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HYPERMOBILITY OF JOINTS IN ADOLESCENT SWIMMERS

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[A]Study Design; [B]Data Collection; [C]Statistical Analysis; [D]Manuscript Preparation

Abstract Joint hypermobility (JH) can be an advantage in many sports. On the other hand, it can also be one of the risk factors for developing pain or injury. The objective of the study was to compare JH diagnostic methods in adolescent swimmers, to locate the most common position of JH and assess its effect on swimming performance. This was a diagnostic study. The study group comprised 40 adolescent swimmers (20 female and 20 male) aged 13–18 years. Three diagnostic methods were used to assess joint hypermobility: Beighton score (BS), Sachse's criteria (SC), modified by Kapandji, and the Grahame and Hakim questionnaire (GHQ). In addition, questionnaire designed for the study was also applied. Joint hypermobility was identified in 62.5% of the swimmers by the BS, 22.5% by the SC and 57.5% by the GHQ. In addition, 75% of the swimmers indicated joint pain in the shoulder. JH was most often localized in knee joints regardless of the method used. Based on the results of the BS and GHQ and the level of athletes' sports performance, higher sports performance was associated with more frequent occurrence of JH. A diagnosis of JH in swimmers is influenced by the method so there is a need for unified diagnostic criteria for JH in this group. In adolescent swimmers, JH is more common in large limb joints, and appears to contribute to better results.

Key words: range of motion, swimming, hypermobility

Introduction

Joint hypermobility (JH) is defined as increased range of motion localized in a single joint or in a group (Castori et al., 2017) which exceeds their physiological passive or active ranges. It can be caused by greater connective tissue elasticity or laxity of the passive stabilization system (joint capsules and ligaments). Such changes result in the joint crossing its physiological barrier but not its anatomical barrier (Brzozowska & Sajewicz, 2020).

Joint hypermobility is regarded as *localized* (LJH) when located in one to five joints, and *generalised* (GJH) when present in more than five joints, in the upper and lower limbs, and in the limbs and axial skeleton (Castori et al., 2017). LJH is most often observed in a single small joint or large joint; however, it can also be bilateral. The causes can range from past trauma, joint disease, surgery to training, and there can be a family history. GJH is generally congenital and may be inherited (Castori et al., 2017). In such cases, the lower limbs and pelvis should be assessed to support spine growth and to prevent overload changes and body posture disorders (Ewertowska et al., 2021).

Flexibility is regarded as a key performance indicator in swimming and plays an important role in injury prevention (Reichmuth et al., 2021). Joint mobility is needed to improve swimming performance (Conti, 2015). Elite swimmers perform approximately 2500 repetitions of shoulder movements during each training session (Van de Velde et al., 2011), which demands increased range of motion in the upper limb joints (Radlińska & Berwecki, 2015). In addition, greater knee external rotation improves speed and kick length during breaststroke, (Strzała et al., 2012) and an increased range of hip external rotation, knee external rotation and ankle supination can improve results by 28.2% (Jagomägi & Jürimäe, 2005). Increased joint mobility is considered beneficial, especially in the butterfly stroke (Baeza-Velasco et al., 2013).

However, although increased range of motion can increase speed in swimming, it can also be a source of injuries. In swimming, repetitive arm movements may impair dynamic stabilisation of the humeral head (Wanivenhaus et al., 2012). For example, the combination of glenohumeral laxity with shoulder instability appears to increase the risk of arm injury by exerting a negative impact on the anterior shoulder joint capsule and ligaments; this has been reported in 40% to 91% swimmers (Wanivenhaus et al., 2012). Furthermore 86% of breaststroke swimmers have reported at least one episode of knee pain localized in the medial or anterior knee compartment. In addition, increased range of internal arm rotation (Riemann et al., 2011) and more frequent arm injury have been noted among young swimmers (Junge et al., 2016).

JH is commonly diagnosed using the Beighton score. However, this evaluation may be inadequate for diagnosing JH among swimmers as it does not include any tests dedicated to arm joints (Frydendal et al., 2018; Liaghat et al., 2018). Recent studies have highlighted the difficulties associated with selecting the correct method for assessing JH in swimmers; however, none have compared different diagnostic methods. Therefore, aim of the present study was to evaluate the effectiveness of JH diagnostic methods in a group of adolescent swimmers. It also examines the location of JH in the swimmers and assesses the effect of JH on the sports performance in swimming.

