and palmaris longus activation, while other kinematic and neuromuscular parameters remained largely unaffected. Additionally, fatigue impaired shooting accuracy, particularly in 'Airball' and 'Short or uncontrolled shot did not score' categories. These results suggest that fatigue disrupts technical execution and fine motor control, while the fundamental biomechanics of shooting remain stable.

Previous research demonstrated that fatigue can impair motor skills and accuracy, particularly in less experienced athletes (Knicker et al., 2011; Lyons et al., 2006; Mulazimoglu, 2014). More skilled players tend to maintain their performance under fatigue, likely due to greater motor control efficiency and refined movement strategies (Knicker et al., 2011; Lyons et al., 2006; Mulazimoglu, 2014). Similar findings have been reported in tennis, where fatigue-related declines in stroke accuracy were more pronounced in non-expert players than in skilled athletes, except under extreme fatigue conditions (Rupcic et al., 2020). In the present study, fatigue was induced in a controlled manner, targeting the triceps muscle at 40% MVIC, rather than engaging the entire upper body. Given that the participants were not elite-level players, the observed decline in shooting accuracy aligns with the idea that moderate fatigue is sufficient to impair precision in less experienced athletes. Based on previous findings, we anticipate that higher-

intensity fatigue protocols will lead to significant decreases in EMG median frequency and overall reductions in EMG amplitude across multiple muscle groups (Ali et al., 2015; Apriantono et al., 2006; Hill et al., 2016). Furthermore, such protocols are expected to produce broader and more pronounced impairments in whole-body posture, alterations in movement patterns, and changes in joint angles affecting both the upper and lower extremities (Henderson et al., 2003; McDonald et al., 2019; Minning et al., 2007; Murdock & Hubley-Kozey, 2012).

Despite the decline in shooting accuracy, joint angles (ankle, knee, hip, shoulder, and elbow) and most joint angular velocities remained unchanged, suggesting that fundamental shooting mechanics were preserved. However, elbow angular velocity showed a significant reduction (-5.08%), indicating that fatigue may compromise rapid elbow extension, a critical movement in the shooting sequence. This aligns with previous findings demonstrating that fatigue-induced changes in kinematics often manifest in specific movement components rather than across entire movement patterns (Erculj & Supej, 2009; Tsia et al., 2006). Interestingly, ball release variables, including velocity (Vx, Vy), ball release height, and ball release angle, did not significantly change post-fatigue. While prior research has shown that fatigue can alter ball velocity in sports such as soccer and basketball, those studies typically employed higher-intensity fatigue protocols involving whole-body exertion (Apriantono et al., 2006). The moderate fatigue level in this study, focused solely on the upper extremity, may explain why larger-scale kinematic disruptions were not observed.

EMG analysis revealed that triceps brachii (both medial and lateral heads) activity remained stable, suggesting that triceps function was not significantly affected by the applied fatigue protocol. Consistent with our results, previous research also indicates that basketball-specific fatigue does not impact Triceps Brachii EMG activation in the shooting arm during a three-point jump shot in adolescent athletes, emphasizing its stability and consistent role in the shooting motion despite fatigue (Peterca & Dolenec, 2019). However, palmaris longus activation significantly declined (-4.68%), indicating reduced wrist stability and grip control, which could contribute to altered shot release mechanics. Similar reductions in wrist muscle activation have been reported following localized upper extremity fatigue protocols (Balestra et al., 2001; Peterca & Dolenec, 2019). Considering the function of the palmaris longus in stabilizing wrist flexion, its fatigue-related decline may have contributed to less controlled ball release, leading to more frequent airballs and missed shots.

While prior studies have reported significant reductions in muscle activation following fatigue (Ali et al., 2015; Rashid et al., 2020), these effects are often observed under more intense conditions. The moderate intensity of the 40% MVIC fatigue protocol may explain why major EMG alterations were limited to the palmaris longus rather than affecting the entire upper limb.

Strengths and limitations

This study provides a detailed analysis of fatigue's impact on basketball shooting by integrating kinematic, neuromuscular, and performance-related parameters. It examines the triceps brachii and palmaris longus, key muscles in elbow extension and wrist flexion, to offer deeper insights into their roles in shooting mechanics under fatigue-induced conditions. These muscles have not been extensively explored in previous research on basketball-related fatigue, and their inclusion brings a fresh perspective on their contribution to shooting mechanics. The study also enhances its practical relevance by assessing free throw performance, a fundamental basketball skill, under both pre-fatigue and post-fatigue conditions.

However, some limitations should be acknowledged. The controlled testing environment may not fully reflect in-game conditions, where psychological factors, defensive pressure, and reactive decision-making can influence shooting mechanics. Additionally, the lack of physiological measures (e.g., heart rate, blood lactate) limits the ability to quantify overall systemic fatigue levels. Another limitation of this study is the lack of detailed information regarding participants' individual strength training histories, which may have influenced their neuromuscular responses to the fatigue protocol. Future research should consider incorporating game-like scenarios and higher-intensity fatigue protocols to explore whether more pronounced kinematic disruptions occur under realistic competitive conditions.

CONCLUSION

This study demonstrated that fatigue negatively impacts elbow kinematics, palmaris longus neuromuscular function, and shooting accuracy in adolescent basketball players. Specifically, elbow angular velocity decreased, and palmaris longus activation declined, suggesting impairments in wrist stability and grip control, both crucial for consistent shot release. To mitigate fatigue-related declines in shooting accuracy, basketball training programs should incorporate fatigue-resistant exercises targeting wrist stabilizers and upper limb endurance. Players may also need to adjust their release mechanics to compensate for fatigue-induced

changes in elbow velocity and grip stability, ensuring consistent shooting performance throughout a game. By implementing these evidence-based training strategies, coaches and athletes can enhance fatigue resilience, ultimately improving game-time shooting accuracy and overall performance.

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Declaration of conflicting interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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SLOW GAIT SPEED IS ASSOCIATED WITH FRAILTY IN OLDER ADULTS FROM NURSING HOMES

POČASNA HOJA JE POVEZANA S STAROSTNO KRHKOSTJO PRI UPORABNIKIH DOMOV ZA STAREJŠE

ABSTRACT

Age-related frailty is a condition of diminished physiological reserves that increases the risk of falls, disability, hospitalisation and mortality. Frailty is usually associated with a lack of physical activity. The aim of this study was to determine whether a frail phenotype can be identified by gait speed. 94 older residents (83.6 ± 7.9 years, 68% women) from Slovenian nursing homes were included as study participants in this cross-sectional study. Frailty was assessed using Fried's Frailty Phenotype Protocol and gait speed was measured over a distance of 4.5 m. We used relative risk to determine whether gait speed was an indicator of frailty. Most of the residents were pre-frail (63%) or frail (16%). Gait speed was significantly lower in the frail group by -0.21 s (U = 331.5; p < 0.001) and a gait speed ≤ 0.457 m/s increased the risk of frailty by 40% (RR=1.40 (CI 1.15-1.70); p=0.0008). We suggest using gait speed as a simple indicator of potential frailty in nursing homes. Persons at risk should be included in a detailed diagnosis and advised on suitable measures. In particular, physical activity seems to prevent the occurrence of frailty.

Keywords: exercise, aged, nursing homes, geriatric syndrome

IZVLEČEK

Starostno krhkost označujejo zmanjšane fiziološke rezerve, kar povečuje tveganje za padce, invalidnost, hospitalizacijo in umrljivost. Krhkost je običajno povezana tudi s pomanjkanjem telesne dejavnosti. Namen te študije je bil ugotoviti, ali je krhke starostnike mogoče prepoznati na osnovi hitrosti hoje. V prečno-presečno raziskavo je bilo vključenih 94 uporabnikov domov za starejše (83,6 ± 7,9 let, 68% žensk) v zahodni Sloveniji. Krhkost je bila določena z metodo Friedovega fenotipa krhkosti in hitrost hoje je bila izmerjena na dolžini 4.5 m. Da bi ugotovili, ali je hitrost hoje pokazatelj morebitne krhkosti, smo uporabili metodo relativnega tveganja. Večina uporabnikov je bila pred-krhkih (63%) ali krhkih (16%). Hitrost hoje je bila v skupini krhkih značilno nižja za 0.21 s (U = 331,5; p < 0,001) in hitrost hoje ≤ 0,457 m/s je tista, ki poveča tveganje za krhkost za kar 40% (RR=1,40 (CI 1,15-1,70); p=0,0008). Predlagamo uporabo hitrosti hoje kot preprostega pokazatelja potencialne krhkosti v domovih za starejše. Ogrožene posameznike je potrebno vključiti v poglobljeno diagnostiko ter ustrezne intervencije, pri čemer ima telesna dejavnost pomembno vlogo pri preprečevanju krhkosti.

Ključne besede: telesna aktivnost, starostniki, domovi starejših občanov, geriatrični sindrom

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INTRODUCTION

Frailty is a state of reduced physiological reserves that increases the risk of disability. One of the main causes of frailty is lack of physical activity, accompanied by episodes of physiological loss due to illness, injury and reduced recovery (Buchner & Wagner, 1992). Frailty is prevalent in older adults and represents a burden on the healthcare system (Walsh et al., 2023) while increasing the risk of falls (Yang, Lin, Jiang, Chu, Gao, Tong & Wang, 2023), fractures (Kojima, 2017), cardiovascular morbidity (Liu, Tou, Gao, Gwee, Wee & Ng, 2022) and cognitive impairment (Searle & Rockwood, 2015).

The prevalence of frailty and prefrailty among community-dwelling older adults (75-84 years) in Slovenia is 22.2 % and 45.8 % respectively and is in line with data for European countries (20.3 % for frailty and 48.5 % for prefrailty) (Jazbar, Pišek, Locatelli & Kos, 2021). Both the frail and the prefrail state are significant predictors of admission to a nursing home (Kojima, 2018). Nursing home residents are expected to be very frail, but there is little evidence of frailty in the literature (Kojima, 2015). Two systematic reviews and meta-analyses provide a pooled estimate of the prevalence of frailty (40.2% and 51.5%) and prefrailty (20.0% and 53.3%) in nursing homes (Kojima, 2015; Veronese et al., 2021).

One of the most common diagnostic method for physical frailty is the Fried' s frailty phenotype, in which frailty is defined as meeting 3 or more of the following 5 components: unintentional weight loss, self-reported fatigue, weakness, slow walking speed and low physical activity (Fried et al., 2001). Thus, the assessment of frailty requires five predefined variables, which may not always be convenient. Simpler instruments seem to be a useful indicator of frailty. For example, a gait speed of less than 0.8 m/s is a highly sensitive indicator of frailty in community-dwelling older people (Clegg, Rogers, & Young, 2015). From a kinesiological perspective, it is important to recognize that most causes of frailty are potentially reversible to some degree (Buchner & Wagner, 1992) and that physical activity plays a crucial role in reducing frailty (Huang, Chou, Liang, Lin, Chen & Wu, 2023). Encouraging data based on a survey showed that, in median residents of Slovenian nursing homes exceeded the limits for low physical activity (Šporin & Zerbo Šporin, 2021).

The aim of the present study was to determine whether a frail phenotype can be identified in older adults from nursing homes based on gait speed. We first determine the prevalence of frailty using Fried's Frailty Phenotype Protocol and then assess the diagnostic ability of gait

speed in frail individuals. We hypothesize that residents with a slower gait speed are more likely to be frail.

METHODS

Participants

Older adults from six nursing homes in western Slovenia were invited to participate in a study investigating the prevalence of sarcopenia and frailty. To be eligible, residents had to be 65 years or older, able to stand and walk (including with mobility aids) and score above 18 on the Mini-Mental State Examination (Granda, Mlakar & Vodušek, 2003). Participation was voluntary and free of charge, and we received written informed consent from 128 people. After excluding those who were unable to complete the Fried`s frailty phenotype assessment protocol, a total of 94 participants were included in the study. All measurements were performed in the nursing homes by trained staff. We adhered to the ethical guidelines of the Declaration of Helsinki and obtained approval from the National Medical Ethics Committee of the Republic of Slovenia (No. 0120-321/2017-4).

Study protocol

In the cross-sectional study, the prevalence of frailty and prefrailty was assessed according to the guidelines on frailty phenotype (Fried et al., 2001). Components such as unintentional weight loss, poor endurance and energy, weakness, slowness and low physical activity level were assessed. A frailty phenotype was confirmed by the presence of three or more of the previously listed components, while the presence of one or two components indicated a prefrailty state. *Unintentional weight loss* was defined as weight loss of ≥ 4.5 kg in the past year. *Poor endurance and energy:* self-reported exhaustion using a CES-D scale (Orme, Reis & Herz, 1986). This criterion was met if participants scored 2 or 3 on at least one questions. *Weakness* was measured by handgrip strength using a hand-held hydraulic dynamometer SH5001 (SAEHAN Corporation, Changwon, Korea), twice for each hand, with the best result (kg) used for scoring (Roberts, Denison, Martin, Patel, Syddall & Cooper, 2011). Cut-off values were stratified by gender and body mass index (BMI) according to Fried and colleagues' criteria. In men, handgrip strength of less than 29 kg (BMI ≤ 24), 30 kg (BMI = 24.1–28.0) or 32 kg (BMI > 28) was considered the cut-off point for weakness. For women, handgrip strength of less than 17 kg (BMI ≤ 23.0), 17.3 kg (BMI = 23.1–26.0), 18 kg (BMI = 26.1–29.0) or 21 kg (BMI > 29.0) was considered the cut-off point for weakness (Liu, Chen, Jiang, Zhou & Tang,

2020). *Slowness* was assessed by walking time on the 4.5 m marked walking track with manual time measurement. The shortest time of two trials was considered. Cut off values were stratified by gender and height. Men's height ≤ 173 cm; walking time ≥ 7 seconds and > 173 cm; walking time ≥ 6 seconds, women's height ≤ 159 cm; walking time ≥ 7 seconds and > 159 cm; walking time ≥ 6 seconds were considered positive for slowness (Fried et al., 2001). The gait speed was given in m/s (Maggio et al., 2016). In nursing home residents, a gait speed of less than 0.475 m/s was associated with a greater health risk (Kuys, Peel, Klein, Slater & Hubbard, 2014). Low physical activity level was determined using the modified Minnesota Leisure Time Physical Activity Questionnaire and calculating kilocalories (kcal) expenditure per week (Taylor, Jacobs, Schucker, Knudsen, Leon & Debacker, 1978). Energy expenditure bellow 383 kcal/week in men and 270 kcal/week in women meets the criteria for frailty.

Data analysis

Microsoft Office Excel (MS for Windows 365 MSO, 2017) was used for data collection. The data was presented descriptively using median values and interquartile ranges (Mdn (IQR)). The Mann-Whitney U test for independent samples was used to assess differences in walking time and gait speed between frail/prefrail (e. g. frail group) and non-frail (e. g. non-frail group) participants. The association between gait speed and frailty was assessed using the relative risk (RR) with 95% confidence intervals (CI). We analysed whether there was a difference in the prevalence of frailty and prefrailty in an exposed group with participants with a gait speed of less than 0.475 m/s and a non-exposed group with participants with a gait speed of more than 0.475 m/s. IBM SPSS Statistics 29.0.0.0 software (SPSS inc., Chicago, IL) was used to analyse the data.

RESULTS

The mean age of the nursing home residents in our sample was 83.6 ± 7.9 years. Of the 94 participants in the study, 64 (68 %) were women and 30 (32%) were men. According to Fried`s frailty phenotype, most of them were prefrail (63%), followed by non-frail (21%) and frail (16%) (Figure 1).
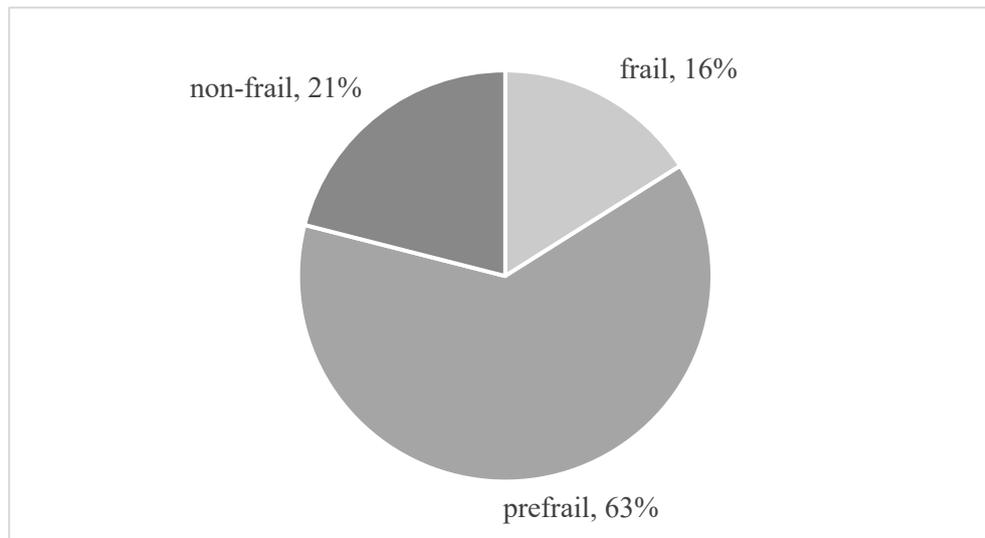
Figure 1. Percent of frail, prefrail and non-frail nursing home residents.

From here, prefrail and frail participants were combined into one frail group. The median walking time and gait speed over a distance of 4.5 m with IQR were 6.32 s (1.29) and 0.70 m/s (0.15), respectively, in the non-frail group, while they were 8.96 s (4.38) and 0.49 m/s (0.25) in the frail group. A Mann-Whitney test showed that the walking time in the frail group was significantly higher (U = 1146.0; $p < 0.001$) and the gait speed significantly lower (U = 331.5; $p < 0.001$) than in the non-frail group (Table 1, Figure 2).

Table 1. Walking time and gait speed on a 4.5 m long track in frail and non-frail nursing home residents.

	Mdn (IQR)		U (p)
	Frail group	**Non-frail group**	
Walking time (s)	8.96 (4.83)	6.32 (1.29)	1146.0 ($p < 0.001$)
Gait speed (m/s)	0.49 (0.25)	0.70 (0.15)	331.5 ($p < 0.001$)

Notes. Mdn = median; IQR = interquartile range; U = Mann – Whitney U; p = level of statistical significance
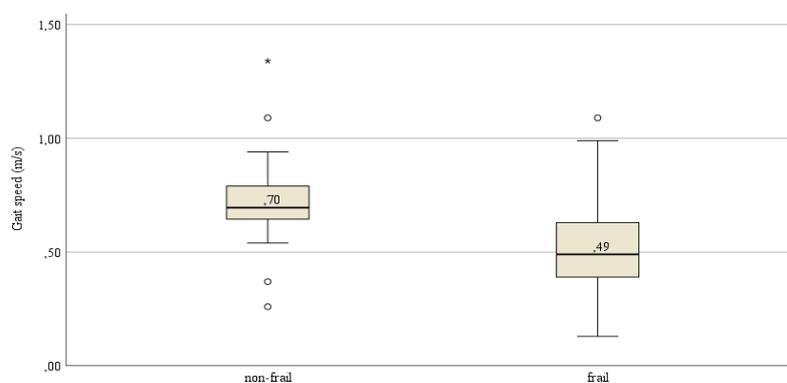
Figure 2: Median gait speed with percentiles in frail and non-frail nursing home residents.

We used relative risk to determine whether gait speed indicates frailty. The risk of frailty and prefrailty was 40% higher in the exposure group with a gait speed ≤ 0.457 m/s than in the non-exposure group of nursing home residents with a gait speed > 0.457 m/s (RR=1.40 (CI 1.15-1.70); p=0.0008) (Table 2).

Table 2. The distribution of frailty cases in the exposed and non-exposed group with regard to the gait speed.

		Frailty or prefrailty		Total (%)
		yes	**no**	
Gait speed ≤ 0.457 m/s	yes n (%)	36 (95%)	2 (5%)	38 (40%)
	no n (%)	38 (68%)	18 (32%)	56 (60%)
				94 (100%)

Notes. n = number

DISCUSSION

Age-related frailty is associated with a high risk of falls, disability, hospitalisation and mortality (Fried et al., 2001). Consequently, detection and intervention are therefore important. The protocols for determining frailty are not easy to use. Therefore, in nursing homes it is useful to find easily measurable parameters such as gait speed to assess possible frailty.

Studies on frailty are very heterogeneous, with the mean prevalence of frailty in nursing homes ranging from 19.0 to 75.6% (Kojima, 2015). We found 16.0% frail residents, which is consistent with the lowest mean prevalence from the previously mentioned article. The result seems positive, but an important piece of information from our study is that in a sample of Slovenian nursing homes we have 63.0% prefrail residents who may become frail and are at high risk of negative outcomes if not included in interventions.

Physical performance factors are associated with frailty in nursing homes. Compared to non-frail people, frail people have lower physical and muscular performance (Buckinx, Reginster, Petermans, Croisier, Beaudart, Brunois & Bruyère, 2016). Gait speed correlates to frailty and functional and physical decline (Mierzwicki, 2024). As we had expected, the frail group showed a longer median walking time of 2.64 s (p < 0.001) and a lower gait speed of – 0.21 s (p < 0.001) over a 4.5 m distance compared to the non-frail group. The association between reduced gait speed and frailty, especially in women, is evident in older people living in the community

(Binotto, Lenardt & Rodríguez-Martínez, 2018), but less is known about this association in nursing homes.

Walking faster than 1.0 m/s is associated with better survival in community-dwelling older people, but the usual gait speed in long-term care is 0.475 m/s (Kuys, Peel, Klein, Slater & Hubbard, 2014). Therefore, we use this threshold to isolate residents at higher risk of age-related decline in functionality and reserve. Those with a gait speed ≤ 0.457 m/s have a 40.0% higher risk of frailty than faster walkers (RR=1.40 (CI 1.15-1.70); p=0.0008). Similarly, a recent study by Chan, Fung, Chan & Yang (2024) found that gait speed is an important indicator of frailty in nursing home residents. A walking test is easy and safe to perform and lower speed values are significantly associated with frailty. Slow walkers should be addressed to proper interventions. Interventions to improve frailty-related status include exercise, nutrition, multicomponent interventions and personalised geriatric care models (Walston, Buta & Xue, 2018). Exercise-based interventions appear to be effective in preventing the onset of frailty (Eidam et. al., 2024), but also in reversing or mitigating it (Bray, Smart, Jakobi & Jones, (2016). In particular, supervised and controlled resistance training is an effective intervention in the treatment of frailty (Lopez, Pinto, Radaelli, Rech, Grazioli, Izquierdo & Cadore, 2018).

Strengths and limitations

This study has potential limitations. The results obtained may not reflect physical performance and frailty prevalence among all Slovenian nursing home residents. In addition, we included only participants who met specific inclusion criteria.

CONCLUSION

Results of our study show that 63% of pre-frail and 16% of frail nursing home residents need to be addressed to prevent negative health outcomes. We propose to find them with a simple approach using a gait speed test, because slow walkers (≤ 0.457 m/s) have a 40.0% higher risk of frailty.

Acknowledgments

Declaration of Conflicting Interests

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STRESSED BUT STILL IN THE GAME: HOW FOCUS AND REM SLEEP SHAPE DAILY ENGAGEMENT IN ELITE ATHLETES

POD STRESOM, A ŠE VEDNO V IGRI: KAKO OSREDOTOČENOST IN REM SPANJE OBLIKUJETA VSAKODNEVNO ZAVZETOST VRHUNSKIH ŠPORTNIKOV

ABSTRACT

Elite athletes experience substantial psychological and physical stress that can undermine motivation and engagement in daily training and competition. Drawing on the Job Demands–Resources (JD-R) model, this study examines how daily sport-related stress affects sport engagement in elite athletes, focusing on the mediating role of attentional focus and the moderating role of REM sleep. Nineteen professional female handball players from Slovenia participated in a 60-day experience sampling study during the competitive season. Participants completed daily mobile surveys assessing stress, focus, and engagement, and wore validated Oura rings to track nightly REM sleep. In total, 1,020 daily observations were collected and analyzed using multilevel modeling. The results indicate that higher levels of perceived stress were associated with lower sport engagement the following day. This negative relationship was positively mediated by attentional focus: although stress tended to impair concentration, individuals who maintained higher attentional focus remained more engaged. Importantly, REM sleep moderated this relationship such that the negative impact of stress on engagement was slightly attenuated following nights with more REM sleep. The study extends JD-R theory by identifying REM sleep as a physiological buffer against stress. Practically, the results support interventions targeting stress management, attentional control, and sleep quantity to maintain sport engagement. We used a lagged daily design in which stress reported on Day 1 and REM sleep recorded during Night 1 predicted focus and engagement assessed on Day 2. The study demonstrates the value of combining self-reports with objective sleep tracking to understand within-athlete fluctuations in well-being and performance.

Keywords: sport engagement, sport-related stress, attentional focus, REM sleep, job demands–resources model

IZVLEČEK

Vrhunski športniki doživljajo znatne psihološke in telesne obremenitve, ki lahko oslabijo motivacijo in zavzetost za vsakodnevne treninge in tekmovanja. Na podlagi Modela delovnih zahtev in virov (JD-R) v prispevku preučujemo, kako dnevni delovni stres vpliva na športno zavzetost vrhunskih športnikov, pri čemer je naš glavni cilj preučiti vlogo osredotočenosti kot mediatorja in REM spanja kot moderatorja. V raziskavi je sodelovalo devetnajst poklicnih rokometašic iz Slovenije, ki so v času tekmovalne sezone sodelovale v 60-dnevni študiji z metodo izkustvenega vzorčenja. Udeleženke so vsak dan izpolnjevale mobilne vprašalnike o stresu, osredotočenosti in zavzetosti ter ponoči nosile validirane prstane Oura, ki so beležili njihovo REM spanje. Skupno je bilo zbranih 1.020 dnevnih opazovanj, ki smo jih analizirali z uporabo večnivojskega modeliranja. Rezultati kažejo, da so bile višje ravni zaznanega stresa povezane z nižjo športno zavzetostjo naslednji dan. V tej negativni povezavi kot mediator nastopa osredotočenost. To pomeni, da kljub temu, da stres zmanjšuje koncentracijo, športnice z višjo ravnijo osredotočenosti ohranjajo večjo zavzetost pri športu. Ključna ugotovitev je tudi, da REM spanje omili negativni vpliv dnevnega delovnega stresa na zavzetost, ki je nekoliko manjši po nočeh z več REM spanja. Študija bogati teorijo JD-R z vključitvijo REM spanja kot fiziološkega blažilca stresa. S praktičnega vidika rezultati podpirajo aktivnosti za obvladovanje stresa, nadzor osredotočenosti in količino spanja za ohranjanje športne zavzetosti. Uporabili smo zamaknjen dnevni raziskovalni dizajn, v katerem smo stres merili zvečer, REM spanje ponoči, osredotočenost in zavzetost pa nato ocenili naslednji dan. Študija tudi poudarja pomen kombinacije samoocenjevanja in objektivnega spremljanja spanja za razumevanje dobrega počutja in uspešnosti športnikov.

Ključne besede: zavzetost pri športu, s športom povezan stres, osredotočenost, REM spanje, model delovnih zahtev in virov

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INTRODUCTION

Elite athletes face continual psychological and physical demands. Striving for excellence in high-pressure sporting environments requires extended training sessions, frequent competitions, rigorous travel schedules, and constant performance expectations – all contributing to elevated stress levels (Nicholls & Polman, 2007; Lundqvist & Sandin, 2014). While short-term stress can be motivating, prolonged or excessive stress impairs emotional well-being, reduces motivation, and undermines athletic performance (Fletcher & Sarkar, 2012). Recent reviews confirm that stress is a pervasive and multifaceted issue for elite athletes, encompassing both competitive and organizational dimensions (Nuetzel, 2023; Halson et al., 2021). These effects are not only cumulative but also fluctuate significantly from day to day, highlighting the need for research that captures within-person processes in real time (Tenenbaum et al., 2013; McCormick et al., 2015).

