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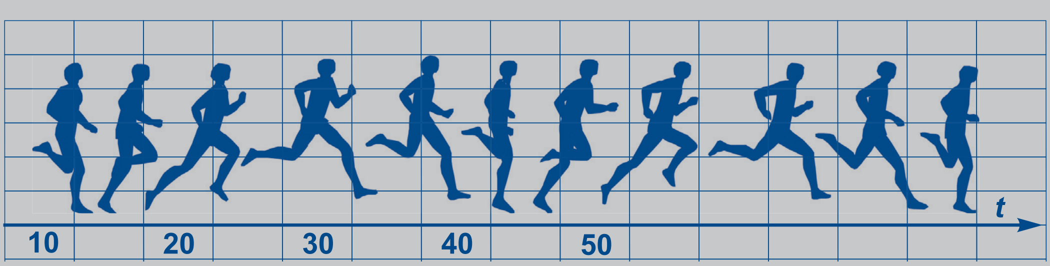

UNIVERSITY OF PHYSICAL EDUCATION IN KRAKOW, POLAND

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AGE-RELATED AND EXPERIENCE--RELATED DIFFERENCES IN SELECTED MOTOR COGNITIVE ABILITIES OF SOCCER PLAYERS

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Authors' contribution:

A. Study design/planning
B. Data collection/entry
C. Data analysis/statistics
D. Data interpretation
E. Preparation of manuscript
F. Literature analysis/search
G. Funds collection

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Abstract:

Background: Soccer players constantly experience rapidly changing situations that challenge them to receive and process stimuli, make fast and correct decisions, and perform actions at specific moments. The aim of the present study was to analyze age and experience-related differences in the level of brain speed, disjunctive reaction time, and reaction speed of soccer players.

Methods: A total of 111 soccer players ($x=12.414$; $s=1.921$) divided by age and level of experience participated in the study. The diagnosis of brain speed and disjunctive reactivity was carried out with the BrainHQ Hawk Eye test and BrainHQ Agility test using the Witty Sem system. Reaction speed was diagnosed with the Fitro Agility Check test using the Fitro Agility system. The Mann-Whitney U test and the Kruskal-Wallis analysis of variance were used to determine the significance of age and experience-related differences in the level of brain speed, disjunctive reaction time, and reaction speed of the soccer players.

Results: Statistically significant differences ($p<0.01$) in favor of older age categories were observed between disjunctive reaction time and brain speed. Younger soccer players showed significantly lower levels of lower limb reaction speed in both directions of the sagittal plane than older players ($p<0.01$). Less experienced soccer players demonstrated significantly lower levels of lower limb reaction speed in both directions of the sagittal plane than more experienced counterparts and lower levels of brain speed and disjunctive reaction time ($p<0.01$).

Conclusions: The study demonstrates that perceptual and motor-cognitive abilities in soccer players improve significantly with age and experience, highlighting the impact of long-term soccer training. Key findings include age-related changes in lower limb reaction speed and improvements in complex reaction times and cognitive processing. These results suggest that the training process positively influences motor-cognitive development and underline the importance of tailoring training to players' sensory periods for optimal outcomes.

Introduction

In team sports like football, players constantly experience rapidly changing situations to which they must react appropriately. In addition to the control of the ball, players need to keep track of the positions of the opposing players as well as teammates on the field in their field of vision. The individual player's performance, among other factors, influences the speed of perceiving the situations, processing stimuli, and making the right decisions to perform the actions at the exact moment [1,2]. It is the reaction to visual stimuli from the periphery that may be one of the key components of performance in soccer. It can be concluded that sport-specific performance in many sports is partly dependent on motor control, coordination, decision-making, and other cognitive functions [3]. The cognitive variations that occur in the analysis, choice, coding, and general management of a soccer player's visual input during a competition or in training are known as visual software that includes the following skills: eye tracking, concentration, eye-foot coordination, speed and span of recognition, eye-body coordination, visual adjustability, visual reaction time, and visual memory [4]. The close interplay of motor and cognitive skills suggests a connection between physical and cognitive domains in youth athletic development [5,6]. The study [7] suggests that cognitive and motor development are linked, and they also indicate that specific cognitive and motor skills may differ depending on age or gender. It is possible that the correlation of motor and cognitive skills changes with age as different skills mature at different rates.

The importance of perceptual-cognitive abilities in sports games has been addressed by several authors in their studies [8,9-11]. According to [12], the complexity of the environment (typical of open-skill sports) in which sports training is performed plays a crucial role in cognitive and motor development in children. [13] In their research that investigated the relationship between cognitive function and sport-specific performance, the authors demonstrated better sport-specific performance in athletes with superior cognitive function.

Perceptual-cognitive training interventions in sports have been addressed by several authors [14-17], but the conclusions are ambiguous despite the changes in the observed parameters. A study on perceptual-cognitive skills of youth soccer players addressed several crucial limitations in the current literature [18], and emphasized the need to (a) examine age-related differences in perceptual-cognitive performance in more detail, (b) investigate to what extent the expertise of soccer players differ in regard to their perceptual-cognitive abilities, and (c) capture perceptual-cognitive performance with a measurement tool that better reflects the demands of the dynamic environment that athletes encounter in-game.

The aim of the study was to analyze age and experience-related differences in the level of brain speed, disjunctive reaction time, and reaction speed of soccer players. The study was supported by the grant project VEGA 1/0481/22 entitled "Relationship between motor docility and cognitive abilities of students."

Materials & Methods

The research sample consisted of 111 soccer players (x=12.414; s=1.921) who participated in the study divided by age $C1U_{10/11}$ (n=41; x=10.543; s=0.632); $C2_{U12/13}$ (n=36; x=12.292; s=1.118); $C3_{U14/15}$ (n=34; x=12.197; s=2.421) and level of experience $K1_{1\text{-}3\ years}$ (n=25; x=10.725; s=1.202); $K2_{4\text{-}6\ years}$ (n=48; x=11.883; s=1.423); $K3_{7\text{-}9\ years}$ (n=38; x=13.794; s=1.747).

The diagnosis of motor-cognitive abilities (brain speed and complex disjunctive reaction time) was carried out using the Witty Sem system. In all tests, the participant's task was to respond to 15 visual stimuli in the shortest possible time. In the first BrainHQ Agility test, the Random Multicolour and Multisymbol test (complex reaction time testing hereafter referred to as CR), the participant's task was to respond as quickly as possible to a semaphore displaying a lowercase letter (a) in green, while the other semaphores displayed other letters and numbers in different colors. In the second BrainHQ Hawk Eye test (or Peripheral Vision test), the speed with which the brain can analyze events determines the effectiveness of the reaction and the ability to remember them. The test challenges the participant's visual precision by asking him/her to locate specific symbols (birds) in his/her peripheral vision, even when they appear for a short time. In this test, the number of correct answers (hereafter BSH) and the mean reaction time (BSRT) were monitored. Brain speed quality (BSQ) was calculated by dividing the mean reaction time by the number of correct answers. The reaction speed of lower limbs was diagnosed by the Fitro Agility Check test on the Fitro Agility system. The system consists of four contact switch mattresses (rear left, rear right, front left, and front right) connected by means of an interface to the computer. Special software measures the times the participant needs to accomplish foot contact with the mattress corresponding with the position of the visual reaction stimulus in one of the four corners of the screen. The test consisted of 1 set of 16 stimuli (blue circles on the screen, 4 in each direction, with random generation of their locations). The mattresses are located at the outside corners of 40 cm square. The mean of the best 4 reaction times in each direction was calculated.

Median (Me) and quartile range (QR) were used as descriptive statistics. Kruskal-Wallis analysis of variance was used to determine the significance of age and experience-related differences in the level of brain speed, disjunctive reaction time, and reaction speed of the soccer players. The effect size coefficient $\eta 2$ was used to evaluate the significance of the statistically tested differences. The classification was used to assess the $\eta 2$ coefficient: 0.0 - 0.009 - no effect; 0.010 - 0.059 - small effect; 0.060 - 0.139 - medium effect; $0.140 \geq 0.2$ - large effect. The significance of differences was evaluated at the significance level $\alpha = 0.05$. Statistics were processed using Statistica 13.5 software.

Results

The first part of the analysis is aimed at answering the research question of how the level of selected motor-cognitive indicators changes with the increasing age of soccer players. In terms of age differences (Figure 1), the results indicate a continuous decrease in reaction time for lower limbs on both sides of sagittal plane between 10 and 15 years of age. As the graph shows, it is evident that the dominance of the left and right lower limbs is constantly changing during the observed period. At the beginning of the period studied, there was a slight dominance of the right limb (1.92 %) but in the U15 group, there was a noticeable dominance of the left (3.28 %).

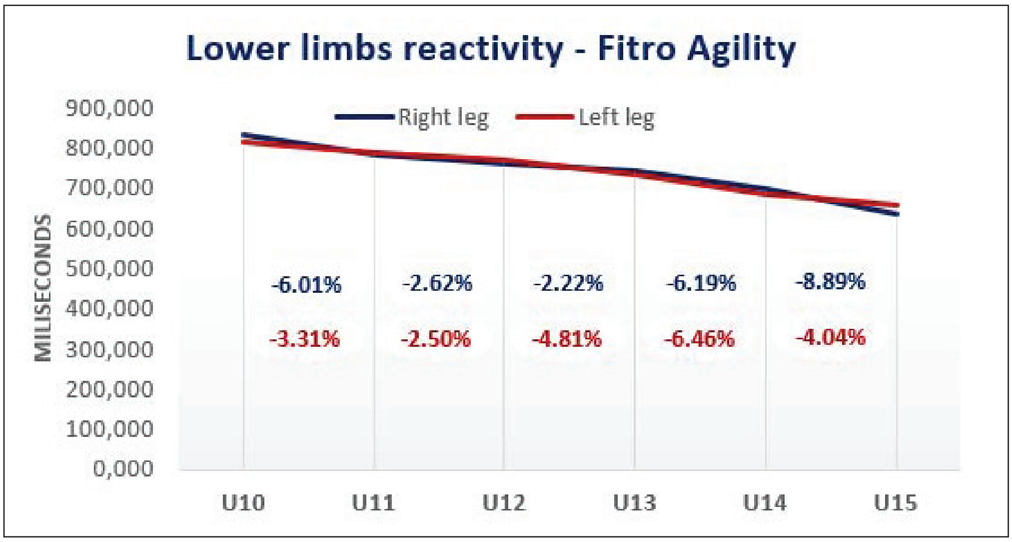

Figure 1. The level of soccer players lower limbs reactivity according to the age level

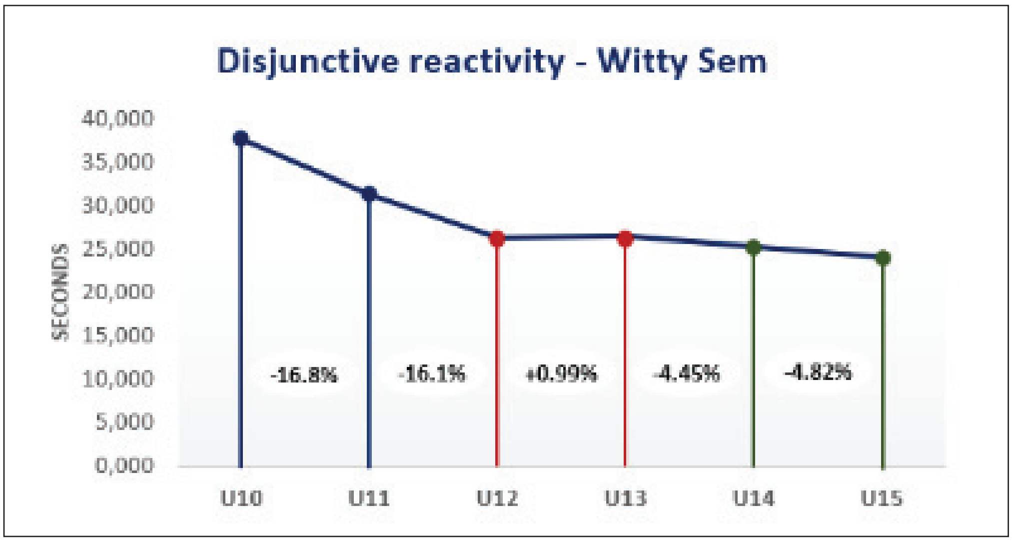

Figure 2. The level of soccer players complex disjunctive reactivity according to the age level

The results suggest possible long-term effects of soccer training, which may point towards further investigation in this area of laterality. Positive changes in disjunctive reaction time are presented in Figure 2 with a slight regression between the studied groups of U12 and U13. The similar positive age-related changes in brain speed quality (Figure 3) are evident in the period up to U11 with a subsequent regression up to the U13 age group.

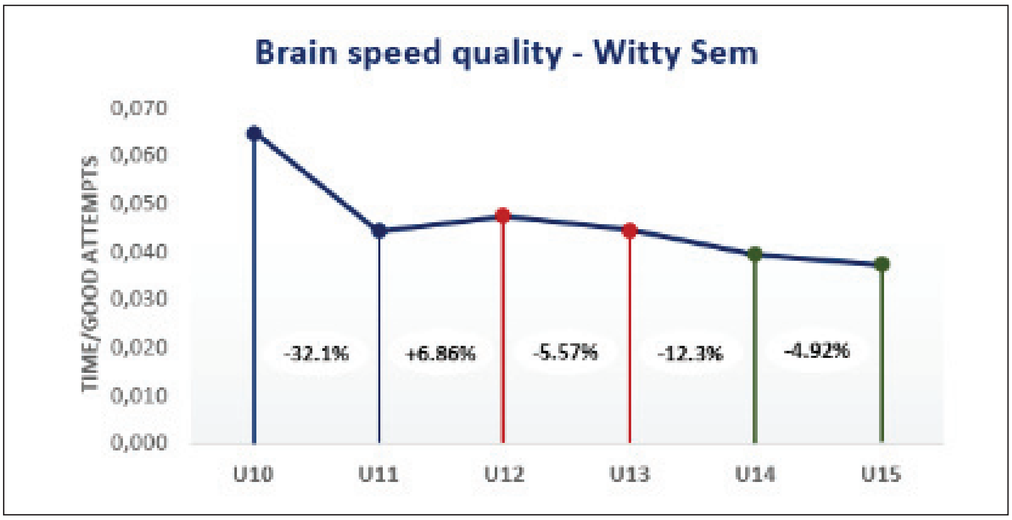

Figure 3. The level of soccer players brain speed quality according to the age level

In the next part of the analysis, we divided the research sample by competition categories into three parts: U10-U11 (younger players), U12-U13 (older players), and U14-U15 (juniors). In the basic data analysis (Table 1), attention was focused on motor-cognitive abilities such complex disjunctive reactivity (CDR), left and right lower limb reactivity level (RLR, LLR), brain speed average reaction time (BSRT), brain speed number of good attempts (BSGA) and brain speed quality (BSQ).

Table 1. Basic characteristics of brain speed, disjunctive reactivity, and reaction speed of soccer players – age category view

	$C1_{U10/11}$ (n=41)					$C2_{U12/13}$ (n=36)					$C3_{U14/15}$ (n=34)				
	Me	QR	Min	Max	x	Me	QR	Min	Max	x	Me	QR	Min	Max	x
BSRT	***0.501***	*0.207*	*0.251*	*1.413*	***0.648***	***0.501***	*0.353*	*0.251*	*1.413*	***0.529***	***0.501***	*0.146*	*0.178*	*1.000*	***0.456***
BSGA	***12.000***	*1.000*	*10.000*	*13.000*	***11.550***	***12.000***	*2.000*	*10.000*	*13.000*	***11.971***	***12.000***	*1.000*	*11.000*	*14.000*	***12.242***
BSQ	***0.044***	*0.023*	*0.019*	*0.141*	***0.057***	***0.042***	*0.037*	*0.019*	*0.141*	***0.046***	***0.042***	*0.014*	*0.013*	*0.091*	***0.038***
CDR	***32.530***	*10.340*	*22.870*	*57.140*	***35.214***	***26.235***	*7.215*	*18.460*	*35.650*	***26.353***	***23.110***	*5.200*	*17.450*	*44.210*	***24.588***
RLR	***802.00***	*191.00*	*297.00*	*1408.0*	***813.54***	***736.00***	*148.00*	*481.00*	*1922.0*	***755.58***	***645.50***	*137.00*	*416.00*	*1131.0*	***666.90***
LLR	***812.00***	*225.00*	*131.00*	*1188.0*	***804.90***	***720.00***	*157.00*	*431.00*	*1196.0*	***741.76***	***627.00***	*159.00*	*309.00*	*1195.0*	***661.70***

Note: CDR – average complex disjunctive reaction time (Witty Sem); BSQ – brain speed quality (average reaction time divided by number of good attempts); BSGA – brain speed good attempts; BSRT – brain speed average reaction time; RLR – right leg average reaction time; LLR – left leg average reaction time; Me – median; QR – quartile range; Min – minimum value Max – maximum value; x – average

Positive age-related tendencies can be registered (Table 1 and 2) when significant changes are monitored in the following indicators: complex disjunctive reactivity ($CDR_{C1\ vs.\ C2}$ = -25.16%; p=0.000 / $CDR_{C2\ vs.\ C3}$ = -6.70%; p=0.000); brain speed indicators ($BSQ_{C1\ vs.\ C2}$ = -20.15%; p=0.010 / $BSQ_{C2\ vs.\ C3}$ = -16.90%; p=0.000); lower limb reaction speed ($RLR_{C1\ vs.\ C2}$ = -7.12%; p=0.000 / $RLR_{C2\ vs.\ C3}$ = -11.74%; p=0.000 / $LLR_{C1\ vs.\ C2}$ = -7.85%; p=0.000 / $LLR_{C2\ vs.\ C3}$ = -10.79%; p=0.000). With the increasing age of soccer players, continual significant improvement is observed in all indicators of motor-cognitive abilities.

Table 2. Multiple median comparisons of brain speed, disjunctive reactivity, and lower limb reaction speed of soccer players – age view

	Kruskal-Wallis Anova test			Multiple comparisons of median values					
	H	**Df**	***p***	**Age grouping**			**U**	***P***	**η^2**
CDR	39.278	2	**0.000****	$C1_{U10/11}$	vs.	$C2_{U12/13}$	273.5	**0.000****	**0.292‡**
				$C1_{U10/11}$	vs.	$C3_{U14/15}$	160.00	**0.000****	0.426‡
				$C2_{U12/13}$	vs.	$C3_{U14/15}$	432.00	0.052	0.055

BSGA	16.401	2	**0.0003****	$C1_{U10/11}$	vs.	$C2_{U12/13}$	484.00	**0.013***	**0.07^{0}†**
				$C1_{U10/11}$	vs.	$C3_{U14/15}$	329.00	**0.0001****	**0.184‡**
				$C2_{U12/13}$	vs.	$C3_{U14/15}$	480.5	0.190	0.021
BSRT	14.813	2	**0.0006****	$C1_{U10/11}$	vs.	$C2_{U12/13}$	465.5	**0.012***	**0.083†**
				$C1_{U10/11}$	vs.	$C3_{U14/15}$	334.00	**0.0001****	**0.179‡**
				$C2_{U12/13}$	vs.	$C3_{U14/15}$	516.00	0.432	0.008
BSQ	15.649	2	**0.0004****	$C1_{U10/11}$	vs.	$C2_{U12/13}$	459.5	**0.010****	**0.087†**
				$C1_{U10/11}$	vs.	$C3_{U14/15}$	323.00	**0.0001****	**0.191‡**
				$C2_{U12/13}$	vs.	$C3_{U14/15}$	511.5	0.422	0.010
				$C1_{U10/11}$	vs.	$C2_{U12/13}$	25931.00	**0.000****	0.054
RLR	161.344	2	**0.000****	$C1_{U10/11}$	vs.	$C3_{U14/15}$	15457.00	**0.000****	**0.263‡**
				$C2_{U12/13}$	vs.	$C3_{U14/15}$	18056.5	**0.000****	0.131†
LLR	125.330	2	**0.000****	$C1_{U10/11}$	vs.	$C2_{U12/13}$	25098.5	**0.000****	0.051
				$C1_{U10/11}$	vs.	$C3_{U14/15}$	15925.5	**0.000****	**0.209‡**
				$C2_{U12/13}$	vs.	$C3_{U14/15}$	18797.5	**0.000****	**0.109†**

Note: CDR – average complex disjunctive reaction time (Witty Sem); BSQ – brain speed quality (average reaction time divided by number of good attempts); BSGA – brain speed good attempts; BSRT – brain speed average reaction time; RLR – right leg average reaction time; LLR – left leg average reaction time; H – value of the Kruskal-Wallis Anova test criterion; df – degrees of freedom; U – value of the Mann-Whitney U test criterion; p – p value of Kruskal-Wallis Anova test; p – p value of Mann-Whitney U test; * – statistical significance at the level of $p < 0,05$; ** – statistical significance at the level of $p < 0,01$; η^2 – effect size (0,0 – 0,009 no effect; 0,010 – 0,059 small effect; 0,060† – 0,139† medium effect; 0,140‡ ≥ 0,2‡ large effect)

The second part of the analysis is aimed at answering the research question of how selected motor-cognitive indicators of football players change as their experience increases. Soccer players were divided according to the number of years of active and continuous participation in the training and competition process into three groups (Figure 4).

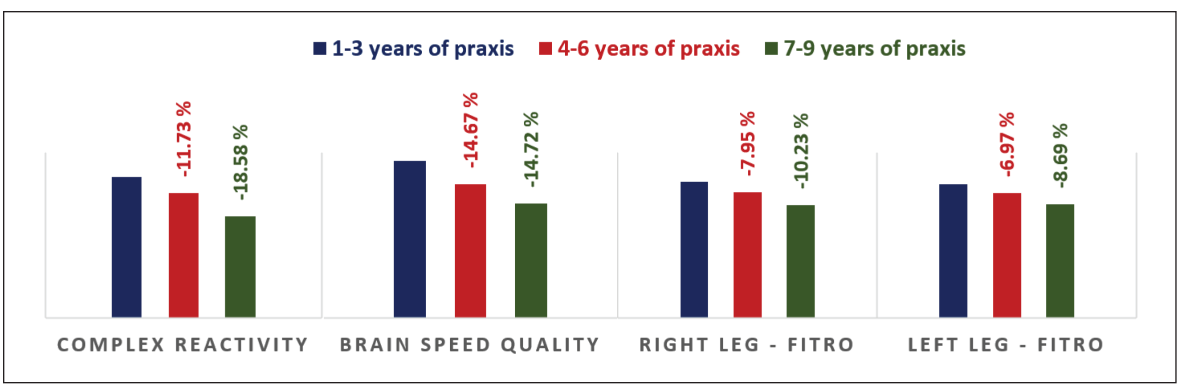

Figure 4. Differences in the level of selected motor-cognitive abilities - level of experience view

In terms of experience level, the results indicate an increase in most of the observed cognitive abilities (Table 3 and 4): complex disjunctive reaction time ($CDR_{K1\ vs.\ K2}$ = -11.73%; p=0.011 / $CDR_{K2\ vs.\ K3}$ = -18.58%; p=0.000); brain speed indicators ($BSQ_{K1\ vs.\ K3}$ = -30.29%; p=0.011); lower limb reaction speed ($RLR_{K1\ vs.\ K2}$ = -7.95%; p=0.000 / $RLR_{K2\ vs.\ K3}$ = -10.23%; p=0.000 / $LLR_{K1\ vs.\ K2}$ = -6.97%; p=0.000 / $LLR_{K2\ vs.\ K3}$ = -8.69%; p=0.000). The results in the studied groups of soccer players indicate that motor-cognitive abilities such as complex disjunctive reaction time, brain speed indicators, and reaction speed of lower limbs significantly improve with experience.