Material and methods

This was a diagnostic study. The participants were recruited from two sport clubs KS OLIMPIA Lublin and AZS UMCS Lublin. Participation in this study required consent from the coaches, participants and parents. The study was approved by (Jozef Pilsudski University of Physical Education in Warsaw) Research Ethic Committee (SKE 01-06/222). The inclusion criteria were as follows: age between 13 and 18 years, at least three years of training experience and at least six training sessions per week. The exclusion criteria comprised training in a sport other than swimming, connective tissue diseases, injures in the previous six months.

The study group comprised 40 adolescent swimmers (20 female and 20 male) aged 13–18 years. The characteristics of the participants are presented in Table 1. In addition, demographic data, the number of training sessions per week, training experience and anthropometric data (height, weight) were collected.

Table 1. Participant characteristics

Parameter	Unit	Mean (SD)
Sex		
Female	n (%)	20 (50)
Male	n (%)	20 (50)
Age	years	15.5 (1.9)
Height	cm	170 (9.7)
Weight	kg	60 (11.8)
Training sessions per week	n/w	8.2 (2.2)
Training experience	year	7.3 (2.5)
Sport performance level		
Provincial/regional championships level	n (%)	24 (60)
National championships level	n (%)	16 (40)

The diagnosis of JH was carried out by using three methods: Beighton score (BS), Sachse's criteria (SC) modified by Kapandji, and the Grahame and Hakim questionnaire (GHQ). In addition, demographic data, the number of training sessions per week, training experience and anthropometric data (height, weight) were collected. First of the test used in the study was the nine-point hypermobility BS test (Smits-Engelsman et al., 2011). The BS is a highly reliable clinical tool that shows substantial to excellent inter- and intrarater reliability when used by raters of variable backgrounds and experience levels (Bockhorn et al., 2021). The range of motion was measured by goniometry, with a minimum of five points being accepted as the cut-off for determining JH; this value was selected based on two different studies with young swimmers (Frydendal et al., 2018; Liaghat et al., 2018). The second method was the SC modified by Kapandji (Lewit, 2010). The procedure comprising 13 tests was carried out in group of teenagers and used to examine the level of joint mobility and range of motion in the lumbar spine, thoracic spine, cervical spine and peripheral joints (Mikołajczyk et al., 2012) using a goniometer and perpendicular projection. A score of at least seven positive tests was interpreted as JH (Stodolna-Tukendorf et al., 2011). The third method to detect hypermobility was GHQ (Hakim & Grahame, 2003), in which a positive response to at least two questions out of five possible is indicated as joint hypermobility. The sensitivity and specificity of GHQ was analysed in cohort studies and valued sequentially 84% and 80% (Hakim & Grahame, 2003).

In addition, information on highest sporting achievement, a subjective assessment of joint hypermobility, the effect of range of motion on swimming technique and joint pain episodes was collected in the questionnaire designed for the study (supplement 1) consisting of twelve, single-choice questions.

Testing was carried out at Aqua Lublin swimming pools complex on the pool deck. Every swimmer was examined individually. Testing was performed before training session. Order of the testing was the same for every participant. First BS testing was performed, followed by SC and finished with GHQ. Consent was required to take part in the study. Each participant was instructed to wear convenient sportwear, without footwear, and was informed about the aims and the content of the study protocol. The participants were informed that they could resign from study at any point. Each participant was examined individually according to the study protocol. After the study, participants and coaches were informed about the results.

Statistical analysis

The results of this study were analysed using Statistica 13.3. The Shapiro-Wilk test was used to determine the distribution. As the data was found to have a normal distribution, the mean and standard deviation were recorded and used in all calculations. The data were analysed using Spearman's rank correlation coefficient. The statistical significance was set at $p < 0.05$.

Results

Positive joint hypermobility (JH) was diagnosed for 62.5% of the swimmers based on the BS, 22.5% according to the SC and 57.5% according to the GHQ.

A strong, significant corelation was found between sum of the positive answers in GHQ and sum of C answers in SC (Table 2; $p < 0.0001$).