A particularly vulnerable domain in this regard is sport engagement; a state marked by high vigor, dedication, and absorption in sport-related tasks (Lonsdale et al., 2007). Engaged athletes tend to be more committed, focused, and emotionally invested in their performance, which predicts greater achievement and lower burnout risk (Hodge et al., 2009). However, elevated stress may compromise athletes' ability to sustain engagement. In occupational contexts, stress consistently reduces daily work engagement (Sonnentag, 2003; Bakker & Demerouti, 2007), raising the question of whether the same holds true for elite athletes. In this study, we conceptualize *work stress* as perceived sport-related stress; that is, the psychological pressure and strain athletes experience in relation to their daily training, performance demands, recovery expectations, and sport-related responsibilities. We therefore hypothesize:

> *H1: Sport-related stress negatively affects sport engagement of elite athletes.*

Evidence points to attentional focus as a possible central mechanism in this relationship. By attentional focus, we refer to the athlete's capacity to maintain concentration on task-relevant cues while resisting internal or external distractions during training or competition (Wulf, 2013). Stress often leads to intrusive thoughts, emotional distraction, or cognitive overload, impairing concentration (Laborde et al., 2014; Wilson et al., 2009). In sport, reduced focus is linked to poor decision-making, increased performance errors, and lower task involvement (Janelle, 2002; Nideffer, 1990). Athletes who struggle to concentrate may find it harder to immerse themselves in training or competition, even when physically prepared. Studies using the Test of Attentional and Interpersonal Style (TAIS) highlight that maintaining focus under

pressure is critical for elite performance (Nideffer, 2002). day-to-day changes in focus explain how stress leads to disengagement. However, few studies have explored whether day-to-day changes in focus explain how stress leads to disengagement. One notable exception is Van Yperen et al. (2015), who found that attentional states fluctuate meaningfully and relate to daily motivation in athletes. Similarly, McCormick et al. (2018) emphasized the dynamic nature of focus under pressure, but did not test it as a mediator between stress and engagement. To address this gap, we propose:

H2: Attentional focus mediates the relationship between sport-related stress and sport engagement of elite athletes.

Beyond cognitive mechanisms, REM sleep (Rapid Eye Movement sleep) is emerging as a vital yet underexplored personal resource in elite sport. REM sleep is the stage of sleep associated with vivid dreaming and emotional processing (Blumberg et al., 2020). REM sleep supports emotional processing, neural plasticity, and stress regulation (Walker & van der Helm, 2009; Goldstein & Walker, 2014). Neurophysiological evidence shows that REM sleep dampens noradrenergic activity linked to arousal and fear responses, enabling emotional recovery (van der Helm et al., 2011). Psychologically, REM sleep may enhance stress resilience by facilitating overnight emotional recalibration (Suchecki et al., 2012). While general sleep quality is associated with engagement and performance in both workplace (Litwiller et al., 2017) and athletic contexts (Samuels, 2008), the moderating role of REM sleep in daily sport engagement remains largely unexplored. Accordingly, we hypothesize:

H3: REM sleep moderates the relationship between sport-related stress and sport engagement of elite athletes.

Our conceptual model (Figure 1) is grounded in the Job Demands–Resources (JD-R) framework (Bakker & Demerouti, 2007), which posits that stress, as a demand, depletes personal energy and reduces engagement unless counterbalanced by resources – whether external or internal. Applied to elite sport, we conceptualize REM sleep as a replenishable personal resource that may buffer the negative effects of daily stress. We also examine attentional focus as a key pathway through which stress undermines athletes' capacity to stay buffered and committed to sport tasks. To test this model in real time, we used a lagged day-level design, in which perceived stress was assessed on Day 1, REM sleep recorded during the following night (Night 1), and focus and engagement measured on Day 2.
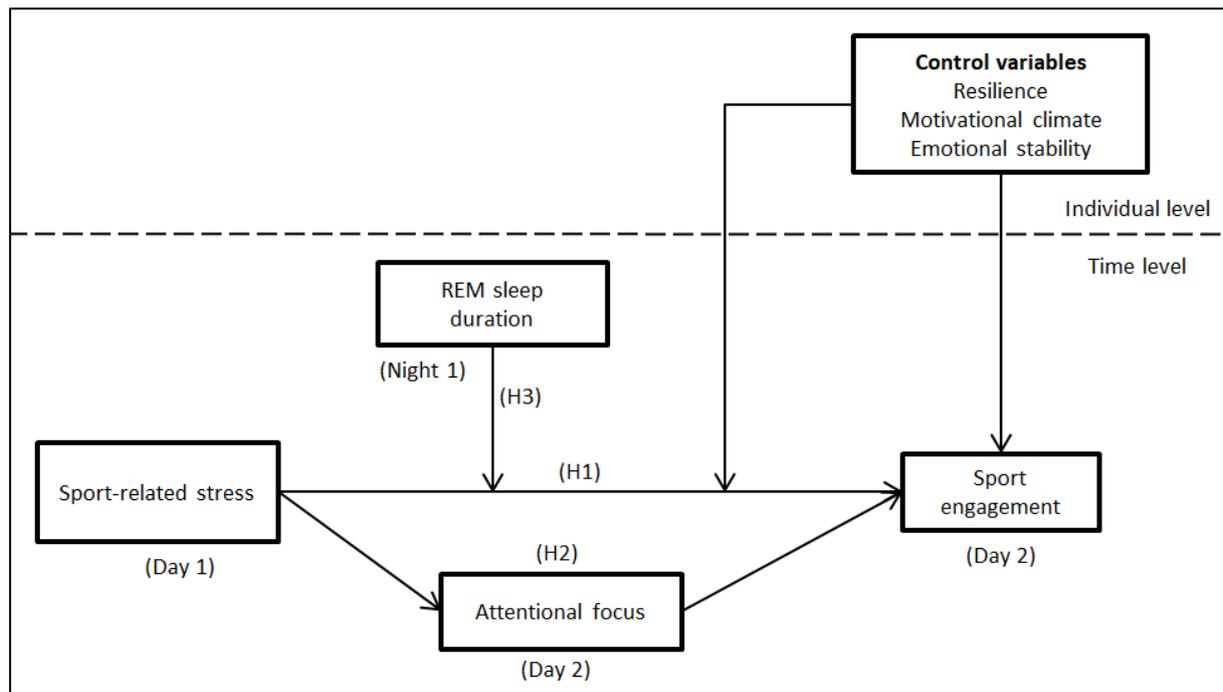
Figure 1. The hypothesized model.

METHODS

Participants

Nineteen female professional handball players from RK Krim Mercator (Ljubljana, Slovenia) took part in the study. The club competes at the highest national level and regularly in the European Champions League, making these athletes highly experienced and accustomed to intense training and competitive pressure. The sample represented nearly the entire first-team roster for the 2022/2023 season. Participants had a mean age of 24.3 years (SD = 3.2, range 19–30) and averaged 12.3 years of playing experience. All were full-time athletes training daily. Inclusion criteria were team membership and being healthy enough to train and compete during the study period. While players with sleep-related conditions were not efouxplicitly excluded, none reported such issues during pre-study screening.

All participants provided written informed consent. The study was approved by the Institutional Ethics Committee of the University of Ljubljana. Data were treated confidentially. To encourage daily compliance, players received personalized feedback on their sleep and wellness data post-study.

Design and procedure

We used an experience sampling method (ESM) with daily diary surveys over a two-month mid-season period (December 2022 to January 2023), which included regular training, league matches, and a brief winter break. Each participant wore an Oura Ring (Gen2), a validated wearable device that tracks physiological signals and estimates nightly REM sleep duration. The Oura Ring has shown high agreement with gold-standard polysomnography for sleep detection and good accuracy in identifying sleep stages (de Zambotti et al., 2019), making it suitable for research use.

Participants received a mobile survey link each evening at 9:00 PM and were asked to complete it before bedtime, reflecting on that day's training or competition. The survey took approximately 3–5 minutes and measured perceived stress, attentional focus, and sport engagement. Responses were time-stamped, and adherence was monitored. Compliance was high, with participants completing surveys on 89% of study days (range: 80–100%), resulting in 1,020 of 1,140 possible daily observations (19 athletes × 60 days).

At the end of the study, sleep data were exported from participants' Oura profiles – accessed via the app's sharing feature – and matched to their daily survey responses. The analysis focused on REM sleep duration. To examine the interaction between sleep and stress on next-day outcomes, we temporally aligned data so that stress was assessed on Day 1, REM sleep during the following night (Night 1), and focus and engagement on Day 2. This lagged design allowed us to explore how prior-day stress and sleep jointly influence next-day cognitive and motivational states.

Measures

All psychological measures in the daily survey were adapted from validated instruments to capture state-level (daily) experiences. Unless otherwise noted, responses were recorded on 5-point Likert scales (1 = very low/strongly disagree, 5 = very high/strongly agree), referencing "today" or "today's training/match". The model includes four key variables:

- *Perceived stress (independent variable)*: Daily stress was assessed using a shortened version of the Perceived Stress Scale – PSS (Chiu et al., 2016), adapted for day-level reporting. Four items were selected and reworded to reflect daily experience. The items were: "Today, how often did you feel that difficulties were piling up so high you could not overcome them?", "Today, how often did you feel unable to control the important things in your life?", "Today, how often did you feel confident about your ability to handle personal problems?" (reverse

coded), and "Today, how often did you feel that things were going your way?" (reverse coded). Athletes rated the extent to which they felt stressed or overwhelmed that day. A mean score of the four items (two reverse-coded per PSS guidelines) represented daily stress, with higher values indicating greater perceived stress.

- *Sport engagement (dependent variable)*: Engagement was measured using a brief version of the Athlete Engagement Questionnaire – AEQ (Lonsdale et al., 2007), capturing daily expressions of confidence, vigor, dedication, and enthusiasm. To keep the survey brief, we used one item for each dimension. Specifically, athletes rated: "Today, I felt energetic and vigorous in my sport activities", "Today, I was enthusiastic about playing/training", "Today, I felt confident in my sport capabilities", and "Today, I was dedicated to giving my best in my sport". The mean of these four items indexed daily sport engagement (higher scores reflect stronger engagement).

- *Attentional focus (mediator)*: Focus was measured using two items based on the Test of Attentional and Interpersonal Style – TAIS (Nideffer, 1990), targeting two key aspects of sport-relevant attention: narrowing focus on task-relevant cues and resisting distraction. The items were: "Today, I was able to stay focused on my training/competition tasks without getting distracted", and "I concentrated well on what was important during practice or the game today". Responses were averaged, with higher scores indicating better attentional focus. While these items were derived from an established instrument, they have not been formally validated for daily (state-level) use, and results should be interpreted with this limitation in mind.

- *REM sleep duration (moderator)*: Measured in minutes, REM sleep was tracked nightly using the Oura ring. Given existing validation studies supporting its accuracy in detecting REM sleep, we used the recorded values as an objective indicator of REM sleep quantity.

To account for individual differences that could influence engagement or stress reactivity, we measured three baseline (once, at the start of the study) *control variables* using single-item indicators for brevity. Resilience (Smith et al. 2008) was assessed with "I tend to bounce back quickly after difficulties", adapted from the Brief Resilience Scale. Motivational climate (Newton et al., 2000) was captured by "Our team environment motivates me to improve and do my best", reflecting perceptions of a supportive vs. pressuring environment. Emotional stability (John & Srivastava, 1999) was measured with "I see myself as emotionally stable (not easily upset or anxious)", indexing general emotional resilience. All items were rated on a 1–5 scale.

Statistical analysis

Given the nested structure of our data (daily observations within individuals), we employed multilevel modeling (hierarchical linear modeling) to test our hypotheses. A two-level model was specified, with daily measures at Level 1 and person-level variables at Level 2. Analyses were conducted using the MLmed macro in SPSS. The analytic procedure included the following steps:

- *Data preparation*: Daily stress (Day 1), REM sleep (Night 1), and next-day attentional focus and engagement (Day 2) were temporally aligned to assess how stress and sleep affect subsequent cognitive–motivational states. Level-1 predictors (stress, focus, REM) were person-mean centered to reflect within-person variation, while Level-2 controls (resilience, motivational climate, emotional stability) were grand-mean centered.

- *Descriptive statistics*: Means, standard deviations, and intercorrelations among study variables were calculated to assess distribution and relationships.

- *Hypotheses testing*: We used multilevel models to test three key effects. Significance of the indirect effect was determined using bootstrapped confidence intervals.

RESULTS

Descriptive statistics

Descriptive statistics, including means, standard deviations, and within-/between-person correlations, are presented in Table 1.

Table 1. Descriptive statistics (means, standard deviations, and pairwise correlations).

Variables	Mean	SD	Sport-related stress	Attentional focus	Sport engage-ment	REM sleep duration	Resilience	Motiva-tional climate	Emotio-nal stability
Sport-related stress	2.05	1.01	-						
Attentional focus	4.11	0.54	.036	-					
Sport engagement	4.13	0.56	.018	.653**	-				
REM sleep duration	70.78	35.81	.109	-.108	.027	-			
Resilience	3.54	0.62	.099	.049	.169*	.211**	-		
Motivational climate	3.89	0.49	.074	.149*	.162*	-.063	.215**	-	
Emotional stability	3.54	0.52	.110	.124	-.105	-.307**	.018**	.164**	-

Notes: **p < .01; *p < .05; †p < .10.

Hypotheses testing

Table 2 presents the hypothesis testing results. For H1 (X → Y), daily stress was found to significantly predict lower next-day engagement (−0.7402, p = 0.0044). For H2 (X → M → Y),

attentional focus was found to significantly and positively mediate the negative relationship between stress and engagement (0.2029, p = 0.0271). Finally, H3 (X × W → Y) was supported, showing that REM sleep moderates the link between stress and engagement.

Table 2. Results of longitudinal analyses using MLmed

Moderated-mediation model	Predicting Focus as mediating variable	Predicting Sport engagement as outcome variable
Within-effects (across time)		
Constant	4.05 (2.29)	2.98 (1.98)
Sport-related stress	0.271 (0.120)	-0.740** (-0.257)
Attentional focus		0.750** (0.065)
Indirect effect of Focus		0.203** (0.092)
Interaction effect: REM sleep duration × Stress		0.000** (0.000)
Between-effects (between individuals)		
REM sleep duration		0.000 (0.000)
Sport-related stress	-0.160 (0.239)	0.017 (0.270)
Attentional focus		0.701* (0.242)
Resilience	0.069 (0.309)	0.247 (0.236)
Motivational climate	0.635 (0.437)	0.025 (0.361)
Emotional stability	0.029 (0.016)	-0.024 (0.013)
Indirect effect of Focus		-0.113 (0.183)
Interaction effect: REM sleep duration × Stress		0.000 (0.000)
Moderated model fit (BIC)		1177.306

Notes: **p < .01; *p < .05; †p < .10.

DISCUSSION

Theoretical implications

This study explored how daily stress affects sport engagement in elite athletes, focusing on the roles of attentional focus and REM sleep. Using intensive longitudinal data from professional female handball players, we found that daily stress undermined athletes' engagement by disrupting their ability to stay mentally focused (H1), consequently highlighting attentional focus as a key mediating mechanism in this process (H2). However, when athletes had sufficient REM sleep the night before, this negative effect of stress was significantly reduced (H3). Together, these findings confirm that daily engagement in sport is shaped not only by psychological demands like stress, but also by the athlete's cognitive resources and physiological recovery.

Our results align with recent evidence showing that psychological stress is one of the most significant predictors of well-being and performance variability in elite athletes (Nuetzel, 2023;

Halson et al., 2021). While most studies have emphasized cumulative or chronic effects, our day-level approach complements this by revealing short-term fluctuations in engagement as a function of daily stress and recovery. For example, Savage and Torgler (2011) showed that stress impacts performance under pressure, consistent with our finding that stress impairs engagement unless buffered by sleep and attentional control.

To our knowledge, this is among the first studies to combine experience sampling with objective sleep tracking in elite sport and apply the JD-R model to within-person variation in sport engagement. Our findings highlight the intertwined roles of psychological and physiological processes in athletes' daily motivation and well-being.

Our results extend JD-R theory into elite sport. Within this framework, daily stress functions as a demand that drains personal energy, reducing engagement unless buffered by sufficient resources. We demonstrated the demand–strain pathway at the individual level by showing that, even within the same athlete, higher stress was associated with lower engagement. This pattern is consistent with findings from workplace research (Demerouti et al., 2001), where elevated stress has been linked to reduced work engagement. Crucially, we identified attentional focus as a mediating mechanism. Sport and cognitive psychology suggest that stress taxes attentional and working memory resources – through worry, distraction, or self-monitoring – limiting the ability to stay task-focused. By measuring focus daily, we showed that stress impaired concentration, which in turn lowered engagement. This bridges JD-R with attentional control theory, indicating that stress weakens top-down focus, likely diminishing the intrinsic rewards of sport activity. Future models of athlete burnout and motivation would benefit from including cognitive mediators like focus as part of the daily loss cycle driven by demands.

We also contribute to JD-R research by identifying sleep – specifically REM sleep – as a key personal resource in sport. While JD-R includes personal resources like self-efficacy, sleep remains underexplored in this context. Our data show that athletes who had more REM sleep the previous night were less vulnerable to the disengaging effects of stress. REM sleep supports emotional processing and physiological recovery (Walker & van der Helm, 2009), and our results suggest it bolsters resilience against daily stressors. Put simply, better REM sleep seemed to buffer the effects of stress, helping athletes maintain stable engagement. Schleupner and Kühnel (2021) similarly found that good sleep promotes work engagement via improved mental health. Our study complements this by demonstrating a direct moderating effect of REM

sleep on a daily timescale. These findings integrate physiological recovery into the JD-R framework and reinforce the role of the mind–body connection in sustaining athlete motivation.

Practical implications

Our findings have clear practical implications. First, the robust negative impact of stress on engagement suggests that stress management is essential for maintaining athlete motivation. Coaches and organizations should monitor stress levels – whether sport-related or stemming from life events – and offer appropriate support such as counseling, rest, or coping skills training. Proactive stress management may help prevent engagement dips that could evolve into poor training quality or burnout.

Second, since focus plays a mediating role, it is important to support athletes in maintaining attentional control under pressure. Mindfulness exercises, pre-performance routines, and attentional refocusing techniques are already common in sport psychology. Our findings offer additional support for these approaches, showing that staying focused not only improves performance but also helps athletes remain engaged and enjoy their sport. Coaches might incorporate drills that simulate pressure and train athletes to redirect attention using cue words or routines. Enhancing this cognitive buffer could reduce athletes' susceptibility to everyday stress.

Third, our results emphasize the protective value of quality, particularly REM-rich, sleep for recovery and mental resilience. While it is well known that poor sleep impairs performance, we show that even within normal variation, more REM sleep helps insulate athletes from the effects of stress. Teams should promote sleep hygiene and consider tracking sleep (e.g., using wearables like Oura rings) to ensure athletes are not just getting enough sleep but enough REM sleep. Adjusting training schedules, improving sleep environments, and teaching relaxation techniques could enhance REM duration. The finding that stress had minimal impact on engagement after nights of high REM sleep offers a powerful message: better sleep may help athletes stay motivated under pressure. This is especially important during intense competition periods, when stress peaks and recovery is crucial. Sports organizations may even consider adjusting early training times post-travel to allow full REM sleep cycles.

Limitations and suggestions for future research

This study has several limitations. First, the small and homogeneous sample – 19 elite female handball players from one team in Slovenia – helped control for extraneous variation but limits

generalizability. Results may differ in male athletes, other sports, or non-elite populations. Replication in larger and more diverse samples is needed to assess broader applicability. Future studies could also explore how these dynamics unfold in different types of sports (e.g., endurance vs. power-based disciplines), in mixed-gender or male teams, and in settings where interpersonal dynamics may influence engagement. Investigating how team-level processes interact with individual-level stress and recovery would offer a valuable extension of the present model.

Second, we relied on self-reported measures of stress, focus, and engagement. Although we used validated instruments (adapted PSS, TAIS, AEQ), self-reports are susceptible to mood and social desirability bias. Still, the within-person daily design – where participants serve as their own controls – helps reduce some of these concerns. Future studies could benefit from adding objective indicators such as coach ratings or training data to triangulate engagement.

Third, causal interpretation is constrained by the observational design, as stress, focus, and engagement were measured around the same time each day. While our model assumes stress affects focus, which in turn shapes engagement, these processes likely unfold dynamically and may influence each other reciprocally. We attempted to structure the timing so that perceived daily stress could precede training focus and end-of-day engagement. Nonetheless, future studies could apply lagged analyses (e.g., prior-day stress predicting next-day engagement) or experimental manipulation (e.g., stress induction) to strengthen causal inference. Fourth, while the moderated mediation model fit the data well, unmeasured day-level factors (e.g., training intensity, coach behavior) may also affect engagement. We included baseline resilience, team climate, and training stability to account for some stable third variables, but daily confounds remain possible.

Finally, although the Oura ring offers a practical way to estimate REM sleep, it does not directly measure brain activity, and sleep staging errors may occur. We assume such errors are random. Validation studies for Oura Gen2 support the reliability of our REM estimates, yet future research should consider polysomnography or complementary measures (e.g., subjective sleep quality, daytime fatigue) for a more comprehensive view. While we focused on REM sleep due to its theorized role in stress and emotional regulation, other dimensions – such as total sleep time, deep sleep, and sleep consistency – may also influence stress-related outcomes. Our findings offer a starting point for deeper exploration of sleep's role in athletic recovery.

CONCLUSION

Despite its limitations, this study offers novel insights into the daily mechanisms that shape sport engagement. Our findings highlight how stress, cognitive focus, and sleep quality interact dynamically to influence motivation and involvement in sport. Elevated perceived stress can undermine engagement, primarily by impairing the athlete's ability to maintain focused attention. However, sufficient REM sleep appears to buffer against these negative effects, helping athletes remain engaged even under pressure. Altogether, the results underscore the multifaceted nature of athlete well-being, where psychological demands and internal resources – such as stress and focus – are closely intertwined with physiological recovery processes like sleep. This interplay ultimately shapes how athletes experience and sustain their engagement on a day-to-day basis.

Declaration of interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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MONITORING THE SUBJECTIVE INTERNAL LOAD IN ELITE LEVEL KUMITE-KARATE ATHLETES: ROLE OF THE REST PERIODS DURATION, BREATHING TECHNIQUES, AND TRAINING VOLUME

SPREMLJANJE SUBJEKTIVNE NOTRANJE OBREMENITVE PRI VRHUNSKIH KUMITE-KARATE ŠPORTNIKIH: VLOGA TRAJANJA POČITKA, DIHALNIH TEHNIK IN OBSEGA TRENINGA

ABSTRACT

Objectives: Study aimed to investigate interdependent effects of rest periods duration, breathing techniques, and training volume, on the set Rating of Perceived Exertion in elite-level karate athletes. Equipment and methods: Nine elite-level athletes (males = 6) participated in this study. We organized six training sessions, each consisting of 200 gyaku-zuki strikes divided into five sets with 40 repetitions per set, with varying rest and breathing techniques (kime, kiai, and without exhalation). The sessions included both short (30 seconds) and long (90 seconds) rest periods, and the training volume was analyzed separately for each of the five sets. Internal load measures were collected from participants during the between-set pauses. Results: The three-way within subject ANOVA have showed the that shorter rest (p = 0.013, η^2 = 0.561) and a higher number of sets (p = 0.000, η^2 = 0.861) lead to higher subjective responses compared to longer rest and fewer sets. Contrary, the subfactors of breathing techniques did not show significant effects (p > 0.05). Conclusion: This study provides insights into the advantages of rest period duration and training volume on subjective load during kumite-karate training sessions for elite-level karate athletes, suggesting that incorporating these factors could be a beneficial approach in designing kumite-karate training.

Keywords: karate training, gyaku-zuki, kime, kiai, World Karate Federation

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IZVLEČEK

Cilji: Študija je bila namenjena raziskovanju medsebojno odvisnih učinkov trajanja počitka, dihalnih tehnik in obsega vadbe na nastavljeno oceno zaznanega napora pri karateistih na elitnem nivoju. Oprema in metode: V tej študiji je sodelovalo devet vrhunskih športnikov (moški = 6). Organizirali smo šest treningov, od katerih je vsak obsegal 200 gyaku-zuki udarcev, razdeljenih v pet serij s 40 ponovitvami na serijo, z različnimi tehnikami počitka in dihanja (kime, kiai in brez izdiha). Treningi so vključevali kratke (30 sekund) in dolge (90 sekund) počitke, obseg treninga pa je bil analiziran ločeno za vsakega od petih sklopov. Meritve notranje obremenitve so bile zbrane od udeležencev med premori med serijami. Rezultati: Tristranska ANOVA znotraj subjekta je pokazala, da krajši počitek (p = 0,013, η^2 = 0,561) in večje število nizov (p = 0,000, η^2 = 0,861) vodita do višjih subjektivnih odzivov v primerjavi z daljšim počitkom in manj nizi. Nasprotno pa podfaktorji dihalnih tehnik niso pokazali pomembnih učinkov (p > 0,05). Zaključek: Ta študija zagotavlja vpogled v prednosti trajanja časa počitka in obsega treninga glede subjektivne obremenitve med treningi kumite-karateja za vrhunske karateiste, kar nakazuje, da bi lahko bila vključitev teh dejavnikov koristen pristop pri načrtovanju treninga kumite-karateja.

Ključne besede: trening karateja, gyaku-zuki, kime, kiai, Svetovna Karate Zveza

INTRODUCTION

Monitoring the training load is intricately related to the training configuration variables (intensity, volume, rest duration, etc.) and can be measured through external and internal load indicators. External load involves tracking objective workload measures (i.e., total work), while internal load pertains to the physiological and psychological stress experienced by the athlete in response to the training sessions, ultimately determining both acute and chronic changes in training outcomes (McGuigan et al., 2021; McLaren et al., 2018). Various objective methods, such as heart rate monitoring, blood markers, or maximum oxygen consumption, can be utilized to measure the level of internal load (McLaren et al., 2018). However, despite the demonstrated validity and objectivity of these methods, their practicality is hindered by the need for specific equipment and organizational challenges. Alternatively, a subjective method based on perceived exertion of training (RPE) has been advocated to quantify internal load (McGuigan et al., 2021; McLaren et al., 2018; McLaren et al., 2017). This approach is grounded in notions demonstrating a strong correlation between RPE and physiological (heart rate, lactate, oxygen consumption) as well biomechanical (e.g., kinetic and kinematic variables, electromyography) and psychological (mood state, motivation, mental stress) measures across various types of training (Borg, 1998; Lagally et al., 2004; Milanez et al., 2011; Robertson & Noble, 1997). The use of RPE is based on the idea that athletes can assess their stress levels during exercise, as well as post-training or competition, ensuring a more personalized and nuanced approach to exercise prescription (Eston, 2012). In available literature, there are two types of the RPE, the one collected through training sessions – set RPE, and the one collected > 10 min. after training sessions – session RPE, and it is worth mentioning that the first RPE derivate is much more unexplored (Halson, 2014; Scott et al., 2016).

Karate, renowned globally as an engaging martial art, is defined by explosive, intermittent, and quick movements performed either by the upper or lower part of the athlete's body (Chaabene et al., 2012). Despite the existence of two distinct forms of karate – kumite (sparring) and kata form (technique without an opponent) – a significant portion of research (Beneke et al., 2004; Helmi Chaabène et al., 2014; Iide et al., 2008; Mori et al., 2002) on the physiological and performance analysis of karate athletes has predominantly centered around kumite matches, whether in real competitions or simulations. Results from these studies demonstrate that kumite karate involves brief, high-intensity actions interspersed with extended periods of low-to-moderate-intensity actions, highlighting the involvement of both aerobic and anaerobic pathways in energy production. Consequently, karate can be classified as a sport exhibiting

moderate-intensity interval characteristics (H Chaabène et al., 2015). On the other hand, limited data exist regarding specifics of kumite training and how training configuration affects internal load during training session, especially in elite athletes. Previously, only Milanez and co-workers (2011) explored the correlation between objective (heart rate, blood lactate) and subjective (RPE) measures of internal load during a karate session, noting a strong correlations ($r = 0.91 - 0.96$). However, their study did not exclusively address how interval load is influenced by different training configurations.