Table 3. Multiple median comparisons of brain speed, disjunctive reaction time, and reaction speed of soccer players –years of experience view

	Kruskal-Wallis Anova test			Multiple comparisons of median values					
	H	**Df**	***p***	**Level of experience grouping**			**U**	***P***	**η^2**
				K1$_{1-3\ years}$	vs.	K2$_{4-6\ years}$	371.00	**0.011***	**0.089†**
CDR	26.518	2	**0.000****	K1$_{1-3\ years}$	vs.	K3$_{7-9\ years}$	115.00	**0.000****	**0.387‡**
				K2$_{4-6\ years}$	vs.	K3$_{7-9\ years}$	517.00	**0.001***	**0.134†**
				K1$_{1-3\ years}$	vs.	K2$_{4-6\ years}$	468	0.261	0.015
BSGA	7.912	2	**0.019***	K1$_{1-3\ years}$	vs.	K3$_{7-9\ years}$	266.5	0.008**	0.097†
				K2$_{4-6\ years}$	vs.	K3$_{7-9\ years}$	684.00	**0.047***	0.038
				K1$_{1-3\ years}$	vs.	K2$_{4-6\ years}$	465.5	0.270	0.016
BSRT	6.985	2	**0.034***	K1$_{1-3\ years}$	vs.	K3$_{7-9\ years}$	267.00	**0.011***	**0.097†**
				K2$_{4-6\ years}$	vs.	K3$_{7-9\ years}$	693.5	0.070	0.035
				K1$_{1-3\ years}$	vs.	K2$_{4-6\ years}$	468.5	0.289	0.015
BSQ	7.256	2	**0.027***	K1$_{1-3\ years}$	vs.	K3$_{7-9\ years}$	265.00	**0.011***	**0.099†**
				K2$_{4-6\ years}$	vs.	K3$_{7-9\ years}$	682.5	0.057	0.039
				K1$_{1-3\ years}$	vs.	K2$_{4-6\ years}$	21958.5	**0.000****	**0.103†**
RLR	122.174	2	**0.000****	K1$_{1-3\ years}$	vs.	K3$_{7-9\ years}$	11555.5	**0.000****	**0.220‡**
				K2$_{4-6\ years}$	vs.	K3$_{7-9\ years}$	32012.5	**0.000****	**0.092†**
				K1$_{1-3\ years}$	vs.	K2$_{4-6\ years}$	20402.0	**0.000****	**0.034**
LLR	75.430	2	**0.000****	K1$_{1-3\ years}$	vs.	K3$_{7-9\ years}$	11742	**0.000****	**0.145‡**
				K2$_{4-6\ years}$	vs.	K3$_{7-9\ years}$	30461	**0.000****	**0.064†**

Note: EXP –years of experience in soccer; CR – average disjunctive reaction time (Witty Sem); BSQ – brain speed quality (average reaction time divided by number of good attempts); BSGA – brain speed good attempts; BSRT – brain speed average reaction time; RLR – right leg average reaction time; LLR – left leg average reaction time; H – value of the Kruskal-Wallis Anova test criterion; df – degrees of freedom; U – value of the Mann-Whitney U test criterion; p – p value of Kruskal-Wallis Anova test; p – p value of Mann-Whitney U test; * – statistical significance at the level of $p < 0,05$; ** – statistical significance at the level of $p < 0,01$; η^2 – effect size (0,0 – 0,009 no effect; 0,010 – 0,059 small effect; 0,060† – 0,139† medium effect; 0,140‡ ≥ 0,2‡ large effect)

Table 4. Basic characteristics of brain speed, disjunctive reaction time, and reaction speed of soccer players - years of experience view

	K1$_{1-3\ years}$ (n=25)					K2$_{4-6\ years}$ (n=48)					K3$_{7-9\ years}$ (n=38)				
	Me	QR	Min	Max	x	Me	QR	Min	Max	x	Me	QR	Min	Max	x
BSRT	***0.501***	*0.207*	*0.251*	*1.413*	***0.643***	***0.501***	*0.280*	*0.251*	*1.000*	***0.561***	***0.501***	*0.146*	*0.178*	*1.413*	***0.487***
BSGA	***12.000***	*1.000*	*10.000*	*13.000*	***11.609***	***12.000***	*1.000*	*11.000*	*13.000*	***11.833***	***12.000***	*1.000*	*10.000*	*14.000*	***12.135***
BSQ	***0.042***	*0.023*	*0.019*	*0.141*	***0.057***	***0.042***	*0.029*	*0.019*	*0.091*	***0.049***	***0.042***	*0.014*	*0.013*	*0.141*	***0.041***
CDR	***33.020***	*7.845*	*23.480*	*57.140*	***34.135***	***27.360***	*8.240*	*18.460*	*54.600*	***30.130***	***23.110***	*6.290*	*17.450*	*36.820*	***24.532***
RLR	***810.00***	*185.00*	*297.00*	*1408.0*	***823.71***	***738.00***	*167.00*	*456.00*	*1156.0*	***758.19***	***655.00***	*154.00*	*358.00*	*1195.0*	***680.65***
LLR	***817.00***	*226.00*	*131.00*	*1188.0*	***810.43***	***729.00***	*167.00*	*452.00*	*1188.0*	***753.97***	***654.00***	*205.00*	*309.00*	*1922.0*	***688.47***

Note: CDR – average complex disjunctive reaction time (Witty Sem); BSQ – brain speed quality (average reaction time divided by number of good attempts); BSGA – brain speed good attempts; BSRT – brain speed average reaction time; RLR – right leg average reaction time; LLR – left leg average reaction time; Me – median; QR – quartile range; Min – minimum value Max – maximum value; x – average

Discussion

As shown by the results, motor-cognitive abilities such as complex disjunctive reaction time, brain speed indicators, and reaction speed of lower limbs significantly improve with the acquired experience of soccer players. Moreover, with the increasing age of soccer players, continual significant improvement is observed in all indicators of motor and cognitive abilities. [18] revealed that the perceptual and cognitive skills of elite and sub-elite youth players might significantly improve during adolescence. Another research study [19] supported this idea of improvement specifically in adolescent youth soccer players with increasing age. [20] pointed out that at a very early age, football players practice tactical and cognitive abilities, which in turn contribute to improving their cognitive profile.

In terms of changes in motor and cognitive functions observed in individual age categories, the results show positive tendencies in the level of disjunctive reaction time with a slight regression between the studied groups of U12 and U13. Similar positive age-related changes in brain speed quality are evident in the period up to U11, with a subsequent regression up to the U13, and between U13 and U15 age groups. [4] considered peripheral vision as a skill that enables the players to move the ball fast, avoid clashing with other players, and react to the ball's shifting direction in a short time. The disrupted continuity of age-related improvement in the level of selected motor and cognitive functions in the above-mentioned age categories could be caused by several factors. One of them is that age differences within the same category, which at most can represent almost a year in age difference between athletes in the same category, can lead to great differences in cognitive abilities [21,22]. This factor needs to be considered in the future direction of similar research.

Another interesting finding was that soccer players in the younger age showed significantly lower level of lower limb reaction speed in both directions of the sagittal plane than older players. Previous research focused on the functional advantages of the dominant leg over the nondominant one [24] for accuracy, reaction time [25], and balance. These findings suggest that each foot was used for different tasks [26]. Furthermore, it is evident that the dominance of the left and right lower limbs' reaction speed is constantly changing during the observed period. At the beginning of the monitored period, there is a slight dominance of the right limb (U10), but in the U15 group, there is a noticeable dominance of the left limb. [27] confirm that laterality had an impact on the players' agility. The dominant eye permits a priority treatment of the information on its visual field and thus allows faster reaction times. The supporting leg permits more reactive strength and a better motor control of push-off actions, thus allowing turning faster on the opposite side. Therefore, each player had a weak side and a strong side during the performance of a 180° rotation, which is why this ability must be improved. [28] found a significant effect of unilateral coordination training with the non-dominant foot on the mental rotation performance of young soccer players so it is important to take a close look not only at the specific type of sport when investigating its influence on visuospatial abilities but also on the relevance of laterality specific impact in motor coordination training.

Considering experienced-related differences, less experienced soccer players demonstrated significantly lower levels of lower limb reaction speed in both directions of the sagittal plane than more experienced counterparts and lower levels of brain speed and disjunctive reaction time. Other studies [29] investigated the perceptual abilities of higher-level players, and it was shown that there are fundamental perceptual and cognitive differences between less experienced and more experienced soccer players. The importance of cognitive functions in open-skill sports has been demonstrated especially in soccer, in which high-level players demonstrated better cognitive abilities than their low-level counterparts [30,31]. In soccer, the ability to analyze movements or situations is associated with sport-specific knowledge and experiences. More experienced soccer players can better predict the movement the opponent is executing by rapidly detecting the cue that directly, or indirectly, precedes the movement and can better anticipate future movements by effectively recognizing situations based on stored memories. [32,33].

Conclusions

The presented results of the research study indicate that there is a significant improvement in perceptual and motor-cognitive abilities considering the potential determination of age and experience of soccer players. The main findings of the research study can be summarized as follows:

The predominance of reaction speed of the left and right lower limbs was constantly changing during the observed period (U10-U15). The results suggest a possible long-term effect of soccer training, which may point towards further investigation in this area of laterality. Potential interventions and investigations into the impact of the training process on reducing differences in fine motor skills of soccer players in the sagittal plane are recommended.

Motor and cognitive abilities such as complex disjunctive reaction time, brain speed quality as well as reaction speed of lower limbs significantly improve with the acquired experience of soccer players. With increasing age of soccer players, continual significant improvement is observed in all indicators of motor-cognitive abilities. It is obvious that with increasing years of practice, the training process of soccer players is highly likely to have positive effects on the continuous development of motor-cognitive abilities and functions. A practical perspective on these results foreshadows that it is important to link the continuous development of these abilities in the training process with adequate consideration of the player's sensory periods.

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EFFECT OF INTEGRATED POSTURAL TRAINING IN INDIVIDUALS WITH TEXT NECK SYNDROME

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Authors' contribution:

A. Study design/planning
B. Data collection/entry
C. Data analysis/statistics
D. Data interpretation
E. Preparation of manuscript
F. Literature analysis/search
G. Funds collection

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Abstract:

Background: Text neck syndrome is a repetitive stress injury caused by prolonged use of electronic gadgets, particularly smartphones. With smartphone addiction surpassing internet addiction, it has led to increased musculoskeletal problems. Currently, symptomatic treatment for text neck syndrome includes neck pain, postural changes, and cervical proprioceptive errors. The condition is chronic and progressive, and timely intervention and postural correction are crucial to minimize early consequences in later life. The aim of this study was to investigate the effect of integrated postural training in individuals with text neck syndrome.

Methods: This study included 80 participants clinically diagnosed with text neck syndrome who were selected based on inclusion and exclusion criteria. They were further divided into two groups, with Group A receiving a conventional exercise program and Group B receiving integrated postural training 3 times a week for 6 weeks. Pre- and post-assessment scores of visual analog scale (VAS), neck disability index (NDI), range of motion (ROM) of the cervical spine, tragus to wall test (TTW), Vernier Caliper measurements for rounded shoulders and cervical joint position error testing (CPJE Testing) were taken and the results were obtained by statistical analysis of the data.

Results: The results of this study showed that there was an extremely significant improvement in neck pain, cervical ROM, forward head posture, and rounded shoulder posture in both the groups with a p-value of <0.0001 except for the CPJE testing, which showed to be significant in the Group B with a p-value <0.0001 as compared to Group A.

Conclusion: The study concluded that integrated postural training showed significant improvement and has been beneficial in relieving pain, improving cervical range of motion, posture, and the cervical joint position error in individuals with text neck syndrome.

Introduction

The phrase "text neck" was coined by an American Dr. Dean L. Fishman, as a repetitive stress injury or overuse problem where a person has their head hung or curved forward and is stooped over for extended periods of time staring at their phone or any other electronic gadgets [1-5]. In text neck syndrome (TNS), the users frequently hold their heads erect for extended periods of time while looking down at the screens of their mobile devices [4,6]. The prevalence of this syndrome in India is around 32 % [7]. According to recent research, 79 % of those aged 18 to 44 years keep their phones with them virtually almost all of the time, with only 2 hours of walking a day without them [8,9] Neck pain and soreness are the most typical symptoms of text neck syndrome. Shoulder pain and stiffness, and upper back pain ranging from persistent, nagging pain to sudden and severe upper back muscular spasms are also observed [2,8,9]. As a result, people with TNS have less strength and endurance in their neck muscles and show postural alterations [6,9,10]. Furthermore, maintaining a forward head posture reduces cervical lordosis in the lower cervical vertebrae and provides a posterior curve in the upper thoracic vertebrae, which helps maintain balance [11]. An adult's head weighs around 10 to 12 pounds when it is in the neutral position and, as the head bends further, the load shifts towards the neck. Simultaneously, as the angle of looking downward increases, the consequent weight of the head over the spine also increases and is calculated to be 27, 40, 49, and 60 pounds at 15°, 30°, 45°, and 60°, respectively [9].

The most prevalent postural alterations in text neck individuals are the forward head posture (FHP) and the rounded shoulder posture (RSP). Forward head posture is specifically characterized by lower cervical flexion and upper cervical extension. Since the head and neck go ventrally in this posture, abnormal cervical flexion and extension occur to maintain the eyes at the horizontal level. This posture also shows a decrease in cervical lordosis, altered thoracic kyphosis, and changes in scapular protraction and downward rotation due to weakness of the rhomboids and middle trapezius and tightness of the pectoralis minor [12,13].

Rounded shoulder posture (RSP) is a forward deviation of the shoulders associated with the protracted position of the scapula, which is caused by a muscular imbalance between a shortened pectoralis minor and a lengthened middle trapezius [14]. RSP also causes weakness of the lower trapezius and serratus anterior, which also in turn contribute to the scapular tilt [8–10]. These altered scapular mechanics are related to the shortening of pectoralis minor length and decreased serratus anterior and lower trapezius activity [14].

These postural deviations can cause constant spinal loading which can further lead to muscular fatigue and overall musculoskeletal dysfunction. Furthermore, due to adopting the text neck posture, there is an increased activation of muscles leading to the formation of trigger points in the upper trapezius and suboccipital muscles, which successively causes neck pain, headaches, and subsequent limitations in cervical and upper thoracic range of motion.[13] Similarly, prolonged FHP has been associated with changes in the cervical proprioceptive function. The FHP causes an imbalance in the length-tension relationship along with decreased functioning of muscle spindles leading to impaired joint position sense in the cervical spine.[13] Text neck can have serious long-term effects if it is ignored and left untreated, which include flattening of the spinal curvature, early onset of arthritis, spinal malalignment, spinal degeneration, disc compression, disc herniation, nerve or muscle damage, inflammation of the cervical ligaments, and irritation of the nerves [6,9,11].

A recent review titled "Evidence-Based Treatment Strategies in Text Neck Syndrome" highlighted the fact that several studies have chosen treatment options such as conventional exercise programs in treating the text neck syndrome, which included ultrasound therapy, manual exercises like neck isometrics, manual traction, cervical muscle stretching, and cervical joint manipulation. This review further discussed that the available treatment options only focused on providing symptomatic relief, whereas postural changes and cervical proprioceptive error remained unaddressed.[2] Also, several studies have incorporated structured exercise programs which included neck isometric exercises, levator scapulae stretch, and range of motion exercises for 4 weeks and have shown positive results in treating neck pain, decreased range of motion of the cervical spine, postural deviations, whereas the cervical proprioceptive error was left untreated [10].

Integrated postural training (IPT) focuses on improving patients' sense of control of their movements and posture. The postural control system is comprised of the visual, vestibular, and somatosensory systems. The visual system controls gaze stability and gaze shifting. The vestibular system controls the body's center of mass. The somatosensory system comprises the mechanoreceptors present from the occiput to the C_3 vertebra. These mechanoreceptors have direct access to the vestibular nuclear complex which is a reflex center that controls vision and neck movement. Meanwhile, these receptors also converge in the central cervical nucleus (CCN) which integrates the vestibular, ocular, and proprioceptive functions. Hence, all three systems work as a group and coordinate the postural control of the neck [15,16]. The integrated postural training focuses on all three systems responsible for maintaining the posture. The IPT consists of cervical proprioceptive training, deep cervical flexor strengthening, McKenzie's approach, and strengthening exercises.

The cervical proprioceptive training includes oculomotor exercises, gaze stability exercises, and eye-head coordination exercises and aims to correct the errors that are seen in these individuals. Similarly, deep cervical flexor (DCF) training indirectly aids in correcting the errors by strengthening the DCF. McKenzie's approach focuses on posture correction while the strengthening exercises such as the Y exercise and rowing exercise strengthen the neck and scapular muscles. Text neck syndrome has been termed an adverse postural phenomenon specifically because of anatomical and bio-mechanical changes seen in the cervical spine and the thoracic spine during prolonged use of handheld mobile devices. These changes further lead to muscular imbalances and postural compensation, which in turn contribute to muscular overuse and fatigue resulting in pain [13,17]. Also, as mentioned earlier, text neck individuals usually show forward head posture, which results in adaptive shortening of the occipital muscles causing the cervical spine to change the alignment and resulting in increased stress of the facet joints and posterior discs. These subsequent changes may then lead to weakness in the deep cervical flexors [18].

Likewise, as mentioned before, the mechanoreceptors are present in high density in the suboccipital and deep cervical muscles and play an important role in maintaining cervical proprioception. Similarly, if this deep cervical muscle performance is impaired, it leads to a loss of proper alignment and posture [18]. Therefore, the weakness of the deep cervical flexors and the improper functioning of the mechanoreceptors lead to cervical joint proprioceptive errors in flexion in patients with text neck syndrome [19]. To correct this error, integrated postural training includes cervical proprioceptive training with deep cervical flexor training, which focuses on correcting the errors and strengthening the muscles. McKenzie's approach to integrated postural training helps correct the postural changes such as forward head posture and rounded shoulders in text neck individuals. Likewise, the rowing exercise and the Y exercise focus on strengthening the lower trapezius, which helps improve posture and strength [20].

Consequently, integrated postural training, involving five different forms of exercise domains, can help reduce pain, improve the range of motion of the cervical spine and strength, and subsequently help improve posture and cervical proprioceptive errors. Therefore, the purpose of this study is to focus on text neck syndrome as a whole and not just the symptoms which is of prime importance.

Material and Methods

This experimental study received approval from the Institutional Ethical Committee of Krishna Vishwa Vidyapeeth, Karad. This randomized controlled trial included 80 participants who were selected based on inclusion and exclusion criteria. The inclusion criteria for the study were individuals between 18- 44 years of age, using mobile phones for more than 3-4 hours per day for texting, with a pain score of more than 4 on the visual analog scale and clinically diagnosed with text neck syndrome. Individuals with a recent history of neck or back surgery, recent history of trauma or fracture, congenital disorders of the cervical spine, and any psychiatric diseases were excluded from the study. The individuals were randomly allocated into two groups (Group A and Group B) using the simple random sampling method. The outcome measures used were the visual analog scale for pain assessment [10,21,22], neck disability index (NDI) [23], cervical joint position error testing (CPJE Testing) [18,24,25], range of motion of the cervical spine [26], Vernier caliper measurements for rounded shoulder posture [27,28,29], tragus to wall test for forward head posture [30,31]. The pre- and post-assessment scores were taken and statistical analysis was carried out using SPSS Software version 23.0 to obtain the results. Group A received the conventional exercise program and Group B received the integrated postural training three times a week for 6 weeks (Table 1, 2). Both groups received a baseline treatment of a hot moist pack for 15 minutes followed by neck isometric exercises.

Table 1. Exercise program for Group A (conventional exercise program)

Exercise	1-14 Days	PR (15-27 Days)	PR (28-42 Days)	Sets
pectoral stretching	15 seconds hold x 10 repetitions	30 seconds hold x 10 repetitions	45 seconds hold x 10 repetitions	3
upper trapezius stretching	15 seconds hold x 10 repetitions	30 seconds hold x 10 repetitions	45 seconds hold x 10 repetitions	3
levator scapulae stretching	15 seconds hold x 10 repetitions	30 seconds hold x 10 repetitions	45 seconds hold x 10 repetitions	3
chin tucks	10 repetitions	5 seconds hold x 10 repetitions	10 seconds hold x 10 repetitions	1
shoulder shrugs	10 repetitions	10 repetitions x 2 sets	10 repetitions x 3 sets	–
scapular retraction	10 repetitions (yellow theraband)	10 repetitions (red theraband)	10 repetitions (blue theraband)	3

Table 2. Exercise program for Group B (integrated postural training program)

Exercise	1-14 Days	15-27 Days	28-42 Days	Sets
oculomotor exercise	10	15	20	1
eye-head coordination exercises	10	15	20	1
gaze stability exercises	10	15	20	1
peep cervical flexor training	10 seconds hold x 10 repetitions	15 seconds hold x 10 repetitions	20 seconds hold x 10 repetitions	1
McKenzie approach head retraction	10 seconds hold x 10 repetitions	10 seconds hold x 10 repetitions	10 seconds hold x 10 repetitions	1
neck extension in the supine position	10 repetitions	10 repetitions	10 repetitions	
neck extension in sitting	-	10 repetitions	10 repetitions	1
left and right lateral flexion	-	10 repetitions	10 repetitions	1
cervical rotations	-	-	10 repetitions	1
neck flexion in sitting	-	-	10 repetitions	1
rowing exercise	10 repetitions	15 repetitions	20 repetitions	1
Y-exercise	10 repetitions	15 repetitions	20 repetitions	1

Statistical Analysis

Statistical analysis of the recorded data was performed using the software SPSS version 26.0. *A paired t-test* was used to determine the results within the group whereas the unpaired t-test was used to determine the results between two groups. The arithmetic means and standard deviations were calculated for each outcome measure. The arithmetic means were derived from adding all the values and dividing by the total number of values. Microsoft Excel was used for drawing various graphs with given frequencies and percentages calculated with the software.