Table 2. Correlation of total score in the three different diagnostic method

Method	Beighton score	Sachse's criteria	Grahame & Hakim questionnaire
Beighton score	1.00	0.69*	0.66*
Sachse's criteria	0.69*	1.00	0.78*
Grahame and Hakim questionnaire	0.66*	0.78*	1.00

** significant at p < 0.05.*

A moderate corelation was indicated between the total score for the BS and sum of C answers in SC ($p < 0.0001$) and between the total score in the BS and total positive answers in the GHQ ($p < 0.0001$). A moderate correlation was indicated between results of JH diagnosis according to SC, BS and GHQ (see Table 3); however, a closer correlation was found between the results of the GHQ and BS.

Table 3. Correlation in diagnosis of joint hypermobility by the three different methods

Method	Beighton score	Sachse's criteria	Grahame & Hakim questionnaire
Beighton score	1.00	0.42*	0.69*
Sachse's criteria	0.42*	1.00	0.46*
Grahame and Hakim questionnaire	0.69*	0.46*	1.00

** significant at p < 0.05.*

According to the BS (Figure 1) JH was localized most often in elbow joints (90% of swimmers) and in the knee joints (85% of swimmers).

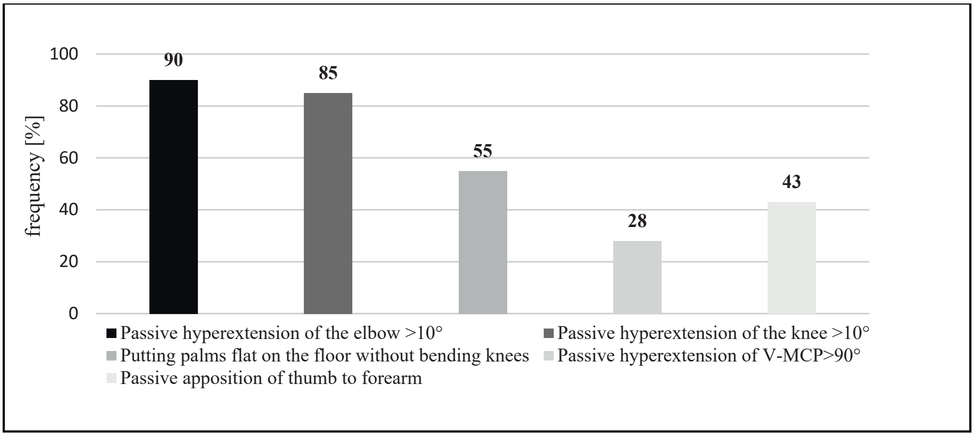

Figure 1. Frequency of specific joint hypermobility according to Beighton score

According to SC (Table 4), JH was localized most often in the knee and hip joints. Based on the original questionnaire, 75% of the swimmers indicated joint pain in the shoulder and 65% in the knee joint.

Table 4. Frequency of specific joint hypermobility based on Sachse's criteria

Test	Frequency (%)
Extension of the knee joints	63
Foreflexion of the trunk	55
Passive abduction in the hip joints	55
Rotation in the hip joints	53
Extension of the elbow joints	45
Passive movement of the thumb to the palmar surface of the forearm	43
Trunk retroflexion	35
Lateral flexion of the lumbar spine	20
Shoulder joint mobility	15
Head and neck rotation	13
Trunk rotation	5
Passive dorsiflexion of the metacarpophalangeal joints	5
General mobility in the shoulder girdle	3

Based on the results of the BS and GHQ and the level of athletes' sports performance (Figure 2), it can be seen that higher sports performance appears to be associated with more frequent occurrence of JH.

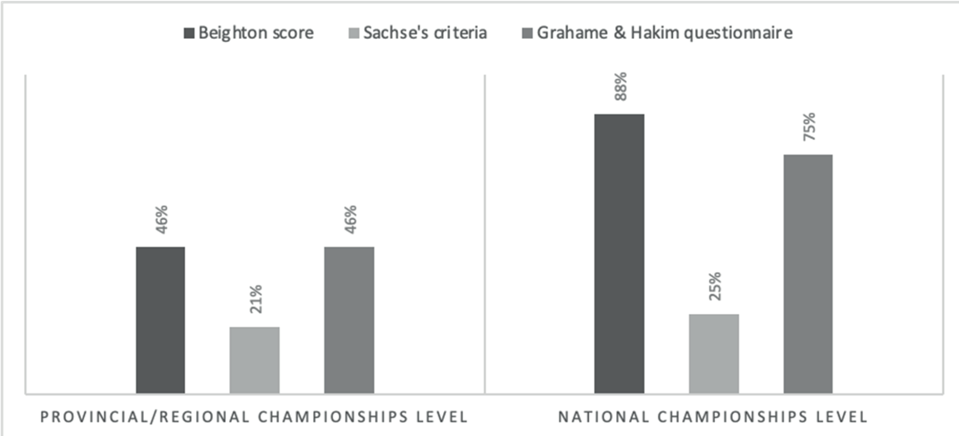

Figure 2. Joint hypermobility occurrence according to the three different methods and level of sports performance