Considering the significance of manipulating *training volume* and *rest periods* in designing strength and endurance-focused training, it is logical to presume that such adjustments might influence internal load parameters during skill-based karate training. The available literature on monitoring karate training is very limited, with no studies found that define techniques, sets, and repetitions, or provide clearly structured training regimens. Additionally, it is important to highlight the existence of two distinct *breathing techniques* in karate: kime, involving the firming of the abdominal wall along with a clear and energetic exhale, and kiai, characterized by a brief shout following kime, aiming to channel the martial artist's energy in a specific attack, consequently enhancing levels of strength and speed in the motor action (Kotarska et al., 2019). Although karate coaches frequently underscoring the importance of *breathing techniques* in karate-specific performance, as far as we know, no study has investigated the effects of different karate breathing techniques on internal load parameters to date. Within the experimental sessions, gyaku zuki technique was applied, as the most used technique in the kumite, with 70% and more of the scoring punches are result from this technique (Laird & McLeod, 2009). Therefore, the objective of the current study was to explore the interdependent impacts of the *rest periods duration*, *breathing techniques*, and *training volume*, on the set RPE in elite-level karate athletes. We hypothesized that set RPE will: a) show higher values in short rest periods (rest period duration 30 sec.) compared to long rest periods (rest period duration 90 sec.), b) rise with higher number of the repetitions (i.e., through sets), and, c) to somehow display difference in the different *breathing techniques*, of GZ performance.

METHODS

Experimental Approach to the Problem

This study, employing a within-subjects design, investigated the combined effects of rest interval duration, breathing technique, and training volume on the set rate of the perceived exertion (RPE) assessment during a set and throughout the session. Participants engaged in one familiarization session and six separate randomized experimental sessions, where the gyaku-zuki (GZ) technique was performed with manipulations in rest period duration, breathing techniques, and training volume. Subsequently, participants provided data on the RPE in each rest period duration.

The first session involved short rest (30 sec.) and kime as the breathing technique. In the second session, the designated breathing technique was kiai, with a 30 seconds rest interval between sets (short rest). The third session, in addition to short rests (30 seconds), required the strike to be performed without simultaneous exhalation. The remaining three sessions described long rest between sets, with the fourth session having kime as the designated breathing technique, the fifth session featuring kiai, and the sixth session executing the strike without simultaneous exhalation.

Sessions were randomized, allowing manipulation of the effects of the rest period duration, breathing technique, and training volume. In all experimental sessions, information on the RPE within the set (set RPE) was collected at a beginning between-set rest period.

Subjects

The subjects in this study consisted of 9 elite karate athletes (males = 6, females = 3). All participants are representatives of Serbia karate team (World Karate Federation association), including medalists in national, Balkan, European, and world competitions, as well as participants in the World Series A events. The characteristics of the participants were as follows: age 20 ± 3.91 years; body height 1.81 ± 0.08 m; body mass 68.44 ± 10.26 kg; body mass index (BMI) 20.98 ± 2.56 kg/m2. Participants did not report any health issues, and no injuries were recorded immediately before, during, or after the experiment that could compromise performance. Prior to the experiment, all participants were briefed on the testing protocol and potential risks (which were minimal). They were also required to sign an informed consent document. The study was approved by the faculty of sport and physical education - Institutional Review Board (No. 02 194/20-2, from 18.02.2020).

Procedure

The experimental sessions were conducted over a 12-day period at a beginning of the summer transitional period, with two days of rest between experimental sessions. Experiments were organized during summer Serbia karate team camp in the summer of the year 2022. Besides experimental sessions, in this camp were performed other training sessions, but in nature they were light, because camp took place in the begging of the between season transitional period. Note that this camp was chosen for experiment realization in counseling with Serbia karate team National coach. Participants executed the GZ strike in all six randomized sessions, consisting of 5 sets of 40 repetitions each (totaling 200 strikes per session). Rest interval duration between sets was manipulated to be either 1) 30 seconds or 2) 90 seconds, along with different breathing techniques: 1) with kime, 2) with kiai, and 3) without exhalation.

Participants performed the GZ technique from the "fudo dachi" stance, involving a simultaneous step forward with the front leg, a strike with the opposite hand, trunk rotation, and the release of the back foot's heel, which remains in the stance. The researchers controlled the rhythm of the GZ strike.

Familiarization Session

This session involved collecting anthropometric measures and familiarizing participants with the research protocol. The research protocol included introducing participants to the RPE CR-10 scale (Table 1) and presenting the type of activity (GZ strike) used during the experiment and its execution method, which is well known technique for athletes of that level. During familiarization with the RPE CR-10 scale, participants were shown the scale with both alphabetical and numerical labels and values, along with an explanation of its use with already described procedures (Sweet et al., 2004).

Table 1. RPE CR-10 scale.

Rating	Descriptor
0	No perceived exertion
1	Very light
2	Light
3	Moderate
4	
5	Hard
6	
7	Very hard
8	
9	
10	Extremely hard

Experimental Sessions

Before the start of each session, all participants had a common warm-up, consisting of 5 minutes of stationary shaping exercises, 5 minutes of running exercises, and 5 minutes of specific karate exercises. Each experimental session involved performing the GZ strike in the air, without a sparring partner, following the rhythm set by the researcher. The strike was performed from the starting position of the "fudo dachi" stance, to which participants immediately returned to execute the next strike promptly. All participants performed the task at maximum intensity. It is very important to stated, that because there were two different experimental rest period durations, two experienced researches carried out all experimental sessions so all participants could simultaneously complete named sessions. The researchers gaved vocal commands to signal the start of testing, execution of strikes, and the end of testing. After each set, at the beginning of each between-set rest period, participants' corresponding internal response (set RPE) to exertion were collected.

Data Collection and Analysis

The experiment was conducted in a sports hall period, between 7:00 AM and 9:00 AM. Experimental sessions were carried out at the begging of the training sessions, so the fatigue couldn't influence on the collected data. The temperature in the hall ranged between 20°C and 23°C. The familiarization session was designed to collect standard anthropometric measures and inform participants about procedures (exercise execution, preferred approach to the test, introduction to the RPE CR-10 scale). Anthropometric measures were taken by the same experienced researcher, following standard procedures recommended by the International

Society for the Advancement of Kinanthropometry (Norton et al., 2000). Body height and weight were measured with an accuracy of 0.5 cm and 0.1 kg, and the Body Mass Index (BMI) was calculated from the obtained data.

Instruments

The instruments used in this research included a stopwatch, used to control the between-set rest period and the rhythm of strike execution (every 2 seconds), and the RPE CR-10 scale, through which participants assessed the subjective response of the perceived exertion.

Statistical analysis

Descriptive statistics were calculated for all experimental data as mean and standard deviation (SD). Normality distribution for all data was assessed by using Shapiro-Wilik test. A repeated measure three-way ANOVA was used to establish effects of applied independent variables (i.e., *rest period duration*: short vs. long; *breathing techniques*: kime vs. kiai vs. without exhalation; and *training volume*: 1st set vs. 2nd set vs. 3rd set vs. 4th set vs. 5th set) on dependent internal load variable set RPE. A Greenhouse-Geisser adjustment was made to the degrees of freedom in case of violation of the sphericity condition. Follow up ANOVAs statistical analysis were processed according to detail explained procedures (Howell & Lacroix, 2012). When the interactions or main effects were revealed, Bonferroni post hoc test with adjustment was applied (Vincent & Weir, 2012).

According to Cohen (Cohen, 2013), the magnitude of difference on the post-hoc test was tested by means of effect size (ES), where difference was considered either very small (0.01), small (0.2), moderate (0.5), large (0.8), very large (1.2) or huge (larger than 2.0) for post hoc test (Sawilowsky, 2009). Percentage differences, along with ES, were calculated in a need of Tables 2 and 3 constructions. On the other hand, the eta squared (η^2) was calculated for the ANOVAs interactions and main effects with the following classification for magnitude effects (Field, 2013): no effect ($\eta^2 < 0.04$), minimum effect ($0.04 < \eta^2 < 0.25$), moderate effect ($0.25 < \eta^2 < 0.64$) and strong effect ($\eta^2 > 0.64$). A significant level of $p < 0.05$ was used for all comparisons. All statistical procedures were analyzed by using SPSS version 20.0 (SPSS Inc., Chicago, IL, USA) and Microsoft Office Excel 2010 (Microsoft Corporation, Redmond, WA, USA).

RESULTS
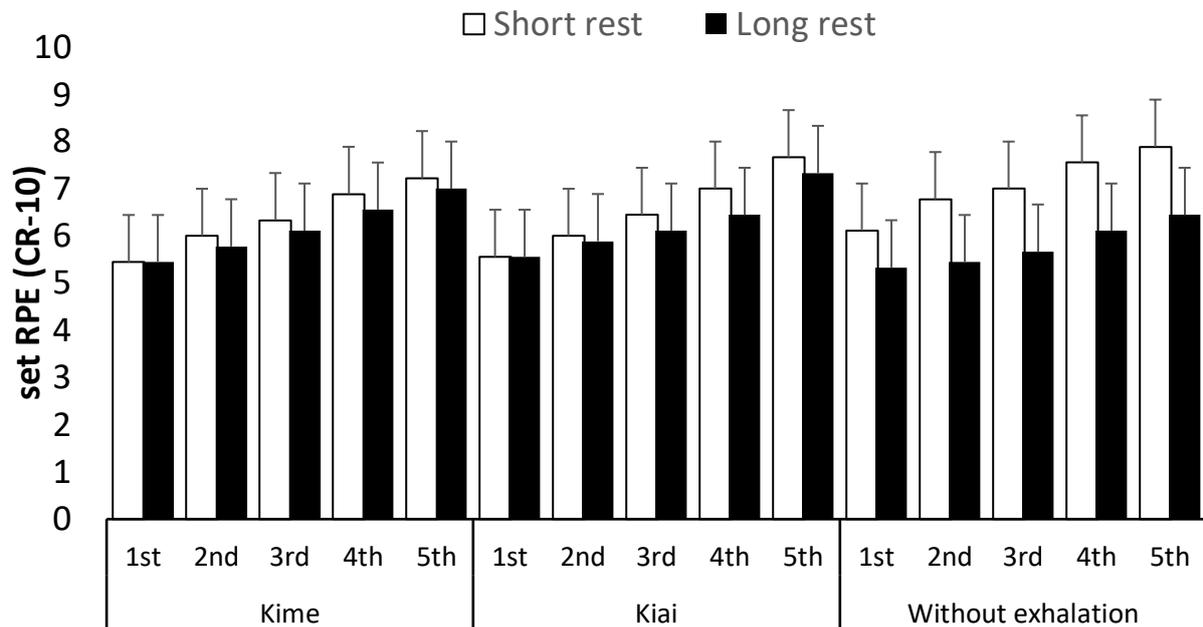
Figure 1. Graphic display of means and standard deviations of the subjective load variable set rating of perceived exertion (set RPE - expressed in values from CR-10 scale), for the rest period duration (short and long rest), breathing technique (kime, kiai, and without exhalation) and training volume (1st, 2nd, 3rd, 4th, and 5th set).

Set rate of perceived exertion (set RPE). The results of this subjective internal load measure are showed in Figure 1. Further, three-way interaction ($p = 0.876$), and two-way interactions *breathing techniques × training volume* ($p = 0.435$) and interactions *rest period duration × breathing techniques* have not reached significance ($p = 0.131$). On the other hand, for two-way interaction *rest period duration × training volume* significance was confirmed ($p = 0.017$), with moderate effect size magnitude ($\eta^2 = 0.351$). Detailed data of the confirmed two-way interaction, which involved percentage differences and effect sizes, highlighted from perspective of training volume and *rest period duration*, are displayed in Tables 2 and 3. Post hoc adjustment Bonferroni have showed that there were no differences between short and long rest sessions on the 1st set ($p = 0.193$). On the contrary, the 2nd set significance was achieved, with short rest sessions showing significantly higher set RPE values than long rest ($p = 0.024$) sessions. Similarly, on the 3rd set set RPE values of the short rest sessions have also showed significantly higher results than on the long rest ($p = 0.008$) sessions. In a case of the 4th set, short rest sessions again confirmed significantly higher values than long rest ($p = 0.014$)

sessions. Further, on the last set (5th), significance was also confirmed in higher values of the short rest, when they were compared with long rest (p = 0.005) sessions. Furthermore, on the short rest sessions, 1st set have showed significantly lower set RPE values compared to 2nd set (p = 0.002), 3rd set (p = 0.000), 4th set (p = 0.000), and 5th set (p = 0.000) values. Set RPE values of the 2nd set have showed significantly lower values than 3rd set (p = 0.017), 4th set (p = 0.000), and 5th set (p = 0.000) values. In the case of the 3rd set, lower set RPE values were detected compared to 4th set (p = 0.002), and 5th set (p = 0.001) values. Additionally, 4th set set RPE values were significantly lower than 5th set (p = 0.016) values. When examining long rest sessions, significances were observed with the set RPE values of the 1st set lower compared to 2nd set (p = 0.008), 3rd set (p = 0.003), 4th set (p = 0.000), and 5th set (p = 0.000) values. Next set (2nd) have showed significantly lower values than 3rd set (p = 0.023), 4th set (p = 0.001), and 5th set (p = 0.000) values. Significantly lower set RPE values of the 3rd set, compared to 4th set (p = 0.002), and 5th set (p = 0.000) values were observed. Finally, set RPE values of the 4th set were observed as lower, compared to the 5th set (p = 0.000) values. Regarding main factor analysis *rest period duration* and *training volume* have showed significance (p = 0.013, p = 0.000, respectively), with *rest period duration* achieving moderate effect ($\eta^2 = 0.561$), and *training volume* achieving strong effect size ($\eta^2 = 0.861$). On the contrary, the main factor *breathing techniques* failed to reach significance (p = 0.795).

Table 2. Presented data through the percentage difference (effect size), and highlighted from perspective of training volume in confirmed two-way interaction rest period duration × training volume.

Training volume	Rest period duration
	SRP vs. LRP
1st	4.55 (0.47)
2nd	8.88 (0.92)
3rd	9.55 (1.17)
4th	10.88 (1.04)
5th	8.78 (1.27)

Notes: SRP - short rest period, LRP, long rest period,

1st – first set, 2nd – second set, 3rd – third set, 4th –

fourth set, 5th – fifth set

Table 3. Presented data through the percentage difference (effect size), and highlighted from perspective of rest period duration in confirmed two-way interaction rest period duration × training volume.

					Rest period duration				
				SRP				LRP	
	1st	vs.	2nd	8.88 (1.49)	1st	vs.	2nd	4.55 (1.17)
			3rd	13.48 (2.67)			3rd	8.70 (1.37)
			4th	20.21 (2.74)			4th	14.53 (1.88)
			5th	24.88 (2.31)			5th	21.39 (2.34)
Training volume	2nd	vs.	3rd	5.06 (1.00)	2nd	vs.	3rd	4.35 (0.93)
			4th	12.44 (3.08)			4th	10.47 (1.79)
			5th	17.56 (2.41)			5th	17.65 (2.59)
	3rd	vs.	4th	7.77 (1.49)	3rd	vs.	4th	6.40 (1.47)
			5th	13.17 (1.66)			5th	13.90 (2.74)
	4th	vs.	5th	5.85 (1.01)	4th	vs.	5th	8.02 (1.92)

Notes. SRP - short rest period, LRP, long rest period, 1st – first set, 2nd – second set, 3rd – third set, 4th – fourth set, 5th – fifth set.

DISCUSSION

This study aimed to investigate the effects of *rest period duration*, *breathing techniques*, and *training volume* on the set RPE in elite-level karate athletes. Specifically, the authors hypothesized that set RPE would: a) be higher in short rest periods (30 seconds) compared to long *rest periods* (90 seconds), b) increase with a higher number of repetitions (i.e., across sets), and c) exhibit differences across the different *breathing techniques* used during GZ performance. Note that these three factors (*training volume*, *rest period duration*, and *breathing techniques*) were observed interdependently. The results showed that *rest period duration* and *training volume* had significant effects both through interaction ($p = 0.017$) and as independent factors (*training volume*: $p = 0.000$, *rest period duration*: $p = 0.013$). However, the *breathing techniques* did not show significant effects in any interaction ($p > 0.05$). The following discussion will focus on understanding and interpreting the main findings related to the subjective internal load variable responses.

Regarding rest period duration, the analysis of set RPE differences between short and *long rest periods* revealed significant effects starting from the 2nd set, with a large effect size (ES = 0.92). This large effect size was maintained through the 3rd set (ES = 1.17) and the 4th set (ES = 1.04), ultimately achieving a very large effect size in the 5th set (ES = 1.27), favoring short

rest periods over long rest periods. Another independent variable showed significance – *training volume* and in this case ES magnitudes were higher in short compared to long rest protocols. In the short rest periods, the ES reached a very large magnitude between the 1st and 2nd sets (ES = 1.49). In the following sets, the ES increased and remained substantial compared to the 1st set (1st vs. 3rd: ES = 2.67; 1st vs. 4th: ES = 2.74; 1st vs. 5th: ES = 2.31). The long rest periods demonstrated a different pattern, with a large effect size between the 1st and 2nd sets (ES = 1.17), which then increased to very large between the 1st and 3rd sets (ES = 1.37) and the 1st and 4th sets (ES = 1.88). Finally, the effect size between the 1st and 5th sets reached a huge level (ES = 2.37).

Unfortunately, no studies have compared the independent or interdependent effects of *rest period duration* and *training volume* in kumite-karate training. The closest comparisons are found in resistance training and body-weight power training, due to their similar set structures. Three previous studies analyzed the effects of *rest period duration* and *training volume* on RPE in resistance training (Farah et al., 2012; Larson Jr & Potteiger, 1997; Woods et al., 2004), and one study examined these effects in body-weight power training (Arsenijević et al., 2023). Woods and co-workers (2004) applied resistance exercises with *rest period duration* of 1, 2, and 3 min. Their results showed that the set RPE was similar between groups that executed different rest period duration, performing knee extension exercises in three sets at 70% of one repetition maximum. Similarly, Larson Jr and Potteiger (1997) conducted experiment with different recovery conditions. Each conditions had length of the 3 minutes, with 1:3 work:rest ratio, in a session of four sets of squat exercise at 85% of the 10-repetition maximum that was performed to failure. Again, obtained results showed no differences in the set RPE between the three recovery conditions (i.e., rest period duration). Conversely, a study by Farah and colleagues (2012), where the same *rest period duration* was applied like in our study (30 sec. and 90 sec. interval of rest between sets sessions), had different findings. In both sessions, five exercises (bench press, knee extension, seated row, knee curl, and frontal rise) were executed at 50% of one repetition maximum through three sets. These differences in the set RPE between two protocols of the *rest period duration* was significant only in the third set and responses were similar for all exercises except for the bench press, and it should be highlighted that the rest period duration in the research (Farah et al., 2012) were comparatively shorter compared to other two researches (Larson Jr & Potteiger, 1997; Woods et al., 2004), which might have caused influence on muscle recovery. Final research that has some similarity with our study was by Arsenijevic and colleagues (2023), who analyzed influence of the different rest period

duration sessions (60 sec. and 120 sec. between sets) and different *training volume* (analyzed for first six sets and for the last six sets – total 144 jumps per session) on the set RPE in body-weight vertical jumping sessions. Results have showed that only *training volume* reached significance, with the first six sets (i.e., small volume; 1st to the 72nd jump) showing lower subjective set RPE responses, compared to last six sets (i.e., large volume; from the 73rd to the 144th jump). Compared to our study, the significant differences in set RPE from the 2nd set onward might be due to the nature of the exercise inducing fatigue (i.e., gyaku-zuki in our study), which differs greatly in loading from the external resistance (i.e., resistance and body-weight) exercises performed in the aforementioned studies.

The important theoretical implications were carried out through this study. Our findings propose that *rest period duration* have showed influence on the subjective internal load, with long *rest periods* that provided lower levels of subjective fatigue, compared to the short rest periods, when performing GZ strike in elite-level kumite-karate athletes. Likewise, *training volume* (sets and reps) structured in this study, demonstrated gradually enlargement of the set RPE from 1st to 5th set, and normally with higher effect size magnitude in the short *rest periods*, compared to long rest periods. This is very practical finding for strength and conditioning experts while monitoring training load, if they are willing to provoke different training stimulus (e.g., higher or lower fatigue) in the training process. Practitioners than should use shorter rest periods and higher number of the repetitions for higher perceptual fatigue, and longer rest periods and lower number of the repetitions for lower perceptual fatigue. Furthermore, this was the first study, to our knowledge, that explored and confirmed influence of the rest period duration and training volume in elite-level kumite-karate athletes.

Contrary to our third hypothesis, the breathing technique did not significantly affect the RPE levels in participants, suggesting that breathing technique is not necessarily relevant for fatigue induction, at least among elite-level karate athletes. This finding is important because no previous study has explored the effects of breathing variants in martial arts training, making it challenging to directly compare our results with earlier research. Several studies, however, have examined the specifics of voluntary breathing and its effects on sports performance in marathon running, cycling, swimming, and resistance training (Blazek et al., 2021; Inbar et al., 2000; Johnson et al., 2007; Kilding et al., 2010). According to previous meta-analyses (HajGhanbari et al., 2013), specific breathing patterns can improve sports performance for some athletes by increasing respiratory muscle strength and endurance. From our data (see Figure 1) it can be seen that study design was appropriate in leading fatigue to high levels of subjective load

(values of set RPE in short rest session were up to 9 in some cases), so the total external load applied was no limiting factor for *breathing technique*. Therefore, although different breathing variants did not alter RPE levels in this study, it seems reasonable to assume that breathing variants may affect kinetic and kinematic performance, or some other training load variables, during specific karate techniques such as gyaku-zuki (GZ). Lastly, future studies should deal with the exploration of other acute training variables on training load in karate-kumite training, which could promote understanding of this specific dose-response in named training process.

The current study has several strengths. Firstly, the sample consisted of elite-level karate athletes, providing valuable insights into training responsiveness in elite-level combat sports. Additionally, we focused on the gyaku-zuki, the most commonly used strike in karate training and competition (Laird & McLeod, 2009). For the first time, we implemented structured and organized training sessions with defined sets, repetitions (total training volume), and *rest period duration*. Although *breathing technique* failed to show any significance, to our knowledge this was the first study to analyze influence of the kime and kiai, as this specific *breathing techniques* in karate are still unexplored. Note that previous research has examined and monitored internal load in karate training but without strictly defined total *training volume* and *rest periods* throughout the sessions (Johnny et al., 2014; Milanez et al., 2011; Tabben et al., 2013).

Concerning the limitations of the study, it should be stated that inclusion of the objective internal load variables (e.g., heart rate, blood lactate levels, etc.) could strengthened the discoveries of the study, but there a lot of confirmation of the relationships between set RPE and objective internal load indicators (Eston, 2012). Another limitation is number of the participants in the study, and is fair to state that is very hard to have available for experiments athletes of this level.

CONCLUSION

Our study underlines the importance of the rest period duration and the *training load* in kumite-karate training, since the obtained findings clearly suggest that longer *rest period duration* are causing less subjective stress, compared to shorter *rest period duration*. Similarly, independent factor *training volume* have showed that lower sets are perceived subjectively easier in comparison to higher number of sets. Specifically, when performing GZ, the manipulation with these two factors in kumite-karate training is desirable in order to provide decrease/increase of

the subjective internal load. Therefore, it appears that the distribution of *rest period duration* between sets, along with the manipulation with the number of sets, in the applied GZ strike, could provide the aforementioned benefits. Hence, it could be concluded that the rest period duration and *training volume* undoubtedly demonstrated potential for its further application in designing kumite-karate training. Unfortunately, *breathing techniques* that are often used in karate sport, failed to display significance on subjective internal load. It is necessary to further explore its effectiveness with respect to other strikes and kicks and the combinations of these two in kumite-karate sport, and to possibly explore effectiveness of other acute training variables (e.g., set structure, number of reps per set, training intensity, etc.) to provide benefits with respect to the acute training effects.

Acknowledgments

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PERSPECTIVE OF PRESCHOOL EDUCATORS ON PHYSICAL EDUCATION: OVERCOMING CHALLENGES AND OFFERING RECOMMENDATIONS

POGLEDI VZGOJITELJEV PREDŠOLSKIH OTROK NA ŠPORTNO VZGOJO: PREMAGOVANJE IZZIVOV IN PRIPOROČILA

ABSTRACT

Background: Incorporating habitual physical activity and building fundamental motor skills in preschool age indeed form a foundation for lifelong health and a healthy lifestyle where qualified preschool teachers can play a pivotal role in influencing this process. Purpose: The presented study aimed to acquire knowledge about preschool teachers' interest in teaching physical education. Methods: The study was conducted in March 2024, involving 112 female preschool teachers from 31 preschools across the Eastern part of Slovakia. An anonymous questionnaire likely encourages open and honest responses, contributing to the reliability of the data. Findings: Even though most teachers are aware of the importance of physical education in children's lives, and many of them are physically active themselves, its implementation is limited by the content of the State Education Program (ISCED 0), the lack of methodological materials and often the negative attitude of the children's caregiver. Conclusion: The results confirmed the need to re-evaluate the content of ISCED 0, especially in the sphere of required competencies, as well as the adjustment of study programs for early child education, where physical education and motor skills development are marginally significant. Furthermore, integrating non-traditional methods, such as bracing and sauna, can further diversify the physical education curriculum and contribute to a more comprehensive and dynamic approach that supports children's health. These methods add variety and motivation, making the learning experience more engaging for the children and the teachers.

IZVLEČEK

Ozadje: Vključevanje redne telesne dejavnosti in razvijanje temeljnih gibalnih sposobnosti v predšolskem obdobju predstavlja temelj za zdravje in zdrav življenjski slog, pri čemer imajo usposobljeni vzgojitelji ključno vlogo pri vplivanju na ta proces. Namen: Študija je bila usmerjena v pridobivanje vpogleda v interes vzgojiteljev za poučevanje vrtčevske športne vzgoje. Metode: Študija je bila izvedena marca 2024 in je zajela 112 vzgojiteljic iz 31 vrtcev z vzhodnega dela Slovaške. Anonimni vprašalnik je verjetno spodbudil odprte in iskrene odgovore, kar prispeva k večji zanesljivosti podatkov. Ugotovitve: Čeprav se večina vzgojiteljic zaveda pomena športne vzgoje v otrokovem življenju in je veliko njih tudi samih telesno aktivnih, je izvajanje gibalnih dejavnosti pogosto omejeno zaradi vsebine državnega izobraževalnega programa (ISCED 0), pomanjkanja metodološkega gradiva in pogosto tudi zaradi negativnega odnosa otrokovih skrbnikov. Zaključek: Rezultati potrjujejo potrebo po ponovni presoji vsebine ISCED 0, zlasti na področju zahtevanih kompetenc, ter po prilagoditvi študijskih programov za zgodnje izobraževanje predšolskih otrok, pri katerih sta športna vzgoja in razvoj gibalnih sposobnosti pogosto zapostavljena. Poleg tega lahko vključevanje netradicionalnih metod, kot sta razgibavanje z oporo (bracing) in savnanje, dodatno popestri kurikulum športne vzgoje ter prispeva k celostnemu in dinamičnemu pristopu, ki spodbuja otrokovo zdravje. Te metode prinašajo raznolikost in dodatno motivacijo, zaradi česar je učna izkušnja bolj privlačna tako za otroke kot tudi za vzgojitelje.

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INTRODUCTION

Physical education in preschool plays a significant role in upbringing and education, assisting in physical, motor, psychological, and social development. (Junger and Palanská 2017, Cheung 2020 et al.). Multiple investigators substantiated the relationship between physical activity (PA) and the development of motor skills (Tanaka et al., 2012; Chen 2013; Larsen et al., 2015) and the subsequent interconnection between specific locomotion skills and other manipulative proficiencies (Haibach et al., 2011) that is the foundation for individual participation in divers form of PA (Wang et al., 2022).