Results

This study included 80 participants divided into two groups of 40 each (Group A and Group B) by simple random sampling. Group A received the conventional exercise program and Group B received integrated postural training 3 times a week for 6 weeks. Among the 80 participants with text neck syndrome, the age of 18-30 years was found to be commonly affected. Forty-two were females and thirty-eight were males. (Table 3)

The pre and post-test mean scores of VAS (at rest) within Group A and Group B showed that the pre-test and post-test means for Group A were 4.65±0.95 and 2.08±0.72, respectively, whereas for Group B was 5.06±0.66 and 2.36±0.76, respectively. The p-value for the pre- and

Table 3. Demographic variables

Variables	Number of individuals (percentage(%))
Age (years)	
18-30	56 (70%)
31-44	24 (30%)
Gender	
Female	42 (52.5%)
Male	38 (47.5%)
BMI (Kg/m^2)	
<18.5	2 (2.5%)
18.5-24.9	36 (45%)
25-29.9	29 (36.25%)
30-34.9	12 (15%)
35-39.9	1 (1.25%)
>40	0 (0%)
Level of Physical Activity	
Sedentary or little active	51 (63.75%)
Active or moderately active	21 (26.25%)
Highly active	8 (10%)
Hand Dominance	
Right	66 (82.5%)
Left	14 (17.5%)

post-test scores was <0.0001, which was considered extremely significant. The pre- and post-test mean scores of VAS (on activity) within Group A and Group B showed that the pre- and post-test means for Group A were 6.097±0.68 and 2.50±0.80, respectively, whereas for Group B were 6.30±0.48 and 2.87±1, respectively. The p-value for the pre- and post test scores was s <0.0001, which was considered extremely significant (Table .4)

Table 4. Comparison of pre- and post-test mean scores of VAS (at rest and during activity) within Groups A and B

VAS (at rest)	Pre-test	Post-test	Mean difference	p-value
Group A	4.65±0.95	2.08±0.72	2.575	<0.0001
Group B	5.06±0.66	2.36±0.76	2.703	<0.0001
VAS (on activity)				
Group A	6.097±0.58	2.50±0.80	3.590	<0.0001
Group B	5.06±0.66	2.87±1.00	3.433	<0.0001

The pre-test and post-test values of the neck disability index were recorded for both Groups A and B respectively. In both groups, the values were extremely significant with a p-value of < 0.0001 (Table 5).

Table 5. Comparison of pre- and post-test mean scores of neck disability index (NDI) within Groups A and B

NDI	Pre-test	Post-test	Mean difference	p-value
Group A	50.4±8.33	25.05±4.66	25.35	<0.0001
Group B	47.42±12.43	20.351±1.70	26.846	<0.0001

The pre-test versus post-test scores of cervical joint position error testing for patients with text neck syndrome were recorded in both Groups A and B. Group A was considered not significant at a p-value of 0.462 and group B was found to be extremely significant at a p-value < 0.0001 (Table 6).

Table 6. Comparison of cervical joint position error (CPJE) test scores within group

CPJE Testing	Pre-test	Post-test	Mean difference	p-value
Group A	5.14±0.39	5.05±0.41	0.09	0.462
Group B	5.11±0.41	4.69±0.390	0.415	<0.0001

The pre-test versus post-test scores of the tragus-to-wall test for patients with text neck syndrome were recorded for both groups A and B. Their values in both groups were extremely significant at a p-value < 0.0001 (Table 7).

Table7. Comparison of tragus-to-wall test (TTW) scores within group

TTW	Pre-test	Post-test	Mean difference	p-value
Group A	11.43±0.49	10.63±0.39	0.80	<0.0001
Group B	11.49±0.57	10.32±0.52	1.17	<0.0001

The pre-test versus post-test scores of Vernier caliper measurement of the right and left sides for patients with text neck syndrome were recorded for both Groups A and B. Both groups were found to be extremely significant with a p-value < 0.001 (Table 8).

Table 8. Comparison of Vernier caliper measurement scores (right) within group

Vernier caliper (Right)	Pre-test	Post-test	Mean difference	p-value
Group A	8.00±0.44	6.21±0.84	1.79	<0.0001
Group B	8.38±0.47	5.77±0.36	2.60	<0.0001
Vernier caliper (left)				
Group A	8.01±0.50	6.46±0.97	1.54	<0.0001
Group B	8.38±0.47	5.99±0.67	2.38	<0.0001

The post-test scores for the measurements of the range of motion between Group A and B were recorded. The p-value for flexion was 0.086, which was considered not quite significant, whereas for extension it was 0.089 which was statistically not significant, for left lateral flexion it was <0.0001, which was considered extremely significant, whereas for right lateral flexion was <0.0263 and was considered significant. The p-value for left rotation was 0.0025 and for right rotation was 0.0091 and both were statistically very significant (Table 9).

Table 9. Comparison of post-test values of the range of motion between the groups

Post-test (ROM)	GROUP A	GROUP B	P VALUE
Flexion	35.03±3.051	33.72±3.62	0.086
Extension	46±3.266	45.9±3.37	0.089
Left lateral flexion	18.9±1.837	20.57±1.357	<0.0001
Right lateral flexion	19.42±1.43	20.07±1.118	0.0263
Left rotation	45.8±3.50	47.82±1.92	0.0025
Right rotation	46.85±2.214	45.3±2.919	0.0091

Discussion

The present study was carried out to assess the effects of integrated postural training in individuals with text neck syndrome. Individuals with text neck syndrome complained about neck pain and upper back pain along with restricted range of motion of the cervical spine, postural changes like forward head posture and rounded shoulders, and, most importantly, cervical joint position error. These issues contribute to an early onset of degenerative changes in the spine. Current evidence suggests that the available treatment strategies focus on the symptomatic treatment of text neck syndrome, which mainly involves addressing neck pain with the help of a conventional physiotherapy approach. Once the conventional exercise program turned out to be effective in managing the neck pain, the postural changes like forward head posture and rounded shoulder posture along with limited range of motion of the cervical spine and the cervical proprioceptive error were left unattended.[2] Due to the paucity of literature on the management of the syndrome, integrated postural training was chosen to be administered in these individuals to help them develop a sense of control over their movement and posture.

Several studies have stated that the severity of neck pain was the highest in text neck syndrome, followed by upper back pain and shoulder pain. Additionally, they assessed the individuals' grip strength, revealing below-average to poor grip strength during extended texting sessions [32]. Evidence has also shown the relation between the weight of the head and the forces acting on the neck over the spine in these individuals. In an upright position, when the ears are aligned with the shoulders, the weight of the head exerts on average around 10-12 pounds due to the forces of the neck muscles used.[9] Also, when the head moves even by an inch during the use of a smartphone, the weight increases as much as six times. This again leads to neck pain which subsequently leads to proprioceptive error during flexion of the cervical spine, specifically because the head lies in constant flexion while using smartphones [19].

Also, a study conducted on the correlation between forward head posture and cervical proprioception revealed that the FHP can cause neck pain, leading to decreased movement of the cervical vertebrae and changes in neck muscle functions.[33-35]It was found that FHP moves the body's center-of-gravity forward, thus inducing mechanical deformation of the joints, vertebrae, and muscles involved in postural control [36]. The deep neck flexor muscles in the cervical vertebrae play a vital role in stabilizing the cervical spine and reducing cervical lordosis during neck movement

[31,37-39]. In individuals with text neck syndrome, FHP is the most common postural change that reduces the range of motion of the neck and increases the bending torque of the surface neck flexor muscles [40]. Prolonged shearing of the vertebra from the FHP sooner or later irritates the small facet cervical joints and the soft tissues and ligaments, which ultimately causes neck and upper back pain leading to trigger points in trapezius, sternocleidomastoid, and rhomboid muscles, along with limitations in cervical range of motion. The hypomobility of the cervical spine and the neck pain then contribute to spinal degeneration at an early age [41]. Similarly, the forward head posture causes maladaptive shortening of the occipital muscles, causing the cervical spine to change alignment, resulting in increased stress on the facet joints and posterior discs, and other posterior elements. This position led to the weakness of deep cervical flexors [2].

Evidence shows that the cervical spine contributes to the proprioceptive input and is reflected in the cervical mechanoreceptors and their connections with the visual and vestibular centers. This proprioceptive sensing of the cervical vertebrae transmits information to correct the misalignment and plays an important role in postural control.[42] In the present study, integrated postural training included an eye cervical re-education program in which the oculomotor exercises and the gaze stability exercises focused on the visual center, whereas the eye-head coordination exercises focused on the vestibular center along with deep cervical flexor strengthening, which worked on the cervical mechanoreceptors and the cervical flexors muscles [43]. The strengthening of the deep cervical flexor muscles helped enhance the strength thereby aiding in the correction of the cervical joint position error [18].

Individuals with text neck syndrome typically present with a forward head posture, which is characterized by a constant isometric contraction of the cervical spine extensors that take over the load of the deep neck flexors, causing subsequent lengthening of the extensors while shortening and weakening the deep neck flexors. The McKenzie method was introduced as a treatment measure for the mechanical problems of the spine.[44] It is one of the most common therapies used for the management of spinal conditions such as forward head posture in which patients are treated with a strategy of appropriate repeated loading that is progressed according to the individual's response with postural correction [45]. The improvement in the symptoms is successively measured in terms of centralization, a phenomenon that has been commonly used [46-49]. Studies have reported that rowing exercises and Y-exercise have been effective in strengthening the shoulder extensors, scapular retractors, and the lower trapezius, thereby correcting forward head posture and rounded shoulder posture [49,50].

The results of the present study showed that there was an extremely significant improvement seen in neck Pain, cervical range of motion, forward head posture, and rounded shoulder posture in both groups with a p-value of <0.0001 except for the cervical joint position error testing, which showed to be significant in the Group B with a p-value <0.0001 compared to Group A. Hence, the results obtained in the present study demonstrated that integrated postural training is more beneficial compared to conventional exercise programs in treating text neck syndrome as a whole.

The present study has certain limitations. One of them is that the population used in the study had a wide range of ages, which could have been narrowed down to a specific and limited age. The study was confined to a smaller geographical area. The study period was brief and did not consider a long-term follow-up. Also, the occupation of the participants was not taken into consideration.

Conclusion

Based on statistical analysis, it was concluded that integrated postural training helped individuals with text neck syndrome achieve the highest level of function by relieving pain, restoring normal joint mobility, and strengthening specific postural muscles, thus improving posture. Physical therapy methods that include a patient-centered approach, home exercises, and postural correction are the prime aspects of managing this syndrome at an early age to avoid the later consequences.

Conflicts of interest: Author declares that there is no conflict of interest.

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Institutional Review Board Statement: The study was accepted by the institutional ethical committee of Krishna Vishwa Vidyapeeth, KIMSDU (Protocol No.: 103/2022-2023) in Karad, Maharashtra. The Helsinki Declaration of 1964 and its subsequent amendments, as well as the ethical requirements of the relevant organizational and national research committees, were followed in all procedures carried out in studies involving human participants.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data availability statement: The data presented in this study are available on request from the corresponding author.

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INVESTIGATION OF SLEEP QUALITY AND MENTAL TOUGHNESS LEVELS OF YOUNG SOCCER PLAYERS IN TERMS OF CHRONOTYPES

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Authors' contribution:

A. Study design/planning
B. Data collection/entry
C. Data analysis/statistics
D. Data interpretation
E. Preparation of manuscript
F. Literature analysis/search
G. Funds collection

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Abstract:

Bacground: The purpose of this research was to determine whether there is a relation between chronotype type and factors known to have a great impact on sports performance such as sleep quality and mental toughness.

Methods: This cross-sectional study was conducted using the questionnaire technique. The population of this research consisted of 8.952 soccer players while the sample size consisted of 370 soccer players, with a confidence level of 95%. In this study, the "Turkish form of Morningness-Eveningness Stability Scale", "Mental Toughness Scale", and "Athlete Sleep Behavior Questionnaire- Turkish Version" scales were used as data collection tools.

Results: There was a positive and statistically significant relation between Morning-Type (M-Type) and Mental Toughness ($p<.005$). In terms of sleep behavior, a statistically significant relation was found between Evening-Type (E-Type) and sleep behavior (sport-related factors), between M-Type and Neither-Type (N-Type) and sleep behavior (sleep quality), between M-Type and sleep behavior (habitual sleep efficiency) ($p<.005$).

Conclusions: Based on the data of this research, it was found that soccer players with M-Type had higher mental toughness than soccer players with E-Type and N-Type. Furthermore, it was concluded that soccer players had low sleep quality in terms of sleep habits. It was found that E-Type soccer players were affected by sport-related factors, M-Type soccer players were affected by habitual sleep efficiency factors, and M-Type and N-Type soccer players were affected by inefficient sleep factors.

Introduction

The repetition of biochemical, physiological, and behavioral rhythms in a regular pattern is called the circadian rhythm or biological clock and is characterized by changes observed over 24 hours [1]. This rhythm is closely related to several physiological and behavioral processes such as body temperature, hormones, cognitive functions, and psychological state [1,2]. The biological diversity of this rhythm is expressed by the term "chronotype" [3], which is divided into three different types: morning (M-type), evening (E-type), and neither (N-type) [4,5]. The N-type are individuals without a clear circadian preference and are categorized in this group because they show intermediate characteristics. M-type individuals go to bed and get up early and reach peak mental and physical performance in the early hours of the day. The E-type are individuals who get up later and reach their best performance in the second half of the day [6,7]. In this context, the duration of exposure to daylight, i.e. the duration of sleep and wakefulness, is one of the most important factors affecting the circadian system [1,8]. Melatonin hormone levels, which are one of the best indicators of sleep onset and affect the behavior and physiology of individuals [9], differ between chronotypes. This situation causes M-type and E-type individuals to differ from each other in terms of 24-hour sleep-wake timing and mental-physical activation [8]. In this context, the sleep and activity timing preferred by individuals depending on their chronotypes affects their behavior, lifestyle, cognitive function, athletic performance, and personality traits [10–15]. However, chronotypes are influenced by many genetic, environmental, and sociocultural factors [6,16–18], with one of the most important factors being age.

Chronotypes change with age. For example, the evening chronotype in youth is likely to be changed by the morning chronotype type in older adulthood [7]. Especially during adolescence, a progressive change towards the E-type starts at about 12-13 years of age [19] and stops at about 14 years of age, followed by a slow change back towards the M-type after 18 years of age [20,21]. However, during the period between 14 and 18 years of age, the tendency towards E-type often means a mismatch with social and community schedules, such as the time of school lessons, the time of training, the opening and closing times of places to eat, drink, and play, which can lead to impairment in terms of cognitive, motor, learning, and social activities and sleep in adolescents [22–24].

Soccer is one of the world's most popular sports practiced during adolescence, especially by boys, and is a team sport with a fascinating role and wide influence [25]. In this age group, training and soccer matches usually take place in the afternoon or evening after school [14]. Therefore, we think that both the tendency towards E-type between the ages of 14 to 18 years and the incompatibility between social community programs will have negative effects on sleep quality, chronotypes, and psychophysiological performance levels of soccer players.

Furthermore, soccer, which has become an indispensable part of social life, provides an opportunity to satisfy basic human impulses such as competition, ambition, struggle, and the desire to win [26]. Therefore, coaches, athletes, and sports scientists agree that psychological characteristics are also necessary in addition to technical, tactical, and physical skills to show the best sports performance [27]. Mental toughness, which is considered one of these psychological characteristics and has been researched extensively recently, is of great importance for coaches and athletes, especially during competition periods [28,29]. Mental toughness is defined as the natural or developed psychological power that enables athletes to cope with their mental needs better than their competitors in competition, training, and other conditions; specifically, to be more task-oriented, self-confident, and controlled under pressure than their competitors and to maintain these abilities [29,30]. In the literature, it has been emphasized in many studies that mental and emotional activities can be affected by circadian rhythm [31–33] and it has been stated that fluctuations can be seen in critical abilities such as mental focus in sports during the day due to the variability of circadian rhythm [34]. Therefore, it is thought that there may be a relation between athletes' chronotypes and mental endurance. Identifying chronotypes with lower levels of mental toughness will enable athletes to take earlier precautions in this regard and provide a strategic advantage when making training plans.

To our knowledge, no research has explored the relations among chronotype, sleep quality, and mental toughness, which are of great importance in sports performance and have been examined in relation to each other. Therefore, the purpose of this study was to examine the relationship between features that are of great importance in sports performance in soccer players, such as chronotype, sleep quality, and mental toughness.

Material and Methods

Population and Sample

The study population consisted of soccer players playing in the Development Leagues (U14, U15, U17 and U19; U19 Elite A League, U19 Elite B League, U17 Elite A League, U17 Elite B League) affiliated with the Turkish Football Federation (TFF) in the 2022-2023 season. Since the total number of athletes playing in these leagues is not published on the TFF official website, the population was calculated by multiplying the total number of teams in the Development League by the total number of players within each team (n=24). In this context, in the review made on the TFF official website, there were 54 teams in the U14 Development League, 72 teams in the U15 Development league, 64 teams in the U16 Development league, 49 teams in the U17 Regional Development league, and 53 teams in the U19 Regional Development league. It was determined that there were 373 teams in total, including 22 teams in the U19 Elite A League, 18 teams in the U19 Elite B League, 21 teams in the U17 Elite A League, and 20 teams in the U17 Elite B League. When the number of teams in a development league (373) was multiplied by the total number of players within each team (n=24), it was determined that there were 8,952 athletes in total. The population for this study consisted of 8,952 athletes. The sample size was determined using the estimated sample size table [35], which is used when the population is known, and it was found that at least 370 athletes should be included in the study, with a 95% confidence level.

After receiving approval from the Graduate Education Institute Ethics Committee, Çanakkale Onekiz Mart University (approval number: 09/24), 370 soccer players playing in the Development League between the ages of 14-19 were recruited using convenience sampling via mobile phone. Participants' consent (or assent and parental consent for individuals who were 17 years of age or younger) was obtained from all participants.

Demographic and sport-related information of the participants is presented in Table 1.

Table 1. Demographic information of the participants

Variables		n	%
Age (year)	14.00	154	41.6
	15.00	74	20.0
	16.00	55	14.9
	17.00	47	12.7
	18.00	23	6.2
	19.00	17	4.6
League	U 14	108	29.2
	U 15	46	12.4
	U 16	75	20.3
	U 17 (regional)	9	2.4
	U 19 (regional)	19	5.1
	U 17 (elite)	58	15.7
	U 19 (elite)	55	14.9
Training time	06:00-12:00	12	3.2
	12:00-18:00	144	38.9
	18:00-00:00	214	57.8
Time of going to school	Before midday	264	71.4
	Afternoon	24	6.5
	Distance education	82	22.2

Note: n = number of participants; % = percentage of total participants

Data Collection Tools

This cross-sectional research was conducted using the survey technique, one of the quantitative research methods. A form prepared by the researchers was used to determine the demographic characteristics of the participants (age, league they play in, training time, and school time). All questionnaires were presented in a random order.

In order to determine the mental toughness levels of the participants, we used the Mental Toughness Scale developed by Madrigal et al. [36] adapted to Turkish by verifying its validity and reliability by Erdoğan [37]. This single-dimensional scale is a five-point Likert-type scale. The Cronbach's alpha internal consistency coefficient of this scale is .87 and the test-retest reliability coefficient is .79. The corrected item-total score correlations of the scale range between .48 and .76.

To determine the chronotypes of the participants, we used the Turkish form of the Morningness-Eveningness Stability Scale (MESSi), developed by Randler et al. [38] and adapted to the Turkish language by Demirhan et al. [16]. The Turkish form of MESSi consists of three sub-dimensions: morning affect (M-Type), eveningness (E-type), and distinctness (N-Type). The scale is a five-point Likert type. This scale consists of 15 items and the factor loadings of the items vary between 0.44 and 0.85.

In order to determine the sleep behaviors of the participants, we used the Athlete Sleep Behavior Questionnaire-Turkish Version developed by Driller et al. [39] and adapted to Turkish by Darendeli et al. [40], with high validity and reliability. The scale consists of four sub-dimensions: sport-related factors, sleep quality factors, habitual sleep efficiency factors, and sleep disturbance, and is a five-point Likert-type scale. The factor loadings of this scale, which consists of 17 items in total, vary between 0.418 and 0.825.

Data Acquisition Process

Within the scope of this research, data were collected electronically between 01.11.2023 and 03.11.2023. A Google Form was created from the questions in the data collection tools and the form link was sent to the mobile phone numbers of the research participants. The data obtained within the scope of this research were uploaded to the Excel sheet (Microsoft 365) and numerical values were assigned to the verbal data. The research data, which was made suitable for analysis, was transferred to the IBM statistical program (SPSS version 26.0, Armonk, NY) for analysis.

Statistical Analysis

In this study, multivariate linear regression analysis was conducted using the IBM Statistics (SPSS version 26.0, Armonk, NY) package program. To ensure the validity of the analysis, careful examination was made to ascertain the fulfillment of assumptions underlying multivariate linear regression. The assumptions of the analysis were normality, homoscedasticity, and multicollinearity. The normality assumption was verified using visual and statistical techniques such as histograms, Q-Q plots, and the skewness and kurtosis test to assess the relation between independent and target variables. The homoscedasticity assumption was employed to evaluate the homogenous distribution of the variance of error terms, determining the quality and accuracy of the regression model. Multicollinearity was examined using techniques such as Variance Inflation Factor to identify the presence of high correlations among independent variables. The results indicated that the assumptions of multivariate linear regression analysis were successfully met, ensuring the reliability of the outcomes of the analysis. The statistical significance level was set at $p<.05$.

Results

The effects of chronotype variables on Mental Toughness and Sleep Behaviors variables are presented in Table 2 below.