Discussion

The three selected methods were found to yield different diagnoses of JH in the group of swimmers, with the greatest discrepancy being found between SC and the other two methods. In addition, JH was diagnosed less frequently by SC than the others. These differences may be due to the fact that the SC assessment of hypermobility includes the largest number of tests and allows the results to be differentiated at three levels (A, B, C) with only one (level C) qualifying as JH.

Our findings also indicate that as the JH score obtained by one method increased, it was accompanied by a similar increase in the other methods. The high statistical correlation for total scores may be due to the fact that some of the tests overlap; however, this does not determine the outcome of the final diagnosis for hypermobility. It is important to note that the cut-off scores for a diagnosis of JH vary across methods, as this may explain the inconsistencies in diagnosis. Previous studies explore the issues associated with selecting an appropriate method for JH evaluation, the occurrence of differences in diagnosis and the value of the methods when studying athletes. One report on dancers using the same methods confirms significant differences exist between methods in the diagnosis of joint hypermobility (Skwiot et al., 2019).

SC allows more joints to be examined. When swimming, a greater range of motion in the shoulder girdle translates into favorable reductions in resistance forces and increased propulsion, and thus a more effective swimming style (Radlińska & Berwecki, 2015). Our study did not indicate any prevalence of JH in the shoulder girdle joints (3% of participants). In the shoulder mobility test, JH was diagnosed in 15% of subjects; however, 75% of subjects reported the presence of pain in the shoulder joint. Shoulder joint pain can be associated with the phenomenon of *swimmer's shoulder* (Matzkin et al., 2016; Struyf et al., 2017). Interestingly, hypomobility of the shoulder complex is considered a risk factor for shoulder pain in male swimmers, and hypermobility in female swimmers (Mise et al., 2022).

Increased extension and pain was observed in the knee joints, as well as increased abduction and rotation in the hip joints. It has been noted that propulsive forces can cause pain and muscle strain through repetitive overstretching in freestyle, backstroke and butterfly, and through the cyclic execution of external rotation in breaststroke (Jansson et al., 2005). The maximal hip abduction movement occurring in breaststroke when initiating a kick can lead to increased knee injuries in swimmers (Wanivenhaus et al., 2012). In addition, 3D computer analysis of lower limb movement during a kick in breaststroke, has shown swimmers to have a large active range of motion of hip rotation (Matsuda et al., 2021).

In the present study, the trunk forward flexion test assessing spinal range of motion, in the SC, indicated the presence of JH in 55% of the swimmers; this has been confirmed in previous research (Corten et al., 2020). However, this might be an insufficient test for athletes, due to the possibility of training such a skill and the fact that the quality of test performance is influenced by the length of the muscles belonging to the hamstring group (Corten et al., 2020). JH may change in lower limb muscle activity, which is a compensatory mechanism for unstable joints; this can result in limiting the lumbar range of motion, and consequently, the trunk forward flexion test. Studies have found that the upright movement of the lumbar spine is necessary for achieving a streamlined body position, regardless of swimming style (Weldon & Richardson, 2001). Recent studies on swimmers have also examined the effects of limited range of motion in the peripheral joints, and the resulting compensation in the spinal joints (Kitamura et al., 2020). Swimmers with lumbar spine pain demonstrated a significant decrease in passive hip extension range as their range of lumbar extension was increased.