PA contributes to children's health, building PA habits developed in childhood tend to persist into adulthood (Larsen et al., 2015). In addition to genetics, two determinants in particular, the family and the preschool environment, can play a significant role in achieving the required level of a child's physical, motor, psychological, and social development. However, we are unable to influence education in the family directly. Nevertheless, we can influence the focus and content of the educational system managed by the state, primarily through a well-prepared and planned program. In the conditions of ongoing social changes in the Slovak Republic in the last three decades, there have been several adjustments to the educational program aimed at preschool children. The search for an educational principle that would become a modern fundamental factor in preschool education in the current social climate of the Slovak Republic was inspired by new insight in psychology that brought reform and respect for the child's needs, encouragement for the child own activity, requirements for individualization and freedom of the child (Dvořáková, 1998). This was also the foundation for creating the new State Education Program (ŠVP) by the International Standard Classification of Education, ISCED 0, valid in the Slovak Republic since 2008, where the entire concept of the educational process moves in this direction, primarily by applying the principle of the child's activity and expanding opportunities for children's activity which is not indicative to teacher inactivity. The teacher's activity in the non-directive management of the educational activity becomes a crucial factor in addition to the program itself. It consists of the premeditated creation of conditions for the effective self-development of the child's personality, which is impossible without the child's activity (Junger, 2009).

However, the most significant change in the educational activity through ISCED 0 is its content, which aims to achieve the set competencies. While the 2008 initiative "Program for the Education and Training of Children in Pre-school," physical education asserted its

independent position. The new ISCED 0 program from 2008 includes physical education exclusively as a component of the seven competencies – (psychomotor competencies). That led the ISCED 0 program to significantly deviate from the PA standards developed by the National Association for Sport and Physical Education in the USA (NASPE 2002), which was generally accepted in most countries in the world (Finn et al., 2002; Burdette et al. al., 2004; Pate et al., 2004; Reilly et al., 2006; Oja et al., 2010; Sigmund & Sigmundová, 2011; Van Cauwenberghe, 2012). Investigation (Junger & Palanská, 2016) compared two guidelines, ISCED 0 and NASPE 2002, rewilded that the PA load implemented in the ISCED 0 framework is insufficient in amount. Additionally, it is conducted subliminally, i.e., in the subthreshold zone of intensity. Due to the criticism within the professional community at that time, ISCED 0 was revised in 2016. To that end, the child's physical and motor skills development was included in the Health and Movement educational section within its third section – Physical Activity and Physical Fitness. As a result of the previous conclusions about the position and importance of the kindergarten teacher in shaping the child, we also formulated our research problem in this direction. The goal of the presented research was to gain knowledge regarding the implementation of individual ISCED 0 educational areas within the daily program of the monitored kindergartens and to become more familiar with the teachers' interest in teaching physical activities within individual forms of daily activities as well as in the educational area of Health and Physical activity.

METHODS

The investigation was carried out in March 2024 An anonymous questionnaire was distributed online to 112 female teachers from 31 preschools in the Košice district (region of the Slovak Republic), whom we contacted on the social network Facebook and via the email addresses of individual kindergartens. 112 teachers from 31 kindergartens sent in their responses. They were experienced teachers with an average age of 38.5 years. Over one-third of the respondents (37.5%) had a university degree and 62.5% had a secondary education. In terms of length of teaching experience, 36.2% of the teachers had more than 21 years of experience, 13.9% had 11-20 years of experience, 8.4% had 6-10 years, and 41.6% had less than 5 years of experience.

The questionnaire, consisting of 18 questions, three of which concerned personnel (age, education, experience), corresponded in its structure and content to the content of the ISCED

0 SVP. That was done to ensure the clarity of the alternatives offered in response to the program's implementation regarding the proclaimed importance and popularity of teaching individual areas. Special emphasis was placed on teaching PA. At the end of the questionnaire, we asked about their relationship to movement and interest in their PA. The ethics board at UPJŠ authorized the study in Kosice, identified as 3/2023. Descriptive statistics and Spearman's rank correlation test were implemented for data processing.

RESULTS

At the onset of the research inquiry, we were interested in which of the educational fields of ŠVP ISCED 0, by their perspective, were the most important for the child's development (Fig. 1). More than half of the respondents, regardless of their age, assigning this position to the Language and Communication. The area of Health and Physical Activity was positioned only in third place, as older teachers mainly consider it essential. The answers to the question of which educational areas they prefer to teach were the opposite. There is the utmost interest in
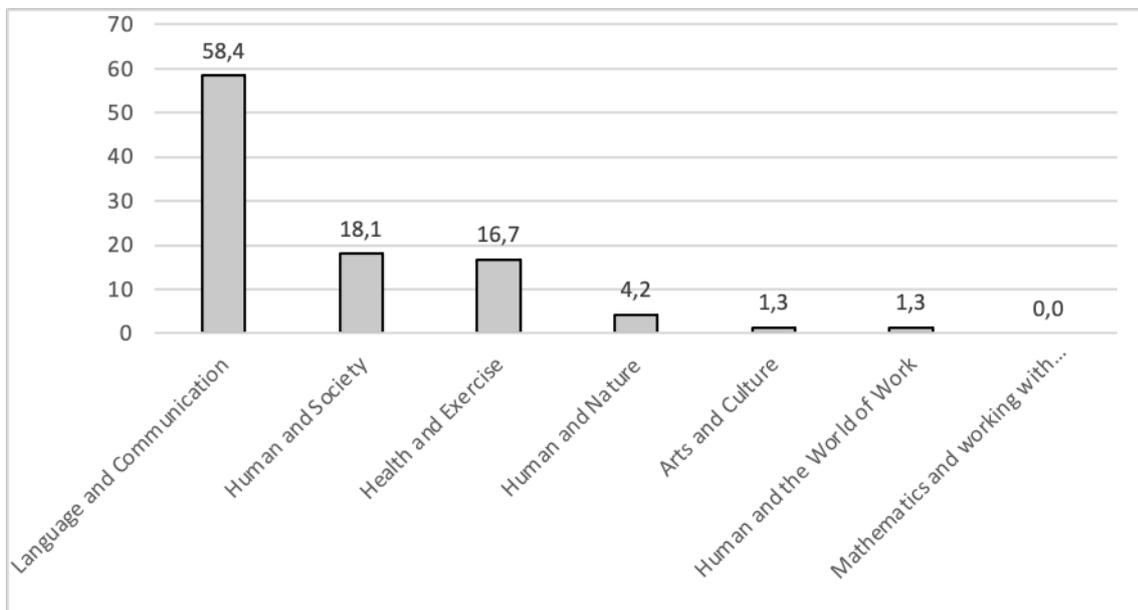
Figure 1. The importance of educational areas on child development in early child education (all values are presented in percentages).

Figure 1 illustrates that Teaching Art and Culture (27.8%) is followed by the area of Health and Physical activity (23.6%). Furthermore, according to the most important, Language and Communication and Human and Society, the first two were placed at the end of interest in their teaching (5.6% and 7.0%, respectively). Neither their age nor the length of their teaching experience significantly impacted the teachers' responses. The difference in responses

regarding significance and popularity was also statistically confirmed by the negative correlation r = - 0, 402. Within the framework of questions related to Health and Physical Activity, 72.2% of the teachers ranked first in Physical Activity and Physical Fitness. With a significant distance, with the importance of 13.9%, they stated Hygiene and Self-service Activities and Health and a Healthy Lifestyle. In this context, we were interested in which activities listed in the Physical Activity and Physical Fitness sub-field the teachers prefer to teach (Fig. 2). The most popular physical activities were interactive games that combine physical activity with music enjoyment. Teachers' least favorite is running, including running over obstacles. In a positive sense, most teachers (83.4%) include morning exercises in their daily routine, and 15.3% do so at least sporadically. Only 20,9% of teachers intermittently emphasize bracing and sauna as crucial activities for enhancing children's health.
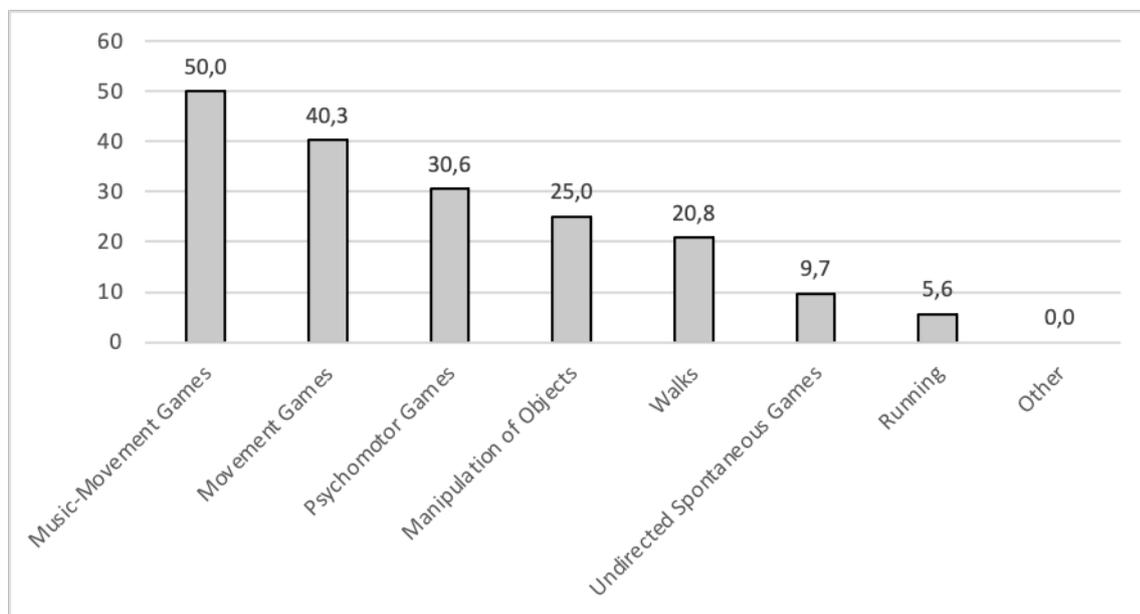
Figure 2. Preschool teachers' preferences for physical activity (all values are presented in percentages).

The use of non-traditional teaching aids for physical activity is directly linked to physical education instruction. Especially when working with children, the tools used play a vital role as a motivator. Only one-third of respondents demonstrate creativity, with half doing so occasionally and others not. When analyzing the shortcomings in teaching physical education in pre-primary education, the respondents had the opportunity to provide additional answers. The most frequently cited response was the lack of favorable conditions or little space for activity (52.8%) and the associated lack of funds to procure the necessary tools and equipment (30.6%); similarly, a limited choice of instructional material for physical activities

for exercise which was stated by (20.4%) of respondents. Surprisingly, 13.9% claime the caretaker's negative attitude towards the PA, along with the child's limited interest.

Where to instigate change in this specified domain, it is essential to equip teachers for its implementation, starting with their education.

Presented investigation discovered that there should not be an issue, as up to 93.1% of teachers express interest in broadening their health and physical education knowledge in a preschool setting. Even those who stated that they were satisfied with the level of methodological support are still interested in enhancing their knowledge in this area. Unfortunately, those who are satisfied with methodological support are less than a third, while the rest evaluated this negatively. As noted before, we have discussed the impact our motivation and participation in PA have on others. Correspondingly, we inquired about teachers' activities during their leisure time. The response aligns with our prior understanding; the primary activity was rest (26.4%). Surprisingly, physical activity and sports were ranked closely behind (20.9%). It was verified by using an ordinal scale from 1-5 that female teachers predominantly exhibit a very positive attitude toward sports activity, with (36.1%) being very positive and (37.5%) positive. As the correlation involves deliberate preparation, we were curious about their engagement in sports activities, referring to sustained sports activities lasting at least 30 minutes (Fig. 3). The most prominent group includes teachers who engage in this activity 1-2 times a week, which might be deemed insufficient for personal development but holds significant importance based on their beliefs. Less than one-fifth of teachers are inactive in this regard.

Comparing physical activity with the acknowledged importance of individual educational areas of ISCED 0 provides an insightful observation. Those teachers who regularly participate in sports or would like to participate in sports activities attribute the most significant importance to *Health and Physical activity*. Furthermore, this was also confirmed in terms of their relationship to sport and their favorite educational area. Half of the teachers with a positive relationship with sports showed *Health and Physical activity* among their favorite educational areas, followed by *Man and society* and *Art and culture*.
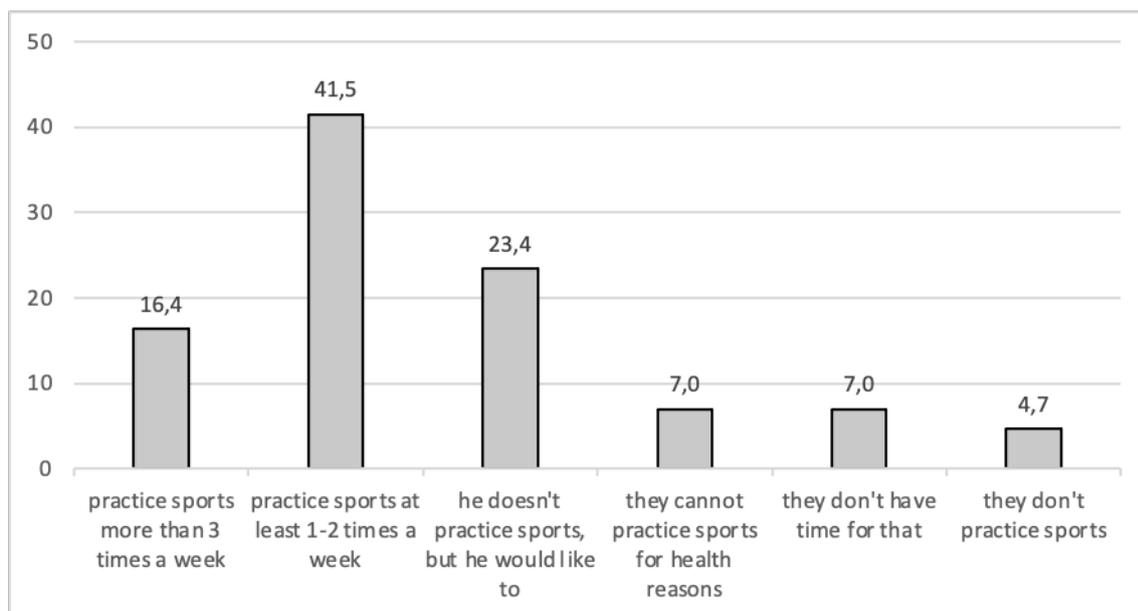
Figure 3. Sport and Recreation activities of the preschool teachers (all values are presented in percentages).

DISCUSSION

As mentioned above, the critical role in early childhood education is played by the ŠVP ISCED 0, which focuses on fostering a child's holistic development through play-based learning and essential skills acquisition. Such a framework outlines the goals, content, and guidelines for educational programs at the preschool level. It serves as a foundation for creating specific schools' programs and developing teaching materials tailored to the needs of preschoolers, providing a structured approach to early childhood education (ISCED 0, 2016).

The entire content of early childhood education is divided into seven educational areas in ŠPV ISCED 0: 1. *Language and communication, 2. Mathematics and working with information, 3. Human and nature, 4. Human and society, 5. Human and the world of work, 6. Art and culture, 7. Health and physical activity.*

Where organizational upbringing is carried out through the various forms of daily activities, these activities include *games and children's choices activity, health exercises, educational activities, outdoor activities, and activities focusing on life management such as (personal hygiene, eating, and resting).*

Understanding the preschool teacher's perspective on the importance of different areas for a child's development and comparing it with their preferences in teaching can provide valuable

insights. It allows for reflecting on the alignment between their educational priorities and personal preferences, contributing to effective teaching strategies.

It was notable that, from the importance perspective, the child's position in society and ability to communicate takes precedence. However, regarding teaching interest, the focus seems to be on art- combining physical activity with art enjoyment connected with the child's health and physical activity. The paradox is that none listed the area of *Man and Nature* among their favorite educational activities. The observation aligns with personal experiences from seminars with preschool teachers, highlighting a divergence between the professional and social perspectives emphasized in educational programs and the practical interests of teachers and children. This suggests a potential disparity between theoretical priorities and the preferences and inclinations in activities, health promotion, and physical activity that are natural to the child.

Notably, within the health and physical activity area, there is a clear emphasis on physical activity and PA skills development. The art - that combine physical activity and game activities are the most popular despite potential space, material, and methodological equipment challenges. The need for more resources due to insufficient investment in education could pose practical constraints on implementing these engaging and beneficial activities. Addressing such resource limitations could enhance the overall effectiveness of health and physical activity programs in preschool education. It is encouraging that two-thirds of teachers demonstrate creativity and willingness to use non-traditional aids and equipment to overcome resource limitations. The fact that almost all teachers express interest in expanding their knowledge in physical education and health is a positive indicator for future improvement. However, the negative attitudes of parents towards PA, coupled with the limited interest of children, could be improved in promoting a holistic approach to health and physical education. Addressing these parental and child perspectives may be crucial for fostering a more supportive environment for PA in early childhood education.

Despite the well-established scientific evidence emphasizing the importance of daily PA for children's health (Hansen, 2005; WHO, 2011; Oja et al., 2010; Timmons et al., 2012), some families still perceive PA negatively. The influence of parents on children's activity, as confirmed by previous research (Finn et al., 2002; Burdette et al, 2004; Chen & Zhu, 2005; Devjak et al., 2013; Junger, 2014, Junger and Palanská 2017; Huang et al., 2022) underscores the crucial role parental attitudes play in shaping children's behavior. The link between the implementation of PA in preschool and the teachers' level of PA has been scientifically

confirmed (Chen & Zhu, 2005; Cheung, 2020; Huang et al., 2022), and our findings support this connection (Junger & Palanská, 2017). Nevertheless, despite varying levels of personal PA among teachers, their positive attitude toward PA and sports can influence and motivate children, where teachers' convictions and motivations play a crucial role in shaping children's perceptions and engagement in PA (Devjak et al., 2013).

Observing a positive correlation between teachers' importance to health and PA and their engagement in sports and PA is compelling. This connection highlights the potential impact of a teacher's active lifestyle. The alignment between personal practices and professional priorities can contribute to a more effective and authentic approach to promoting a healthy lifestyle among children. As we have already stated in the results section, one's own sports activity also plays a very significant role in recognizing the importance of individual ISCED 0 educational areas and choosing the most favored. Moreover, universities implementing early childhood education and elementary education study programs should respond to this, allowing students to better prepare for future teaching careers within their practical subject skills. In the current absence of such practical subjects, students and future teachers are less likely to understand the importance of PA in their lives as well as in the future development of children.

Our findings indicate that preschool teachers are aware of PA's significance in early childhood development. However, several external and systemic factors limit the practical implementation of PA in preschool settings; these include Restrictions within the State Educational Program (ISCED), which provides limited space for flexible or extended PA integration—a lack of adequate methodological materials to support teachers in delivering high-quality PA classes. Parents often do not prioritize or support active engagement in PA. Finally, the potential for innovative approaches (e.g., integrating PA through play-based learning and integrative thermoregulation strategies), which are not yet widely applied but appear promising, are factors that limit PA. Based on these insights, our conclusion that while awareness is present, implementation is hindered by structural and contextual barriers is advisable and is well justified by the evidence.

Strengths and limitations

The presented research has several strengths. Using a cohort sample (education, experience) ensures a representative cohort group for analysis. Anonymity encourages honest responses, and the freedom to formulate precise questions enhances objectivity. The fact that the

obtained results do not require subjective interpretation adds credibility to the presented findings, contributing to the overall robustness of the presented research. In relation to the weaknesses can be incorporated recognition that answers may reflect teachers' lifestyles and attitudes towards PA. Additionally, if there are indications of low-quality institutional education impacting the responses, it underscores the need to improve teacher training programs. Considering these aspects can help refine the interpretation of our research findings and guide future steps for enhancing teacher preparation and PA promotion in an education setting.

CONCLUSION

The presented research results highlight a need for re-evaluation of the current ISCED 0 program, particularly in the area of required competencies. The observation that a child's entire physical and motor development is treated merely as a component rather than a distinct objective underscores a potential divergence. Recognizing its importance as an irreplaceable component of development and education suggests a more prominent role in the program, possibly as a standalone objective. It can be stated that structured study programs of early child education play a significant role in sport orientation, where prospective teachers do not have the opportunity to acquire the basic skills necessary for future teaching in kindergarten in practically oriented sport related subjects. That is one of the most important requirements also in connection with the role played by teachers in selecting and implementing individual areas of the ISCED 0 educational program. From a motivational point of view, to increase the effectiveness of education through physical activity, it is advisable to pay more attention to the use of non-traditional forms and aids as well as cold adaptation, or sauna bathing of children within the educational program.

Presumably, the ISCED 0 ISCED ECE set up in this way is also one of the reasons why female teachers attach greater importance to children's education to theoretical areas focused on the child's ability to communicate and child position in society, even though they prefer to teach areas focused on the art- that combine physical activity with art enjoyment. Exploring non-traditional forms and methods can motivate participation and effectiveness in PA. However, we emphasize a holistic approach to enhancing the child's health. Strategies such as bracing, and sauna and diverse and engaging PA contribute to a comprehensive program. This approach addresses physical well-being and promotes a more appealing and holistic health improvement for children.

Declaration of Conflicting Interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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DIFFERENCES IN THE STRUCTURE OF PARTICIPANTS' ACTIVITIES IN RHYTHMIC GYMNASTICS TRAINING DEPENDING ON THE TYPE OF APPARATUS

RAZLIKE V STRUKTURI DEJAVNOSTI UDELEŽENK NA TRENINGIH RITMIČNE GIMNASTIKE GLEDE NA VRSTO ORODJA

ABSTRACT

A sedentary lifestyle remains one of the biggest challenges faced by modern society. Although much is known about the benefits of physical activity, the majority of the population, especially children, do not engage in sufficient physical activity throughout the day. Children's participation in organized physical activities can be of great importance, but these activities must be adapted to the needs of the child and should encourage a certain amount of movement. Therefore, it is important to understand the characteristics of various activities to ensure that children's participation is purposeful. The aim of this study was to determine the active exercise time, the content of the training, and the pedagogical activity of coaches during different phases of rhythmic gymnastics training, which included the use of various apparatus as well as exercises without apparatus. A total of 126 girls, aged 7 to 11, participated in the study, and the activity of 60 girls, as well as six coaches, was analysed over 12 training sessions. Data were collected using the SOFIT instrument, which monitored the girls' activity, the training content, and the pedagogical activity of the coaches. The length of active time in all phases of training depended on the content used, and activity was generally higher in sessions involving apparatus. Coaches spent the most time giving instructions and demonstrating, with the time dedicated to demonstrations being significantly longer when apparatus were used in training.

IZVLEČEK

Sedeči način življenja ostaja eden največjih izzivov sodobne družbe. Čeprav je veliko znanega o koristih telesne dejavnosti, večina prebivalstva, zlasti otroci, čez dan ne dosega priporočene ravni gibanja. Otroško vključevanje v organizirane telesne dejavnosti je lahko zelo pomembno, vendar morajo biti te dejavnosti prilagojene otrokovim potrebam in spodbujati določeno raven gibanja. Zato je pomembno razumeti značilnosti različnih aktivnosti, da bi zagotovili smiselno vključevanje otrok. Namen te raziskave je bil določiti čas aktivnega gibanja, vsebino vadbe ter pedagoško dejavnost trenerjev v različnih fazah treninga ritmične gimnastike, ki je vključeval uporabo različnih orodij kot tudi vaje brez njih. V raziskavi je sodelovalo skupno 126 deklic, starih od 7 do 11 let. Analizirana je bila dejavnost 60 deklic ter šestih trenerjev v okviru 12. vadbenih enot. Podatki so bili zbrani z uporabo instrumenta SOFIT, ki je spremljal aktivnost deklic, vsebino vadbe ter pedagoško dejavnost trenerjev. Dolžina aktivnega časa v vseh fazah treninga je bila odvisna od uporabljene vsebine, pri čemer je bila aktivnost na splošno višja pri vadbah z orodji. Trenerji so največ časa posvetili podajanju navodil in demonstracijam, pri čemer je bil čas demonstracij znatno daljši, ko so bila v vadbo vključena orodja.

Ključne besede: sofit, aktivni čas vadbe, vsebina dejavnosti, pedagoška dejavnost trenerjev, faze treninga

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INTRODUCTION

The modern lifestyle of both adults and young people around the world is increasingly characterized by hypokinesis, unhealthy diets (Magriplis et al., 2020), and excessive use of modern technology (Kracht, Joseph, & Staiano, 2020). The prevalence of overweight and obese children is steadily rising (Mirilov & Bjelica, 2004; Kisić-Tepavčević et al., 2008; Lobstein & Brinsden, 2019). In 2019, the World Obesity Federation projected that by 2025, 206 million children and adolescents aged 5 to 19 would be living with obesity, a number expected to increase to 254 million by 2030 (Lobstein & Brinsden, 2019). The growing obesity epidemic in children and adolescents is largely explained by a bio-socioecological framework, which emphasizes the interaction between biological predispositions, socioeconomic status, and environmental factors in the development and accumulation of excess fat (Jebeile et al., 2022).

Physical activity and its benefits for maintaining and improving health are well-documented. At younger ages, it contributes to harmonious physical development, prepares children for physiological efforts, helps balance physical and psychological pressures, and encourages the development of habits for using leisure time during both youth and adulthood (Ostojić et al., 2009). Also, physical activity has been identified as a predictor of quality of life mediated by self-concept perception and mood in adolescents (Vaquero-Solís et al, 2021). However, sedentary behaviour remains one of the most significant challenges of modern life, as a large portion of the population does not meet the minimum recommended levels of physical activity. In developed countries, approximately 60-70% of the population fails to achieve the minimum physical activity required to maintain health and energy (Miles, 2007). This decline in physical activity, particularly within the family and broader community, combined with the reduced opportunities for children to engage in physical exercise at school, is often cited as a key factor contributing to the insufficient physical activity among today's youth (Hardman & Marshall, 2005; Trudeau & Shephard, 2008). Furthermore, the restrictive measures during the COVID-19 pandemic have exacerbated the issue of insufficient physical activity and excessive sedentary behavior among children and adolescents (Povšič, Kastelic, & Šarabon, 2022).

In response to the growing number of obese children since the early twentieth century, experts have recommended that children engage in physical activity for at least 30 minutes, with an optimal goal of 60 minutes per day (Strong et al., 2005). Achieving this level of activity solely through school physical education classes is insufficient, making it necessary to involve children in organized physical activities during their free time (Benavente-Marín et al., 2024).

The importance of physical activity is thus amplified, though it must be purposeful and tailored to the child's needs to promote adequate movement. Promoting physical activity and sport with a focus on health and leisure, and tailoring programmes to gender and age-specific needs, are essential to maintain motivation and ensure a healthier, more active population (Ávalos-Ramos et al., 2024). Taking this into account, as well as the fact that children's active time has so far been monitored mainly in physical education classes, there is a need to define active time within the framework of the different physical activities that children engage in during their free time, in order to achieve a sufficient amount of movement.

When it comes to girls, their interests in choosing the type of activity are mostly directed towards aesthetic sports, among which rhythmic gymnastics is one of the activities that girls choose most often (Peral-Suárez et al., 2020). Rhythmic gymnastics, a sport primarily aimed at females, offers a wide range of motion structures that can benefit children of both genders. This activity can have a multifaceted positive impact on the physical development of children who engage in it (Radisavljević, Lazarević, & Moskovljević, 2006; Dobrijević et al., 2015). Given its potential for enhancing physical activity, rhythmic gymnastics or its components are highly recommended for children during their growth and development. Moreover, this form of exercise can significantly increase active exercise time, as it can be organized in various ways, incorporating apparatus and non-apparatus exercises to maximize total active time (Dobrijević et al., 2023). A solid understanding of training structure and the application of specific exercises at different training stages can significantly enhance the effectiveness of training time. Therefore, the aim of this research was to evaluate the active exercise time, training content, and the pedagogical activity of the coach during different phases of rhythmic gymnastics training, incorporating both apparatus and non-apparatus exercises.

METHODS

This research has a cross-sectional study design. The method of descriptive and comparative analysis was used in this research, along with using objectively gathered data in trainings of rhythmic gymnastics, with the application of the SOFIT instrument. The research was carried out in November and December of 2022. A total of 12 training sessions were analysed, three of which had without apparatus exercises as their exercise content, three with a rope, three with a ball, and three with hoop exercises. All training sessions were attended by girls divided into recreational groups, who had 60-minute training sessions twice a week.