Table 2. Multivariate linear regression analysis of test results of the effect of chronotype variables on Mental Toughness and Sleep Behaviors variables

DV	IV	Coefficients						Model Summary				ANOVA		
		B	Std.E	Beta	t	p	Pr	R	R^2	Adj. R^2	F	Reg. df	Res. df	p
MT	C	2.803	.238		11.780	.000								
	M-Type	.213	.051	.233	4.214	.000**	.215							
	E-type	-.015	.119	.019	.080	.075	.080							
	N-Type	.076	.257	.286	.186	.177	.186	.353	.125	.118	17.390	3	366	.000
SBSRF	C	2.797	.287		9.748	.000								
	M-Type	-.031	.061	-.030	-.515	.607	-.027							
	E-type	.098	.041	.128	2.382	.018*	.124							
	N-Type	-.067	.055	-.068	-1.207	.228	-.063	.160	.025	.017	3.188	3	366	.024
SBSQ	C	3.853	.236		16.360	.000								
	M-Type	-.272	.050	-.301	-5.446	.000**	-.274							
	E-type	-.033	.034	-.050	-.977	.329	-.051							
	N-Type	-.099	.045	-.117	-2.179	.030*	-.113	356	.127	.120	17.726	3	366	.000
SBHSE	C	3.232	.293		11.043	.000								
	M-Type	-.256	.062	-.235	-4.117	.000**	-.210							
	E-type	-.006	.042	-.007	-.136	.892	-.007							
	N-Type	-.072	.056	-.070	-1.273	.204	-.066	269	072	.065	9.500	3	366	.000
SBSD	C	1.373	.237		5.782	.000								
	M-Type	-.052	.050	-.060	-1.023	.307	-.053							
	E-type	.016	.034	.025	.459	.647	.024							
	N-Type	-.042	.046	-.052	-.912	.363	-.048	.101	.010	.002	1.252	3	366	.291

*p<0.05; **p<0.01; IV: Independent variables; DV: Dependent variables; C: Constant; MT: Mental Toughness; SBSRF: Sleep Behavior (sport-related factors); SBSQ: Sleep Behavior (sleep quality); SBHSE: Sleep Behavior (habitual sleep efficiency); SBSD: Sleep Behavior (sleep disturbance); Reg. df: Regression df; Res. Df: Residual df; Pr: Partial; Std.E: Standard Error

In Table 2, the chronotypes of the participants explain 11% of the changes in Mental Toughness (Adj. R2= 0.118). While M-Type has a significant positive relation with Mental Toughness (β= 0.23, t (36) = t 4.21, p<.001, Pr2= 0.04), no significant relation was found for other types. Furthermore, a one-unit change in M-Type leads to a 0.213 change in Mental Toughness. A significant relation was found between E-Type and Sleep Behavior (sport-related factors) (β= 0.12, t (36) = t 2.38, p<0.005, Pr2= 0.01), but E-Type can explain only 0.01% (Adj. R2= 0.017) of the changes in Sleep Behavior (sport-related factors). No significant relation was found between M-Type and N-Type and Sleep Behavior (sport-related factors). A negative significant relation was found between Sleep Behavior (sleep quality) and M-Type (β=-0.30, t (36) = t -5.44, p<0.001, Pr2=-0.54) and N-Type (β=-0.11, t (36) = t -2.17, p<0.005, Pr2=-0.22). M-Type and N-Type explained only 12% of the changes in Sleep Behavior (Adj. R2=0.120). Moreover, there is a negative and significant relation between M-Type and Sleep Behavior (habitual sleep efficiency) (β=-0.235, t (36) = t-4.11, p<0.001, Pr2=-0.42). M-Type explains 0.06% (Adj. R2=0.065) of the changes in Sleep Behavior (habitual sleep efficiency). No significant relation was found between E-Type and N-Type variables and Sleep Behavior (habitual sleep efficiency). Finally, no statistically significant relation was found between M-Type, E-Type, and N-Type variables and Sleep Behavior (sleep disturbance) variables.

Discussion

The results of this research, which was carried out to determine whether there is a relation between chronotype and factors known to have a great effect on sportive performance such as sleep quality and mental toughness, were remarkable. As a result of this research, it has been determined that there is a positive and statistically significant relation between M-Type and Mental Toughness. In terms of sleep behaviors, a statistically significant relation was found between E-Type and Sleep Behavior (sport-related factors), between M-Type and N-Type and Sleep Behavior (sleep quality), and between M-Type and Sleep Behavior (habitual sleep efficiency). Although the findings were statistically significant, the chronotypes of the participants explained 11% of the changes in Mental Toughness. Although this rate is quite low, it shows that chronotype may have an effect on mental toughness in athletes. Since there is no research in the literature directly examining athletes' chronotypes and mental endurance, these findings are very important.

Mental toughness is often associated with an athlete's ability to focus, avoid failure, cope with pressure, mental flexibility, and maintain resilience in the face of challenging situations [41]. On the other hand, the fact that M-Type individuals go to bed early and get up early, their cognitive and physical performance is higher in the morning [42,43], adrenaline hormone is secreted more in the morning [44], and normal body temperature is reached 1-3 hours earlier than other chronotypes. A study [42] suggests that these may be important parameters affecting mental toughness. Therefore, conducting research on these parameters will provide important contributions to the literature.

Having different chronotypes leads to different results in daily life. In particular, since sociable hours and the endogenous circadian rhythm in the E-type do not match, people gain more unstable sleep habits, their sleep duration shortens, and accordingly, situations such as decreased daytime cognitive function and fatigue bring about mental and physical problems [45]. The fact that 96.7% of the participants in our study trained in the afternoon and at the same time 71.4% went to school before noon (Table 1) suggests a mismatch between chronotype and social time. The endogenous circadian rhythm and social clock time did not match potentially because M-Type athletes train in the afternoon/evening and E-Type athletes go to school before noon. This may have affected the sleep behaviors of athletes.

It is noteworthy that the differences between the chronotypes of the participants and their sleep behaviors show statistically significant differences in some sub-dimensions. However, it is quite low that E-Type predicts 0.01% of the effect of sport-related factors, and M-Type and N-Type predict 0.12% of the effect of sleep quality. Furthermore, the fact that M-Type can predict 0.06% of the effect of habitual sleep efficiency is also a very low rate. Therefore, it is thought that there are other factors affecting the sleep behaviors of our research group. In order to make this issue more understandable, it is recommended that studies be carried out to consider other issues that may be effective with chronotypes.

It is clear that circadian rhythm plays a major role in regulating the sleep-wake cycle. When the sleep-wake cycle is disrupted continuously or recurrently, circadian rhythm-related sleep disorders occur [46]. Studies have shown that individuals with E-Type have worse sleep quality than individuals with M-Type [47,48]. Since individuals with E-Type are exposed to artificial light at night more than individuals with M-Type, melatonin production is impaired, and melatonin-related sleep duration and sleep quality change [48]. Melatonin is a hormone secreted from the pineal gland in the brain and its secretion increases in the dark. Melatonin regulates many systems in the body with circadian rhythm [49]. In addition to melatonin, hormones such as leptin, ghrelin, glucagon, insulin, adiponectin, cortisol, and corticosterone are directly related to sleep quality and duration, sleep-wake cycle, and regulation of circadian rhythm

[50]. Disruption of circadian rhythm causes sleep disorders and thus a decrease in sleep quality [47,48]. The findings of our study also showed that chronotypes may have a statistical effect on sleep behaviors, albeit at a low rate. However, in order to understand this issue more clearly, it is recommended that research be conducted with mixed models in which in-depth interviews and biochemistry tests are applied in addition to scales.

Study Limitations

The limitations of the research are the study sample including only soccer players in the Development Leagues affiliated with the Turkish Football Federation, encompassing only players aged 14 to 19 years, and including only male soccer players. Therefore, it is recommended that researchers plan their future studies by considering these factors.

Conclusions

In conclusion, it has been observed that athletes with the chronotype of M-Type exhibit higher levels of mental toughness compared to those with E-Type and N-Type. Furthermore, it has been deduced that athletes have poor sleep quality habits. It has been determined that athletes with E-Type are influenced by sport-related factors, while athletes with M-Type are affected by habitual sleep efficiency factors. Furthermore, it has been found that athletes with M-Type and N-Type are influenced by factors leading to inefficient sleep. These findings are of significant importance in identifying key factors that affect athletes' performance. Understanding how individual characteristics such as chronotype and sleep habits influence athletes' mental toughness and performance is a fundamental step in developing training programs and performance-enhancement strategies. Specifically, it was found that athletes with an M-Type chronotype have an advantage in terms of mental toughness, highlighting the need to consider this in training and preparation for competitions. Additionally, given the impact on sleep quality, optimizing athletes' sleep habits and schedules can be a crucial strategy to enhance overall performance. Therefore, the analysis of individual characteristics of athletes and sleep habits plays a vital role in advancing research in sports science and maximizing athletes' potential.

Practical implications

The results of this study can be taken into consideration by coaches, health professionals, and researchers who want to improve the performance of athletes. Athletes can use these findings to optimize their performance by understanding their sleep behaviors and chronotypes. Healthcare professionals can evaluate the information in this research to improve athletes' sleep quality and support their performance. Researchers can benefit from the results of this study to better understand the factors affecting the mental endurance of athletes and develop new strategies.

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Institutional Review Board Statement: The study adhered to the principles of the Declaration of Helsinki and received approval from the Graduate Education Institute Ethics Committee, Çanakkale Onekiz Mart University, Türkiye (Approval number: 09/24).

Informed consent statement: The participants and their legal guardians were informed about the research protocol in detail and gave their written informed consent to participate in the study.

Data availability statement: The data presented in this study are available on request from the corresponding author.

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THE EFFECT OF MINDFULNESS MEDITATION THERAPY ON PERFORMANCE, PRE-COMPETITION STRESS, AND SALIVARY CORTISOL IN FEMALE PISTOL SHOOTERS

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Authors' contribution:

A. Study design/planning
B. Data collection/entry
C. Data analysis/statistics
D. Data interpretation
E. Preparation of manuscript
F. Literature analysis/search
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Abstract:

Bacground: This study aimed to investigate the effect of a 6-week mindfulness meditation therapy (MMT) program on shooting performance, pre-competition stress, and salivary cortisol levels in female shooters.

Methods: Nineteen shooters (mean age ± standard deviation: 15.5±1.5 years, and body mass index: 22.9±2.7 kg/m^2) completed the study protocol in two groups: MMT (n=10) and control (n=9). The MMT group performed five 20-minute training sessions per week, while the control group did not receive any intervention. 10 m pistol shooting performance, pre-competition stress (using a standard scale), and salivary cortisol levels (using an ELISA kit) were measured twenty-four hours before and after the intervention. The independent samples t-test and the paired samples t-test were used to compare the intergroup and intragroup differences, respectively, with a significance level set at $p<0.05$.

Results: No significant differences were found between the groups in the pre-test measurements ($p<0.05$). Compared with the waitlist control shooters, shooting performance scores were higher (a 2.1% increase vs. a 0.2% reduction, $p=0.030$), while pre-competition stress (a 10.5% vs. a 1.7% reduction, $p=0.002$) and cortisol levels (a 23.8% vs. a 0.6% reduction, $p=0.002$) were lower in MMT group following the intervention.

Conclusion: It seems that the six-week MMT program has a positive effect on the pistol shooting performance of female shooters by decreasing pre-competition stress and salivary cortisol levels. Hence, the implementation of this psychological training protocol for female shooters is recommended.

Introduction

Air pistol shooting in the Olympics demands intense mental focus and precise movement for success. It is a static activity that requires strict control of body segments and posture to align the rear sight aperture and the foresight through proprioceptive feedback and gaze fixation on the target or between the target and the weapon to increase shot precision [1].

Pre-competition stress is a critical factor affecting a shooter's performance. Stress is one of the most extensively studied phenomena in sports psychology. It has been suggested that stress is a bio-hormonal response to the social-psychological environment (e.g., an official shooting competition), and internal and external stimuli [2]. Moreover, various competitive conditions create pressure in the psychological dimension, which changes the physiological response of athletes. Stress induces negative effects on both the psychological and physical aspects of an athlete's performance, depending on its severity and the athlete's perception [2-4]. The main mechanism proposed in this regard is an increase in the activity of the limbic system, especially the amygdala and the hippocampus region, which sends signals to the posterior medial part of the hypothalamus [5]. The final product of the hypothalamus-pituitary-adrenal (HPA) axis is cortisol, activated in response to psychological and physical stress conditions [2].

Cortisol is a reliable physiological marker of HPA axis functions, and its level increases following the perception of a competitive demand, resulting in the activation of the HPA axis [6]. Psychological training such as mindfulness meditation therapy (MMT) has been recommended in this regard to help athletes better cope with stress and psychologically disturbed situations during competition [7]. Mindfulness is defined as a non-judgmental, conscious, purposeful focus, understanding, and acceptance of the present moment. In this approach, the focus is on encouraging individuals to mindfully observe their internal and external thoughts and feelings without judgment, allowing them to fully experience these thoughts and feelings [8]. During recent decades, mindfulness has been used in the sports domain to help athletes improve their abilities to accept, realize, and effectively control their attention, and improve their body perception ability [7,8].

Likewise, the literature review indicates that mindfulness-based training is effective in enhancing some important physiological and psychological factors that affect shooting performance. For instance, John et al. reported that four weeks of MMT enhanced shooting performance and influenced the HPA axis by reducing salivary cortisol in male elite shooters [1]. In another study, Samadi et al. found that a mindfulness-based protocol used for six weeks was effective in decreasing pre-competition stress among young male shooters [2]. Despite the potential benefits of mindfulness training in sports, there is currently insufficient evidence to determine its effectiveness in female shooters, highlighting the need for further research. Therefore, the purpose of this study was to investigate the effect of a 6-week MMT program on pre-competition stress, salivary cortisol concentration, and shooting performance in female pistol shooters. Our hypothesis is that implementing the MMT protocol will improve shooting performance while reducing stress and cortisol levels in such athletes.

Material and Methods

Participants

The study participants were female adolescent pistol shooters. The sample size calculation for this study was performed using G*Power 3.1.9.4 [9], assuming a two-tailed t-test, a test power of 80% (1-β), a significance level of 0.05, and a large effect size. This calculation indicated that at least 16 participants (8 participants in each group) needed to be enrolled in this study. However, to account for the possibility of a decrease in the number of participants during the research period, the final sample size was set at twenty shooters. The inclusion criteria consisted of regular pistol shooting training for at least one year, no use of medications or supplements that affect the study variables, and regular menstrual cycles during the last three months (self-reported by participants). Additionally, the shooters were not in the early follicular period of their menstrual cycle (1-7 days after the onset of menstruation) on the testing days. One participant withdrew for personal reasons during the study, resulting in the inclusion of data from nineteen shooters in the final analysis. The participants were randomly assigned to two groups, MMT (n=10) and control (n=9), using a random-numbers table and a simple form of randomization. This research was conducted in accordance with the Declaration of Helsinki. All shooters were given a clear explanation of the procedure, and written informed consent was also obtained from both the shooters and their parents or legal guardians. The present study protocol was approved by the Institutional Review Board of the University (PH-721366).

Study procedure

This research used a between-subjects randomized design to investigate the effects of MMT on stress, salivary cortisol levels, and shooting performance. During the initial visit, all shooters were acquainted with the research procedure, the MMT protocol, and measurements. Additionally, body height, body mass, and baseline values were measured during this session. The anthropometric measurements were conducted in accordance with the protocols outlined by the International Society for the Advancement of Kinanthropometry (ISAK) [10]. Their standing height was measured using a stadiometer, accurate to the nearest 0.1 cm. Furthermore, body mass was measured using a portable scale (ONYX, Germany) with an accuracy of 0.1 kg. Twenty-four hours after the pre-test measurements, the MMT protocol began. Finally, the post-test measurements were performed twenty-four hours after the end of the last training session, under the same conditions as the pre-test (i.e., time of day and the testing order).

On testing days, cortisol levels were measured by collecting saliva samples during the post-awakening period (60 minutes after awakening). A standard stress scale was then completed by the shooters, and finally, the shooting performance test was conducted. The shooters were asked to abstain from exercising and consuming caffeine or alcoholic beverages for twelve hours leading up to the testing [1]. Furthermore, they were asked to maintain their daily diet routines during the study and follow a similar diet, based on the food recording sheets, as much as possible for 48 hours before the measurements [11].

Training protocol

The MMT protocol comprised five 20-minute sessions per week (Saturday to Wednesday, in the morning at 9:00 to 10:00) across six weeks of training. To begin the MMT training, the shooters were instructed to adopt a posture that ensured an erect spine and shoulders resting on the mat, with their hands placed on the upper abdomen. They were also advised to position their head slightly forward with the support of a small towel roll. The shooters could either fully close their eyes or drop their upper lids and were given one minute to adapt to the posture. As the meditation session progressed, they were instructed to undergo three minutes of stabilization through Shavasana. The technique recommended by Coulter (2001) was used for Shavasana training [12]. The shooters were asked to relax, and subsequently, they engaged in meditation, which included Pranayama for four minutes while in the supine position, with their eyes closed. During this meditation, their respiration was maintained at a constant frequency of 0.2 Hz, synchronized with the sound of a metronome (i.e., five breaths per minute for four minutes). The shooters were then guided through a mindfulness exercise known as body scan, which involves focusing attention on various joints of the body without labeling the sensations as “good” or “bad,” in a sequence from distal to proximal. This was followed by another 4-minute Pranayama exercise at the constant frequency as above and was also ended with three minutes of Shavasana. They were instructed to raise their hands if they experienced any discomfort during the meditation, and if so, to stop the session immediately [1,2].

Salivary cortisol measurement

To minimize the effects of circadian variations, all shooters woke up at 8:00 am (after seven hours of night sleep) and were then referred to the laboratory at 9:00 am. Saliva samples were collected after washing the mouth with distilled water during a 10-minute rest on a comfortable chair in a quiet, controlled room with an ambient temperature between 20-24 °C. The shooters were fasting for eight hours. At each sampling time, approximately three ml of saliva were collected in sterile tubes with lids. Subsequently, the samples were centrifuged at 3,000 rpm (4 °C) for 15 minutes and subsequently stored in a freezer at -20 °C until the final laboratory tests. The salivary concentration of cortisol in all samples was measured using a commercial ELISA kit (Cortisol Saliva Elisa, DKO020, DiaMetra, Italy) following the manufacturer’s instructions.

Stress measurement

The Perceived Stress Scale (PSS) was used to determine the effect of the MMT protocol on pre-competition stress [13]. The PSS is a 14-item self-report measure designed to assess the degree to which individuals appraise situations in their lives as stressful. The scale includes direct queries about current levels of experienced stress, and feelings and thoughts during the last month [13]. Moreover, this scale is widely used to measure the effects of meditation on the perception of stress [14-16]. All shooters responded to questions on a 5-point Likert scale, ranging from “Never” to “Very Often.” The scores were then summed, and the total score was used in the final analysis as the outcome variable.

Shooting performance measurement

The standard indoor pistol shooting tests were conducted in accordance with the rules set forth by the International Shooting Sport Federation (ISSF) [17]. After preparation and sighting for 15 minutes, the shooters completed 60 competition shots in a standing position to the standard 10-point paper targets in a 10 m distance within 90 minutes. Each shot had a maximum score of 10, and the total score, calculated as the sum of 60 shots, was considered the shooters’ record.

Statistical analysis

Data were analyzed using SPSS software version 22, with a significance level set at $p<0.05$. The Shapiro-Wilk test was applied to determine the normality of the data distribution. Descriptive statistics were presented as mean ± standard deviation (SD). The paired samples t-test was utilized for comparing the differences from pre- to post-test in each group, while the independent samples t-test was used to compare the possible differences between the groups.

Results

Somatic characteristics of shooters are presented in Table 1. There were no significant differences between the groups regarding age ($p=0.711$), standing height ($p=0.514$), body mass ($p=0.733$), and body mass index ($p=0.821$).

Table 1. Mean ± standard deviation of descriptive characteristics in mindfulness meditation therapy (MMT) and control groups

Variables	MMT (n=10)	Control (n=9)	p-value
Age (years)	15.4±1.3	15.7±1.8	0.711
Height (cm)	159±9.5	156.3±7.6	0.514
Body mass (kg)	58±10.3	56.4±9.1	0.733
Body mass index (kg/m^2)	22.8±2.2	23.1±3.4	0.821

The contrast between groups in pistol shooting performance is outlined in Figure 1. It was observed that during the post-test measurement, the shooters in MMT group scored higher than the waitlist control shooters, with the MMT group reaching 546.7 and the control group reaching 528.8 points ($p=0.030$). These results were obtained even though the two groups did not differ significantly in the pre-test ($p=0.514$).

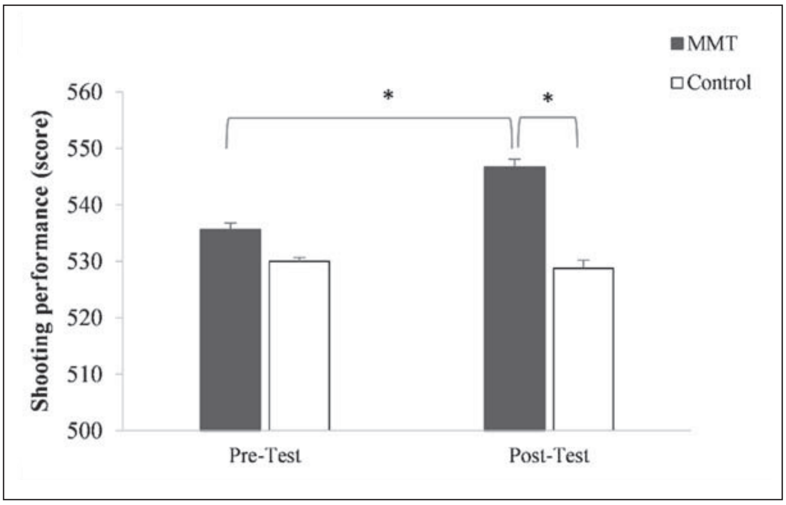

Figure 1. Changes in shooting performance scores between pre- and post-test results in mindfulness meditation therapy (MMT, n=10) and control (n=9) groups. Data are presented as mean and standard deviations; $^{*}p<0.05$

Figure 2 illustrates pre-competition salivary cortisol contrasts between the groups before and after the intervention. Although no significant difference was found between the groups in the pre-test measurement ($p=0.477$), the MMT group had lower cortisol concentrations than the waitlist control group in the post-test ($p=0.002$).
Figure 3 shows the changes in pre-competition stress scores between the groups from pre- to post-intervention. There were no statistically significant differences in stress in the pre-test ($p=0.332$). However, a significant decrease in stress scores was observed in the MMT group compared to the control group in the post-test measurement ($p=0.002$).

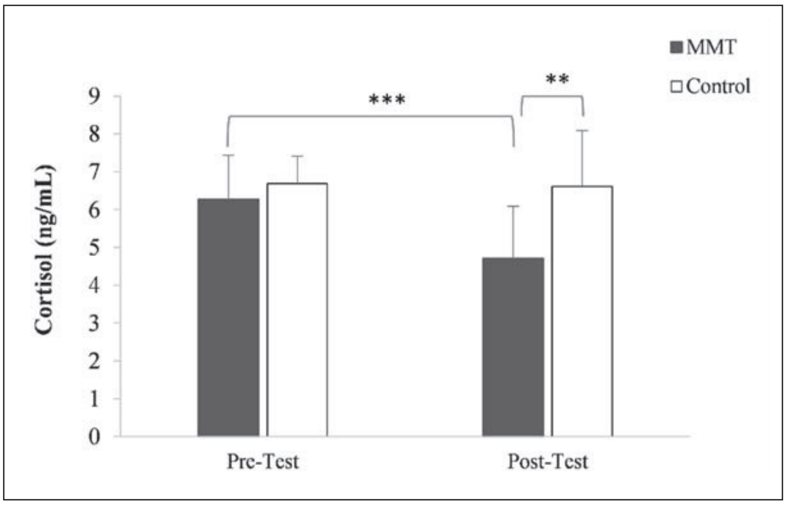

Figure 2. Changes in pre-competition salivary cortisol levels between pre- and post-test results in mindfulness meditation therapy (MMT, n=10) and control (n=9) groups. Data are presented as mean and standard deviations; $^{**}p<0.01$, $^{***}p<0.001$

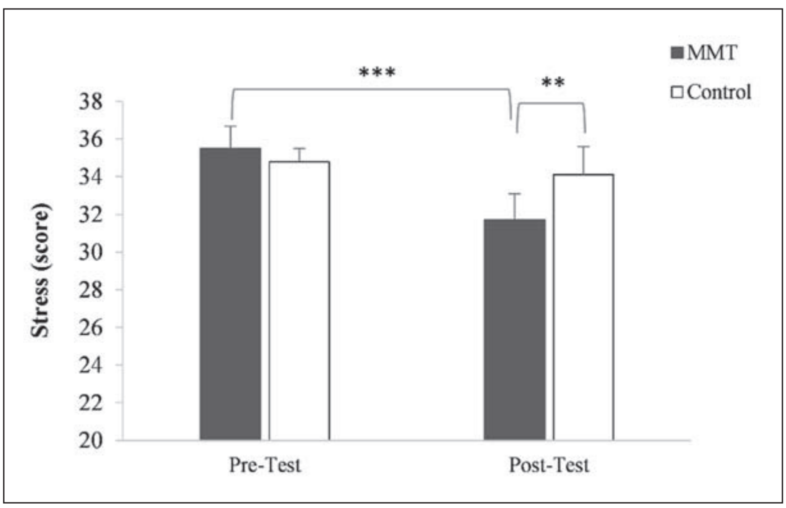

Figure 3. Changes in pre-competition stress scores between pre- and post-test in mindfulness meditation therapy (MMT, n=10) and control (n=9) groups. Data are presented as mean and standard deviations; $^{**}p<0.01$, $^{***}p<0.001$

Discussion

The purpose of this study was to examine the effect of a psychological mindfulness-based intervention called the MMT protocol on pre-competition stress, salivary cortisol levels, and shooting performance in female pistol shooters. The findings revealed that the MMT protocol used in the present study led to higher scores in 10 m pistol shooting records (a 2.1% increase vs. a 0.2% reduction) and lower stress (a 10.5% vs. a 1.7% reduction) and cortisol levels (a 23.8% vs. a 0.6% reduction).