Our findings indicate that, regardless of the diagnostic method, the presence of JH in swimmers is more common among those with the highest sporting achievements. Previous studies of athletic performance in swimming focus on the effect of increased range of motion on swimming speed (Kitamura et al., 2020; Wanivenhaus et al., 2012) as well as on swimming technique, (Strzała et al., 2012) which also influences performance. Swimmers with longer training experience had the highest sports performance and were characterized by a higher incidence of JH. Previous studies have also noted that the range of internal rotation at the shoulder joint decreases as swimmers continue their careers from junior to youth levels (Riemann et al., 2011). However, to determine the impact of hypermobility on sports performance and the changes in JH occurring over the course of training, further studies based on repeated testing on athletes over time and monitoring changes in the ranges of motion are needed.

Limitations

The number of participants in the study was relatively small. The participants were not divided according to the duration of training experience. Also, although the JH assessment was performed using three methods, each test was performed only once.

Conclusions

In swimmers, a diagnosis of joint hypermobility (JH) depends on the diagnostic method used. JH was found to be more common in the large limb joints, and to promote better athletic performance. The most appropriate approach for assessing JH in swimmers appears to be the method based on Sachse's criteria, modified by Kapandji, taking into account three categories of hypermobility. Future studies on the effect of the JH on athletic performance in swimming should include larger groups of athletes and repeated measurements over time and should account for the length of training.

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AEROBIC PERFORMANCE OF PAVOL JOZEF ŠAFÁRIK UNIVERSITY STUDENTS IN KOŠICE IN REFLECTION ON THEIR PHYSICAL ACTIVITY AFTER COVID-19 PANDEMIC

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Abstract The aim of our paper was to evaluate the level of aerobic performance in students of Pavol Jozef Šafárik University in Košice (UPJŠ) in reflection to their physical activity (PA) after the COVID-19 pandemic. The research pool for the assessment of the COVID-19 pandemic impact on PA consisted of 675 UPJŠ students (466 females and 209 males). Aerobic endurance data were obtained from the results of a 20-meter multistage endurance shuttle run (beep test). In our research, we found a negative impact of the COVID-19 pandemic on students´ PA in almost 1/4 of all the respondents. Considering current standard for both sexes, women showed better results than men did in aerobic performance. Comparing the aerobic performance in the groups of students with and without the negative effect of pandemic on PA, we found a significant difference ($p < 0.01$) in the male group. Comparing our VO2max results with a similar study by Zadarko et al. (2010), we observed a significant decrease in performance in the „excellent" (–11.9%) and „fair" (–6.3%) norms in women. However, we found an increase in the „good" level (+24.4%). We recorded a decrease in the number of performances in the „superior" (–14.7%) and „excellent" (–9.3%) norms in males and we observed an increase in the „fair" (+13.7%) and „poor" (+10.6%) groups.
Our results confirmed negative impact of the pandemic on undergraduates´ physical activity. Repeated PA restriction in the future may not only permanently reduce aerobic fitness of physically active people, but also increase the risk of various health problems.

Key words: VO_2max, beep test, lifestyle

Introduction

In March 2020, the World Health Organization (WHO) declared a global pandemic of COVID-19. Following measures to limit the spread of SARS-CoV-2 coronavirus infection, most normal life and work activities worldwide, including academic activities, suddenly shifted to online form of communication and education (Webb et al., 2021). The consequences of changes in the psychosocial sphere, staying in the place of residence with increased time demands on work and school activities, were particularly evident in the reduced level of physical activity (PA) in the lives of university students even before the pandemic measures were applied (Calestine et al., 2017; Van Dyck et al., 2015). Compared to childhood, college students generally have lower levels of PA. Previous and subsequent studies have shown that there is an increase in physical inactivity during the transition from adolescence to adulthood, including college (Crombie et al., 2009; Jung et al., 2008; Pullman et al., 2009). A review study by López-Valenciano et al. (2021) provided data that during the period of the pandemic declaration, a significant number of students did not meet even the minimum recommendations for physical activity set by the WHO. A general decrease in PA was found, particularly for light and vigorous activity. A decline in PA during the COVID-19 pandemic was also observed among Slovak university students (Boržíková & Lenková, 2021; Líška et al., 2021). However, among the countries Poland, Slovakia and the Czech Republic, Slovak undergraduates had the highest median PA, measured as MET score (Líška et al., 2024). Assessment of aerobic performance in undergraduate students yielded results of varying levels with many students showing a decline in aerobic capacity levels, which may affect their health and exercise performance in various activities (Tongprasert & Wattanapan, 2007). Cardiopulmonary endurance and overall physical fitness are very important for students´ health and good level of their aerobic performance (Liu, 2023). It is very likely that the general decline in PA has exacerbated problems related to aerobic fitness in the context of the COVID-19 pandemic. The aforementioned studies have demonstrated significant reductions in student PA, resulting in lower aerobic fitness with potential long-term health consequences (Anderson et al., 2022). In recently presented work, significant gender differences in the impact of the COVID-19 pandemic on PA levels among college students have been reported. Baceviciene & Jankauskiene (2021) found a significant decrease in PA among males, with activity decreasing from a mean of 78.77% to 58.77%. No significant changes were observed in females during pandemic restrictions. These findings that PA levels declined more significantly in men than women during the pandemic were later confirmed by other research. This difference was often associated with higher levels of sedentary behaviour, particularly in men who had a more active lifestyle before the pandemic (Eek et al., 2021; Márquez Ramos, 2021; Puccinelli et al., 2021) and the relation between perceived changes in PA and general life satisfaction and perceived physical capacity. A total of 1318 participants (mean age 47.8 SD 12.6; 82.1% women. Only 25% of all students met WHO recommendations for PA during the pandemic versus 50% pre-pandemic, indicating a significant decrease in PA after the restrictions were implemented. Students with a regular exercise regime before the introduction of anti-pandemic restrictions were more likely to maintain some level of aerobic activity during the restrictions, highlighting the importance of routine PA (Herbert et al., 2020; López-Valenciano et al., 2021; Olfert et al., 2022). These findings confirm the importance of PA in a person's life and highlight the importance of established exercise habits prior to the pandemic and their positive impact on mental health and overall well-being during periods of isolation.