The ethical board of the Faculty of Sport and Physical Education, University of Belgrade, approved the study. Informed consent was obtained for all individuals included in this study, which parents or legal guardians signed. The research was conducted in accordance with the ethical standards outlined in the Declaration of Helsinki, originally adopted in 1964 and revised in 2013.

Sample of respondents

The total sample of respondents was comprised of 60 girls aged 7 to 11 who train according to the rhythmic gymnastics school program, which is in accordance with the requirements of the competitive code of points and propositions established by the Gymnastics Association of Serbia (https://www.gssrb.rs/propozicije-program-takmicenja). The sample consists of girls exclusively because, for now, in Serbia, there is no program aimed at the male population. The 12 training sessions that were mentioned were realized by six coaches, also female, and a total of 126 girls participated. In each training, the activity of five randomly selected girls and their coach was analysed, meaning that the activity of a total of 60 girls and six coaches was observed.

Sample of variables

Eighteen variables in total were observed and analysed in this research. Apart from the variable referring to the total duration of training (UT), the remaining 17 variables were divided into three groups according to the observed content. The first group of variables, a total of 5, refers to the activity of the athletes. The second group of variables, a total of 6, refers to training content, while the third group of variables, numbering 6, refers to the pedagogical activity of the coaches. System For Observing Fitness Instruction Time – instrument „SOFIT", was used for observing the mentioned variables (McKenzie, Sallis, & Nader, 1992; McKenzie, & Smith, 2017).

By using the „SOFIT" instrument, the activity of the participants was coded from **1** to **5**, while emphasizing that codes **1** to **4** signified that the participant was passive. Code **1** means that the participant was lying down, code **2** that she was sitting, code **3** meant standing, and code **4** indicated the participant walking. Code **5** signified that the participant was active.

Context distributed to the majority of the participants (51%) which are included in it in the observed interval is measured within **training content**. The codes belonging to these training contents are as follows: „**M**" (*Management)* – choosing the team, changing equipment, moving from one place to another, teacher instruction, roll-call, discussing the excursion; „**K**" (*Knowledge*) - information: history, technique, tactics, rules, behavior; „**F**" (*Physical fitness*) – aerobics, shaping exercises, weight activities, agility exercises, testing, warm-up, relaxation exercises; „**S**" (*Skill practice)* – Teaching technique, studying forms of movement, practicing the learned techniques; „**G**" (*Game*) - games (elementary), competitive; „**O**" (*Other*) – this time looks like rest when the students can choose whether they want to participate or not.

Pedagogical activity of the coach is defined through six activities. Codes within this category mark the following: „**P**" (*promotes fitness*) - promotes „fitness", cheers on, supports activities, encourages and spurs on the participants; „**D**" (*Demonstrates fitness*) – demonstrates; **I** (*Instructs Generally*) – gives general instructions and knowledge, describes training content (rules, technique, tactics), corrects mistakes; supports the rhythm and tempo of exercise performance with the use of voice or by providing timing; „**M**" (*Management*) – sets up equipment, does roll-call, guides the participant to other tasks; „**O**" (*Observes*) – monitors the whole class, observes; „**T**" (*other task*) – other activities.

The protocol for gathering data

Five previously prepared observers performed the observation of the activity of participants, training content, and the pedagogical activity of the coaches, by applying the „SOFIT" instrument. All training sessions were recorded as video material (Crotti, Rudd, Weaver, Roberts, O'Callaghan, Fitton Davies, & Foweather, 2021; Fairclough, Weaver, Johnson, & Rawlinson, 2018), which was later analysed according to standard procedures (McKenzie, Sallis, & Nader, 1992; McKenzie, & Smith, 2017). Each phase of observation lasted for 20 seconds, divided into 10 seconds of observing and 10 seconds of coding. The trained observer followed the training activities for 10 seconds, and then wrote down the observed parameters (codes) on the observation form in the next 10-second period. So as not to disrupt the continuity of observation and data recording, a sound signal announced the beginning and the ending of the interval to the observers.

Statistical data analysis

Statistical data analysis was performed in the SPSS 21 and Excel 2015 programs. Standard descriptive indicators were shown for all of the observed variables, these being average value (Mean), standard deviation (SD), minimum value (min) and maximum value (max). Normalcy of distribution was tested via the *Kolmogorov-Smirnov* test. The significance of differences in variable values between different training sessions with different apparatus was tested by applying the univariant ANOVA. As an integral part of ANOVA, the *Bonferroni* post-hoc test was applied to all the variables whose mean values proved to be significantly different, in order to determine the specific differences between pairs of trainings with different apparatuses. Differences in acquired results for the whole training were tested, as well as for each of the individual training phases. All statistical procedures were performed in seconds, but for better visibility, the results are shown in minutes. All values less than 0.05 were considered significant.

RESULTS

Table 1 shows the results of the training analysis according to phases (introductory, preparatory, main, and ending phase). The share of the introductory phase in the entire training is from 19.3% to 24.7 % and differs depending on the apparatus used in the training. The share of the preparatory phase in the entire training is from 30.7% to 39.5 %, while the share of the main phase is between 27.7% and 35.2 % of the total training time. The share of the final phase is between 7.7% and 11.6% of the total training time.

Table 1. Time parameters of participant activity, training content and pedagogical activity of the coach by phases of training

Variables		Introductory phase		Preparatory phase		The main phase		The final phase	
		Mean ± SD	min - max	Mean ± SD	min - max	Mean ± SD	min - max	Mean ± SD	min - max
TPD		13,4 ± 2,4	11,0 - 20,0	21,4 ± 4,3	12,3 - 28,3	18,0 ± 3,9	8,7 - 23,3	5,7 ± 2,7	1,0 - 9,7
Participant activity	1	0,0 ± 0,0	0,0 - 0,0	0,5 ± 0,4	0,0 - 1,7	0,0 ± 0,1	0,0 - 0,3	0,1 ± 0,3	0,0 - 1,7
	2	0,2 ± 0,3	0,0 - 1,3	2,0 ± 1,1	0,0 - 4,7	0,5 ± 0,8	0,0 - 3,7	0,5 ± 0,7	0,0 - 2,7
	3	5,5 ± 1,6	1,7 - 8,7	2,6 ± 1,3	0,3 - 5,7	5,6 ± 3,0	0,3 - 12,7	1,2 ± 1,2	0,0 - 5,7
	4	0,7 ± 0,6	0,0 - 2,0	0,3 ± 0,4	0,0 - 2,0	0,6 ± 0,8	0,0 - 3,7	0,3 ± 0,4	0,0 - 1,3
	5	6,9 ± 2,3	1,0 - 12,7	15,7 ± 4,2	2,3 - 22,7	11,2 ± 3,1	5,7 - 18,3	3,5 ± 2,1	0,0 - 8,3
Training content	M	1,8 ± 0,8	0,7 - 5,0	2,0 ± 1,6	0,0 - 6,3	1,8 ± 1,4	0,0 - 5,3	0,8 ± 0,6	0,0 - 2,3
	K	4,5 ± 1,6	0,7 - 8,0	3,5 ± 1,8	0,0 - 8,3	4,6 ± 2,7	0,3 - 13,0	1,1 ± 1,0	0,0 - 5,3
	F	2,6 ± 1,6	0,0 - 6,7	9,9 ± 3,1	2,0 - 16,7	0,8 ± 1,1	0,0 - 4,7	1,4 ± 1,8	0,0 - 7,0
	S	3,5 ± 2,3	0,0 - 8,3	4,5 ± 3,0	0,0 - 12,3	10,0 ± 3,3	0,7 - 15,7	1,0 ± 1,3	0,0 - 7,0
	G	0,3 ± 0,9	0,0 - 3,3	0,0 ± 0,0	0,0 - 0,0	0,0 ± 0,2	0,0 - 1,3	0,8 ± 1,2	0,0 - 3,7
	O	0,6 ± 0,6	0,0 - 2,3	1,2 ± 0,8	0,0 - 3,3	0,6 ± 1,1	0,0 - 5,0	0,3 ± 0,4	0,0 - 1,7
Coach pedagogical activity	P	0,0 ± 0,2	0,0 - 0,7	0,1 ± 0,2	0,0 - 1,0	0,0 ± 0,0	0,0 - 0,3	0,1 ± 0,2	0,0 - 1,0
	D	2,9 ± 1,5	0,3 - 6,3	8,2 ± 4,5	1,0 - 18,0	4,6 ± 2,4	0,3 - 9,3	1,0 ± 1,0	0,0 - 3,7
	I	4,9 ± 2,6	0,7 - 11,7	6,8 ± 4,0	0,7 - 15,3	7,3 ± 3,1	2,7 - 17,3	2,4 ± 1,8	0,0 - 9,3
	M	2,3 ± 1,3	0,3 - 7,3	2,5 ± 1,5	0,0 - 6,3	1,9 ± 1,0	0,0 - 4,3	0,9 ± 0,6	0,0 - 2,3
	Ot	2,4 ± 1,7	0,0 - 7,0	3,0 ± 2,5	0,0 - 8,3	3,7 ± 3,3	0,0 - 11,7	1,0 ± 1,2	0,0 - 5,0
	T	0,7 ± 0,7	0,0 - 3,0	0,6 ± 0,6	0,0 - 2,0	0,3 ± 0,4	0,0 - 1,7	0,1 ± 0,2	0,0 - 1,0

Notes: TPD – training phase duration; Mean – mean value, SD – standard deviation, min – minimum value, max – maximum value; M – management; K – knowledge; F – Physical fitness; S – skill practice; G – game; O – other; P – promotes fitness; D – demonstrates; I – instructs generally; Ot – observes; T – other tasks. All variables are expressed in minutes.

Graph 1 shows the analysis results of participant activity for training phases depending on the type of apparatus used.
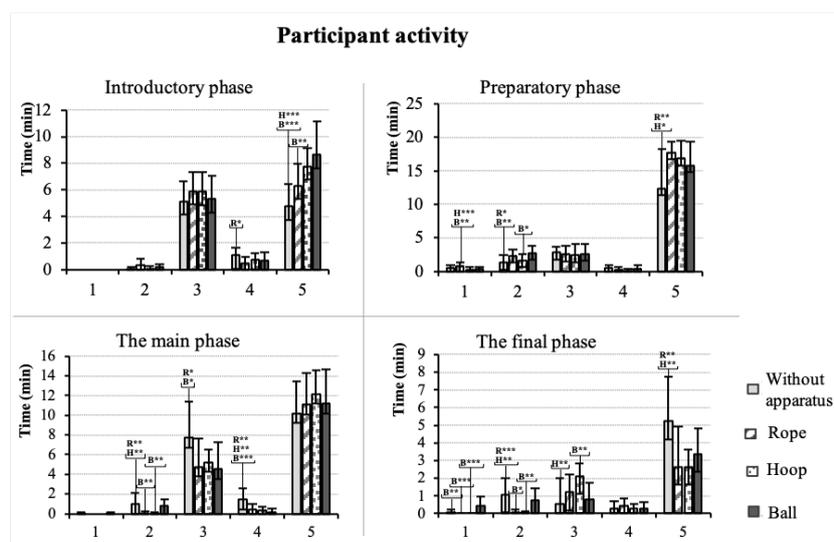
Graph 1. Participant activity - time parameters by phases of training: significantly different from: R – rope, H - hoop, B – Ball; activity code 1 –laying down, 2 – sitting, 3 – standing, 4 – walking, 5- active. *p<0,05, **p<0,01; ***p<0,001*

Graph 2 shows the analysis results of training content for training phases depending on the type of apparatus used.
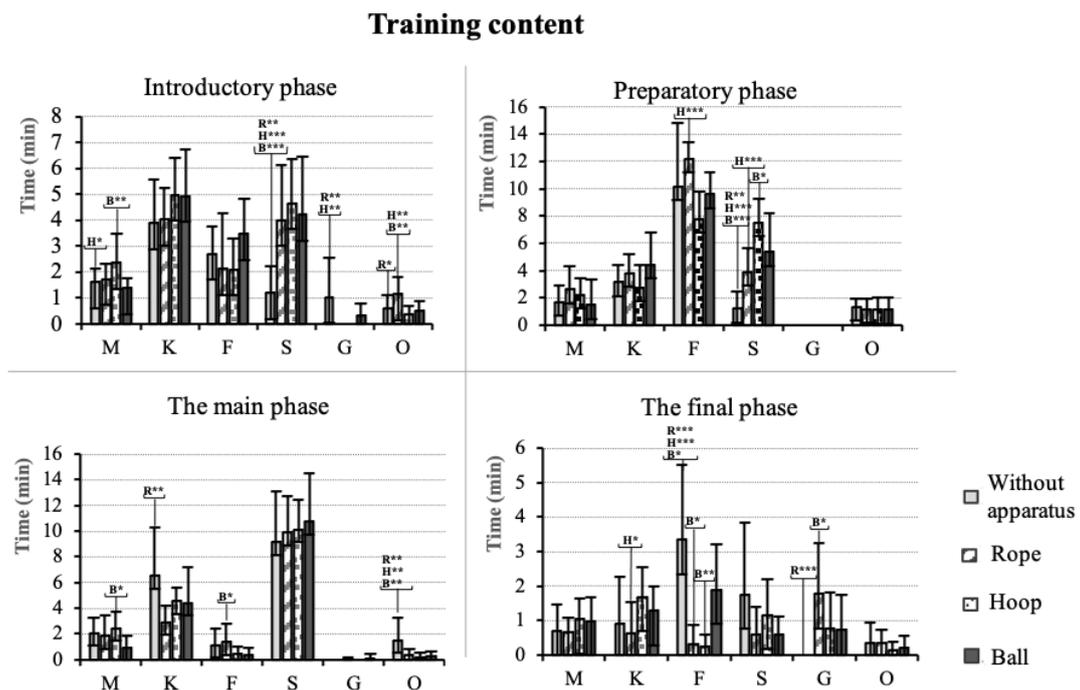
Graph 2. Training content - time parameters by phases of training: significantly different from: R – rope, H - hoop, B – Ball; M – management; K – knowledge; F – Physical fitness; S – skill practice; G – game; O – other. *p<0,05, **p<0,01; ***p<0,001*

Graph 3 shows the analysis results of the coach pedagogical activity for training phases depending on the type of apparatus used.
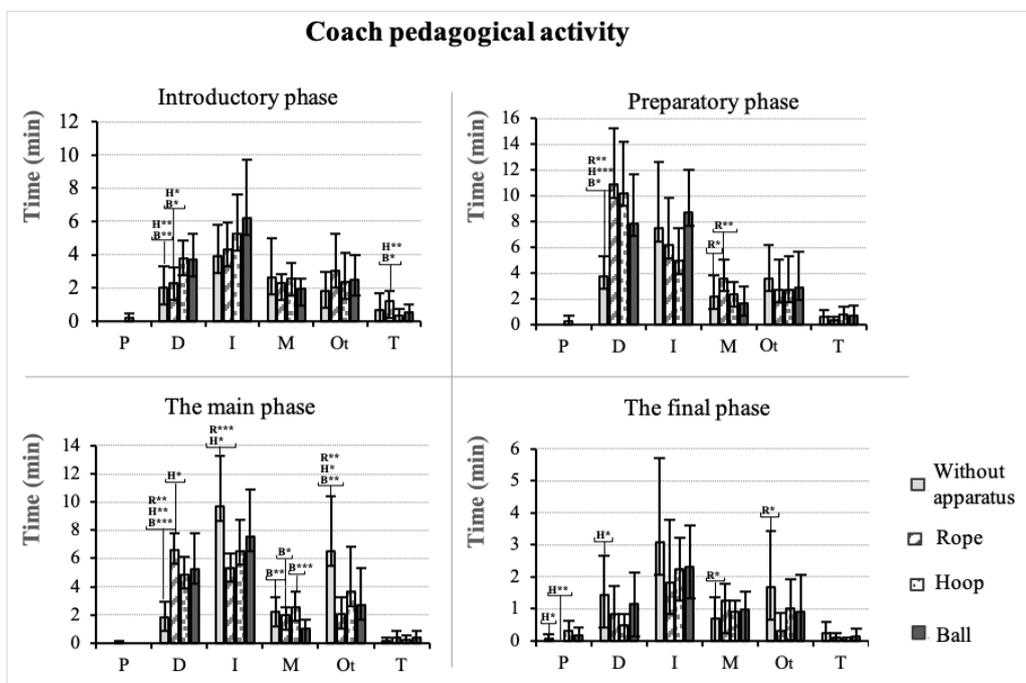
Graph 3. Coach pedagogical activity - time parameters by phases of training: significantly different from: R – rope, H - hoop, B – Ball; P – promotes fitness; D – demonstrates; I – instructs generally; M – management; Ot – observes; T – other tasks. *p<0,05, **p<0,01; ***p<0,001*

DISCUSSION AND CONCLUSION

The duration of the introductory phase is between 19.3% and 24.7% of the total training time and depends on the applied content. For the most part, **the introductory phase** lasts longer in training, where apparatus exercises are performed. The reason for this is that coaches often use the introductory phase of the training for practicing or perfecting already learned apparatus techniques through simple forms of body exercises with their girls, as well as for methodically fitting the applied techniques to the needs of further phases of the training (Moskovljević and Dobrijević, 2018; Jastrjembskaia & Titov, 1999). Compared to physical education lessons in which this phase of the lesson lasts around 8.9 % of the total lesson time (Marković et al., 2013, 2017), this stage accounts for a significantly greater amount of total time in rhythmic gymnastics training.

In the introductory stage of training, girls were active from 4.7 to 8.6 minutes on average, which comprises 40.5 – 58.1 % of this stage's total duration and this time varies depending on the apparatus used in the training. Specifically, active exercise time is the shortest within without apparatus training, although the total duration of this stage is shorter in relation to training sessions with apparatuses (Graph 1). Girls are active for a significantly longer time in this stage when they practice apparatus techniques in training, which is especially evident with hoop and ball. This can be explained by the fact that girls often practice certain apparatus techniques in between dynamic series (running, hopping, and the like), which are less intensive. In this way the coach uses the training time more rationally and increases the total active time of its practitioners. When it comes to rope training, active exercise time when compared to the ball is significantly smaller statistically. Here we should bear in mind that in this stage of the training the techniques mostly used are those of passing through the rope via running or hopping, which is very intense and demands frequent breaks in order to rest between dynamic series. In this way the active exercise time is shorter, but that is expected and justified in view of the high intensity of work.

From the aspect of training content, in this phase a lot of time is devoted to listening to the coach, who provides information and instructions related to performing a certain technique. This can be ascribed to the characteristics of the sport branch and the need to perform all the techniques properly, so the coach often makes suggestions to correct even the smallest technical errors (Örs, 2020). Since this is a general characteristic of this branch of sport, there is no difference in this parameter between the various apparatus. When it comes to training content,

general fitness exercises are practiced the most in this phase. Specifically, the means of training are mostly connected to natural forms of movement regardless of the apparatus used, so the differences in time of application for these exercises did not register between sessions with different apparatus. Girls spent significantly more time performing specific techniques in sessions with apparatus, which was expected considering the point of using apparatuses in this phase is precisely the perfection of learned apparatus techniques combined with body exercises.

The coach spent most time on giving instructions in this phase, and it often coincides with the active exercise time of the girls, because the coach uses the chance to point out mistakes during the performance of the exercise, and suggest the necessary corrections. Also, a portion of time is also expended on organization, which is characteristic of this training phase (Moskovljević and Dobrijević, 2018). The teacher activity is similar in a physical education lesson (Marković et al., 2017), since the goals of this phase are quite alike in both cases. The time the coach spends demonstrating exercises is not great in this phase, due to the fact that familiar apparatus and body techniques are used. Still, it is greater if apparatus content is in question, especially with hoop and ball, because sometimes it is necessary to additionally explain the way to connect the body and apparatus techniques. The rope demonstration time is significantly shorter, owing to the intensity of the exercises.

The share of **the preparatory phase** in the total training is from 30.7 – 39.5 %, which is around three times longer than in physical education lessons (Marković et al., 2013, 2017). The reason for this lies in the fact that different training tasks are dealt with in this phase of rhythmic gymnastics training, apart from the physiological and organizational introduction to practice. Namely, certain body and apparatus techniques are often practiced and perfected in this phase, in accordance with the achieved preparation level of the organism, and its comprising part is also exercises for the development of agility and other motor abilities (Chiriac, et al., 2020). Comparing sessions with various apparatuses, the difference in the duration of this phase is noticed only between without apparatus and rope sessions, probably due to the need to prepare the rope in a special way for different exercises (folding it into two, three, or more parts, combined with holding it with arms and legs, and the like), which demands certain preparation time, and naturally extends the duration of this whole phase.

Girls were active for 67.4 – 78.9 % of the total duration of the preparatory phase, which is expected, because the frontal way of work is performed most often in this phase, as well as in physical education lessons (Marković et al., 2017). Differences in time actively spent in this

phase occur between without apparatus training and those with rope and hoop. More active time in the preparatory phase with apparatuses is probably caused, just like with the introductory phase, by performing certain apparatus techniques which are of lower work intensity, during organizational activities, or listening to instructions. In this phase girls were sitting between 1.3 to 2.6 minutes on average, which is not a long-time interval, but it proved to be significantly greater in apparatus training sessions. This can be attributed to the girls' needs for rest after exercises in which the apparatus served to increase exertion or complexity of exercises.

Training content in this phase consisted mostly of shaping exercises, just like in physical education lessons (Marković et al., 2017), although specific technique is present with sessions with hoop and ball as well. Significant differences in applying exercises of general fitness appeared between sessions with rope and hoop. Within the rope training more time was devoted to general preparation exercises, since the specific rope technique is more difficult to combine with shaping exercises. Here it is often used statically, just for posture correction or for increase in exertion and movement amplitude.

The average time for giving instructions is approximately equal in all types of training, while time for the coach demonstrating the exercise is significantly greater in apparatus training when compared to those that are without apparatus. This result is expected, because the girls need to know the exact position of the body and the movement of the apparatus while performing the exercise, which often demands repeated demonstrations. In comparison to physical education lessons (Marković et al., 2017), coaches spend a lot more time on giving instructions and demonstrating exercises compared to teachers, and less time on actual observation of the girls' activities without active participation.

The results of analysis which describe **the main phase of training**: Total duration of the main phase ranged between 16.6 and 21.1. minute, which comprises 27.7 – 35.2 % of total training duration. Compared to physical education lessons, where this phase has a share of 64.8% in total lesson duration (Marković et al., 2013, 2017), a significantly shorter duration of this phase in rhythmic gymnastics training can be observed. However, from previously analysed phases it can clearly be seen that the rhythmic gymnastics training concept is such that practicing, and even the beginning of the instruction of certain specific techniques is started in previous phases of the training. In this manner the means of training are distributed throughout all training phases in accordance with the goal and methodical principles, in order to meaningfully and rationally distribute the exertion of the practitioners. The duration of this phase within without

apparatus training is significantly longer when contrasted with this phase within training with apparatuses. On the one hand, without apparatus exercises form the foundation of rhythmic gymnastics (Moskovljević and Dobrijević, 2018), and they need to be properly mastered so that apparatus techniques can be built on top of them, therefore coaches particularly focus on them and devote a lot of time to their practice. On the other hand, the organization of these training sessions is such that the coach must assist individually and help the girls when they are learning certain body techniques (e.g. pre-acrobatic elements, jumps, with positioning, or correcting balance forms and the like), so this organization demands a longer duration of the main phase.

Out of the total duration of the main phase, the girls were active for about 48% of the time in prop-free training sessions, while active time in apparatus training amounted to about 68% of the total time. Contrasted to student activity in the main phase in physical education lessons, which amounts to a little more than 38 % (Marković et al., 2013), it can be concluded that the organization of rhythmic gymnastics training is particularly good in this aspect.

Statistical analysis did not show significant differences in active exercise time during this phase between the different sessions, which can be explained by the fact that the analysis covers data on the duration of the active exercise time, and not its percentage in relation to the total duration of this phase. The percentage of active exercise time in this phase is lower within without apparatus training, because it is necessary to ensure enough time for recovery between exercise repetitions when practicing many techniques (e.g. jumps, pre-acrobatic elements, turns), so the exercisers can perform the desired technique properly and without risk of injury. In relation to this, there are results that speak to the duration of standing of the practitioners in this phase, which is the longest within without apparatus exercises.

Training content, whether with or without one of the apparatuses, mostly consists of one specific technique, i.e. learning new elements of the technique or perfecting already learned techniques, which is customary for this phase of the rhythmic gymnastics training (Jastrjembskaia & Titov, 1999). Similarly, a lot of time in this phase is devoted to listening to information and explanations, above all about a specific technique, as being the most represented in this phase. The most time on these explanations is spent in without apparatus training sessions, and the reason for that is the aforementioned place of without apparatus exercises in the rhythmic gymnastics system. Unlike the contents of the basic phase of rhythmic gymnastics training, students spend most time playing during physical education lessons, which

accounts for 35% of this phase, then in lesson organization, around 34 %, whereas they spend only 10% of the time on training a certain technique (Marković et al., 2017).

When it comes to the pedagogical activity of the coach, most time on average in this phase of the training is spent on giving instructions and demonstration. Within without apparatus training, the average time for giving instructions and correcting mistakes is far greater compared to trainings with apparatuses, while time spent on demonstration is significantly shorter. Due to the demanding technique of without apparatus exercises, as well as the inability to achieve a certain level of organism preparation for its performance, coaches often use better practitioners for demonstration, and they give instructions orally. It is the opposite when working with apparatuses. The technique of handling the apparatus, and especially details significant for its successful performance, must be well demonstrated and precisely emphasized by the coach, so it could be more clear to the girls what is being asked of them and to perform the exercise as regularly as possible. In physical education lessons teachers usually observe student activities in this phase, about 28% of the time, or give students the necessary instructions for exercise performance, with 24% of the time usually spent on that (Marković et al., 2017).

The results of the analysis **describing the final phase of the training**: Compared to all the others, the duration of this phase is the shortest, and its share of the total training duration is between 7.7 – 11.6%. When speaking of physical education lessons, this phase is also the shortest, and its share of the total lesson duration is merely 2.9% (Marković et al., 2017). The differences in duration of this phase between different training sessions are not significant, because its goals and tasks are mostly the same regardless of the differences in training content.

During the final phase of the training the girls were active between 2.6 and 5.2 minutes on average, that is, 56 – 74% of the total duration of this phase. The differences compared to physical education lessons are great, because the students are just slightly active in this phase, only about 0.6 minutes (Marković et al., 2013, 2017). The time that the girls spend in various inactive positions in this phase (lying down, sitting, standing up) is relatively short (Table 1), but it differs between training sessions with different apparatuses. The time spent in the prone or sitting position is greatest when the ball is used, which was probably caused by rests between series of strength exercises in which this apparatus is often used to increase exertion. Differences occurring in standing time are probably conditioned by the mere content of the training, rather than the type of apparatus used.

The contents of this training phase are mostly exercises for improvement of general fitness, then specific technique exercises, and in small percentage, games. Exercises for developing general fitness were mostly practiced within without apparatus training, most frequently as exercises of strength and agility, with the aim of improving these motor abilities, as being very significant for performing most technical elements. Games were not very present in this phase, but we should bear in mind that specific movement structures from the program of group contents, such as collaborations, imply interaction between the practitioners and are very interesting for children. Multiple training tasks are solved with their application, aside from learning or perfecting certain techniques, girls satisfy their need for playing as well. In physical education lessons the content of this phase mostly consists of activities related to organization, and teachers solve all planned goals and tasks of the lesson in the basic phase (Marković et al., 2017).

Pedagogical activity of the coach means mostly giving instructions and demonstrations in the final phase as well. Compared to certain apparatus training sessions, during without apparatus training coaches spend significantly more time demonstrating exercises. Linking these activities of the coach with the aforementioned content of this phase of the training, it is confirmed yet again that performance of all movements is extremely important in rhythmic gymnastics training, including exercises for improving general fitness. The coaches spent significantly less time on organization within without apparatus training. The reason for this is probably that that part of the time which is used for putting away and sorting the apparatuses within the apparatus training, is distributed to other activities in without apparatus training.