The results of the present study are consistent with those of John et al., who reported a 2.6% increase in pistol shooting performance following a 4-week mindfulness-based training in the experimental group, while the waitlist control shooters exhibited a 0.9% reduction from baseline [1]. Similar findings have been reported by Solberg and colleagues, who found that engagement in a mindfulness protocol (once a week for seven weeks) seems to improve performance in elite rifle shooters compared with a control condition with no intervention [18]. The pressure on shooters is likely to increase as the importance of the competition rises, although this may vary depending on experience, the level of competition, and motivation. The heightened stress experienced during competitions may lead to an increased need for stress-reducing techniques [18]. Indeed, coping with stress is a crucial issue in pistol shooting as a precision sport, and the management of stress has a significant impact on athletes' performance [7]. The importance of mindfulness training approaches in stress adjustment has been widely acknowledged [8]. Therefore, the reduction in stress levels observed in the present study may partially account for the improvement in shooting performance scores.

Salivary cortisol levels, as a reliable physiological marker of HPA axis, appear to be linked with psychological variables such as stress [1]. Stressful conditions (e.g., shooting competitions) can lead to significant changes in athletes' psychological and behavioral responses, and may even trigger psychological disorders, ultimately impacting the athletes' performance [19]. Furthermore, competitive stress also increases the activity of the autonomic nervous system (ANS) with the release of catecholamines, and the HPA axis activity resulting in releasing higher levels of cortisol [20]. In fact, there is a consensus that the psychological arousal associated with a competitive environment can affect the HPA axis and consequently increase the production and secretion of cortisol [20,21]. This is consistent with previous research, such as a study involving Norwegian Navy Special Operations Forces (SOF) members, which found that acute physical stress caused by exercise led to a reduction in shooting score and an increase in shot-group dispersion, highlighting the impact of stress on shooting performance [22]. Considering that the shooters in the present study did not engage in any physical activity before the shooting competition and the measurement conditions were similar between the groups, the reduction of cortisol levels in the experimental group seems to be attributed to the MMT protocol. Thus, the decrease in cortisol levels observed in this study may contribute to the reduction in stress and the improvement in shooting performance.

In line with the current results, Samadi et al. (2021) concluded that a mindfulness training approach used for six weeks was effective in decreasing pre-competition stress among male shooters [2]. Another study confirmed a significant reduction in salivary cortisol levels following the MMT protocol in elite male shooters [1]. Furthermore, a study on the effect of music therapy on pre-competition stress and shooting performance demonstrated that relaxation therapies, such as music therapy, may decrease pre-competition stress and enhance shooting performance by reducing salivary cortisol levels [23]. These findings support the notion that managing stress and cortisol levels can have a positive impact on shooting performance.

Conclusions

The findings of this study indicate that the six-week psychological training program using mindfulness and meditation therapy effectively enhanced the pistol shooting performance of female adolescent shooters by reducing pre-competition stress and salivary cortisol levels.

Practical Implications

Our study found that the MMT protocol had a positive impact on pre-competition stress and salivary cortisol levels in shooters. Given the potential link between these factors and improved shooting performance scores, we recommend implementing similar psychological skills training programs for athletes in closed-skill accuracy sports, such as shooting.

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Institutional Review Board Statement: The present study protocol was approved by the Institutional Review Board of the University (PH-721366).

Informed consent statement: Written informed consent was obtained from both the shooters and their parents or legal guardian involved in the study.

Data availability statement: The data presented in this study are available on request from the corresponding author.

Conflict of interest: The authors declare no conflict of interest.

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RELATIONSHIPS OF BODY BUILD AND PHYSICAL ACTIVITY WITH THE PHYSICAL FITNESS OF HIGH SCHOOL STUDENTS

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Authors' contribution:

A. Study design/planning
B. Data collection/entry
C. Data analysis/statistics
D. Data interpretation
E. Preparation of manuscript
F. Literature analysis/search
G. Funds collection

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Abstract:

Background: Physical fitness determines resourcefulness, i.e. the ability to effectively solve various tasks faced by a person and, therefore, to cope with various situations. The aim of this study was to investigate the relationships of body build and physical activity with physical fitness in high school students.

Methods: The research covered 194 students (104 women and 90 men) aged 16-18, attending randomly selected high schools in the Rzeszów district. The research methods were a diagnostic survey and the Eurofit test battery. The Mann-Whitney U test, Pearson's chi-square test, and Spearman's rank correlation were used in the analyses.

Results: Statistically significant relationships were found between the preferred forms of physical activity ($p=0.041$, $p=0.008$) and the subjective assessment of physical fitness ($p=0.015$) and the sex of the respondents. There were statistically significant sex-related differences in the Sit-and-Reach ($p<0.001$), Standing Broad Jump ($p<0.001$), Hand Grip ($p<0.001$), Sit-Ups ($p<0.001$), Bent Arm Hang ($p< 0.001$), Shuttle Run ($p<0.001$), and Endurance Shuttle Run ($p<0.001$). In both groups, there were statistically significant relationships between the subjective assessment of physical fitness and the results of physical fitness tests ($p<0.05$).

Conclusions: Women chose dancing more frequently and considered their physical fitness to be average, while men preferred team sports and assessed their physical fitness as very good. Women are characterized by greater flexibility, and men by greater explosive strength of lower limbs, static strength, strength endurance of trunk muscles, speed and agility, and cardiorespiratory endurance. In both groups, the higher the subjective assessment of physical fitness, the better the results of individual physical fitness tests.

Introduction

Physical activity is defined by the World Health Organization as any body movement produced by the skeletal muscles, resulting in the expenditure of energy [1]. It is one of the factors determining positive health [2].
Nowadays, as a result of technological progress, there is a tendency towards moving away from an active lifestyle and onto one that involves, among others, spending time in front of a computer, TV, or traveling by car. Due to lack

of exercise, health problems arise in the form of various diseases [3-6]. The research by Puszczałowska-Lizis and Kułaga [3] shows that high school students are aware of the positive relationship between physical activity and health, but this knowledge is often not reflected in everyday life.

Brophy et al. [7] and Maszczak [2] drew attention to population changes in the physical fitness of young people over the last decades. These changes are disturbing because, according to Przewęda [8], efficiency determines resourcefulness, i.e. the ability to effectively solve various tasks faced by a person and, therefore, to cope with various situations. The author emphasized that physical fitness is based on pillars such as: "being able" (meaning human motor capabilities), "knowing" (meaning motor skills, necessary knowledge, and experience acquired in the learning process), and "wanting" (determining human involvement in performing the motor task before it is performed).

Adolescence is one of the key periods of a person's life. Physiological changes occur as health habits develop, which may influence lifestyle in adulthood [3,9,10]. The above considerations became the reason for undertaking the topic of the present study, the aim of which was to examine the relationships of body build and physical activity with the physical fitness of high school students.

Research questions:

1. How often do the respondents undertake extracurricular physical activity and does sex determine frequency and preferred forms and influence subjective assessment of physical fitness?
2. Are there sex-related differences in physical fitness test results?
3. What are the relationships between BMI, the frequency of taking part in extracurricular physical activity, the subjective assessment of physical fitness and the results of physical fitness tests performed on the subjects?

Material and methods

Participants

The research covered 194 students attending randomly selected high schools in the Rzeszów administrative district, including 104 women (54% of the group) and 90 men (46% of the group) aged 16-18.

The qualifying criterion for the study was age between 16 and 18 years, not practicing competitive sports at the time of research or in the recent past prior to the study, and written informed consent to participate in the study. The following exclusion criteria were adopted: deformities, past diseases, and/or injuries of the musculoskeletal system. Table 1 presents the characteristics of the respondents.

Table 1. Characteristics of study population

	Women	Men	Statistics
Age, n (%)			
16 years	41 (39.0)	30 (33.3)	$\chi^2(2)=0.84$; $p=0.657$
17 years	30 (29.0)	30 (33.3)	
18 years	33 (32.0)	30 (33.3)	
Body mass [kg], $\bar{x}\pm SD$	53.88±7.30	69.62±9.36	$Z=-10.07$; $p<0.001$*
Body height [cm], $\bar{x}\pm SD$	164.65±5.40	175.43±6.19	$Z=-9.72$; $p<0.001$*
BMI, $\bar{x}\pm SD$	19.84±2.19	22.58±2.35	$Z=-7.29$; $p<0.001$*
Body build, n (%)			
Underweight	32 (31.0)	4 (5.0)	$\chi^2(2)=26.48$; $p<0.001$*
Normal weight	69 (66.0)	74 (82.0)	
Overweight	3 (3.0)	12 (13.0)	

n – number of subjects; % – percent of subjects; χ^2 – value of the chi-square test statistic; $\bar{x}$ – arithmetic mean value; SD – standard deviation; Z – value of the Mann Whitney U test statistic; p – probability value
*$p<0.05$

Examination protocol

The procedures included the following research tools:

1. Author's survey to collect sociodemographic data and information on the physical activity of the participants.
2. The Eurofit European Test of Physical Fitness was used to assess the physical fitness of the participants [10, 11]. The participants performed the following tests:
   – Flamingo Balance test – assessment of static balance;
   – Plate Tapping – assessment of the speed of movements of the upper limb;
   – Sit-and-Reach – assessment of flexibility;
   – Standing Broad Jump – assessment of lower limb explosive strength;
   – Hand Grip – assessment of static strength. A manual spring dynamometer „Saehan", SH5002 (manufactured by SAEHAN Corp. Bongamgongdan, Masanhoewon-gu, Changwon-si, Gyeongsangnam-do, Republic of Korea) was used to perform the test;
   – Sit-Ups – assessment of trunk muscle strength endurance;
   – Bent Arm Hang – assessment of shoulder girdle and arm functional strength;
   – Shuttle Run 10×5 metres – assessment of speed and agility;
   – Endurance Shuttle Run – assessment of cardiovascular-respiratory endurance [11,12].

   Tests of motor skills are part of the battery of tests known as Eurofit Physical Fitness Test Battery, which was designed by the Council of Europe in 1988 [11].
3. OMRON BF500635 medical scale (manufactured by Omron Ltd., Japan), for measuring body weight (measurement accuracy ± 0.1 kg).
4. GPM anthropometer (manufactured by Vitako Ltd., Switzerland), for measuring body height (measurement accuracy ± 0.1 cm).

Based on collected data, body mass index (BMI) was calculated, which defines height-to-weight proportions for each study participant.

The research was carried out with the approval of the Bioethics Review Committee at the University of Rzeszow (Resolution no. 3/04/2020) and the consent of the heads of the facilities where it was conducted. In order to maintain the reliability of the research process, all tests were carried out in the morning in school gymnasiums, using the same measuring instruments. The subjects took part in the tests in gymnastic clothes. All procedures were carried out in full compliance with the Declaration of Helsinki. All participants were provided with detailed information on the aims and methods to be used throughout the study, and gave their written informed consent to participate.

Statistical analysis

The consistency of pertinent variables with reference values in normal distribution was verified using the Shapiro-Wilk test. The collected research results were analysed with the use of the Mann-Whitney U test, chi-square test, and Spearman's rank correlation in Statistica 13.1 by StatSoft (StatSoft Inc., Tulsa, OK, USA; StatSoft, Krakow, Poland). The level of statistical significance was set at $p<0.05$.

Results

Data in Table 2 indicate statistically significant relationships between the preferred forms of physical activity and the subjective assessment of physical fitness depending on the sex of the respondents. Women chose dancing more frequently ($p=0.041$), while men preferred team sports ($p=0.008$). Women were more likely to consider their physical fitness as average, and men as very good ($p=0.015$). Other forms of physical activity included cycling, horse riding, tennis, and indoor climbing.

Table 2. Extracurricular physical activity and subjective assessment of physical fitness depending on the sex of the participants

	Women	Men	Statistics
Extracurricular physical activity, n (%)			
Yes	76 (73.0)	67 (74.0)	$\chi^2(1)=0.05$; $p=0.829$
No	28 (27.0)	23 (26.0)	
Frequency of extracurricular physical activity, n (%)			
Every day	14 (13.0)	14 (16.0)	$\chi^2(2)=0.44$; $p=0.802$
Once a week	39 (38.0)	36 (40.0)	
2-3 times a week	51 (49.0)	40 (44.0)	
Preferred forms of extracurricular physical activity n (%)			
Running (cross-country, jogging, etc,)	29 (38.0)	25 (37.0)	$\chi^2(1)=0.01$; $p=0.917$
Swimming	42 (55.0)	33 (49.0)	$\chi^2(1)=0.52$; $p=0.472$
Dancing	25 (33.0)	12 (18.0)	$\chi^2(1)=4.16$; $p=0.041$*
Strength exercises	25 (33.0)	32 (48.0)	$\chi^2(1)=3.28$; $p=0.070$
Team sports games	2 (3.0)	10 (15.0)	$\chi^2(1)=7.00$; $p=0.008$*
Other	15 (20.0)	16 (24.0)	$\chi^2(1)=0.36$; $p=0.548$
Subjective assessment of physical fitness, n (%)			
Perfect	2 (2.0)	5 (6.0)	$\chi^2(5)=14.02$; $p=0.015$*
Very good	23 (22.0)	30 (33.0)	
Good	38 (36.0)	33 (37.0)	
Average	35 (34.0)	12 (13.0)	
Low	5 (5.0)	9 (10.0)	
Very low	1 (1.0)	1 (1.0)	

n – number of subjects; % – percent of subjects; χ^2 – value of the Chi-square test statistic; p – probability value
*$p<0.05$

The data in Table 3 indicate that the values obtained in the Sit-and-Reach test were higher in the group of women ($p<0.001$). Furthermore, men had higher values in the case of Standing Broad Jump ($p<0.001$), Hand Grip ($p<0.001$), Sit-Ups ($p<0.001$), Bent Arm Hang ($p<0.001$), and lower values in Shuttle Run ($p<0.001$) and Endurance Shuttle Run ($p<0.001$) tests.

Table 3. Cross-sex comparison of results obtained in individual physical fitness tests

Sex	$\bar{x} \pm SD$	Max-Min	Q_{25}	Me	Q_{75}	Z	p
Flamingo Balance test [number of falls or loss of balance in 60 s]							
Women	3.40±2.54	18.00-1.00	2.00	3.00	5.00	-1.55	0.120
Men	3.91±2.71	15.00-0.00	2.00	3.00	5.00		
Plate Tapping [s]							
Women	12.47±2.32	18.76-8.23	10.98	12.13	14.15	1.61	0.106
Men	11.88±1.99	17.30-8.41	10.37	11.57	13.36		
Sit-and-Reach [cm]							
Women	12.90±8.08	30.00-(-7.00)	8.00	14.00	19.00	6.34	<0.001*
Men	5.53±6.67	22.00-(-11.00)	2.00	7.00	10.00		

Standing Broad Jump [cm]							
Women	167.86±14.10	205.00-130.00	160.00	170.00	175.50	-9.29	<0.001*
Men	195.24±18.49	252.00-162.00	180.00	195.00	208.00		
Hand Grip [kg]							
Women	17.73±7.14	77.00-7.00	15.00	18.00	20.00	-11.30	<0.001*
Men	30.77±5.23	41.00-17.00	28.00	31.00	35.00		
Sit-Ups [maximum number of correctly performed sit ups in 30 s]							
Women	24.53±3.59	31.00-13.00	22.00	25.00	27.00	-5.25	<0.001*
Men	27.18±3.23	37.00-13.00	25.00	27.00	29.00		
Bent Arm Hang [s]							
Women	9.60±11.76	59.97-0.00	0.00	5.94	14.16	-6.28	<0.001*
Men	23.56±21.31	120.52-0.00	12.13	18.35	28.56		
Shuttle Run 10×5 m [s]							
Women	16.66±1.40	20.05-14.18	15.64	16.59	17.56	4.47	<0.001*
Men	15.65±1.40	18.95-12.36	14.75	15.63	16.41		
Endurance Shuttle Run [number of shuttles]							
Women	39.23±15.57	101.00-17.00	28.50	37.00	47.00	-6.93	<0.001*
Men	56.59±17.50	101.00-26.00	42.00	53.00	69.00		

$\overline{x}$ – arithmetical mean value; SD – standard deviation; Max – maximum value; Min – minimum value; Q_{25} – lower quartile; Me – median; Q_{75} – upper quartile; Z – value of the Mann Whitney U test statistic; p – probability value
* p<0.05

The data in Table 4 indicate that in the group of men, there were statistically significant positive relationships between the BMI values and the values obtained in the Flamingo Balance test (R=0.26; p=0.013) and Shuttle Run 10×5 m (R=0.22; p=0.037) and a negative relationship between BMI and Bent Arm Hang (R=-0.29; p=0.006). In the group of women, there was a statistically significant positive relationship between the frequency of extracurricular physical activity and Sit-Ups values (R=0.23; p=0.018).

Both in women and men, there were statistically significant negative relationships between the subjective assessment of physical fitness and the following tests: Flamingo Balance test (women: R=-0.28; p=0.003 and men: R=-0.33; p=0.001), Plate Tapping (women: R=-0.26; p=0.007 and men: R=-0.35; p=0.001), and Shuttle Run 10×5 m (women: R=-0.40; p<0.001 and men: R =-0.31; p=0.003). Moreover, in both groups, there were statistically significant positive relationships between the subjective assessment of physical fitness and the following tests: Sit-and-Reach (women: R=0.30; p=0.002 and men: R=0.31; p=0.003), Standing Broad Jump (women: R=0.32; p=0.001 and men: R=0.33; p=0.001), Sit-Ups (women: R=0.43; p<0.001 and men: R=0.44; p<0.001), Bent Arm Hang (women: R=0.29; p=0.003 and men: R=0.51; p<0.001), and Endurance Shuttle Run (women: R=0.50; p<0.001 and men: R=0.36; p<0.001). In men, there was a statistically significant positive relationship between the subjective assessment of physical fitness and Hand Grip (R=0.37; p<0.001).

Table 4. Relationships between BMI, frequency of extracurricular physical activity, and subjective assessment of physical fitness with physical fitness test results

Test	**BMI**		**Frequency of extracurricular physical activity**		**Subjective assessment of physical fitness**	
	Women	**Men**	**Women**	**Men**	**Women**	**Men**
			R **p**			
Flamingo Balance test	0.12 0.207	0.26 0.013*	-0.01 0.939	-0.18 0.093	-0.28 0.003*	-0.33 0.001*
Plate Tapping	0.01 0.938	0.02 0.822	-0.07 0.480	0.01 0.952	-0.26 0.007*	-0.35 0.001*

Sit-and-Reach	-0.04 0.705	-0.16 0.124	-0.03 0.751	0.09 0.416	0.30 0.002*	0.31 0.003*
Standing Broad Jump	-0.02 0.848	-0.16 0.136	0.01 0.939	0.05 0.673	0.32 0.001*	0.33 0.001*
Hand Grip	0.18 0.063	0.20 0.057	0.16 0.098	-0.16 0.143	0.11 0.263	0.37 <0.001*
Sit-Ups	-0.04 0.680	-0.06 0.576	0.23 0.018*	0.17 0.104	0.43 <0.001*	0.44 <0.001*
Bent Arm Hang	-0.13 0.198	-0.29 0.006*	-0.02 0.847	0.00 0.980	0.29 0.003*	0.51 <0.001*
Shuttle Run 10×5 m	0.14 0.163	0.22 0.037*	0.09 0.390	-0.20 0.064	-0.40 <0.001*	-0.31 0.003*
Endurance Shuttle Run	-0.09 0.386	-0.20 0.064	-0.13 0.200	0.13 0.206	0.50 <0.001*	0.36 <0.001*

R – Spearman's rank correlation coefficient; p – probability value
*p<0.05

Discussion

Results of our research showed that over 70% of the women and men surveyed undertook extracurricular physical activity. The majority of respondents, regardless of sex, declared that they engaged in this activity once or two to three times a week. The above data are similar to those obtained in previous research by Puszczałowska-Lizis and Kułaga [3], in which the majority of high-school students from Dąbrowa Tarnowska, Poland, had three or four hours of free time after school and engaged in physical activity, on average, twice a week. In turn, Kremer et al. [13] showed that only 33% of students in selected Australian schools engaged in extracurricular physical activity. Similar results were reported by Song et al. [14], as 35% of students from selected schools in China reported participating in extracurricular physical activity. Hallal et al. [15], in a report on adolescents aged 15 years or older, carried out in 122 countries around the world, concluded that the frequency of physical activity decreased with age, especially in the case of females. Over 80% of respondents declared after-school physical activity of less than one hour a day.

Our research found that sex determines the preferred forms of physical activity and the subjective assessment of physical fitness. Women chose dancing more frequently and considered their physical fitness to be average, while men preferred team sports and assessed their physical fitness as very good. Similar results were obtained by Bochenek and Grabowiec [16] among young people from secondary schools in Janów Lubelski, Biała Podlaska, and Łuków, Poland. The females preferred jogging and considered their physical fitness to be average, while men more often chose team sports and the gym and considered their physical fitness as very good. Nowak [17], based on the results of research on high-school graduates aged 18-19 from Silesian, Opole, Łódź, and Lesser Poland Voivodeships, showed that men, compared to women, assessed their physical fitness much higher and considered it to be high. Similarly, Lubans [18], in research on 249 students from 10 secondary schools in Australia, found a higher self-assessment of the level of physical fitness in males.