Rhythmic gymnastics training, as a supplementary activity, can greatly increase the time spent actively practicing physical activities on a daily basis and can, therefore, indirectly influence health improvements in children. Also, rhythmic gymnastics contents and principles of exercise organization can be used within the framework of other physical activities, as they are suitable for increasing active exercise time in different phases of training, and they accordingly contribute to better organization and effective use of time.

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The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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EFFECT OF ANAEROBIC TRAINING ON SERUM PARAOXONASE 1 (PON1) ACTIVITY AND ROLE OF PON1-L55M POLYMORPHISM

UČINEK ANAEROBNEGA TRENINGA NA AKTIVNOST SERUMSKE PARAOKSONAZE 1 (PON1) IN VLOGA POLIMORFIZMA PON1-L55M

ABSTRACT

Paraoxonase (PON) enzyme family (paraoxonase 1, 2 and 3) has antiatherosclerotic properties. The decreased PON1 enzyme activity (EA), PON1 level and PON1-L55M polymorphism (PON1P) are risk factors for atherosclerosis. Effects of anaerobic training on PON1 levels and the role of PON1P are unclear. In present study, the effects of anaerobic training on serum PON1 level, PON1EA, high density lipoprotein (HDL) and its subgroups' paraoxonase activities (HDLPON1EA, HDL2PON1EA, HDL3PON1EA) as well as the role of PON1P were investigated. The trained male athletes group (handball, basketball, volleyball) (AG: n=36, age=20.56±2.42 years) and the control group (CG: n=39, age=22.26±3.44 years) participated in this study. The PON1 and HDL's PON1 enzyme activities, the protein levels of PON1 enzyme, oxidized low-density lipoprotein (oxLDL) levels and the PON1P (from genomic DNA samples) were determined. Serum PON1EA, HDLPON1EA, HDL2PON1EA and HDL3PON1EA enzyme activities of the athletic homozygous LL and M carrier (Mc) groups were not significantly different from sedentary, however the indicated enzyme activities of the athletic LL homozygous group were significantly higher than athletic Mc group (p<0.05). While the control genotype groups were compared, the control LL (CLL) genotype group had higher serum PON1EA (38.7%), HDLPON1EA (37.2%), HDL2PON1EA (41.9%) and HDL3PON1EA (33.1%) values than control Mc (CMc) genotype. These findings indicate that the genetically higher PON1EA and HDL and its subgroups' PON1EA in LL genotype group may have an important role in the beneficial effects of anaerobic training. However, the Mc genotype group was genetically negatively affected from anaerobic training. Therefore, it was concluded that high intensity training may be a risk factor for atherosclerosis in athletes with Mc genotype.

Keywords: Paraoxonase 1, Paraoxonase 1-L55M polymorphism, Anaerobic training, Atherosclerosis.

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Encimska družina paraoksonaz (PON) – paraoksonaza 1, 2 in 3 – ima antiaterosklerotične lastnosti. Znižana encimska aktivnost PON1 (EA), raven PON1 in polimorfizem PON1-L55M (PON1P) predstavljajo dejavnike tveganja za aterosklerozo. Vplivi anaerobnega treninga na raven PON1 in vloga PON1P še niso povsem pojasnjeni. V tej študiji so raziskovali vplive anaerobnega treninga na serumsko raven PON1, encimsko aktivnost PON1 (PON1EA), lipoprotein visoke gostote (HDL) in paraoksonazno aktivnost njegovih podskupin (HDLPON1EA, HDL2PON1EA, HDL3PON1EA), kot tudi vlogo PON1P. V raziskavi so sodelovali moški športniki (rokomet, košarka, odbojka) – športna skupina (AG: n = 36, starost = 20,56 ± 2,42 let) in kontrolna skupina (CG: n = 39, starost = 22,26 ± 3,44 let). Določili so PON1 in HDL-odvisno encimsko aktivnost PON1, ravni beljakovin encima PON1, ravni oksidiranega lipoproteina nizke gostote (oxLDL) ter polimorfizem PON1P (iz genomskih DNA vzorcev). Serumske vrednosti PON1EA, HDLPON1EA, HDL2PON1EA in HDL3PON1EA pri športnikih z homozigotnim LL genotipom in nosilcih M alela (Mc skupina) niso bile statistično značilno različne od neaktivnih posameznikov. Vendar pa so bile omenjene encimske aktivnosti v športni skupini z LL genotipom statistično značilno višje kot pri športnikih Mc skupine (p < 0,05). Pri primerjavi genotipskih skupin v kontrolni skupini je imel LL genotip (CLL) višje vrednosti serumske PON1EA (za 38,7 %), HDLPON1EA (za 37,2 %), HDL2PON1EA (za 41,9 %) in HDL3PON1EA (za 33,1 %) v primerjavi z Mc genotipom (CMc). Ti izsledki kažejo, da ima genetsko višja PON1EA ter višja PON1 aktivnost HDL in njegovih podskupin pri osebah z LL genotipom lahko pomembno vlogo pri koristnih učinkih anaerobnega treninga. Nasprotno pa je bil Mc genotip genetsko neugodno prizadet zaradi anaerobnega treninga. Zato so raziskovalci zaključili, da je lahko visoko intenziven trening dejavnik tveganja za aterosklerozo pri športnikih z Mc genotipom.

Ključne besede: Paroksonaza 1, Paroksonaza 1-L55M polimorfizem, anaerobni trening, ateroskleroza

INTRODUCTION

Coronary heart diseases (CHD) are among the leading main causes of death in the world. Low protein levels and activities of the paraoxonase enzyme family members (PON1, PON2 and PON3) are considered as a risk factor for CHD (Mackness et al., 1998). This multigene family is localized between q21.3 and q22.1 on the long arm of chromosome 7 in humans (Hegele, 1999). PON1 is the first identified and most studied member of this enzyme family (Deakin & James, 2004) and it has much more clarity compared to PON2 and PON3 (Li et al., 2003). It is known that PON1 has antioxidant, anti-inflammatory and antiatherosclerotic properties by protecting high-density lipoproteins (HDL) and low-density lipoproteins (LDL) from oxidation (Rajkovic et al., 2011; Priyanka et al., 2019). Oxidized low-density lipoproteins (oxLDL) causes endothelial dysfunction and poses a risk for coronary artery diseases (Levitan et al., 2010). Therefore, knowing PON1 and oxLDL levels is extremely important in predicting coronary artery disease.

PON1 has the ability to hydrolyze paraoxon (PON1 enzyme activity, PON1EA, PON1 activity) and phenylacetate (arylesterase activity, ARE) in addition to being able to hydrolyze the oxidized lipids of HDL and LDL (Gan et al., 1991). This enzyme mainly synthesised from the liver is located on HDL and its subgroups (HDLs: HDL2 and HDL3) found in the blood (Aviram et al., 1998; Deakin et al., 2002). Additionally, PON1 can dissociate from the HDL in physiological conditions and increased free PON1 is associated with diseases with high oxidative stress (OS) (Kontush et al., 2010). Studies showed that PON1 activity, HDL2 and HDL3 levels were associated with CHD (Mackness et al., 2003; Deakin & James, 2004). Therefore, knowing the PON1 activities of HDL and its subgroups may be important role to understand risk factors for CHD.

Factors such as age, diet, smoking, environmental conditions, disease status affect PON1 activity (James et al., 2000; Senti et al., 2001) however, its activity is mainly determined by polymorphisms. It has been shown that there are more than 160 polymorphisms in the coding region of the PON1 enzyme, introns that do not participate in protein coding and in the promoter region (Costa el al., 2005). Studies indicate that polymorphisms in the promoter region of PON1 T(-107)C, G(-824)A, G(-907)C have a strong effect on gene expression and enzyme levels in serum (Li et al., 2003). However, the most common polymorphisms due to amino acid changes in the coding region of PON1 occur in the 55th and 192nd codons. While the polymorphism in the 55th codon arises from the Leucine/Methionine (L/M) change, the polymorphism in the

192nd codon arises from the Glutamine/Arginine (Glu/Arg) change. A study on PON1-Q192R polymorphism revealed differences in PON1 activity according to Q and R alleles (Superko et al., 2012). Another study on the PON1-L55M polymorphism (PON1P) reported differences in PON1 activity and concentration according to the L and M alleles. Garin et al. (1997) showed that the amino acids sequence in leucine/methionine polymorphism at position 55 (L55M) has been associated with changes in PON1 serum concentrations and has also been reported to have an association with cardiovascular disease. In addition, it is known that PON1 polymorphisms are associated with CHD (Zhang et al., 2021).

Another important factor affecting PON1 activity is exercise. In studies investigating the relationship between exercise and PON, aerobic exercises (acute/chronic) were mostly examined. Most of these studies showed that aerobic training increased PON1 activities and protein levels (Mahdirejei et al., 2015; Taylor et al., 2015; Benedetti et al., 2018; Russo et al., 2018). In the study by Nalcakan et al. (2016) it was reported that aerobic exercises increased PON1 activity and especially in the QQ phenotype, PON1 activity was significantly higher than control group. There are also studies showed that regular aerobic training had not significantly effect on PON1 activities and protein levels (Silva et al., 2011; Kotani et al., 2012).

In the literature review, it is seen that the number of studies examining the relationship between anaerobic training and PON levels is quite limited. It is not clear to what extent PON enzymes are affected depending on the amount of OS created by high-intensity anaerobic training. In present study, the effects of anaerobic training on serum PON1 levels, PON1EA, HDL and its subgroups' paraoxonase activities (HDLPON1EA, HDL2PON1EA, HDL3PON1EA) as well as the role of PON1P were investigated.

METHODS

Participants

An athlete group (AG: n=36, age=20.56±2.42 years) consisting of healthy male aged between 18-35 years who regularly engage in anaerobic training (basketball, volleyball, handball), not being a smoker, alcohol, drugs or antioxidants users and a control group (CG: n=39, age=22.26±3.44 years) who have not exercised for at least 3-4 months, non-obese (Body mass index, BMI <30) joined in this study. The experimental procedures including possible risks were verbally explained to the participants after which they signed informed consent. The

present study was approved by the local university Ethics Committee and all data was collected in accordance with the Declaration of Helsinki.

Training details

AG trained for a total of 13 h, 5 days a week, 2,5 h/day. The training sessions included high-intensity running, technical-tactical exercises, vertical-horizontal jumpings, plyometrics, strength and power exercises (2 days/week) with high intensity loading. Additionally, aerobic and anaerobic endurance and speed training were executed.

Physical measurements

An electronic medical scale (Seca 769, Germany) was used for measuring the height and body weight of the participants and all measurements were done with shorts and without socks. BMI was calculated based on height and body weight by using BMI = m (kg) / h2 (m2) formula (McArdle et al., 2000).

Blood Sampling and Analysis

Following the physical measurements venous blood samples were obtained in 9-mL serum vacuum tubes, one with EDTA and heparinized blood at rest 3-4 hours after lunch. Serum blood with EDTA samples and heparinized blood tubes were kept at room temperature for 20 minutes. Serum blood tubes for 10 minutes centrifuged at 2000g and serum samples were separated. The serum samples were stored in the freezer (-82°C) for the measurements of the following parameters. DNA samples required for polymorphisms were isolated from blood with EDTA. All biochemical variables were determined within 1 month after obtaining the serum samples.

Analysis of PON1 and oxLDL protein concentrations

Concentrations of PON1 and oxLDL were determined using enzyme-linked immunosorbent assays by measuring absorbance at 450 nm on a microplate reader (Diareader ELX800G; Dialab GmbH, Vienna, Austria). ½ dilution was applied to serum samples for the analysis of PON3 and oxLDL levels. The commercial kits (Elabscience Biotechnology, Wuhan, China) were used for analysing oxLDL levels. Serum concentrations of PON1 and oxLDL were determined by means of standard curves constructed with purified PON and oxLDL proteins in a single batch. The coefficients of variation of PON1 and oxLDL were less than 10%.

Analysis methods of PON1 activity

Spectrophotometer device (Shimadzu UV 1700, Japan) was used to measure serum PON1 activity. Measurements of serum PON1 activity were conducted manually based on the method used by Eckerson et al. (1983). According to this method, serum PON1 activity was determined using paraoxon (diethyl p-nitrophenylphosphate, Sigma Chemical Co, St. Louis, MO, USA) as the substrate with an autoanalyzer (Modular DP, Japan). Paraoxon hydrolysis rates were determined by recording the absorbance at 412 nm and 37°C, which provided a measurement of p-nitrophenol release. PON1 activities were measured in 800-mL assay mixtures containing 1 mmol/L paraoxon, 1 mmol/L $CaCl_2$, and 5 mL of serum in 50 mmol/L TriseHCl buffer (pH 7.4), as described. One unit of paraoxonase activity was defined as 1 mmol p-nitrophenol formed per min under the above assay conditions.

Analysis HDL and it's subgroups' PON1 activity

HDL-containing (HDL and HDL3) supernatants were isolated from serum according to method of Kostner et al. (1985) depending on a differential precipitation process. The method is based on the selective precipitation of lipoproteins by varying the pH and the polyethylene glycol (PEG 20000) polymer (Ma: 20.000, Merck, Darmstadt, Germany) concentrations of the reagent. In this method, the cholesterol and PON1 activity levels of HDL2 were estimated by calculating the difference between HDL and HDL3.

Analysis of lipids and lipoprotein levels

Serum total cholesterol (TC) and serum tri-glycerides (TG) levels were measured according to standardized enzymatic methods by using commercial kits (Dialab Gmbh Wien, Austria) and autoanalyzer (Modular DP, Roche Diagnostics, Tokyo, Japan). Low-density lipoprotein cholesterol (LDL-C) was determined as described by Friedewald et al. (1972).

Determination of total antioxidant status (TAS) and total oxidant status (TOS)

Total antioxidant status (TAS) and total oxidant status (TOS) were measured from serum samples by using a microplate reader (Biotek Epoch2, USA) and commercial kits (Rel Assay Diagnostics, Turkey). In this method, by adding the dark blue-green ABTS radical to the sample, the substance combined with the antioxidants in the sample creates a new color. The change in absorbance seen at 660 nm is associated with the participant's total antioxidant level. The oxidants present in the sample oxidize the ferrous ion-chelate complex to ferric ion. Ferric ion forms a colored complex with chromogen in acidic medium. The color intensity which can

be measured spectrophotometrically, is related to the total amount of oxidant molecules present in the sample. It was given as mmol Trolox Eq/L for TAS and mmol H2O2 Eq/L for TOS. The ratio of serum TOS to TAS was accepted as oxidative stress index (OSI).

Distribution of PON1-L55M phenotypes

DNA isolation was carried out from blood samples with EDTA using a commercial kit (DNeasy Blood Tissue Kit, QIAGEN®-Hilden, Germany) and following the procedure specified in the kit. Genotyping: In order to investigate the SNP regions, the relevant region of the gene was amplified by PCR (SimpliAmp, Thermal Cycler, Singapore) and DNA sequence analysis was performed (MiSeq System, Illumina) and genotypes were determined.

PON1-Revers Primer: 5'- ACACTCACAGAGCTAATGAAAGCC -3'

PON1-Forward Primer: 5'- GAAGAGTGATGTATAGCCCCAG -3'

PON1 activity ratios were used to classify the phenotypes of each participant as LL, LM, MM. Due to the small number of MM and LM homozygote genotype groups, the M carrier (Mc = MM + LM) were combined to form carrier group in order to make the statistical analysis safer.

YOYO IR-1 test

Participants performed the YOYO IR-1 test which is an incremental increasing interval shuttle run test at track & field (Figure 1).

Figure 1. Image of participants during YOYO IR-1 test

In this test, shuttle runs of 2x20 m were run and active rest was carried out at a distance of 10 m (2x5m) for 10 seconds between each shuttle run (after the completed distance of 40m).

Individuals in the test were asked to adjust their speed according to the auditory signals. The test was terminated when the 40m distance was not completed even though the signal was received and the next 40m was not completed either (Bangsbo et al., 2008). This test was completed in 10-20 minutes depending on the condition level of the participants.

Statistical analyses

SPSS Windows version 24.0 package program was used in the statistical analysis. The Shapiro Wilk test was used to examine whether the obtained data showed a normal distribution. The Student t test was used to compare the normal data features in two independent groups and the Mann Whitney U test was used to compare the non-normal data features in two independent groups. Relationships between numerical variables were analysed with the Spearman correlation coefficient. In the comparison of numerical data in more than two independent groups, Kruskal Wallis test and Dunn multiple comparison test were used for non-normal data. As descriptive statistics, mean±standard deviation, median (min-max) were given for numerical variables, and number and % values were given for categorical variables. In addition, the effect of exercise and polymorphism interaction on all parameters were examined by two-way analysis of variance (ANOVA). The significance level was accepted as $p<0.05$ in all statistical analyses.

RESULTS

VO2max and YOYO values of athletic group (AG) were found higher than control group (CG) ($p<0.05$). The oxLDL values of AG were higher compared to CG ($p<0.05$). While no significant difference was found between AG and CG groups in TOS values ($p>0.05$), TAS values of AG were lower than CG ($p<0.05$). Moreover, OSI values of AG were higher than CG ($p<0.05$). However, no difference was found between AG and CG in terms of PON1 protein levels and activities ($p>0.05$) (Table 1).

Table 1. Physical, physiological and biochemical parameters of athletic and control groups (means±standard deviation).

	AG (N=36)	CG (N=39)	T	P
AGE (years)	20.56 ± 2.42	22.26 ± 3.44	2.45	**0.016**
HEIGHT (cm)	190.01 ± 7.61	178.81 ± 7.44	-6.44	**0.001**
WEIGHT (kg)	87.08 ± 14.25	77.2 ± 11.85	-3.27	**0.002**
BMI (kg/m^2)	24.03 ± 3.05	24.08 ± 2.77	0.06	0.949
YOYO (m)	1127.78 ± 504.5	857.95 ± 272.02	-2.91	**0.005**
VO$_2$max (ml)	45.87 ± 4.24	43.61 ± 2.29	-2.90	**0.005**
HDL2PON1EA (U/L)	40.59 ± 32.66	43.9 ± 44.27	0.36	0.716
HDL3PON1EA (U/L)	54.83 ± 38.72	50.8 ± 33.26	-0.48	0.629
HDLPON1EA (U/L)	95.42 ± 70.27	94.7 ± 72.77	-0.04	0.965
SERUMPON1EA (U/L)	107.09 ± 80.08	104.06 ± 81.98	-0.16	0.872
PON1 (ng/mL)	292.73 ± 315.12	355.75 ± 31.68	0.87	0.387
oxLDL (pg/mL)	279.94 ± 54.72	255.48 ± 39.42	-2.23	**0.029**
TAS (mmol/L)	0.87 ± 0.3	1.02 ± 0.25	2.35	**0.021**
TOS (µmol/L)	18.39 ± 3.7	17.59 ± 7.39	-0.58	0.560
OSI (TOS/TAS)	26.12 ± 19.9	18.29 ± 10.38	-2.16	**0.034**
TC (mg/dL)	156.36 ± 44.94	157.03 ± 26.32	0.08	0.937
LDL-C (mg/dL)	78.75 ± 25.06	85.38 ± 25.97	1.13	0.263
TG (mg/dL)	101.83 ± 52.18	118.79 ± 58.97	1.32	0.193
HDL-C (MG/DL)	**50.83 ± 12.27**	**47.79 ± 8.81**	**-1.24**	**0.219**

Notes: p<0.05, p<0.01; **AG** = Athletic group; **CG** = Control group; **BMI** = Body mass index; **HDL2PON1EA** = HDL2's paraoxonase 1 activity; **HDL3PON1EA** = HDL3's paraoxonase 1 activity; **HDLPON1EA** = HDL's paraoxonase 1 activity; **SERUMPON1EA** = Serum paraoxonase 1 activity; **PON1** = Paraoxonase 1; **oxLDL** = Oxidized low-density lipoprotein; **TOS** = Total oxidant status; **TAS** = Total antioxidant status; **OSI** = Oxidative stress index (TOS/TAS ratio); **TC** = Total cholesterol; **LDL-C** = Low-density lipoprotein cholesterol; **TG** = Total tri-glycerides; **HDL-C** = High-density lipoprotein cholesterol.

Paraoxonase findings of genotype groups

VO2max and YOYO values of LL phenotype in athletes (ALL) were found higher compared to the control group (CLL) (p<0.01). No significant difference was found between the athletic and control groups in terms of PON1 protein levels and activities in the LL phenotype and M carrier group (p>0.05). Moreover, there was no significant difference between the athletic and control groups in terms of biochemical parameters in the LL phenotype and Mc carrier group (p>0.05) (Table 2).

Table 2. Comparison of biochemical parameters of ALL/CLL groups and AMc/CMc groups in PON1-L55M genotype (means±standard deviation).

	ALL (n=16)	CLL (n=16)	P	AMc (n=20)	CMc (n=23)	P
AGE (years)	20.41±3.03	21.15±2.01	0.273	20.64±2.64	23.65±4.14	**0.037**
HEIGHT (cm)	191.5±5.8	177.8±6.1	**0.001**	188.8±8.7	179.5±8.3	**0.001**
WEIGHT (kg)	86.43±8.95	75.89±9.22	**0.003**	87.6±17.61	78.11±13.51	0.053
BMI (kg/m^2)	23.58±2.51	24.02±2.67	0.634	24.4±3.44	24.12±2.9	0.774
YOYO (m)	1245±518.43	837.5±222.7	**0.009**	1034±485.63	872.17±305.75	0.192
VO$_2$max (ml)	46.86±4.36	43.43±1.87	**0.007**	45.09±4.08	43.73±2.57	0.208
HDL2PON1EA (U/L)	55.49±38.4	58.3±56.85	0.871	28.68±21.56	33.88±30.42	0.527
HDL3PON1EA (U/L)	69.65±41.45	63.16±30.29	0.617	42.98±32.76	42.2±33.11	0.938
HDLPON1EA (U/L)	125.13±79	121.46±78.83	0.896	71.66±53.2	76.08±63.45	0.807
SERUMPON1EA (U/L)	142.29±91.8	134.82±94.88	0.823	78.93±57.3	82.66±65.59	0.845
PON1 (ng/mL)	341.65±432.27	298.91±225.85	0.728	253.59±17.26	395.28±359.22	0.117
oxLDL (pg/mL)	270.8±56.28	248.69±38.18	0.203	287.25±53.75	260.21±40.42	0.067
TAS (mmol/L)	0.82±0.3	1.08±0.26	0.015	0.92±0.3	0.99±0.24	0.406
TOS (μmol/L)	17.82±3.48	18.39±7.3	0.781	18.85±3.89	17.04±7.57	0.341
OSI (TOS/TAS)	29.5±27.49	17.82±7.07	0.110	23.42±10.77	18.62±12.31	0.184
TC (mg/dL)	162.13±60.44	153.63±23.69	0.604	151.75±28.03	159.39±28.27	0.380
LDL-C (mg/dL)	75.31±24.01	79.69±23.24	0.604	81.45±26.17	89.35±27.5	0.342
TG (mg/dL)	100.44±59.69	129.13±70.81	0.225	102.95±46.9	111.61±49.56	0.561
HDL-C (mg/dL)	52.19±9.1	48.06±9.56	0.221	49.75±14.47	47.61±8.47	0.551

Notes: $p < 0.05$, $p < 0.01$; **ALL** = LL-phenotype in athlete group; **CLL** = LL-phenotype in control group; **AMc** = M-carriers phenotype (LM + MM) in athlete group; **CMc** = M-carriers phenotype (LM + MM) in control group; **BMI** = Body mass index; **HDL2PON1EA** = HDL2's paraoxonase 1 activity; **HDL3PON1EA** = HDL3's paraoxonase 1 activity; **HDLPON1EA** = HDL's paraoxonase 1 activity; **SERUMPON1EA** = Serum paraoxonase 1 activity; **PON1** = Paraoxonase 1; **oxLDL** = Oxidized low-density lipoprotein**; TOS** = Total oxidant status; **TAS** = Total antioxidant status; **OSI** = Oxidative stress index (TOS/TAS ratio); **TC** = Total cholesterol; **LDL-C** = Low-density lipoprotein cholesterol; **TG** = Total tri-glycerides **HDL-C** = High-density lipoprotein cholesterol

While LL phenotype and the M carrier group were compared in the athletic group, serum PON1 activity was lower in the M carrier group ($p < 0.05$). Additionally, HDLPON1 activity of athletic group was found lower in the M carrier group than LL phenotype ($p < 0.05$). Moreover, the PON1 activity of the HDL subgroups (HDL2PON1EA, HDL3PON1EA) of the M carrier group in the athletic group was lower than LL phenotype ($p < 0.05$). While LL phenotype and the M carrier group were compared in the control group, no difference was found in terms of biochemical parameters ($p > 0.05$) (Table 3). However, the control LL (CLL) genotype group had higher serum PON1EA (38.7%), HDLPON1EA (37.2%), HDL2PON1EA (41.9%) and HDL3PON1EA (33.1%) values than control Mc (CMc) genotype.

Table 3. Comparison of biochemical parameters of ALL/AMc groups and CLL/CMc groups in PON1-L55M genotype (means±standard deviation).

	ALL (n=16)	AMc (n=20)	P	CLL (n=16)	CMc (n=23)	P
AGE (years)	20.41±3.03	20.64±2.64	0.798	21.15±2.01	23.65±4.14	0.155
HEIGHT (cm)	191.5±5.8	188.8±8.7	0.282	177.8±6.1	179.5±8.3	0.472
WEIGHT (kg)	86.43±8.95	87.6±17.61	0.799	75.89±9.22	78.11±13.51	0.572
BMI (kg/m^2)	23.58±2.51	24.4±3.44	0.432	24.02±2.67	24.12±2.9	0.916
YOYO (m)	1245±518.43	1034±485.63	0.217	837.5±222.7	872.17±305.75	0.701
VO$_2$max (ml)	46.86±4.36	45.09±4.08	0.222	43.43±1.87	43.73±2.57	0.684
HDL2PON1EA (U/L)	55.49±38.4	28.68±21.56	**0.012**	58.3±56.85	33.88±30.42	0.090
HDL3PON1EA (U/L)	69.65±41.45	42.98±32.76	**0.045**	63.16±30.29	42.2±33.11	0.051
HDLPON1EA (U/L)	125.13±79	71.66±53.2	**0.021**	121.46±78.83	76.08±63.45	0.054
SERUMPON1EA (U/L)	142.29±91.8	78.93±57.3	**0.016**	134.82±94.88	82.66±65.59	0.068
PON1 (ng/mL)	341.65±432.27	253.59±178.26	0.446	298.91±225.85	395.28±359.22	0.667
oxLDL (pg/mL)	270.8±56.28	287.25±53.75	0.378	248.69±38.18	260.21±40.42	0.372
TAS (mmol/L)	0.82±0.3	0.92±0.3	0.327	1.08±0.26	0.99±0.24	0.285
TOS (μmol/L)	17.82±3.48	18.85±3,89	0.412	18.39±7.3	17.04±7.57	0.584
OSI (TOS/TAS)	29.5±27.49	23.42±10.77	0.370	17.82±7.07	18.62±12.31	0.815
TC (mg/dL)	162.13±60.44	151.75±28.03	0.499	153.63±23.69	159.39±28.27	0.508
LDL-C (mg/dL)	75.31±24.01	81.45±26.17	0.473	79.69±23.24	89.35±27.5	0.259
TG (mg/dL)	100.44±59.69	102.95±46.9	0.888	129.13±70.81	111.61±49.56	0.368
HDL-C (mg/dL)	52.19±9.1	49.75±14.47	0.561	48.06±9.56	47.61±8.47	0.877

Notes: p<0.05, p<0.01; **ALL** = LL-phenotype in athlete group; **AMc** = M-carriers phenotype (LM + MM) in athlete group; **CLL** = LL-phenotype in control group; **CMc** = M-carriers phenotype (LM + MM) in control group; **BMI** = Body mass index; **HDL2PON1EA** = HDL2's paraoxonase 1 activity; **HDL3PON1EA** = HDL3's paraoxonase 1 activity; **HDLPON1EA** = HDL's paraoxonase 1 activity; **SERUMPON1EA** = Serum paraoxonase 1 activity; **PON1** = Paraoxonase 1; **oxLDL** = Oxidized low-density lipoprotein**; TOS** = Total oxidant status; **TAS** = Total antioxidant status; **OSI** = Oxidative stress index (TOS/TAS ratio); **TC** = Total cholesterol; **LDL-C** = Low-density lipoprotein cholesterol; **TG** = Total tri-glycerides; **HDL-C** = High-density lipoprotein cholesterol.

No statistically significant difference was found between the 2 genotype groups in terms of L55M genotype distribution or their alleles frequencies (Table 4).

Table 4. Genotypes and alleles frequency of PON1-L55M polymorphism in athletic and control groups.

Polymorphism	Genotype /Allele	Group	AG (n = 36)	CG (n = 39)	Total (n = 75)	χ^2 /p
		LL	16 (44.4)	16 (41.0)	32 (42.7)	
	Genotype	LM	16 (44.4)	17 (43.6)	33 (44.0)	
PON1-L55M		MM	4 (11.1)	6 (15.4)	10 (13.3)	0.311/0.856
	Allele	L	48 (66.7)	49 (62.8)	97 (64.7)	
		M	24 (33.3)	29 (37.2)	53 (35.3)	0.242/0.622

Notes: p<0.05; Note: AG, CG, and Total are presented as number (%). Abbreviations: AG = athletic group; CG = control group; L = leucine; M= methionine; PON = paraoxonase.

Important correlations

In athletic group; A significant correlation was found between YOYO and oxLDL (r=-0.391; p<0.05). In the ALL group; a significant correlation was found between serum PON1EA and HDLPON1EA (r=0.991; p<0.001). Additionally, PON1 activities of HDL subgroups were also

correlated with each other. Significant correlations were found between HDLPON1EA and HDL2PON1EA (r=0.988; p<0.001) and HDL3PON1EA (r=0.990; p<0.001). Also, a significant correlation was found between HDL2PON1EA and HDL3PON1EA (r=0.958; p<0.001). In AMc group; a significant correlation was found between serum PON1EA and HDLPON1EA (r=0.995; p<0.001) and TBARS (r=-0.499; p<0.05). Significant correlations were found between HDLPON1EA and HDL2PON1EA (r=0.969; p<0.001) and HDL3PON1EA (r=0.987; p<0.001). Also, a significant correlation was found between HDL2PON1EA and HDL3PON1EA (r=0.915; p<0.001).

In control group; No significant correlation was found between parameters in the control group. In the CLL group; a significant correlation was found between serum PON1EA and HDLPON1EA (r=0.991; p<0.001). Moreover, PON1 activities of HDL subgroups were also correlated with each other as athletic group. Significant correlations were found between HDLPON1EA and HDL2PON1EA (r=0.952; p<0.001) and HDL3PON1EA (r=0.817; p<0.001). A significant correlation was found between HDL2PON1EA and HDL3PON1EA (r=0.599; p<0.05). In CMc group; a significant correlation was found between serum PON1EA and HDLPON1EA (r=0.997; p<0.001). Significant correlation was detected between HDLPON1EA and HDL2PON1EA (r=0.999; p<0.001). Moreover, a significant correlation was found between HDLPON1EA and HDL3PON1EA (r=0.999; p<0.001). Also, a significant correlation was found between HDL2PON1EA and HDL3PON1EA (r=0.995; p<0.001).

DISCUSSION

The main finding of the present study was that no significant difference was found between AG and CG in terms of PON1 protein level and activity. However, serum PON1EA, HDL2PON1EA, HDL3PON1EA and HDLPON1EA values were found significantly higher in athletic LL phenotype (ALL) compared to the M carrier group (AMc) (p<0.05). No difference was found between the LL phenotype in the control group (CLL) and the M carrier groups (CMc). In addition, there were no significant differences between the AG and CG groups in terms of TG, TC, HDL-C and LDL-C levels (p>0.05) whether polymorphisms were taken into account or not.

The effects of anaerobic training on PON1 protein levels and activities

While genotypes are not taken into consideration there were no significant differences in the PON1 protein levels and activities between athletes and control groups ($p>0.05$) although OSI (including oxLDL) levels were higher ($p<0.05$). These findings can be interpreted as anaerobic training have no effect on athletes' PON1 protein level and serum PON1 activity but increases OSI (including oxLDL). There are many studies in the literature stating that exercise increases PON1 protein levels and activities. However, those studies showed the effect of aerobic not anaerobic exercises/training on PON1. Sang et al. (2015) showed that walking and low-intensity running training performed 5 times a week for 10 weeks increased PON1 activity. Another study showed that PON1 protein level and activity increased significantly after a single session of aerobic exercise on the treadmill (Taylor et al., 2015). There is a study in the literature reporting that PON1 protein levels increased after ultramarathon running (Benedetti et al., 2018). Russo et al. (2018) stated that aerobic training for 3 months increased PON1 activity. There are other studies reporting that endurance training and walking exercises significantly increased PON1 protein levels and activity (Kotani et al., 2012; Mahdirejei et al., 2015). A study showed that PON1 concentration and activity increased after an endurance test performed on a treadmill (Otacka-Kmiecik et al., 2021). In addition, another study stated that repeated endurance tests (3 endurance tests) performed on the treadmill increased PON1 activity (Otacka-Kmiecik et al., 2023). However, in the studies mentioned above the effects of aerobic processes have been revealed and it has been shown that low-medium intensity exercises (acute/chronic) have a positive effect on PON1. In our study, the effect of long-term training (chronic anaerobic training) in handball, basketball and volleyball branches where anaerobic processes are at the forefront, on PON1 was investigated. There are also studies in the literature reporting the positive effect of high-intensity exercises on PON1. Zibad et al. (2015) reported that strength training performed with the intensity in 80% of 1 repetition maximum increased the activity of PON1. Turgay et al. (2015) showed that long-term anaerobic exercise trainings increase PON1 activity. However, TaheriChadorneshin et al. (2017) stated that the effect of maximum effort training on PON1 activity and lipid profile have not yet clear. In our study, we examined anaerobic training which includes significantly intense high-intensity exercises and found that these trainings had no effect on PON1 protein level and activity. The main reason for this may be that the OSI values of the athletic group were higher than the control group. The high OSI value may have suppressed the PON1 increase.

The genotype groups' serum PON1 levels and activities profile (the role of PON1 polymorphism-PON1P)

In this present study, serum PON1EA, HDL2PON1EA, HDL3PON1EA and HDLPON1EA values were significantly higher in athletic LL phenotype (ALL) than M carrier group (AMc) ($p<0.05$). However, in control group, there was no significant difference between the LL phenotype (CLL) and the M carrier groups (CMc) ($p>0.05$). These findings show that the M carrier group was affected negatively by anaerobic training for the specified parameters whereas the LL group affected positively in terms of both serum PON1EA and PON1 activities of HDL subgroups. In this respect, our study findings are similar to the study results of Yigittürk et al. (2020). In the study by Yigitturk et al. (2020) examining the effect of hypoxic training on PON1 and the role of PON1–Q192R and PON1–L55M polymorphisms, it was stated that training under hypoxic conditions the PON1 activity was increased, especially in the QQ and LL groups compared to carrier groups. However, unlike our study they examined the effect of training under hypoxic conditions.

The mentioned differences between the genotype groups for serum PON1 protein levels and serum or HDL subgroups' PON1 activities may mainly be due to the PON1P. It is well known that low PON1 protein levels and enzyme activity are related to the CHD. In the light of this information, it can be concluded that athletes in the LL genotype group may have an advantage in terms of prevention of CHD when they perform high intensity exercises such as jumping, interval running, strength, speed and plyometric training which are used in basketball, volleyball and handball. On the contrary it can be said that M carrier group is negatively affected by anaerobic training and thus has risk for CHD due to the decrease in PON1 protein level and activity with these training. Therefore, future studies are needed to investigate training protocols for the prevention of CHD in the M carrier group.

CONCLUSION

These findings indicate that LL genotype had higher serum PON1EA. LL genotype group also had higher HDL and its subgroups' PON1EA. Therefore, it can be said that the LL genotype group performing anaerobic training is more advantageous in preventing CHD. However, the M carrier genotype group was genetically negatively affected from anaerobic training and this may be considered as a risk factor for CHD. It can be concluded that carry out studies on special training protocols to protect the M carrier genotype group which is negatively affected by

anaerobic training from CHD by reducing the potential risks related to OS. In addition, findings of present study show that anaerobic training has no significant effect on all lipids and lipoprotein levels. Moreover, this study indicates that the PON1P is not related to all lipid and lipoprotein concentrations. In this study, the sample group was limited to athletes in anaerobic sports branches such as basketball, volleyball and handball. It is recommended to conduct further studies with a large number of participants in different branches, with different gender, age, diet, environmental conditions.

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Conflicts of interest

On behalf of all authors, the corresponding author states that there is no conflict of interest.

Funding

Data availability statement

The datasets generated for this study are available on request to the corresponding author.

Ethics approval

This project was approved by the Ege University Medical Research Ethics Committee, İzmir, Turkey with 20-10T/48 reference number. All data was collected in accordance with the Declaration of Helsinki. Participants were informed about the details of the study and all provided written informed consent.

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DO PEOPLE WITH DIFFERENT PERSONALITIES REACT DIFFERENTLY TO THE INTERVENTIONS OF ACCEPTANCE AND COMMITMENT THERAPY?

ALI SE LJUDJE Z RAZLIČNIMI OSEBNOSTNIMI LASTNOSTMI ODZIVAJO RAZLIČNO NA INTERVENCIJE TERAPIJE SPREJEMANJA IN PREDANOSTI?

ABSTRACT

This study evaluated the effectiveness of Acceptance and Commitment Therapy (ACT) interventions in changing psychological flexibility processes in young physically active adults aged 20 to 25 years (N = 30). It also examined the moderating role of personality traits, measured with the Big Five Questionnaire (BFQ). Participants self-selected into either an experimental group, which completed eight weekly ACT-based interventions, or a passive control group. All participants completed the BFQ and the Multidimensional Psychological Flexibility Inventory (MPFI) at baseline. The MPFI was administered again after 10 weeks, while personality was assessed only at baseline. The study showed that at baseline, psychological flexibility processes differed between the groups, with the experimental group reporting lower flexibility. After 10 weeks, no significant differences remained. The ACT interventions were associated with a reduction in inflexibility processes in the experimental group, while the control group also showed a decrease in flexibility processes. Within the experimental group, the personality trait of dominance negatively predicted changes in most psychological flexibility processes. While previous research supports the effectiveness of ACT interventions for mental health, this study expands current understanding by focusing on a physically active young adult sample and assessing both flexibility and inflexibility processes. Personality traits, particularly dominance, may moderate ACT intervention outcomes.

Keywords: acceptance and commitment therapy (ACT), psychological flexibility, personality traits, dominance, young adults

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IZVLEČEK

Predstavljena študija je preučevala učinkovitost intervencij terapije sprejemanja in predanosti (ACT) na spremembe v procesih psihološke fleksibilnosti pri fizično aktivnih mladih odraslih, starih med 20 in 25 let (N = 30). Poleg tega je bilo s pomočjo vprašalnika Velikih pet (BFQ) ocenjeno tudi, kakšno vlogo imajo pri tem osebnostne lastnosti. Udeleženci študije so se sami razvrstili bodisi v eksperimentalno skupino, ki je končala osem tedenske ACT-intervencije, bodisi v pasivno kontrolno skupino. Vsi udeleženci so na začetku študije izpolnili vprašalnik BFQ in večdimenzionalni vprašalnik psihološke fleksibilnosti (MPFI). MPFI so udeleženci izpolnili še enkrat po desetih tednih, medtem ko se je njihova osebnost ocenila le na začetku študije. Študija je pokazala, da so bili procesi psihološke fleksibilnosti med skupinama na začetku študije različni, pri čemer je eksperimentalna skupina izražala nižjo fleksibilnost. Po desetih tednih razlik med skupinama ni bilo več. Pri eksperimentalni skupini so bile ACT-intervencije povezane z zmanjšanjem procesov nefleksibilnosti, medtem ko so se v kontrolni skupini zmanjšali procesi fleksibilnosti. V eksperimentalni skupini je dominantnost, kot osebnostna lastnost, negativno napovedovala spremembe pri večini procesov psihološke fleksibilnosti. Medtem ko prejšnje raziskave podpirajo učinkovitost ACT-intervencij na duševno zdravje, ta študija širi trenutno razumevanje vpliva intervencij na procese fleksibilnosti in nefleksibilnosti, s poudarkom na vzorcu fizično aktivnih mladih odraslih. Osebnostne lastnosti, predvsem dominantnost, lahko vplivajo na učinke ACT-intervencij.

Ključne besede: terapija sprejemanja in predanosti (ACT), psihološka fleksibilnost, osebnostne lastnosti, dominantnost, mladi odrasli

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INTRODUCTION

Acceptance and Commitment Therapy (ACT) is a form of psychotherapy that belongs to the third wave of behavioural therapies. It is a therapeutic approach based on the processes of mindfulness, acceptance, present moment, commitment and behavioural activation, with the aim of promoting psychological flexibility (Hayes et al., 2006). It is an evidence-based therapy that is effective in working with various psychological problems. It is a procedural form of psychotherapy that focuses on promoting the therapeutic processes of psychological flexibility (Hayes et al., 2011).

Psychological flexibility, as conceptualised within ACT (Hayes et al., 2006), represents a set of adaptive cognitive and behavioural processes that are critical to understanding human responses to complex environments. It encompasses the ability to recognise and adapt to changing situational demands, reconfigure mental resources, shift perspectives, and balance competing wants, needs, and life domains (Kashdan & Rottenberg, 2010). Doorley et al. (2020) operationalize psychological flexibility as the tendency to respond to situations in ways that facilitate the pursuit of valued goals, arguing that psychological flexibility is most important in situations that are challenging and stressful. Research supports associations of psychological flexibility with self-compassion, satisfaction with job performance, and general well-being (Hayes et al., 2006; Kashdan & Rottenberg, 2010; Yadavaia et al., 2014), while psychological inflexibility is associated with an overwhelming number of constructs including, but not limited to, depression, anxiety, stress, substance abuse, negative body image, eating disorders, pain catastrophizing, thought suppression, job burnout, and workplace absenteeism (Bluett et al., 2016; De Boer et al., 2014; Hayes et al., 2006; Lloyd et al., 2013; Luoma et al., 2011).

A well-known concept in the field of ACT is experiential avoidance, which is a facet of psychological inflexibility. When a person is unwilling to stay in touch with a particular private experience (body sensation, emotions, thoughts, memories), behavioural therapists refer to this phenomenon as experiential avoidance, in other words, emotional avoidance or cognitive avoidance (Hayes et al., 1996). The extensive literature highlights the negative effects of experiential avoidance on mental health, in which people adopt inflexible behavioural patterns to avoid unwanted internal states such as depression, anxiety, obsessive-compulsive symptoms, and addictions, among many other psychological and behavioural challenges (Akbari et al., 2022; Luoma et al., 2011).

The ACT method has also been applied to people without severe somatic illness or psychopathological problems, where ACT interventions have shown positive or promising results in smoking cessation (Bricker et al., 2014; Gifford et al., 2004), weight maintenance (Forman et al., 2015; Lillis et al., 2011; Lillis & Kendra, 2014), and physical activity promotion (Butryn et al., 2011; 1993 et al., 2021). However, little is known about the factors that contribute to individual differences in response to ACT interventions (and processes within ACT) and how these differences can be identified and better understood. For example, which ACT processes experience the most notable changes in response to different personality traits, contributing to a more accurate understanding of the dynamic relationship between personality and ACT? To begin answering these questions, we turn to the topic of personality and the Big Five as relevant predictors of individual differences in ACT adoption.

Personality represents a relatively consistent and unique sum of an individual's psychological, cognitive, and physical traits (Musek, 1993). Personality traits are not just attributes that a person possesses. Personality traits also fundamentally shape and influence how people experience emotions (Eldesouky & English, 2019), which emotion regulation strategies they use (Gresham & Gullone, 2012) and traits also determine the ability to regulate (Ivcevic & Brackett, 2014). In recent decades, the five-factor model of personality has become the predominant model for understanding personality structure and is now the most commonly used model in personality psychology.

The Big Five traits are ideal for predicting individual differences in emotion regulation, especially in the context of psychological flexibility, as research has shown a direct link between psychological flexibility and neuroticism, extraversion and conscientiousness (Gloster et al., 2011; Kashdan et al., 2020; Kashdan & Rottenberg, 2010; Steenhaut et al., 2019). Steenhaut et al. (2019) have even shown that personality has an indirect influence on well-being via psychological flexibility in older and young adults. There is growing evidence for the effectiveness of psychological flexibility interventions based on ACT, particularly in the sports domain (Mooney, 2022), but there remains limited evidence for the moderating role of specific personality traits in influencing the outcomes of these interventions.

The contribution of Big Five personality traits in predicting individual differences in the adoption of ACT interventions

Several views have been proposed for a better understanding of the relationship between personality traits and psychological flexibility. According to Kashdan & Rottenberg's (2010)

conceptualization, flexibility is highly dependent on the exact configuration of each individual's personality traits, noting that the dimensions of neuroticism and openness to experience are consistent with the five-factor model of personality. Individuals with high neuroticism scores often show persistence on self-related issues that divert attention from adaptive behaviors such as problem solving and efforts to achieve personally valuable goals (O'Brien & DeLongis, 1996). People with high levels of neuroticism have difficulty choosing strategic responses (Gunthert et al., 1999) and have difficulty disengaging from negative thoughts and feelings. This obstacle not only stands in the way of a full connection with the present moment, but also hinders alignment with values and commitment (Kashdan & Rottenberg, 2010). Better acceptance correlates with a stronger commitment to actions and behaviors that align with one's values (Hayes et al., 2011).

In the recent study by Kashdan et al. (2020), a significant relationship was found between negative emotionality and avoidance tendencies, indicating a resistance to acceptance of negative emotions and stress in athletes. Conversely, conscientiousness showed a positive correlation with increased utilization (using one's internal resources to overcome obstacles and move toward valued goals, even in the presence of discomfort or adversity) and decreased avoidance, suggesting a proactive use of internal resources to overcome challenges. Of note, the combined influence of conscientiousness and open-mindedness led to favorable results in all subscales of psychological flexibility. Athletes characterized by an open-minded personality showed an increased tendency to accept stress and negative emotions (Rutherford, 2021). Psychological flexibility even proves to be a crucial mechanism to explain the relationship between personality and well-being, as it fully explains the effect of personality on well-being in almost half of the models.

This exploration of the intricate relationships between personality, psychological flexibility, and well-being sets the stage for an intriguing investigation: are there discernible moderating effects of personality on the development of psychological flexibility through ACT interventions?

The present research

The existing literature emphasizes the role of personality as a moderator that enhances well-being through positive psychological interventions (Ng, 2015). Given that positive psychological interventions have been shown to enhance well-being (Bolier et al., 2013; Gander et al., 2016; Sin & Lyubomirsky, 2009; Tejada-Gallardo et al., 2020), our study seeks

to extend this understanding by examining the nuanced interplay between personality traits and the cultivation of psychological flexibility through ACT.

Our investigation examines changes in specific processes as well as global factors of psychological flexibility and inflexibility in young, physically active adults following ACT-based group interventions, which so far have not been extensively researched. Previous research in this area has primarily relied on a global measure (AAQ) that does not distinguish between individual processes of flexibility and inflexibility, leaving the distinct effects of ACT on individual processes largely unexplored. Additionally, this study explores the moderating and predictive roles of personality traits in the adoption of ACT processes, with the aim of identifying personality profiles most likely to engage with and benefit from ACT interventions, thereby supporting improved psychological functioning in physically active populations.

METHODS

Participants

A total of 60 participants were included in the study, 29 of whom signed up for the experimental group and 31 for the control group. The participants were between 20 and 25 years old. Of these participants, 31 were female and 29 were male, i.e. both genders were equally represented. All participants were physically active students who exercised more than five hours per week. None of the participants had previous experience with psychological interventions or training, and all were physically healthy and had no psychopathological symptoms. The experimental group participated in eight one-hour ACT interventions over an eight-week period and were psychologically assessed before and after the intervention. The control group only received the psychological assessments. The 29 participants in the experimental group had an average age of 21.61 years ($SD = 3.33$), 14 of whom were female (48.3%). The mean age of the control group was 21 years ($SD = 3.25$), of which 17 were female (54.8%). Participants were recruited using a systematic approach. Methods such as the snowball system and online advertisements were used, with the latter also being distributed via student organisations. All participants took part in the study voluntarily. Before the study began, participants were informed about the purpose and procedures of the study and signed an informed consent form. All participants completed the follow-up survey. This study was

approved by the Ethics Committee for Sport at the Faculty of Sport, University of Ljubljana, Slovenia.

Measures

Big Five Questionnaire designed to measure personality traits in individuals aged 14 and older (BFQ, Slovene edition; Caprara et al., 1997) evaluates the five capital domains of personality along with ten facets: energy (subcategories activity and dominance), acceptability (subcategories cooperation and kindness), consciousness (subcategories precision and perseverance), emotional stability (subcategories emotional control and impulse control) and openness (subcategories openness for culture and openness for experience). Participants were required to rate the extent to which each statement described them, using a 5-point scale ranging from 1 (strongly disagree) to 5 (strongly agree). The questionnaire consists of 132 items grouped into ten scales. In addition to the five dimensions of personality and their sub-dimensions, the BFQ includes an additional scale of sincerity, which assesses an individual's tendency to provide socially desirable responses. The BFQ was translated, adapted, and standardized for use in the Slovenian context and has adequate psychometric properties. The reliability coefficients of the BFQ dimensions in the Slovenian context were high (energy α = .83; agreeableness α = .76; conscientiousness α = .83; emotional stability α = .87; openness α = .80; and sincerity α = .80) (Bucik et al., 1997).

Multidimensional psychological flexibility inventory (MPFI) consists of five items (i.e., statements) for each of the six dimensions of pflexibility (PF) and the six dimensions of psychological inflexibility (PI), respectively, totalling 60 items. The dimensions include (PF/PI): acceptance/experiential avoidance; contact with the present moment/lack of contact with the present moment; self as context/self as content; defusion/fusion; committed action/inaction; and values/lack of contact with values (Rolffs et al., 2018). Participants were required to rate the frequency of experiencing each statement over the past two weeks, using a 6-point scale ranging from 1 (never true) to 6 (always true). The English MPFI has demonstrated strong psychometric properties, including robust support for a model with 12-factor loadings onto two higher-order factors, significant correlations with the most widely-used measures of inflexibility (i.e., AAQ, AAQ-II, and AFQ-Y), and estimated Cronbach's α values for the different subscales ranging from .87 to .95. In the first sample, the Cronbach's α values for the six subscales of PF range from .82 to .94, while for the six subscales of PI, the values range from .83 to .94. In the second sample, the Cronbach's α values for the six

subscales of PF range from .73 to .90, and for the six subscales of PI, the values range from .70 to .89 (Rolffs et al., 2018).

Procedure

The ACT interventions were conducted at the Faculty of Sport in Slovenia under the guidance of a trained facilitator with a background in physical education. To ensure standardization and optimal delivery of the ACT interventions, supervision was provided by a licensed clinical psychologist. The ethical considerations of the study were reviewed and approved by the ethics committee for ethical issues related to sports. After the initial measures of personality (Big Five Questionnaire, BFQ) and psychological flexibility (Multidimensional Psychological Flexibility Inventory, MPFI), the experimental group was introduced to the ACT approach in the first session, where participants were familiarized with ACT constructs such as psychological flexibility, destructive normality, and rational framing theory. The group was also informed about the purpose of the interventions, the program structure, and the roles and responsibilities of the participants. The interventions were conducted over a period of eight weeks, with one 45-minute session per week. This means that the experimental group received a total of 6 hours of ACT interventions. The program consisted of six modules based on the processes of ACT, with a separate intervention assigned to each process. They were presented in the following order: values clarification, defusion, present moment, acceptance, self as context, committed action. The program was predominantly text-based and included information on each topic, wellbeing tasks, experiential exercises and relevant metaphors. All exercises were available to participants in the form of a flashcard at the interventions and were also accessible in digital form throughout the program. Participants were encouraged to follow the modules of the program, but also had the opportunity to explore and tailor the content to their individual needs. Participants completed ACT exercises and recorded their experiences on reflection paper, which was kept in a secure locker until the next intervention. Participants also had full access to personalized feedback on their questions related to the interventions and exercises during and after the intervention. The final intervention served to summarize the entire program and provided participants with the opportunity to ask final questions and make additional entries in their reflection papers if they wished to revisit or extend certain exercises. The purpose of the tailored feedback, given in accordance with ACT principles, was to tailor the content of the program to each participant's needs by guiding them step-by-step through the program content, motivating participants, encouraging behavioral activation when needed, and empathetically encouraging them to continue despite potential

challenges. The final session served as a follow-up, during which the MPFI was measured again. The control group, who had only completed the initial psychological measurements, underwent a second MPFI assessment after eight weeks without any intervention.

Data collection took place between February and September 2023 at the Faculty of Sport in Ljubljana (Slovenia). After informed consent, participants completed the questionnaires individually and anonymously. A series of standardized self-assessments were conducted at the beginning of the study and again after eight weeks. Statistical analysis revealed no significant age differences between the experimental group ($n = 29$) and the control group ($n = 31$). The data was analyzed using SPSS version 15.0 and Excel.

RESULTS

Table 1. Comparison of personality traits of groups of participants.

	Experimental group		Control group				
	M	*SD*	*M*	*SD*	*t*	*sig (t)*	Cohen's *d*
Lie scale	31.24	5.15	31.32	5.59	-0.06	0.48	5.38
Dynamism	38.38	6.10	40.32	6.40	-1.20	0.12	6.26
Dominance	37.79	5.78	38.65	6.44	-0.54	0.30	6.13
Cooperativeness	43.48	3.88	43.39	5.70	0.08	0.47	4.91
Politeness	39.93	5.44	39.26	7.60	0.39	0.35	6.64
Scrupulousness	40.72	6.13	39.65	7.68	0.60	0.28	6.97
Perseverance	43.38	7.20	43.68	5.21	-0.18	0.43	6.25
Emotion control	35.59	6.41	38.58	9.19	-1.47	0.07	7.97
Impulse control	33.41	6.42	34.06	7.60	-0.36	0.36	7.06
Openness to culture	36.38	5.83	35.45	6.07	0.60	0.27	5.95
Openness to experiences	40.21	6.10	38.84	4.72	0.97	0.17	5.42
Energy	76.17	10.24	78.97	11.44	-0.99	0.16	10.88
Friendliness	83.41	8.65	82.65	11.43	0.29	0.39	10.18
Conscientiousness	84.10	11.24	83.32	8.97	0.30	0.38	10.13
Emotional stability	69.00	11.51	72.65	15.18	-1.04	0.15	13.53
Openness	76.43	10.37	74.29	7.70	0.90	0.18	9.06

The results in Table 1 show that there were no differences in the personality traits between the participants in the experimental group and the control group. No differences were found in either the 5 main traits or the 10 sub-traits of the Big Five model. There were also no

differences in the lie scale, i.e. we can truly say that the personality structure of the two groups of participants was the same.

Table 2. Group comparison of psychological flexibility and inflexibility subscales before and after the intervention.