In our material, sex-related differences can be found in the results of motor skills tests. Women showed better results in the Sit-and-Reach test, while men had better results in the Standing Broad Jump, Hand Grip, Sit-Ups, Bent Arm Hang, Shuttle Run, and Endurance Shuttle Run tests. Similarly, Sauka et al. [19] reported better results in 17-year-old men in Latvia in tests assessing the level of endurance, muscle strength, and speed, while women achieved better results in the Sit-and-Reach flexibility test. Cruz Estrada et al. [20] demonstrated a relationship between the results of the Flamingo Balance test and the Sit-and-Reach test and the gender of adolescents aged 15-17 from three different high schools in Toluca, Mexico. Women scored better on these tests than men. Tomkinson et al. [10], based on the analysis of the European normative values for physical fitness of children and adolescents aged 9-17 years, representing 30 countries, found that girls had better flexibility, while boys achieved better results in tests assessing cardiorespiratory endurance and musculoskeletal fitness. According to the authors, the main mechanism driving gender-specific discrepancies in physical fitness is differences in somatic structure. Furthermore, Lovecchio et al. [21] reported better Standing Broad Jump and Bent Arm Hang results in 16-year-old male subjects from Italy. Piccino and Colella [22] also reported better results for selected physical fitness tests, such as the Standing Broad Jump and the 10x5-m Shuttle Run among 460 students in male Italian secondary schools. The authors found that gender-related differences in this respect deepen with age.

In our study, it was noted that in the group of men, an increase in the BMI value was associated with an increase in the number of falls or loss of balance during the 60s of the Flamingo Balance test and an increase in the time of the 10×5-m Shuttle Run, and a decrease in the time of the Bent Arm Hang. Živkovic et al. [23] found that an increase in BMI was accompanied by worse results in the Standing Broad Jump, Sit-Ups, and Bent Arm Hang and an improvement in the Hand Grip test results in 13-year-old adolescents. Research by Kondapalli et al. [24] in India showed a decrease in agility and speed in obese and overweight individuals, stating that motor ability decreases with an increase in fat mass. A similar project was carried out by Jopkiewicz and Nowak [25] among youth from Kielce, Poland. It was found that individuals with normal body structure or underweight showed better performance in Eurofit tests compared to their overweight peers, except the Hand Grip test, in which young people with higher BMI achieved better results.

We found that in women, an increase in the frequency of extracurricular physical activity is associated with an increase in the maximum number of correctly performed Sit-Ups in 30 s. There are no similar reports in the literature, hence, it is difficult to compare these data with the results obtained by other authors. Among the few are Arnaoutis et al. [26], who, as a result of research on children and adolescents from Greece, showed a relationship between the frequency of physical activity and the results of the Eurofit test.

Our research found that in both groups, the higher the subjective assessment of physical fitness, the better the results of individual physical fitness tests. Balsalobre et al. [9], in their study on Spanish youth using a self-assessment questionnaire and three Eurofit tests (Sit-and-Reach, Hand Grip, Shuttle Run 10×5 m), indicated positive correlations between the subjective assessment of physical fitness and the results of the Hand Grip and 10×5-m Shuttle Run tests. Furthermore, Mayorga et al. [27], in their research on children aged 10-12, noted relationships between self-assessment and the objective evaluation of physical fitness.

Scientific publications, including our research, indicate the need for activities aimed at promoting a healthy lifestyle, especially in terms of maintaining healthy body mass and height proportions. It is also necessary to popularize rational ways of managing free time and to encourage people to take up extracurricular physical activity. Doing so will allow them to develop appropriate healthy habits that will pay off in adulthood.

Conclusions

1. Over 70% of the women and men surveyed undertook extracurricular physical activity. Sex determines the preferred forms of physical activity and the subjective assessment of physical fitness. Women chose dancing more frequently and considered their physical fitness to be average, while men preferred team sports and assessed their physical fitness as very good.
2. Sex-related differences were found in the results of motor skills tests. Women showed better performance in the Sit-and-Reach test, while men had better results in the Standing Broad Jump, Hand Grip, Sit-Ups, Bent Arm Hang, Shuttle Run, and Endurance Shuttle Run tests.
3. In the group of men, an increase in the BMI value was associated with an increase in the number of falls or loss of balance during the 60s of the Flamingo Balance test and an increase in the time of 10×5-m Shuttle Run, as well as a decrease in the time of the Bent Arm Hang. In women, an increase in the frequency of extracurricular physical activity is associated with an increase in the maximum number of correctly performed Sit-Ups in 30 s. In both groups, the higher the subjective assessment of physical fitness, the better the results of individual physical fitness tests.

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THE RELATIONSHIP BETWEEN ISOKINETIC KNEE FLEXION AND SQUAT JUMP PERFORMANCE

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A. Study design/planning
B. Data collection/entry
C. Data analysis/statistics
D. Data interpretation
E. Preparation of manuscript
F. Literature analysis/search
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Abstract:

Background: Measurement of explosive power of the lower limbs is considered a powerful diagnostic method in the evaluation of the performance of athletes. To date, this issue has not been sufficiently explored. In the theoretical part, we attempted to use the available literature to approach this problem from the point of view of previous authors. The study aimed to verify and determine the existence of relationships between the isokinetic strength of the extensor muscles during the entire period of adolescence in athletes from the Presov club.

Methods: This study was carried out on adolescent athletes (n=21) who competed at the national level in the category of junior age. The average age was 15.3 years, body height was 173 cm, and body weight was 56 kg. Individual jumps (SJ, CMJ, and CMJ FA) were measured using the Optojump system. Isokinetic measurements of peak force and average force were performed using a bilateral version with a special adapter and IsoForce2 device at angular speeds of 50°.s-1, 70°.s-1, 90°.s-1, 125°.s-1, and 155°. s-1. We determined the relationships between individual variables using the Pearson correlation coefficient (r).

Results: Peak force values measured at an angular velocity of 155°.s-1 on Izoforce2 correlated with SJ and CMJ jumps at the significance level set at $p < .05000$. With average force measured on isokinetic equipment, a significant relationship was demonstrated at an angular velocity of 155°.s-1 in SJ, CMJ, and CMJ FA jumps at the significance level of $p < .05000$. The measured average values at an angular velocity of 125°.s-1 were correlated at the significance level of $p < .05000$ only in SJ and CMJ FA jumps.

Conclusion: The results of the study indicated a relationship between vertical jumps and the values of measured on isokinetic devices, which supports the assumption of the importance of these muscle parts for vertical jumps as one of the limiting factors of performance in athletics. Due to the small number of people examined and the high variability of the results in similar studies, we recommend confirming the results in further measurements performed at higher angular velocities of 180°.s-1 to 230°.s-1 in different periods of the athletes' training.

Introduction

The evaluation of athletes' physical performance has its justification for all age levels in every sport. It is used in assessing talents, effectiveness of intervention programs, or work quality control. The objectivity of the diagnostic results depends on the composition of the tests and their properties such as validity and reliability [1]. According to Glatthornet al. and Myung et al. [2,3] verification of the reliability and validity of the Optojump jumping ergometer was based on the results of tracking the high level of reliability of the data obtained during the test and re-test [4]. This points to a negligible measurement error of the Optojump ergometer. From the available studies and findings, one can conclude that the test items aimed at monitoring the vertical jump can be used for the objective assessment and diagnosis of the explosive power of the lower limbs. Comparison of the explosive power of the lower limbs is considered an important diagnostic method of the evaluation of the level of strength performance in athletes. Hespahnol et al. [5] stated that this issue is not yet sufficiently researched [6]. Also, they stated that no study has examined differences in the level of explosive power of the lower limbs in youth categories using vertical jump tests. Adequate technical performance in vertical jumps depends on a complex neuromuscular approach as well as the involvement of individual segments of the body.

When diagnosing and developing explosive strength, one must also take into account the strength component, with its most sensitive period of development from the age of 13 years. Muscular strength is one of the most important components of performance in athletics, whether in terms of performance or injury incidence. During the vertical jump, the extensors of the knee joint (quadriceps muscles) are significantly involved in the movement [7]. The study [8] emphasized that a major role in the vertical jump is played by the quadriceps femoris.

Based on a thorough review of scientific studies, one can state that currently more than 75% of the studies dedicated to isokinetic research are focused on testing the knee area. Furthermore, most dynamometers are designed primarily for testing and rehabilitation of the knee joint [9]. The knee area was tested using a wide range of angular velocities. However, the acceleration and deceleration phases of the movement are also associated with a significant increase in test speeds, and thus the movement changes to essentially isotonic. Therefore, testing at high angular velocities does not seem to yield useful information. The most ideal speed values of are in the range of 60 to 180°.s-1. These speeds are used in many studies and at the same time meet the basic requirements of reproducibility and validity of testing [9]. The relationships between the isokinetic strength of the knee joint extensors and vertical jumps have been addressed by several studies [10-16].

Rouis et al. [15] examined different types of jumps and compared them with different speeds and parameters obtained from isokinetic testing. As part of the methodology, various recording devices and methods were used. The aforementioned study was conducted on both men and women (none during puberty) of various sports such as football, volleyball, basketball, and fire-fighting sports. The authors performed measurements in different periods of training of athletes at different performance levels.

The discrepancy we observed in the previous studies is that the authors performed isokinetic measurements on the dominant and non-dominant limbs (right and left by some authors). The results were correlated with those of squat jump (SJ), countermovement jump (CMJ), and countermovement jump with free arms (CMJ FA), but these were performed in a bilateral version. The most recent meta-analysis [17] stated that unilateral training has a more significant effect on jumping and force quality in unilateral force patterns and that bilateral training has a more significant effect on jumping and force quality in bilateral force patterns. Therefore, we decided to use an adapter in our study to perform the extension on the isokinetic device with both legs at the same time. The results of these studies were also different and inconsistent, so we decided to carry out the measurements in this area. We assumed that all vertical jumps would be correlated with higher angular velocities of 125°.s-1 and 155°.s-1 at the significance level of $p < .05000$. The aim of the study was to find out which angular velocities correlate with three types of vertical jump.

Material and Methods

The monitored group consisted of 21 athletes from the Presov athletics club, who regularly train and participate in all-Slovak athletic events. The anthropometric indicators that characterized the research group are shown in Table 1. The values of were measured using the InBody 720 analyser.

Table 1. Basic anthropometric valuess

EF (n=21)	Decimal age (years)	Body height (cm)	Body weight (kg)	Body fat (%)	Body mass index ($kg.cm^{-2}$)	Skeletal muscle (kg)
Med*SD	15.2±1.14	173±8.4	56±8.1	13.9±5.7	19.7±1.8	25.7±3.9
Min	14	158	47	7.8	16.7	21
Max	18	185	79.4	25	24	36

Note: EF – experimental file, n = frequency, DA – decimal age, Med. – median values, SD – standard deviation, Min – minimum, Max – maximum, cm – centimeter, kg – kilogram, % – percentage.

We evaluated the vertical jump height using the Optojump device. The jumps were performed from one place at a time, not consecutive repeated jumps. For each method of vertical jump, the participant had one practice and two measured attempts, with the better of them counted. After the instruction, the participants stood in the center of the Optojump and performed 3 types of jumps. The first test was SJ, followed by CMJ, and the last was CMF FA. When performing experiments without countermovement, we paid attention to the correct execution. If a countermovement occurred before the rebound, the attempt was invalid and the subject performed it again. Between individual variants of jumps, the participants had at least a 1- minute rest interval. The obtained measurements are given in cm.

About an hour after the vertical jumps, we tested the strength of the quadriceps extensors on the IsoForce2 isokinetic equipment. IsoForce2 is a universal, height-adjustable pulley with a hydraulic concentric piston, which, thanks to its universality, allows performing several movements and muscle strength tests in both isokinetic and isometric modes [12]. The order of the participants was the same as for the jumps. We moved a table to the IsoForce2, which had an adapter fixed in the middle and allowed extension in the knee joint with both legs at the same time. Using a carabiner, we connected the adapter to the pulley, which was at a height of 48 cm from the ground. The table was loaded with counterweights and centered in the center of the pulley. The participant sat on it so that the foreleg formed an angle of 90° with the femur. The participant rested the cylinders of the adapter on the whistle above the instep (Figure 1).

Figure 1. Position of the tested person on Iso+Force2 when testing knee extension

Before the actual testing, all participants tested the resistance of the isokinetic device at an angular velocity of 125°.s-1 and performed 5 to 10 familiarization repetitions. After everyone became familiar with the IsoForce2 device, the testing itself followed. The participant sat on the table, assumed the initial position, firmly grasped the handles with his or her hands, and, without command, tried to perform 5 repetitions with maximum effort with both legs towards the adapter up to full extension in the knee. The first set where the participant performed 5 repetitions was performed at an angular velocity of 50°.s-1. Each repetition in the set was performed at maximum effort from the starting position after a 1-2 second pause. This was followed by a break of 20 seconds, when the angular velocity was adjusted to 70°.s-1 and the participant again performed 5 repetitions at maximum effort. Again, the angular velocity was adjusted to 90°.s-1 for 5 reps, 20-second rest. This was followed by speed adjustment to 125°.s-1, 5 repetitions, 20 seconds break, and then adjusting the speed to 155°.s-1, 5 repetitions, 20 seconds break. We did not perform measurements at a speed of 230°.s-1. After the completion of the measurement of one participant at all angular velocities, the measurement of another followed. IsoForce2 measures peak force (maximum measured force in a given repetition in kg) and average force (average force of a given repetition in kg) that the participant was able to develop in the concentric phase of the movement. These monitored data have significant value in terms of the evaluation of performance for sports and rehabilitation. At individual speeds, we calculated the average value from 5 repetitions from both the peak force and average force values. We converted this reasonable value to relative strength so that heavier participants, who achieved higher values in kilograms in this test, were not favored.

We recorded the data obtained by measurement in tables (Tables 2 and 3). The results provided a more detailed look at the level of monitored parameters of the athletes' strength performance. We subjected the data obtained during the testing of the research files to a logical and objective analysis, then they were statistically processed and evaluated. When choosing descriptive basic statistics, we used median, minimum, maximum, and quartile range values. Based on the methods of mathematical statistics, we used the Spearman correlation coefficient to determine the significance of the differences in the relationships between the parameters measured using the jumping ergometer and the isokinetic strength of the knee flexors. We evaluated the statistical significance level ($p<0.05$).

Results

Jumps are among the basic forms of locomotion that should be mastered already in lower age categories. Table 2 shows the heights of vertical jumps in individual test items of the monitored set. The basis of the evaluation for athletics is the performance in the CMJ test. The SJ test is performed to detect possible deficits in the strength of the flexors and extensors of the knee joint. We recorded the highest achieved values of in the SJ test and, therefore, expected it to be most correlated with the isokinetic knee extension test. In the SJ test, the participants reached an average of 18.6% higher jump than in the CMJ test. Higher values of should be achieved in the CMJ test, and the difference between SJ and CMJ shows the ability to effectively use the elasticity of the muscle-tendon apparatus. The CMJ FA test indicates the coordination of movement when involving the upper limbs. The difference between CMJ and CMJ FA points to the ability to properly time and engage the arm work. In these tests, the difference was only 2.4% in favor of the CMJ FA test (see Table 2). Previous experience with the CMJ FA test can have a positive effect on the test result. For some participants, the technique was not sufficiently mastered because it was their first testing and at the same time, they were young athletes. In subsequent measurements, we expect that this difference may increase in favor of the CMJ FA test

Table 2. Multivariate linear regression analysis of test results of the effect of chronotype variables on Mental Toughness and Sleep Behaviors variables

	Wertical jump height (cm)		
	SJ	**CMJ**	**CMJ FA**
Med±SD	34.9 ±4.4	28.5 ±3.7	29,2±3.19
Min	26.4	21.2	22.1
Max	42.8	35.3	33.7

Note: SJ – squat jump, CMJ – contermovement jump, CMJFA – cauntermovement jump with free arms, cm – centimeter, Med. – median values, SD – standard deviation, Min – minimum, Max – maximum.

Since IsoForce2 allows measurements of the average and peak force developed by the participant during a given movement in the concentration phase, we aimed to find out what angular velocities would correlate with jumps. We also determined whether peak or reasonable values of would be more correlated. Based on the biomechanics of the movement and the muscles involved, we expected a strong correlation between SJ and knee joint extension. Both movements have an initial position of 90° in the knee joint, the main muscles involved are m. quadriceps femoris (knee extension), and are performed from a resting position. Therefore, it is not possible to use the elasticity of the muscle- tendon apparatus as in CMJ and CMH FA.

Table 3 shows the average value of 5 measurements of the peak force and the average force measured when testing the strength of the quadriceps extensors using IsoForce2 in a group of female athletes. We recalculated values of to relative strength so that heavier participants, who achieved higher values of in kilograms in this test were not favored.

Table 3. Multivariate linear regression analysis of test results of the effect of chronotype variables on Mental Toughness and Sleep Behaviors variables

	Average peak force values after conversion to rerelative force at different angular velocities (kg)				
	50°.s^{-1}	70°.s^{-1}	90°.s^{-1}	125°.s-^{1}	155°.s^{-1}
MED±SD	0,67±0.08	0.53±0.07	0.56±0.08	0.52±0.06	0.50±0.06
MIN	0.51	0.46	0.40	0.36	0.35
MAX	0.84	0.73	0.67	0.64	0.58
	Average peak force values after conversion to rerelative force at different angular velocities (kg)				
	50°.s^{-1} max	70°.s^{-1} max	90°.s^{-1} max	125°.s^{-1} max	155°.s^{-1} max
MED±SD	0.47±0,07	0.40±0.05	o^e±o.05	0.35*0.05	0.33±0.04
MIN	0.30	0.31	0.28	0.26	0.24
MAX	0.59	0.51	0.48	0.47	0.41

Note: cm – centimeter, Med. – median, SD – standard deviation, Min – minimum, Max – maximum, s^{-1} – angular velocity

Table 4 illustrates that no significant correlation was observed between vertical jump performance at lower angular velocities (50°.s⁻¹, 70°.s⁻¹, and 90°.s⁻¹) and either peak or average force values. At an angular velocity of 125°.s⁻¹, there was no significant correlation with peak force; however, a statistically significant correlation was found for average force in both CMJ FA and SJ jump types ($p < .05000$). The lack of correlation with CMJ jump results is unexplained, as the CMJ and CMJ FA values were notably similar.

Table 4. Correlation matrix of vertical jumps and different angular velocities

Jumps	Peak force values at angular velocities				
	$50°.s^{-1}$	$70°.s^{-1}$	$90°.s^{-1}$	$125°. s^{-1}$	$155°.s^{-1}$
CMJ	0.233147	0.243S93	0.377283	0.422117	0.49S9S1*
CMJ FA	0.244513	0.204173	0.395192	0.425S19	0.415177
SJ	0.216473	0.177223	0.3S7386	0.403 74S	0.4517S5*
	Yalues or average force at angular velocities				
	$50°.s^{-1}$	$70°.s^{-1}$	$90°.s^{-1}$	$125°.s^{-1}$	$155°.s^{-1}$
CMJ	0.245239	0.231264	0.321610	0.408476	0.530110*
CM HA	0.326931	0.281217	0.390875	0.455574*	0524339*
SJ	0.321234	0.307852	0.399217	0.496370*	0.572459*

Note: SJ – squat jump, CMJ – countermovement jump, CMJFA – countermovement jump with free arms, cm – centimeter, s^{-1} – angular velocity. Correlations marked* are significant at the $p < .05000$ sianificance level.

Discussion

The results show that the highest values of were obtained at low angular velocities whereas the lowest values - at the highest angular velocities. We assumed that higher values of of the peak force and the average force would be correlated with vertical jumps, and the results of some studies indicated a possible connection. The study of volleyball players [11] concluded that a significant positive correlation ($r = 0.817$, $p<0.05$) occurs between the jump height and the maximum muscle torque of the right knee at a low angular velocity of 60°.s-1. The authors explained this by the fact that the quadriceps femoris muscle is important in the jumps often performed by volleyball players. The study [10] also presented similar results for soccer players. Significant correlations with the jump height were found only for the strength of the knee extensors at an angular velocity of 60°.s-1 in both the dominant and non-dominant limbs ($p<0.05$). The author therefore recommends taking into account the decisive role of the muscle strength of the knee extensors during vertical jumps.

As was presented in Table 4, our results did not show any correlation of vertical jumps at low angular velocities of 50°.s-1.70°.s-1.90°.s-1 with peak force or with average force values. The authors of the study [18] also stated that there is no relationship between the maximum performance of the knee joint during the vertical jump and low-speed isokinetic tests.

Moreover, in our experiment no positive correlation at the level of significance was found between jump and peak force measured at an angular velocity of 125°.s-1. However, at this speed, we recorded statistically significant correlations at the significance level of $p < .05000$ for average force in CMJ FA and SJ jumps (see Table 4). We cannot explain why the results did not correlate with the CMJ jump, since the CMJ and CMJ FA values of were very close.

Peak force values measured at an angular velocity of 155°.s-1 on Izoforce2 correlated with SJ and CMJ jumps at the significance level of $p < .05000$ but did not correlate with CMJ FA jump. In the average force measured using the isokinetic equipment, a significant relationship was demonstrated at an angular velocity of 155°.s-1 for all jumps at the significance level of $p < .05000$. Similar results were documented by [15] in 17-year-old elite basketball players. The study found significant correlation coefficients at speeds ranging from 180°.s-1 to 300°.s-1. The highest correlation was found at 240°.s-1. These results were consistent with previous studies [16,19,20] which also observed significant correlations between isokinetic knee extensor strength and vertical jump height only for angular velocities equal to or greater than 180°.s-1. These results suggest that the angular velocity at which peak torque is produced is a key component in determining the strength-height relationship between the vertical jump and isokinetic knee extension. A study of soccer players up to 17 years of age [13] showed that the significance of the results of measuring the isokinetic force of knee extension to determine jumping ability changes throughout the annual training cycle and measurements at angular velocities of 180°.s-1 and higher should be preferred in these measurements.

Conclusions

Peak force measured at an angular velocity of 155°.s-1 using Isoforce2 device were correlated with SJ and CMJ jumps at the significance level of $p < .05000$. With the average force measured using the isokinetic device, a significant relationship was demonstrated at an angular velocity of 155°.s-1 in SJ, CMJ, and CMJ FA jumps at the significance level of $p < .05000$. The average values of measured at an angular velocity of 125°.s-1 were correlated at the significance level of $p < .05000$ only in SJ and CMJ FA jumps. Our results suggest a similar neuromuscular basis for the production of muscle force at high angular velocities as that of most authors who have dealt with the issue. We intend to conduct further testing of the same group of athletes in a different training period and also include an angular speed of 180°.s-1 - 230°.s-1. Based on our findings, we recommend stimulating the speed-power abilities of young athletes with specific stimuli at high speeds with non-maximal resistance.

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Data Availability Statement: All data are presented in the study.

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TRAINING LOADS IN THE STARTING PERIOD OF SPORTS DANCERS IN LATIN AMERICAN STYLE

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A. Study design/planning
B. Data collection/entry
C. Data analysis/statistics
D. Data interpretation
E. Preparation of manuscript
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Abstract:

Background: Undoubtedly, in all areas of physical culture, dance has an extremely positive impact on the formation of virtually all motor skills - conditioning, coordination, also affects agility, speed and flexibility. The aim of this study was to evaluate the level of training loads in a six-week mesocycle during the starting period of athletes of Latin American style sport ballroom dancing and to study the effect of training loads on body fat and energy expenditure.

Methods: The study group consisted of 4 sport-active dance couples with about 12 years of experience. Sport-testers (POLAR H7) were used to evaluate training loads. training logs and a body composition analyzer. Results were compared between men and women.

Results: The men's group showed higher values of the following training indicators: average training time, energy expenditure, average heart rate. Statistically significant differences between male and female dancers showed such factors as average energy expenditure, average percentage of work in the fifth zone of exercise intensity - in favor of men while average percentage of fat burned - in favor of women.

Conclusion: Based on the analysis of energy expenditure and with regard to the classification of work severity, the dancers performed heavy and very heavy work during the competition period, and spent the vast majority of their preparation time in aerobic zones. Accordingly, coaches of Latin American dancers in their own work did not take into account the specific physiological workloads performed by them during dance competitions.

Introduction

The main element of dance is the dancer's body movement: it can be more or less coordinated, faster or slower, but always purposeful. The second element of dance is rhythm. Undoubtedly, in all areas of physical culture, dance has a positive effect on the formation of virtually all motor skills - conditioning (strength, endurance), coordination (in particular, rhythmic movement, balance, spatial orientation, coupling of movements and motor adaptation), as well as agility, speed and flexibility. Dance also improves functional movement and the quality of movement execution. The aesthetics of dance depend not only on the type of movements performed, but also on their tempo and speed variation, where fast and more predictable sequences are judged to be more effortful, less repetitive and more aesthetic than slower, uniform movements. Aesthetics of movements can be universal and influence preferences and perceived difficulty of a dance, according to information theory and effort heuristics in aesthetic evaluation.

As an element of kinesitherapy or choreotherapy, dance plays an important role in the field of rehabilitation, counteracts the aging processes of the body, including aging of the brain, which is confirmed by scientific studies carried out on different continents [1-3]. A properly structured dance intervention can be a safe and effective exercise that can be incorporated into daily life, and regular dancing significantly improves mobility and endurance in older adults, thus contributing to their quality of life. Different styles of dance can also have a positive impact on the functional and metabolic health of the elderly, particularly improving balance [4,5].

In addition, there are studies indicating that dance has a greater effect on brain volume in older adults than traditional aerobic and strength training. Long-term dance programs increase volume in brain regions associated with higher cognitive processes, suggesting that dance, by promoting a variety of processes, is an effective means of counteracting age-related declines in brain structure [6].

Dancing, as a form of activity, has a very good effect on the central nervous system, the formation of correct motor habits and easier memorization as evidenced by the fact that there is evidence showing that dancers are better at encoding effort information due to their learned visuomotor skills, involving fewer cognitive resources than people who have no dance experience [7]. Studies on the effects of dance practice on physical fitness have revealed that dance significantly improves both aerobic and anaerobic capacity, leading to an increase in VO2 max and lactic acid tolerance. Intense and varied dance training can be an effective tool in improving overall fitness and endurance, which has important implications for training programs for both dancers and those involved in other sports.

Practical implications also arise from the need to integrate strength and flexibility exercises with dance programs to optimize results and minimize the risk of injury [8].

When observing the competition of sports dancers, one can easily see aspects of the dancers' visual preparation and choreography. It is much more difficult to see and assess how much physical and training stress accompanies dancers during sports competition and preparation. According to the definition, training loads are the type and amount of work an athlete has done in a given exercise, training unit or cycle [9].

The basic components of exercise loads are their volume and intensity. In the author's own work, an attempt was made to determine trends of conduct in planning training volumes and their intensity in adjustment to the nature of dancers' work at competitions. When aiming to create a structured training plan, it is necessary to consider a set of sport-specific, sport-defining physical, mental and social characteristics. It is also necessary to carefully examine what type of effort the athlete's body must be adapted to in adaptation to the work generated during competition in relation to bioenergetics, and furthermore to know the answer to the question of which muscle fibers predominate during its performance. It is necessary to assess whether the exercise activity will be based on aerobic or anaerobic or mixed metabolism, and it is also necessary to assess whether these are long-term aerobic or short-term anaerobic efforts.

Given the authors' consideration of the intensity of physical exertion during sports dance, defined as very high training loads, and that a combination of training and non-training factors contribute to perceived exertion during dance training, it is necessary to examine the intensity of exertion of Latin American style sports dancers in order not only to determine it, but also to find practical implications for the possibility of creating training programs [10].

The aim of this study was to determine the level of training load in a six- week mesocycle, during the starting period of athletes of Latin American style sport ballroom dancing, holding the "S" dance class, i.e., the International Master Class, based on the evaluation of training load indicators, i.e., time training volume, heart rate, and to study its impact on energy expenditure and the level of fat burned.

Material and Methods

Study group

The study material consisted of 4 dance couples, active in sports with about 12 years of experience. The subjects actively participate in competitions and national and international tournaments. The athletes included in the study were qualified for the program after prior consultation with a physician. During the project, the subjects did not take any pharmacological agents that could affect the level of physical performance, biochemical indicators, and did not follow any special diets. The study initially included 20 dancers with the "S" master class in Latin American style. During the 6-week study, the dancers were asked to record each dance training session. In connection with the above, 4 couples were not included in the study due to the lack of a register of some training units. In addition, 2 couples did not qualify for the Polish Latin American Dance Championships, so they were also excluded from the study group. Finally, 8 dancers (4 dance couples) were included in the study. An example was shown in Figure 1.

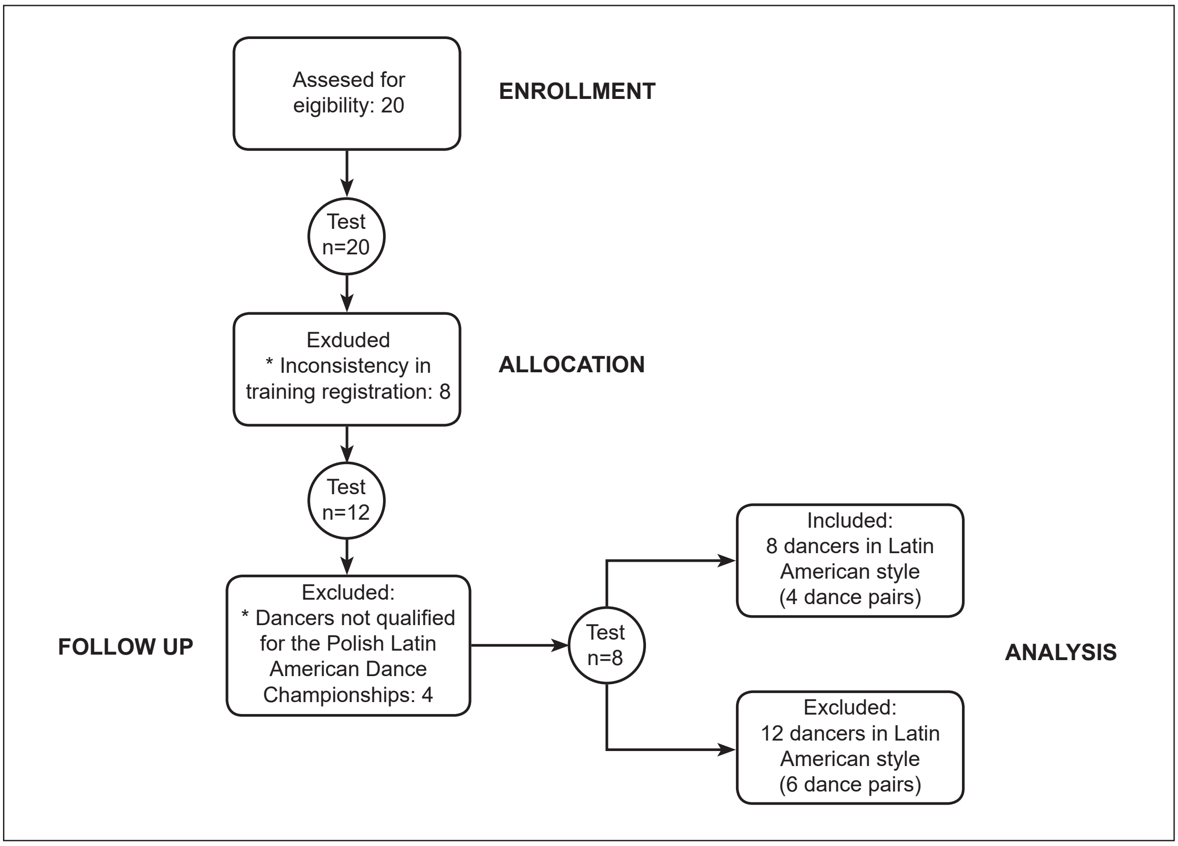


Figure 1. Dancers flow diagram

Purpose of the study

The aim of the study was to determine the level of training load in a six-week mesocycle during the competition period of Latin American style ballroom dance competitors with dance class "S", i.e. International Master Class.

Study project and research tools

Participation in the research project was voluntary, and written consent was an absolute condition of participation. The athletes were informed that they could withdraw from the study immediately, at any time. The study was conducted in accordance with the Declaration of Helsinki. Approval for this project was obtained from the Bioethics Committee at the District Medical Chamber in Krakow (approval number 100/KBL/OIL/2015, date: 3 July 2015).

The group was characterized by comparing dance class, seniority and the following anthropometric factors: age, height, weight, lean body mass (LBM), body fat (PBF) and total body water (TBW), and Body Mass Index (BMI). Body composition analysis was also performed using a JAWON body composition analyzer, model IOI-353 (Jawon Medical Co., South Korea), which directly calculated the percentage of body fat in the subject using the electrical bioimpedance method. Anthropometric characteristics are presented in Table 1.

All workouts were closely monitored using research tools - POLAR H7 sport-testers (Manufacturer-Polar Electro, Kempele Finland) and special POLAR Flow software and workout logs. An example was shown in Figure 2.

Table 1. Basic characteristics of dancers

	Men	Women
Age (years]	20.50±2.65	19.75±1.50
Body height [cm|	185.75±2.99	161.5±2.08
Body mass (kg)	74.8±8.07	52.9±4.76
Fat mass |kg]	7.00±1.35	11.83±2.33
Lean body mass [kg]	67.8±8.16	41.08±2.50
BMI	22.1±2.03	20.23±1.58
Training seniority [years]	11.75±1.71	11.25±4.24
Sports class	S	S

Results are presented as mean values ± standard deviation. For the sports class, the median value is given.

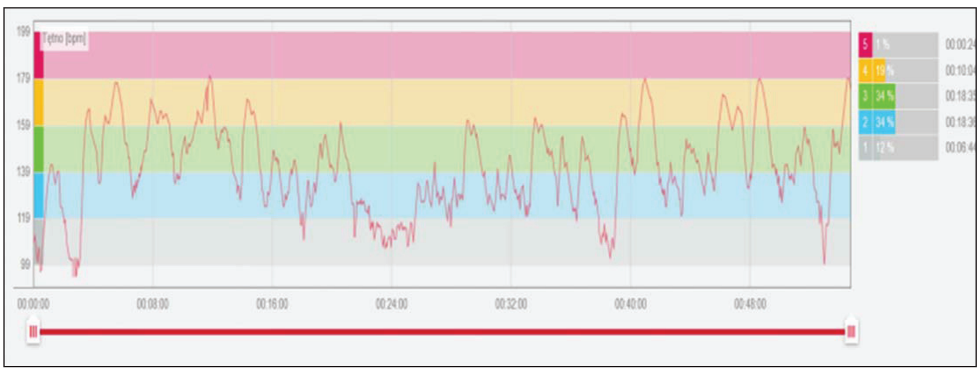


Figure 2. Example of heart rate zone recording

The dancers recorded the following training indicators using the app and measuring strips: training time, energy expenditure [kcal], average heart rate [Hrav], maximum heart rate [Hrmax], percentage of fat burned, and percentage of time worked in the respective exercise intensity zones. The characteristics of specific exercise intensity zones are provided in Table 2.

Table 2. Characteristics of oxygen zones

	HR (beats per minute)	Intensity	Time [minutes]	Transition zone
1	< 130-140	Very small	> 180	Aerabic-maintenance
2	160-180	Moderate	5-180	Aerobic
3	≥ 180	Large	≤ 5	Aerobic-anaerobic
4	≥ 190	Submaximal	0.33-2	Anaerobic (lactic-mtiediated)
5	130-180	Maximal	0.33	Anaerobic (nonlactic-mediated)

Statistical analysis

For characterization, we used the classical statistical measure of clustering of results-the arithmetic mean and the measure of variability-the standard deviation. In the next step, the type of distribution of the variables was examined (Shapiro-Walk test). The non-parametric Mann-Whitney U test was used to determine the statistical significance of differences between the results of the average time of training load, average energy expenditure, average percentage of fat tissue burned in the groups of women (dancers) and men (dancers) and the average percentage of dancer's training time in exercise intensity zones. The results were considered significant at $p<0.05$. Statistical analysis was performed using Statistica 10.0 (SoftStat, Poland).

Statistically significant results were found in the case of: statistical analysis of average energy expenditure (p=0.031), average percentage of fat tissue burned (p=0.029) and training time in the fifth aerobic zone (p=0.030).

Results

The time average of the training unit during the immediate start preparation period of Latin American dancers in the male group was 01:15:13 (Q1 01:10:13, Q3 01:20:14, median 01:17:18) and in the female group was 00:58:10 (Q1 00:52:21, Q3 01:04:00, median 00:54:58), while the weekly time average of training loads in the men's group was 09:39:30 (Q1 09:04:31, Q3 10:14:30 median 10:01:36) in the women's group 08:16:11 (Q1 06:36:20, Q3 07:56:03, median 07:18:56). The data obtained were not statistically significantly different.

The average energy expenditure of male Latin dancers was 853.625 kcal, which was higher than in the group of female Latin dancers, for whom it was 561 kcal per training unit, while the weekly average energy expenditure during the starting period of Latin dancers in the group of male dancers was 6594 kcal, respectively, which was higher than in the group of female dancers, whose average energy expenditure was 4239.2 kcal. These data are shown in Figure 3. Statistical analysis indicated that the results of men and women differed significantly (p=0.0303) with significantly higher results for men.

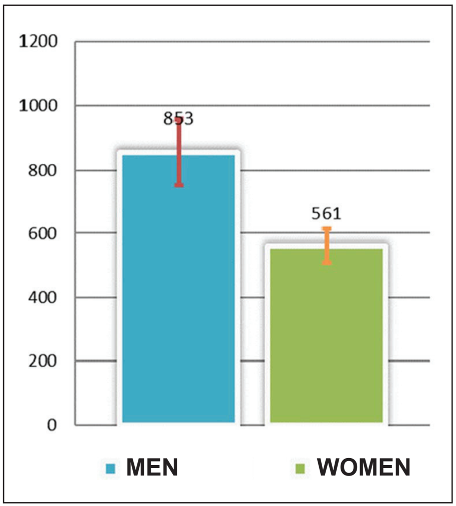
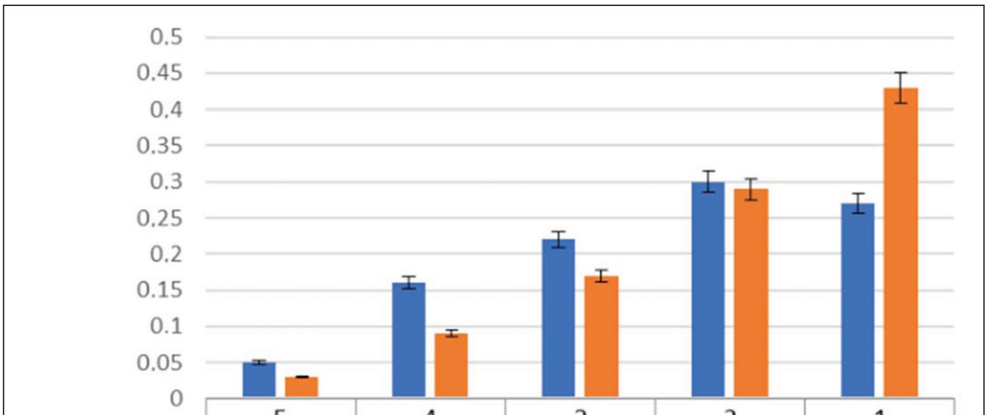


Figure 3. Average values of energy expenditure during the starting period of Latin American dancers in a group of men and women

The mean percentage body fat burned by Latin American dancers during the six-week start period in men is 25.00%, and was significantly lower than in women, for whom the mean value was 40.25% (p=0.0284).

The value of the mean minute heart rate (HR) in the men's group was 128 beats per minute, while in the women's group it was 120 bpm. Statistical analysis found no significant differences between the male and female groups.

The average percentage of work time in the fifth heart rate zone in the men's group was 5%, and in the women's group: 3%. The corresponding figure for the fourth zone was 16% in men and 9% in women. Analyzing the third heart rate zone, in men the average time volume was 22%, while in women it was 17%. Then in zone two in the men's group the average was 30%, in the women's group 29%. Finally, the average percentage of time in zone one in men was 27%, while in women it was 43%. The data is shown in Figure 4.



	5	4	3	2	1
MEN	5.00%	16.00%	22.00%	30.00%	27.00%
WOMEN	3.00%	9.00%	17.00%	29.00%	43.00%

Figure 4. Mean percentage time of the intensity zones of effort in which Latin American dancers exercised during the start period in the male and female groups

Statistical analysis of the results of the study showed statistical significance for the evaluation of: average energy expenditure in the male and female groups, average percent body fat burned, and the evaluation of the average percent work time of male and female athletes in the exercise intensity zones-significant differences were found in the work time in the 5th exercise intensity zone ($p=0.0303$).

Discussion

The results of the physiological indices, especially energy expenditure, allow to conclude that sports dancers, in terms of fitness, must match and often exceed the exercise capacity of athletes of many disciplines. Previous studies of dancers, including under conditions of simulated competition, clearly indicate that this type of activity should be classified as heavy or extremely heavy exertion, characterized by a significant increase in physiological indices (HR-frequency of heart contractions per minute, VO2 max-oxygen ceiling, La-concentration of lactates) during and after exercise [11-13]. Such observations were also confirmed in present study.

In an analysis of the physiological indices obtained in the study, it was indicated that Latin-style dance couples exerted a much higher effort in terms of energy expenditure than recreational ballroom dancers, whose results were presented, among others, in the work of Lankford et al. [13] In addition, Latin- style dancers achieved much lower values of average minute heart rate than the Italian Latin-style dance couples studied in the work of Bria et al. [14]. Similarly, much higher values of heart rate were obtained in their study of dancers by Livv and Wyon [15]. In addition, the obtained results of energy expenditure during the dancers' training allow us to conclude that, for both men and women, the effort involved in sports dance is very heavy. The above observations indicate that such large differences in physiological indices, especially the average minute heart rate, may be due to poor preparation of dancers in the mesocycle during the immediate preparatory period for participation in sports competitions. In their own work, the dancers trained mainly in the first and second zones of exercise intensity devoting too little time to the formation of mixed and anaerobic capacities. It is noteworthy that during competition dancers exert effort mainly in the anaerobic and mixed zones, so during the mesocycle in the period of direct competition preparation (BPS), athletes should work at an intensity level close to the physiological loads at competition during training. The study also reveals the relationship of some of the dancers' anthropometric indices, such as body mass, body fat, lean body mass and BMI in the subjects with the work they do during training in the respective exercise intensity zones. Female dancers burned a percentage more fat than male dancers during training, indicating the energy sources used during exercise. The higher energy expenditure of the partners in the dance couple may have been related to their greater involvement in performing the choreography in the dance or to the higher level of training and adaptation to the effort of their female partners.

The present study focuses on the intensity of training among Latin American dancers during their preparatory period for championships, similar to other research exploring various aspects of dance training. Examining other studies revealed several similarities. First, all studies aim to assess the intensity of training and its impact on the physical fitness and body composition of dancers. In the article by Mu et al. [16]., the aerobic capacity of dancers in the Ukrainia sports dance team was investigated, while Brown et al.[17] examined the impact of training on body composition and dietary habits of contemporary dance students. Furthermore, in the article by Aguiñaga et al.[18], the effect of regular participation in dance classes on the physical health of older adults with mild cognitive impairment was studied. These diverse research perspectives emphasize understanding different aspects of dance training.

Another similarity is the use of various methods to assess training. The present study relies on monitoring training parameters such as training time, energy expenditure, and the percentage of time spent in different intensity zones. Similarly, the articles by Surgeon et al.[19] utilized heart rate measurements and subjective effort assessments, while Sanders et al. [20] used heart rate monitors. The use of diverse measurement methods allows for a comprehensive understanding of training load.

It is also worth noting that all studies highlight the need for further research in this field. The conclusions of the present study suggest that Latin American dancers should spend more time training in mixed and anaerobic zones, which may be crucial for maintaining fitness. Similarly, the study by Surgeon et al.[19] indicates the need for further research on the accuracy of training load assessment in different dance styles, while the study by Aguiñaga et al.[18] suggests that further research could confirm the benefits of dance programs for older adults with cognitive impairments.

These conclusions emphasize the importance of continuing research to better understand the impact of dance training on physical fitness, body composition, and overall health of dancers across different age groups, dance styles, and skill levels. Integrating various measurement methods and analyzing diverse populations of dancers can lead to better-tailored training programs to individual needs and goals, which in turn can contribute to improved athletic performance and overall health of dancers.

Taking into account the above considerations, on the basis of the analysis of our own research, it can be concluded that coaches working with the studied S- champion class athletes in their training plans did not take into account the specificity of physiological exercise loads accompanying sports dance athletes during dance competitions. Confirmation of the above observations can be seen in the low achievements of the group of dancers studied at the competitions crowning the analyzed BPS.

However, it is worth remembering that this method also has its limitations, such as the possibility of measurement errors during training related to the mismatch between the heart rate sensor (pulse oximeter) and the skin of the chest moreover measurements of oxygen zones are averaged values calculated on the basis of basic physiological parameters, while to determine them accurately one would have to perform spirometric measurements and biochemical parameters assessing the effort of exercise.

Conclusions

The surveyed dancers, in preparation for the competition, trained mainly in aerobic zones, achieving very low values of the average minute heart rate (HR). Dancers should work more time in mixed and anaerobic zones during training, especially during the period of maintaining form. Based on the analysis of energy expenditure and in relation to the classification of work severity, the dancers performed heavy and very heavy work during the starting period. The energy expenditure of men during dancing was higher than that of women. During the mesocycle, the average minute heart rate of the male dancers was higher than that of the female dancers. Female dancers on average worked significantly longer in the aerobic (first) zone than male dancers. They also burned percent more body fat than the men.