	Experimental group		Control group				
	M	*SD*	*M*	*SD*	*t*	*sig (t)*	Cohen's *d*
Before intervention							
Global flexibility	**3.74**	**0.50**	**4.18**	**0.66**	**-2.90**	**0.01**	**-0.74**
Acceptance	3.26	0.87	3.71	1.04	-1.83	0.04	0.96
Present moment awareness	4.06	0.76	4.28	0.97	-1.01	0.16	0.88
Self as context	3.78	0.92	4.33	0.90	-2.33	0.01	0.91
Defusion	3.00	0.79	3.54	0.91	-2.42	0.01	0.86
Values	4.34	0.87	4.68	0.89	-1.49	0.07	0.88
Committed action	4.02	0.82	4.54	0.92	-2.29	0.01	0.87
Global inflexibility	**2.77**	**0.55**	**2.50**	**1.00**	**1.29**	**0.20**	**0.33**
Experiential avoidance	3.52	0.90	3.37	1.25	0.51	0.31	1.10
Lack of contact with the present moment	2.35	0.89	2.08	1.01	1.09	0.14	0.95
Self as content	3.11	0.99	2.81	1.24	1.04	0.15	1.13
Fusion	2.91	1.01	2.65	1.41	0.84	0.20	1.24
Lack of contact with values	2.37	0.71	2.01	1.02	1.54	0.06	0.88
Inaction	2.37	1.05	2.10	1.22	0.91	0.18	1.14
After intervention							
Global flexibility	**3.89**	**0.60**	**3.95**	**0.72**	**-0.32**	**0.75**	**-0.08**
Acceptance	3.58	0.84	3.47	0.99	0.45	0.33	0.92
Present moment awareness	4.12	0.81	4.18	0.86	-0.29	0.39	0.84
Self as context	3.94	0.84	4.16	0.88	-0.98	0.17	0.86
Defusion	3.26	0.74	3.40	0.90	-0.64	0.26	0.83
Values	4.30	0.92	4.34	0.90	-0.14	0.45	0.91
Committed action	4.14	0.78	4.12	1.00	0.07	0.47	0.90
Global inflexibility	**2.45**	**0.58**	**2.49**	**0.76**	**-0.24**	**0.81**	**-0.06**
Experiential avoidance	3.11	0.75	3.23	1.07	-0.48	0.32	0.93
Lack of contact with the present moment	2.18	0.87	2.32	0.90	-0.59	0.28	0.89
Self as content	2.50	0.83	2.74	1.25	-0.86	0.20	1.07
Fusion	2.44	0.83	2.62	1.17	-0.68	0.25	1.02
Lack of contact with values	2.13	0.75	2.12	0.85	0.07	0.47	0.80
Inaction	2.29	0.97	1.95	0.75	1.53	0.07	0.86

Table 2 shows the dimensions of psychological flexibility and inflexibility of the participants in the experimental and control groups before and after the intervention. Before the intervention, the control group showed a higher statistically significant difference in the factor of global psychological flexibility (t = -2.90, p = .01, d = -0.74.) compared to the experimental group. This difference was also reflected in several dimensions of psychological flexibility, with self as context (t = -2.33, p = .01, d = .91), defusion (t = -2.42, p = .01, d = 0.86), committed action (t = -2.29, p = .01, d = 0.87) and acceptance (t = -1.83, p = .04, d = 0.96) all showing statistically significant differences.

There were no statistical differences in any of the other flexibility dimensions and there were no statistical differences in global inflexibility and its dimensions.

After the psychological flexibility intervention, there were no more statistical differences between the groups.

Table 3. Comparison of baseline and post-intervention psychological flexibility dimensions in the experimental group.

	Before intervention		After intervention				
	M	**SD**	**M**	**SD**	**t**	**sig (t)**	**Cohen 's d**
Global flexibility	**3.74**	**0.50**	**3.89**	**0.60**	**-1.03**	**0.31**	**-0.27**
Acceptance	3.26	0.87	3.58	0.84	-1.73	0.05	1.01
Present moment awareness	4.06	0.76	4.12	0.81	-0.39	0.35	0.86
Self as context	3.78	0.92	3.94	0.84	-0.97	0.17	0.92
Defusion	3.00	0.79	3.26	0.74	-1.58	0.06	0.89
Values	4.34	0.87	4.30	0.92	0.20	0.42	0.92
Committed action	4.02	0.82	4.14	0.78	-0.90	0.19	0.70
Global inflexibility	**2.77**	**0.55**	**2.45**	**0.58**	**2.10**	**0.04**	**0.56**
Experiential avoidance	3.52	0.90	3.11	0.75	2.12	0.02	1.03
Lack of contact with the present moment	2.36	0.91	2.18	0.87	1.09	0.14	0.87
Self as content	3.11	0.99	2.50	0.83	3.61	0.00	0.90
Fusion	2.91	1.01	2.44	0.83	3.02	0.00	0.84
Lack of contact with values	2.37	0.71	2.13	0.75	1.80	0.04	0.70
Inaction	2.37	1.05	2.29	0.97	0.39	0.35	1.05

Table 3 shows some changes in the psychological flexibility of the participants in the experimental group after the intervention they underwent. They were better in acceptance and

there was also less experiential avoidance as the negative counterpart of acceptance. They also found it easier to see out of context as they saw themselves less as content people, there was significantly less fusion and they became more in touch with their values. These changes are reflected in the significant reduction in the global inflexibility factor ($t = 2.10$, $p = .04$, $d = 0.56$), indicating that the ACT interventions reduced participants' psychological rigidity.

Table 4. Comparison of baseline and post-intervention psychological flexibility in the control group.

	Before intervention		After intervention				
	M	*SD*	*M*	*SD*	*t*	*sig (t)*	Cohen's *d*
Global flexibility	**4.18**	**0.66**	**3.95**	**0.72**	**1.33**	**0.19**	**0.34**
Acceptance	3.71	1.04	3.47	0.99	1.34	0.10	0.99
Present moment awareness	4.28	0.97	4.18	0.86	0.55	0.29	1.05
Self as context	4.33	0.90	4.16	0.88	1.13	0.13	0.82
Defusion	3.54	0.91	3.40	0.90	0.85	0.20	0.89
Values	4.68	0.89	4.34	0.90	2.41	0.01	0.79
Committed action	4.54	0.92	4.12	1.00	2.44	0.01	0.94
Global inflexibility	**2.50**	**1.00**	**2.49**	**0.76**	**0.04**	**0.97**	**0.01**
Experiential avoidance	3.37	1.25	3.23	1.07	0.64	0.26	1.29
Lack of contact with the present moment	2.08	1.01	2.32	0.90	-1.71	0.05	0.76
Self as content	2.81	1.24	2.74	1.25	0.44	0.33	0.81
Fusion	2.65	1.41	2.62	1.17	0.17	0.43	0.84
Lack of contact with values	2.01	1.02	2.12	0.85	-0.70	0.24	0.82
Inaction	2.10	1.22	1.95	0.75	0.96	0.17	0.86

Table 4 shows some of the changes that occurred in the control group participants in the dimensions of psychological flexibility, even though they did not participate in the interventions. The post-intervention measurements showed that the control group participants were less clear about their values and less committed to action, while also feeling less in touch with the present moment. These psychological flexibility dimensions were statistically noteworthy, but did not affect either the global flexibility or inflexibility factor in any meaningful way.

The purpose of this experiment was to determine whether certain personality traits predicted changes in psychological flexibility and inflexibility following the ACT-based interventions. First, we wanted to analyse the significant correlations between these two constructs to examine the detailed relationship between them. As can be seen in Table 5, we found several significant correlations. Energy ($r = -0.43$, $p < .05$) and dominance ($r = -0.50$, $p < .01$) showed a negative correlation with changes in global psychological inflexibility, suggesting that lower levels of these traits were associated with greater reductions in inflexibility. Similarly, the psychological inflexibility dimension of inaction, was significantly negatively correlated with dominance ($r = -0.51$, $p < .01$), energy ($r = -0.53$, $p < .01$) and dynamism ($r = -0.42$, $p < .05$). A decrease in inflexibility subscales of experiential avoidance positively correlated with emotional control ($r = 0.41$, $p < .05$), suggesting that participants with more emotional control are less avoidant. Scrupulousness ($r = -0.40$, $p < .05$) was also negatively associated with a decrease in lack of contact with values. Personality traits and sub-traits that correlated with the flexible side of psychological flexibility included the following: An increase in committed action showed three negative correlations with friendliness ($r = -0.49$, $p < .01$), cooperativeness ($r = -0.43$, $p < .05$), and politeness ($r = -0.48$, $p < .01$), suggesting that less agreeable individuals show greater improvements in committed action.

Table 5. Correlation of personality traits and changes in flexibility after flexibility intervention.

	Increase					Decrease			
	Global flexibility	Acceptance	Present moment awareness	Defusion	Committed action	Global inflexibility	Experiential avoidance	Lack of contact with values	Inaction
Lie scale		-0.52**							
Energy						-0.43*			-0.53**
Dynamism									-0.42*
Dominance						-0.50**			-0.51**
Friendliness					-0.49**				
Cooperativeness					-0.43*				
Politeness					-0.48**				
Conscientiousness									
Scrupulousness								-0.40*	
Emotional stability			-0.41*	-0.46*					
Emotion control							0.41*		
Impulse control	-0.39*		-0.49**	-0.47*					

Note:*Correlation is significant at the 0.05 level (2-tailed); **Correlation is significant at the 0.01 level (2-tailed).

Emotional stability and impulse control correlated negatively with an increase in defusion as well as present moment awareness. Acceptance was also found to correlate negatively with a lie scale. The global flexibility factor was significantly associated only with impulse control (r = -0.39, p < .05), suggesting that lower impulse control predicted greater overall increases in psychological flexibility. When we see correlations between personality sub-dimensions and flexibility changes, these are also evident at the personality level. Due to the fact that we found correlations, we also wanted to see whether predictions could be made, i.e. whether personality can influence changes in flexibility.

Table 6. Regression of personality traits on changes in flexibility.

	R	*R* Square	Adjusted R Square	*F*	Sig.	Significant predictors (Beta, sig)
Increase						
Global flexibility	0.80	0.64	0.39	2.57	**0.04**	Dominance (-0.08; 0.00), Lie scale (-0.06, 0.04)
Acceptance	0.74	0.55	0.25	1.81	**0.14**	
Present moment awareness	0.77	0.60	0.32	2.17	**0.08**	Impulse control (-0.81; 0.10)
Self as context	0.77	0.60	0.32	2.17	**0.08**	Dominance (-0.77; 0.00), Cooperativeness (-0.50; 0.04), Friendliness (0.68; 0.03)
Defusion	0.80	0.63	0.38	2.52	**0.05**	Dominance (-0.70; 0.01), Perseverance (0.62; 0.03)
Values	0.77	0.59	0.31	2.11	**0.09**	Dominance (-0.78; 0.00), Scrupulousness (0.78; 0.01), Impulse control (-1.17; 0.02), Emotional stability (1.31; 0.02)
Committed action	0.80	0.64	0.39	2.57	**0.04**	Dominance (-0.67; 0.01), Openness (1.14; 0.04)
Decrease						
Global inflexibility	0.80	0.64	0.37	2.40	**0.06**	Dominance (-0.06; 0.02)
Experiential avoidance	0.71	0.50	0.16	1.48	**0.23**	
Lack of contact with the present moment	0.68	0.47	0.07	1.19	**0.37**	
Self as content	0.74	0.54	0.23	1.74	**0.15**	
Fusion	0.70	0.49	0.13	1.37	**0.28**	
Lack of contact with values	0.68	0.46	0.09	1.25	**0.33**	
Inaction	0.77	0.59	0.31	2.09	**0.09**	Dominance (-0.57; 0.03)

The results in Table 6 show that changes in psychological flexibility can be predicted by personality traits. The increase in defusion and committed action can be predicted with statistical significance. For both characteristics, a higher increase will occur in individuals who have lower dominance. Higher perseverance will help a person to improve in defusion and more openness will lead to more committed action. We also took a closer look at some traits of psychological flexibility where we can speak of a tendency towards statistical significance, e.g. increase in awareness of the present moment, self as context and values, and a decrease in inaction. It is interesting to note that dominance almost always plays an important role, in the sense that changes towards a more psychologically flexible person are more likely to occur in people who are not very dominant. Dominance was the only trait that significantly predicted both global factors: an increase in global flexibility ($p = .04$) and a decrease in global inflexibility ($p = .06$), with the former showing slightly higher statistical significance. Individuals with a lower levels of dominance responded more positively overall to the ACT interventions. They showed a greater increase in adaptive psychological processes (flexibility) and a greater decrease in maladaptive processes (inflexibility). This suggests that individuals with low dominance may be more open to change or more responsive to the core mechanisms of ACT.

DISCUSSION

Research has shown that ACT based interventions promote well-being (Katajavuori et al., 2023) and improve general distress (Prudenzi et al., 2021). To better understand the mechanisms of change in ACT, researchers have investigated the impact of interventions on both psychological flexibility and inflexibility, exploring how underlaying processes contribute to therapeutic change. Our investigation examines changes in specific processes as well as global factors of psychological flexibility and inflexibility in young, physically active adults following ACT-based group interventions, which so far have not been extensively researched. Previous research in this area has primarily relied on a global measure (AAQ) that does not distinguish between individual processes of flexibility and inflexibility, leaving the distinct effects of ACT on individual processes largely unexplored. Additionally, this study explores the moderating and predictive roles of personality traits in the adoption of ACT processes, with the aim of identifying personality profiles most likely to engage with and

benefit from ACT interventions, thereby supporting improved psychological functioning in physically active populations.

Aim 1: A change in psychological flexibility factors

The first aim in our study was to see what changes happened in dimensions of psychological flexibility after ACT interventions in young physically active population. Our data (

Table **3**) show that a change happened on all levels of psychological flexibility dimensions, where most statistical differences happened in inflexibility sub-dimensions. After interventions participants were less seeing themselves as content, were less fused with their thoughts, were able to find more contact with their values and were less avoidant.

The only psychological flexibility process that emerged statistically significant was Acceptance. These changes were also reflected in global factors as well, where intervention group exhibited a statistically significant decrease in global psychological inflexibility ($p =$ .04).

It is important to note that the control group initially showed higher levels of global psychological flexibility compared to the intervention group. However, after the interventions, this gap closed, and the two groups exhibited comparable scores, suggesting a potential effect of the intervention on enhancing flexibility or at least maintaining it.

We emphasise that although the global psychological flexibility factor did not significantly change in the intervention group following the interventions, a notable decline was observed in the control group in the second measurement. Specifically, the control group exhibited a significant reduction in values-based action and commitment, which contributed to a substantial drop in their overall flexibility scores. Young adults, specifically university students are exposed to mental health problems (Auerbach et al., 2018; Bruffaerts et al., 2018), where they can have an effect in both academic as well as personal domains.

Our research shows that even physically active young adults over time become less engaged in committed action and their values become less clear. These two MPFI subscales show strong correlations with current levels of vitality (Rolffs et al., 2018). A decrease in these psychological flexibility processes would suggest a decrease in motivation, diminished sense of purpose and more vulnerability to stress.

To our knowledge, this study is the first to comprehensively evaluate changes across all dimensions of psychological flexibility and inflexibility in response to a group-based ACT interventions.

This study builds on the recent comprehensive review by Rolffs et al. (2018), which synthesised core dimensions of psychological flexibility across current research evaluating outcomes of ACT interventions. Their findings highlighted that ACT interventions lead to significant improvements across global dimensions and sub-dimensions of psychological flexibility and inflexibility, specifically robust improvements in acceptance, global inflexibility, cognitive fusion, self as content, committed action, and defusion. Consistent with these findings, our results also demonstrated that the most notable changes occurred within the dimensions of psychological inflexibility.

These findings suggest that while ACT interventions were theoretically designed to enhance psychological flexibility (Hayes et al., 2006), in practice, they predominantly target psychological inflexibility and its associated processes. Even within our population of healthy, physically active young adults, ACT interventions produced notable changes predominantly in the dimensions of psychological inflexibility.

Our findings also align with the work of Rolffs et al. (2018), the only study to our knowledge that has used the MPFI to examine specific changes in psychological flexibility and inflexibility dimensions following an ACT interventions. Their case study of a single female client who completed a 4-session ACT-based group therapy demonstrated significant improvements in global psychological inflexibility and specific dimensions such as self as content and lack of contact with values, while again not showing any change in dimension of psychological flexibility.

ACT interventions seem to cause similar changes in psychological inflexibility dimensions in a wide range of contexts, including diverse delivery formats, populations, and treatment mechanisms. This suggests that ACT exercises and metaphors do not need to be overly specific for a particular psychological problem or individual for them to be effective at producing immediate relief from negative symptoms.

Although ACT interventions appear effective at relieving negative symptoms by targeting psychological inflexibility, they should also aim to enhance specific psychological flexibility processes of values and committed action.

At the same time the most interesting finding in our first aim was the drop in global psychological flexibility and its processes of values and committed action in the control group. These two MPFI sub-scales show strong correlations with vigour (Rolffs et al., 2018), indicating their importance in sustaining motivation, engagement, and a sense of purpose. Our findings highlight the potential importance of interventions that specifically target these components of psychological flexibility. In particular ACT interventions that emphasise values and committed action may be especially effective in addressing the psychological needs of physically active young adults.

ACT interventions might be better at targeting psychological flexibility processes if they were more informed by individual differences in personality traits.

Integrating personality-focused approaches within ACT interventions could enhance their effectiveness by tailoring them to address individual differences in personality (Kashdan et al., 2020). The literature has begun exploring this approach through the development of the Personalized Psychological Flexibility Index (PPFI) (Jo et al., 2023), which assesses flexibility specifically in the context of personal values and valued goals. This tool may offers valuable insights into how individuals regulate emotions and behaviors in dynamic environments, potentially guiding therapists in selecting or tailoring exercises and metaphors to better suit each individual's unique needs. This approach may foster changes specifically within dimension of psychological flexibility. To expand on this area our second aim in this study was to examine the influence of personality on changes in psychological flexibility dimensions after group ACT interventions in young physically active adults.

Aim 2: Relationship of personality and psychological flexibility

In recent years there has been a big move towards researching the relationship between personality and psychological flexibility (Kashdan et al., 2020). Personality-informed approach can address the designing of psychological interventions to make them more effective (Rebele et al., 2021). Our study focused on researching the influence of personality on the adoption of group based psychological interventions, specifically which psychological flexibility processes are most influenced by which personality traits in physically active young adults.

When we examined correlations between personality traits and psychological flexibility dimensions, we found that developing psychological flexibility through group ACT interventions may be more challenging for impulsive individuals. Specifically, they struggle

to cultivate greater openness and adaptability through processes such as present moment awareness and defusion, as they tend to suppress impulses even during novel experiences that could provide deeper insight into their functioning. Similarly, emotionally stable individuals may be less motivated to develop mindfulness and defusion skills, as they experience fewer intense or distressing emotions and may be less attuned to subtle internal experiences.

In the same vein, energetic and highly dominant individuals who are impatient may find it difficult to engage with ACT interventions, which require experiential and emotional openness to internal experiences. For these individuals, ACT interventions may seem counterintuitive or even threatening, potentially leading to resistance or superficial engagement with group interventions.

Values and values-based committed action are important for a meaningful life (Hayes, 2016; Katajavuori et al., 2023), and personality traits such as conscientiousness and agreeableness may influence individuals' ability to connect with and act on their values. Our findings suggest that individuals who are overly structured and adhere rigidly to rules and personal standards have difficulty clarifying deep personal values or developing new, self-defined flexible values. Following these values can be particularly challenging for agreeable and polite individuals if the new values disrupt social harmony or create interpersonal conflict.

The only trait in our research that positively correlated with the adoption of ACT interventions was emotional stability. Individuals who are calm and emotionally resilient were more willing to experience distress associated with difficult internal experiences through ACT intervention exercises.

These results are particularly relevant for physically active young adults, a population often characterized by ongoing personality trait change, particularly in dimensions such as emotional stability, conscientiousness, and extraversion (Robinson et al., 2015). Traits such as impulsivity and dominance are commonly reinforced in competitive and performance-oriented environments, where quick decision-making and assertiveness are valued. Emotional stability may also be more prevalent due to the psychological benefits of regular physical activity. However, these same traits may hinder engagement with ACT interventions, which require openness, reflection, and experiential processing. This suggests that tailoring ACT approaches to account for the personality profiles typical of this population may improve intervention effectiveness.

To further expand on the relationship between personality dimensions and psychological flexibility processes, we aimed to investigate whether specific personality dimensions could predict changes in particular processes within an ACT intervention. By identifying these predictive relationships, we can gain valuable insights into how individual differences may influence treatment outcomes in physically young adults.

It is noteworthy that personality dimensions predominantly predicted changes in psychological flexibility processes, whereas inflexibility processes were largely unaffected.

Our findings show that trait dominance is a central personality dimension influencing responsiveness to ACT interventions, exerting the strongest and most widespread influence across the majority of psychological flexibility processes.

Dominant individuals tend to prioritise control, assertiveness, and goal-directed behaviour, which can conflict with the foundational principles of ACT interventions. ACT emphasises openness to internal experience, behavioural flexibility, and a commitment to actions guided by personal values rather than rigid goals or externally imposed standards. This mismatch may hinder the effectiveness of ACT for highly dominant individuals, who are more likely to resist the therapeutic stance of relinquishing control and embracing psychological discomfort. Such resistance may also manifest in a tendency toward idealised self-presentation, as suggested by elevated scores on the lie scale. Dominant individuals may also remain passive, avoidant and could struggle with actively engaging in intervention process, limiting their capacity to benefit from key ACT interventions.

Our data shows that dominant physically active young adults may find it difficult to engage with ACT processes such as values, committed action, defusion, and self as context due to the highly structured and externally driven nature of their daily lives. With routines shaped by training programs and academic demands, they may struggle to connect with intrinsic values and also act on them without external direction. Defusion can be particularly challenging, as it involves distancing from rigid self-referential thoughts that align with their control-oriented mindset. Similarly, the process of self as context may conflict with their stable and authoritative self-concept, making it harder to adopt a flexible, observer perspective.

On the other hand, individuals who are emotionally stable and less prone to impulsive behaviour may be better able to connect with their internal values at a deeper level, as they are more capable of tolerating discomfort and maintaining clarity in the face of challenging

internal experiences. Similarly, open individuals are likely to engage more in value-based actions, as they tend to be receptive to new experiences and introspective processes. Those with high levels of perseverance may show greater improvement in defusion skills, as their capacity for sustained effort and persistence supports the development of cognitive distancing from rigid or unhelpful thoughts.

Limitations

First, the study relied solely on self-assessments, which are susceptible to biases such as social desirability and subjective interpretation. Future research could address this limitation by incorporating standardised and clinically validated assessment tools that are less susceptible to such biases. Although personality is typically considered a stable construct, future studies could measure personality traits both pre- and post-intervention to examine whether significant changes occur.

In terms of measuring psychological flexibility and inflexibility, the use of weekly diaries to track fluctuations in psychological flexibility/inflexibility processes during the intervention could provide more detailed insights. This approach would allow researchers to better understand the dynamic nature of psychological flexibility and how ACT interventions affect specific psychological flexibility processes. Furthermore, additional behavioural observations to assess participant engagement and the inclusion of measures of well-being could help to identify potential moderators or mediators within the psychological flexibility processes.

Second, the study design was quasi-experimental, with participants self-selecting into the intervention group. This leads to a potential selection bias, as individuals who are predisposed to change or more motivated are more likely to have participated. Future research using randomised controlled trials (RCTs) would strengthen the causal conclusions and mitigate the selection bias.

Third, the sample was limited to physically active young adults, a population that often shows weaker intervention effects compared to clinical samples. This limits the generalizability of the results to other populations or age groups. Future studies should include a more diverse range of participants to investigate whether personality traits predict changes in psychological flexibility in a broader context.

Fourth, there is a lack of studies that comprehensively examine all dimensions of psychological flexibility and inflexibility, which limits direct comparisons and

contextualization of results. Although our results suggest that ACT interventions primarily influence processes of inflexibility rather than flexibility, these interpretations should be taken with caution after accounting for personality traits. Future research should further investigate how psychological inflexibility and flexibility processes change independently and interactively in different populations to further clarify the treatment mechanisms involved in ACT interventions.

Longitudinal studies are needed to examine the dynamic interplay between personality traits and psychological flexibility over time. By examining how personality traits influence changes in specific psychological flexibility processes, researchers can develop more targeted interventions that promote lasting behavioural change and possibly even personality development.

CONCLUSION

This study aimed to investigate the impact of ACT-based group interventions on the psychological flexibility and inflexibility processes of physically active young adults and to examine the predictive role of personality traits in shaping these changes. Using the MPFI, we were able to assess changes across distinct dimensions of psychological flexibility and inflexibility, allowing for a more nuanced understanding of how ACT interventions influence psychological functioning. Our findings showed that the intervention primarily led to improvements in psychological inflexibility processes, with limited effects observed on flexibility dimensions.

Dominance emerged as the most influential personality trait in predicting changes across several flexibility processes, including values, committed action, defusion, and self as context. This suggests that individuals high in dominance may have difficulty engaging with core ACT principles, which emphasise openness, acceptance, and flexible engagement with personal values. In contrast, individuals with high emotional stability, openness, friendliness, and perseverance demonstrated greater responsiveness to ACT processes, suggesting that these traits may facilitate deeper engagement with the intervention and support sustained psychological change.

The daily life of a physically active young adult is strongly shaped by academic demands and structured training regimens, which may weaken their connection to intrinsic values and make

it more difficult to act in accordance with them. These environmental factors, combined with dominant personality traits, may reduce the capacity to benefit from ACT unless the intervention is adapted to address these barriers directly. Importantly, our findings also suggest that psychological flexibility and inflexibility are not simple opposites but may vary independently, with trait- and context-specific factors influencing each differently.

Overall, this research underscores the value of integrating personality assessment into ACT-based interventions. By identifying traits that either support or hinder engagement with specific ACT processes, interventions can be more precisely tailored to individual needs. Future work should continue to explore how personality-informed adaptations can improve ACT's effectiveness across different populations and settings, particularly in structured, high-demand environments such as those faced by physically active young adults.

Declaration of Conflicting Interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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References: Each statement, finding or thought of others should be backed by a reference. The references in the text should be cited according to the APA system (see: Publication Manual of the American Psychological Association, 6th Edition, 2010; see also: http://www.apastyle.org). In parenthesis, the surname of the author should be given, separated by a comma from the publication year. In the case of more than one author, up to six should be given – before the last surname use "and" instead of a comma. If there are more than six, name only the first and add "et al." Join the names in a multiple-author citation in running text by the word and. In parenthetical material, in tables and captions, and in the reference list, join the names by an ampersand (&). All citations must be included in the list of references given at the end of the article. This list should contain only works that are published or otherwise publicly available. References should be written according to the APA system. All the authors should be given, regardless of their number. If the author is not known, start with the title of the work. If you are citing a work that is in print but has not yet been published, state all the data and instead of the publication year write "in print". Citations such as personal communication, unpublished lectures or presentations and similar are not to be included in the references list. The basic data on the works, such as the author, publisher, title, etc., should be given in the language of the original publication. If the work is not written in English, provide for an English translation of the title in square parenthesis immediately after the original title (see the given reference examples).

Examples of references citation:

Videmšek, M., Šiler, B., & Fišer, P. (2002). Slepa miš, ti loviš! : ustvarjalne gibalne igre za otroke [Hide and seek! : creative motor games for children]. Ljubljana: Fakulteta za šport, Inštitut za šport.

Zupan, A. (2010). Principi reševanja konfliktnih situacij pri učenju smučanja otrok [Principles of resolving conflict situations at teaching children skiing]. Unpublished bachelor's thesis, Ljubljana: Fakulteta za šport.

Filipčič, A. (1993). Zanesljivost in veljavnost izbranih in motoričnih testov v tenisu [Reliability and validity of the chosen motorics tests in tennis]. Unpublished master's thesis, Ljubljana: Fakulteta za šport.

Tomažin, K. (2001). Spremembe površinskega EMG signala pod vplivom periferne utrujenosti: doktorska disertacija [Changes in surface EMG signal under the influence of peripheral fatigue]. Unpublished doctoral dissertation, Ljubljana: Fakulteta za šport.

Schutz, R. W., & Gessaroli, M. E. (1993). Use, misuse and disuse of psychometrics in sport psychology research. In R. N. Singer, M. Murphey, & L. K. Tennant (Eds.), Handbook of research on sport psychology (pp. 901-917). New York: Macmillan.

Cronin, J.B. & Hansen, K.T. (2005). Strength and power predictors of sports speed. Journal of Strength and Conditioning Research, 19(2), 349–357.

Baca, A., Kornfeind, P., & Heller, M. (2007). Two systems for providing KR feedback in table tennis training. In M. Kondrič & G. Furjan Mandić (Eds.), Proceedings book of The 10th Anniversary ITTF Sports Science Congress (pp. 316 - 320). Zagreb: University of Zagreb, Faculty of kinesiology; Croatian Table Tennis Association; International Table Tennis Federation.

APA Style: Reference Examples for Electronic Source Materials. (n.d.). Retrieved June 9, 2011, from http://www.apastyle.org/elecsource.html#77

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