Based on the study's findings, it is recommended that coaches of Latin American-style competitive dancers include short, high-intensity efforts targeting both mixed and anaerobic zones in their training programs. This approach is consistent with the physiological specificity of physical exertion that dancers encounter during competition

Practical implications

The results of this study can be taken into consideration by coaches, health professionals, and researchers who want to improve the performance of athletes. Athletes can use these findings to optimize their performance by understanding their sleep behaviors and chronotypes. Healthcare professionals can evaluate the information in this research to improve athletes' sleep quality and support their performance. Researchers can benefit from the results of this study to better understand the factors affecting the mental endurance of athletes and develop new strategies.

Conflict of Interest: Author declares that there is no conflict of interest.

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Institutional Review Board Statement: The research was approved by the Bioethics Committee at the District Medical Chamber in Krakow (approval number 100/KBL/OIL/2015, date: 3 July 2015).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data presented in this study are available on request from Wojciech Kupczak.

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EFFECT OF FOREARM COMPRESSION SLEEVES ON THE EXERCISE PERFORMANCE OF SPORT CLIMBERS

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Authors' contribution:

A. Study design/planning
B. Data collection/entry
C. Data analysis/statistics
D. Data interpretation
E. Preparation of manuscript
F. Literature analysis/search
G. Funds collection

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Abstract:

Background: Compression garments, i.e. elastic garments with an engineered compression gradient, are widely used in rehabilitation and sport. It is used in sport to improve performance and reduce discomfort during exercise and lower the risk of injury. However, the question of the actual effectiveness of this type of support is controversial, and there is little research in the field of sport climbing, The aim of this study was to investigate the effect of forearm compression garments on the performance of climbing-specific exercises.

Methods: Eleven elite climbers (35.9±7.8 years, 177.7±7.1 cm and 70.3±7.9 kg, IRCRA climbing level 24.6±1.9) took part in a placebo-controlled cross-over design study. The climbers used compression or placebo sleeves, while performing two trials: an intermittent campus board exercise ('reaches') and a traverse climb. During the trials, the number of repetitions and, during the campus board trial, maximum and average power were recorded. Power measurements were taken using a Gyko inertial sensor.

Results: Under compression, statistically significant differences were only observed for the subjective sensation of forearm 'pump' on the campus board trial ($p=0.007$, $ES=0.64$). In the placebo condition, the total number of "reaches" on the campus board, as well as the number of interceptions and time spent on the traverse were statistically significantly lower compared to baseline (respectively, $p=0.032$, $ES=0.74$; p=0. 025, $ES=0.49$ and $p=0.013$, $ES=0.64$).

Conclusion: For elite climbers performing specific climbing activities, forearm compression doesn't significantly improve their performance compared to baseline, but it can prevent it from deteriorating to some extent.

Introduction

The term 'compression garment' refers to pieces of clothing that are smaller in size than the body parts they are worn on. These garments are usually worn on limbs or parts of limbs. Compression garments have been widely adopted for use in a variety of sporting contexts, especially in endurance events [1-4], although the potential benefits of compression on shorter-duration, high-intensity efforts, such as strength, power or speed, have also been suggested [5-8].

There are many reasons why the use of compression can be useful for athletes, at least in theory. These reasons include mechanisms such as preventing DOMS [6,9], improving running economy [10], enhancing somatosensory perception [11], improving proprioception and lowering levels of soft tissue vibrations [12], enhancing peripheral circulation, venous return and blood flow velocity [13], lowering energetic cost of effort [14], reducing perceived exertion of exercise [15]. These mechanisms represent only a portion of the proposed benefits in this area which have been discussed in more detail in several reviews [1,16-19].

The issue of the actual and potential impact of compression on improving operational efficiency, regeneration rate, and injury prevention is debatable, considering the results of research conducted so far. While some confirmed the positive effect of compression on specific parameters, others showed none or almost none. Drawing clear conclusions is difficult due to the large dispersion of research results regarding which support mechanisms were evaluated or which body parts were compressed. The review of Weakley et al. [20] shows that more than 80% (n=175) of studies published in 2010-2020 were devoted to the assessment of the impact of compression of the lower limbs, which is understandable, taking into account, that a broad spectrum of activities, both in sport and recreation, is based on the motor activities of running and jumping (athletic runs, team games, etc.). However, some forms of activity are characterized by high involvement of the upper limbs, whose strength or local endurance are the factors determining the efficiency of the player's operation. Sports climbing is one such activity. Although this sport engages the whole body and almost all muscle groups, the factor that most often forces the climber to stop the activity (resulting in falling off the wall) is the inability to generate an adequate level of strength or power in the muscles of the upper limbs, especially the forearms.

It is difficult to establish a precise hierarchy of motor skills that determine success in climbing in view of the great variety of climbing sub-disciplines: from short bouldering problems to climbing routes of several metres or several tens of metres. Due to the nature of the challenges to the climber's body, they may require strength, explosive strength, power, power endurance, muscular endurance etc. Even in narrowly defined sport climbing, i.e. climbing that involves direct competition among athletes following written rules and being controlled by judges, there are three competitions with different motor and physiological requirements: bouldering, speed climbing and lead. But the common denominator of all of them is a significant load on the upper limbs [21-25]. Identifying factors that support the efficiency of arm muscles is an appropriate course of action in this situation. The question then arises whether such support could not be provided by compression garments? However, there is little research on the use of compression in the upper extremities. Weakley et al. in their review [20] cite only 19 studies that evaluated the effects of shoulder compression, which, according to the authors, makes the knowledge of the effects of compression on these body parts much more modest compared to the lower limbs. Against this background, the data on climbing are even more modest, because according to the best knowledge of the authors, so far only two studies have been conducted on this subject, in which the reactions of the circulatory system and lactate were assessed along with perceived exertion and forearm muscle pain [26] and handgrip strength and endurance [27]. Thus, given the scarcity of information on the effect of wearing compression garments during climbing, this study aimed to investigate the effects of forearm compression on repeated-effort and continuous climbing exercises.

Material and Methods

Participants

A total of 11 elite climbers were recruited for this study. To calculate the sample size, statistical software (G*Power, Dusseldorf, Germany) was used. Given for t-test for paired samples, a large overall effect size of 0.9, an alpha-error < 0.05, and the desired power (1-ß error) of 0.8, the total sample size resulted in 10 participants. Their average age, height, and weight were 35,9±7,8 years, 177,7±7,1 cm, and 70,3±7,9 kg, respectively. athletes with an average training experience of 18.6±7.5 years and a climbing level expressed by the difficulty of the most difficult rock routes (max RP) of 8a+ to 8c or, when converted to the IRCRA (International Rock Climbing Research Association) scale, an average of 24.6±1.9. More detailed characteristics of the participants are presented in Table 1. All participants gave their consent to engage in all testing procedures.

Table 1. Characteristics of participants

Variable	Mean±SD	Median	CI±95%
Age (yrs)	35.91±7.82	34.00	30.66-41.16
Height (cm)	177.73±7.07	178.00	172.98-182.48
Weight (kg)	70.27±7.88	67.50	64.98-75.57
Training experience (yrs)	18.55±7.54	19.00	13.48-23.61
IRCRA level	24.64±1.86	25.00	23.39-25.89
Weekly volume (hrs)	7.00±1.48	7.50	6.00-8.00

Methods

Instruments

VERTICS compression sleeves (Vertics, Wiesbaden. Germany) were used to induce forearm compression. Vertics are made in 75% from polyamide and in 25% from elastane, using two different knitting patterns with different compression properties and decreasing compression from the wrist to the elbow. i.e. in the direction of the pump towards the heart. The size of the sleeves was adjusted individually for each patient according to the manufacturer's instructions.

The Gyko inertial sensor system (Microgate. Bolzano. Italy) was used to record the power (W) generated when performing campus board reaches. It contains a three-dimensional accelerometer (range: ± 2 G). a gyroscope (250°/s-25.000°/s) and a magnetometer (range: ± 4800 μT). It provides recordings at a sampling frequency of 1 kHz. Participants had the Gyko sensor (dimensions: $53 \times 51 \times 23$ mm. mass: 46 g) attached on the upper back of participants using an elastic belt provided by the manufacturer. During measurements the signals were transferred via a Bluetooth 4.0 to the Lenovo PC with the RePower software installed. following the criteria described by the manufacturer.

Procedures

A crossover design was used with all subjects performing trials with compression and non-compression (placebo) sleeves. In both conditions. trials were completed twice – the first trial performed without sleeves (baseline) and the second trial while wearing the sleeves – with 15 minutes' rest between. Between the days of the trial sessions. each participant had a week off. during which they followed their planned training program.

The trial sessions began with a 15-minute warm-up on the bouldering walls following the scheme that the subjects usually use in their training. including an exercise on the campus board. Additionally, at the end of the warm-up. the subjects were familiarized with the traverse. which was the second exercise test. After a 15-minute rest, the subjects proceeded to the actual exercise tests:

1. High-intensity intermittent upper body performance — This test was carried out on a campus board, where the test subjects performed an exercise referred to as 'touches' or 'reaches'. The participant begins the exercise by hanging with both hands on straight arms on the lower rung. then performs a dynamic pull-up. At the peak of the pull-up, he or she lets go of the bar with one hand and reaches for the rung at a height close to his or her full reach. The height of the rung to be reached by the test subjects was predetermined by arm reach and marked with chalk. After touching the marked level. the participant lowered back down to catch the starting rung and repeated the process with the other hand. The rung from which the test subjects performed the pull-ups was made of wood. was 2.5 cm deep. and had a profile that allowed the fingers to bend ('positive' or 'jug-type'). The test subjects' task was to perform as many "reaches" as possible in five cycles of 10 seconds of work followed by 10 seconds of rest. During rests. participants were allowed to dry their hands with their preferred chalk (magnesium carbonate) to ensure friction between the hands and the rung.

2. Bouldering traverse: A series of 14 incut edges were bolted to an approximately 30° overhanging wall. forming a traverse with a difficulty of approximately 6C+ to 7A in the French bouldering rating system. Participants were asked to climb the traverse back and forth until exhaustion. Their performance was evaluated according to two criteria: time to failure (TtF) and the number of moves performed before failure (NoM). The latter was assessed similarly to scoring in climbing competitions: the furthest hold that the athlete used before falling off the wall.

After each trial. participants rated the severity of the exercise and their subjective level of forearm fatigue (a sensation described by climbers as a 'pump'). Additionally, three hours after completing the trials, they were sent a text message asking them to rate their overall fatigue.

Statistical Analysis

Descriptive statistics (means, standard deviations. and 95% confidence intervals for mean values) were used to describe the data. Assumptions of normality and homogeneity of variance were tested with the Shapiro–Wilk and Levene's tests. respectively. To assess differences between baseline and sleeves for both groups. placebo and compression. the t-test for paired samples was used. As a measure of effect size between both conditions. Cohen's d was calculated. and the obtained values were interpreted as recommended by Cohen as: 'trivial' $d < 0.20$. 'small' $d =$ 0.20–0.49. moderate' $d =$ 0.50–0.79. and 'large' $d > 0.80$ [28]. Statistical significance was accepted at $p \leq 0.05$. All analyses were conducted using Statistica 13.3 (Statsoft, Cracow. Poland) software, while the effect sizes were determined using the Stats.xls calculator (missouristate.edu/rstats. accessed on October 21. 2019).

Results

Descriptive statistics (Means±standard deviations. CI±95%) and significance of differences between trials, baseline and with compression sleeves or placebo are included in Table 2. No differences were found between groups in the pre-tests: campus board trial $t_{(20)}$ = -0.39, p= 0.699, traverse $t_{(20)}$ = -0.77. p=0.448.

Campus board trial

The total number of reaches in the forearm compression condition remained similar to that in the baseline trial (mean difference = 0.3. median = 3). resulting in non-significant differences between them (t=-0.22, p=0.834, Cohen's d = -0.05). In the placebo condition, the median difference between reaches in the baseline and test conditions was -4 (mean -4.5). The t-test results revealed a significant difference between pre and post conditions. with a medium-to-large effect size: t=2.49. p=.032. Cohen's d =0.74.

The mean change in power generated during the campus exercise increased by approximately 11 W in the compression condition, while it decreased by approximately 19 W in the placebo condition. In both cases, the differences between the pre-post conditions were not statistically significant, although the effect size in the placebo condition was moderate versus small in the compression condition. In the compression condition, the subjective sense of fatigue in the forearm muscles ('pump') decreased significantly (t=3.36. p=0.007. Cohen's d=0.64) compared to no significant change under placebo conditions. Detailed data are presented in Table 2.

In compression conditions there were a similar number of climbers who performed better than their baseline (i.e.. were able to perform more repetitions) compared to those who performed worse. and the dispersion of individual differences ranged from +6 to -8. Under placebo conditions improvement in results was observed in one subject. One subject achieved the same number of repetitions, while nine subjects performed fewer repetitions. The dispersion of differences in the number of repetitions ranged from -15 to +7.

Bouldering traverse

Both under compression and placebo conditions the number of movements the participants were able to perform and the duration of their persistence on the wall were lower compared to the baseline (means, standard deviations, and CI±95% in Table 2). However, only in the case of placebo was this reduction statistically significant: t=2.62. p=0.025, d=0.49 and t=3.03, p=0.013, d=0.64. respectively. Similar Cohen's d values were observed under both conditions, suggesting a similar magnitude of differences.

Table 2. Performance variables between baseline and forearm compression or placebo

Variable	Baseline trial		Trial with sleeves		Diff. p	ES
	Mean±SD	CI±95%	Mean±SD	CI±95%		
Campus board touches						
Compression sleeves						
Touches [no]	31.1±5.1	27.7-34.5	31.4±5.6	27.6-35.1	.834	-0.05
Avg power [W]	378.0±72.2	329.4-426.5	388.7±77.2	336.9-440.6	.578	-0.15
Max power [W]	514.7±113.6	438.3-591.0	510.2±112.1	434.9-585.5	.901	-0.04
Effort [pts]	7.1±1.6	6.0-8.2	5.9±2.2	4.5-7.4	.007	0.64
Placebo sleeves						
Touches [no]	31.9±4.7	28.7-35.1	27.4±7.8	22.1-32.6	.032	0.74
Avg power [W]	386.3±780.0	332.5-440.0	366.8±59.2	327.0-406.6	.219	0.29
Max power [W]	481.9±71.9	433.6-530.2	460.7±68.8	414.4-506.9	.371	0.31
Effort [pts]	7.2±1.5	6.2-8.2	7.4±1.8	6.2-8.6	.659	0.11

Climbing traverse						
Compression sleeves						
Moves [no]	55.9±23.2	40.3-71.5	48.4±12.5	40.0-57.0	.152	0.42
Time [s]	156.2±72.3	107.6-204.7	131.3±48.4	98.8-163.8	.198	0.42
Effort [pts]	8.3±1.9	7.0-9.6	8.5±1.5	7.4-9.5	.773	-0.11
Placebo sleeves						
Moves [no]	63.6±23.6	47.8-79.5	53.6±18.2	41.4-65.9	.025	0.49
Time [s]	160.2±67.6	114.7-205.6	126.3±40.3	99.1-153.3	.013	0.64
Effort [pts]	8.6±1.2	7.7-9.4	8.6±1.0	7.9-9.2	1.0	-
Subjective assessment of fatigue after 3 hours						
Effort [pts]	Compression sleeves		Placebo sleeves			
	3.4±1.6		3.7±2.1		.531	-0.21

Effort – perception of effort

In compression conditions, two climbers were able to move more (with 16 and 19 moves). two more achieved the same result. and the remaining 7 were not as successful, making 4 to 28 moves fewer than in the first attempt. In placebo conditions, improvement in performance was observed in one person (+4 moves). one obtained the same result as in the baseline, and the remaining climbers achieved worse results (from -1 to -37 moves).

The fatigue evaluation conducted three hours post-experimental session (warm-up. two trials on the campus board. and two trials on the traverse) was not statistically significant, whether under placebo or compression conditions.

Discussion

Although compression garments are becoming increasingly popular in many sports, there needs to be more evidence-based research on the effects of such garments on climbing performance [20,26,27]. Therefore. this study aimed to examine the effects of forearm compression on repetitions to failure. mean power and peak power and perceptions of forearm pump during intermittent campus board exercise and continuous bouldering traverse. Campus board reaches belong to specific climbing exercises for developing upper body power and power endurance in combination with the speed of development of hand-finger strength. In the compression condition. the only statistically significant difference was observed with regard to the degree of perceived forearm fatigue. which was rated as less than at baseline. On the contrary. in the placebo condition. the perception of effort did not differ significantly. while the number of repetitions was significantly lower.

The pattern of results in the climbing trial was similar. except that there was also no difference in perceived forearm fatigue in the compression condition. The differences in the number of moves were - like the number of repetitions in the campus board trial - not statistically significant in compression and significantly different in placebo. With the caveat, however, that the effect sizes were similar in both conditions. The same was true for the time spent on the wall.

In summary, our study suggests that although compression did not improve climbing performance as measured by number of repetitions - either on the campus board or on the climbing wall - but appeared to reduce the degree to which they underperformed in the second series of exercises undertaken after 15 minutes. However, it is essential to note the scatter in individual performance. including. in particular. the climbing trial which, on the one hand, shows the greatest specificity to real climbing situations, while on the other hand. its outcome is dependent on factors that are more difficult to record. such as stepping technique.

Climbing performance under forearm compression has previously been assessed by Limmer, de Marées and Roth [27], who measured Hand Grip Strength and Endurance on a dynamometer, dead hang to failure on a 4 cm rung and laps on a predefined route on top rope belay with no rest between the laps. There was no ergogenic effect of compression in any of these trials, although the differences between the compression, placebo and control (no sleeves) groups were not significant; in the climbing trial the effect sizes suggested a moderate strength of association between the results of the different groups: in total climbing time $\eta2 = 0.078$ while in the distance covered on the wall $\eta2 = 0.073$. However, in contrast to our study, both variables were shortest in the compression group. The only variable within which the authors observed a difference was haemodynamic responses. In another study, Engel et al. [26] found no effect of forearm compression during climbing on physiological responses, such as blood lactate concentration, heart rate, perceived exertion and local forearm muscle pain. Our study differs from those above in that the compression sleeve and placebo sleeve trials were conducted on the same day, which limits the possibility of direct comparisons. We also did not assess any physiological or biochemical parameters, focusing only on what we considered the most critical performance parameters from a practical point of view.

Our study is similar on some points and different on others, which allows for a direct comparison of results in the former. In contrast, in the latter case, such a possibility is limited. The similarity mainly concerns the compression equipment used, which were sleeves from the same company and of the same model. In this way, the effects on compression results that can arise from the use of different types of materials, fibre weaves. etc., are minimised. Our study was unique in that we didn't examine physiological and/or biochemical responses of the body, such as heart rate reactions, lactate concentration or hemodynamics. Instead, we focused on functional outcomes, which we thought could have practical implications for coaches and athletes. In this aspect, the results of our research can be compared to those of Limmer, de Marees and Roth [27]. However, it is important to bear in mind the slightly different pattern of climbing routes in the two studies – boulder traverse done back and forth until exhaustion vs. top rope climbing done in ascent – descent intervals. This may be important because, according to de Geus et al [29], moving vertically and horizontally (as during a traverse) engages the musculoskeletal system in slightly different ways, eliciting slightly different physiological responses, even though the difficulty of the vertical route and the horizontal traverse may be similar.

Despite many studies on the effects of compression on various aspects of performance there is still considerable controversy if athletes could benefit from wearing them. While some studies showed a positive effect of their use. others revealed none, although it is rare to find studies in which compression has a detrimental effect on performance [16.20]. Uncertainty about the true role of ergogenic compression is clearly evident in relation to climbing. given the scarcity of research in this sport. Given this, we believe that our study adds new insights into the potential role of forearm compression in climbing. although it does not dispel all doubts and does not give a clear answer to the question of whether climbers can benefit from using sleeves when training or climbing in competitions or rocks. However, based on the ES values, we can hypothesise that forearm compression may have a moderately positive effect on the sensation of forearm muscle fatigue. commonly referred to as the 'pump'. and prevent the number of repetitions from decreasing in the subsequent effort. In the latter case, especially in relation to upper body interval exercise, albeit with no change in the average or maximum power generated during repetitions. Even if the effect is moderate, it should not be forgotten that in real-life situations, a single move can decide a place at a competition or the completion of a route or bouldering problem. In other words, small ergogenic effects may have practical significance that climbers can take into account in their activities. Especially that the potential ergogenic benefit of wearing compression sleeves on climbing performance outweigh the risks of their detrimental effects. However, it is essential to bear in mind the wide variation in individual athlete responses both in the direction and extent of individual responses. As some studies suggest, among the factors that may contribute to this variation is the belief in the effectiveness of compression [30].

The climbers we studied were not privy to the mechanism of compression, and their beliefs or knowledge of its use in sport were not diagnosed. Thus. given factors such as the lack of conclusive arguments for the ergogenic effect of compression on climbing performance. as well as the variability of individual responses. every climber should try the sleeves under training conditions before deciding whether to use them in real conditions.

Limitations

It is plausible that several limitations could have influenced the results obtained. First of all, we did not assess the degree of compression by simply measuring the circumference of the forearms and adjusting the size of the sleeves according to the manufacturer's recommendations. Although in all cases the sleeves were tight enough that the athletes were assisted in putting them on and taking them off, it cannot be ruled out that the effects of the compression varied slightly from person to person. Another limitation related to the difference in appearance between the compression and placebo sleeves and thus influenced the expectations accompanying the exercise attempts. However, it should also be noted that providing actual placebo conditions is difficult for compression garments due to the perception of less compression [16.26.31]. The relatively small study sample limits the ability to generalise the results. Similarly, the fact that the sample was composed exclusively of men does not entitle the findings to be transferred to female climbers.

Despite the limitations, our study contributes to the knowledge of factors that may support climbing performance.

Conclusions

The results of the study do not allow definite conclusions to be drawn regarding the ergogenic effect of forearm compression in climbers. However. based on the results obtained. some practical suggestions can be suggested:

1. Wearing compression sleeves may cause climbers to feel less fatigued during repetitive tasks. such as campus board exercises or bouldering traverses. This could encourage longer training sessions or more repetitions without a significant increase in perceived effort.
2. Although compression did not statistically improve climbing performance metrics, such as the number of repetitions or moves, it helped alleviate underperformance in consecutive series. As such, climbers may want to consider incorporating compression sleeves to manage fatigue during multiple sets or exercises.
3. The findings emphasize the necessity for more evidence-based research to explore the effects of compression sleeves on climbing performance comprehensively. Future research should focus on larger samples and varied climbing conditions to better understand whether and how these garments can benefit climbers.

Practical implications

The variability in individual performance suggests that responses to compression sleeves can differ significantly among climbers. This range of responses from different athletes creates uncertainty about the effects of using compression sleeves on specific individuals. Therefore, coaches and athletes should use this equipment based on training feedback before deciding to employ it in competition situations or for targeted rock climbing routes.

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