The aim of our study was to evaluate the level of aerobic performance of students at the University of Pavol Jozef Šafárik in Košice (UPJŠ) in reflection of their PA after the COVID-19 pandemic.

Material and methods

The presented results were obtained within the research task of the VEGA project No. 1/0234/22 *"The impact of the Covid 19 pandemic on the preparedness and response of university students to physical stress"*. The Ethics Committee of the University of Pavol Jozef Šafárik in Košice No. 3 /2023 approved the project. The research pool for the assessment regarding the impact of the COVID-19 pandemic on PA consisted of 675 UPJŠ students. The sample of students included 466 females (19.94 ±1.44 years) and 209 males (20.21 ±2.04 years) who attended classes "Sport" and "Sport activities" (Physical Education - PE) organized by the Institute of Physical Education and Sport of the UPJŠ in Košice as a part of their studies. The students studied at the Faculty of Arts (FA), Faculty of Medicine (FM), Faculty of Law (FL), Faculty of Public Administration (FPA), Faculty of Science (FS), and the Institute of Physical Education and Sport (IPES). The representation of female students was FM (43.1%), FA (20.2%), FS (14.4%), FL (14.4%), FPA (4.5%), and IPES (3.4%). For males, the representation was FM (50.2%), FL (15.8%), FS (14.4%), FA (11%), FPA (5.7%), IPES (2.9%).

325 women and 140 men completed the aerobic endurance test (beep test). To assess the impact of the change in PA after the COVID-19 pandemic on students' aerobic performance, we statistically evaluated only the results of the beep test of women (291) and men (126) who marked one of the questions with a positive or negative impact on their PA in the PAR(Q) questionnaire.

Aerobic endurance data were obtained from the results of a 20-meter endurance multistage shuttle run (beep test). These results were converted to estimated maximal oxygen uptake (VO_2max) values according to Léger & Lambert (1982). The probands´ pulse rate was monitored throughout the test using a Polar H10 sensor. All students provided written consent to participate prior to the study, which also confirmed their medical readiness to perform the required test via the PAR(Q) questionnaire. The required PAR(Q) data were collected online. Questionnaires were administered and distributed via Google Forms platform during PE classes. The questionnaire also included two questions in the context of the COVID-19 pandemic, focusing on the frequency of PA before and after the pandemic. The achieved aerobic performance was compared to VO_2max norms developed by Heyward (1998) after recalculation, which we present for both sexes in Table 1 (modified according to Zadarko et al., 2010).

Table 1. Aerobic performance standards for women and men (ml/kg/min)

Age	Very poor	Poor	Fair	Good	Excellent	Superior
20 – 29 (Female)	<23.6	23.6 - 28.9	29.0 - 32.9	33.0 - 36.9	31.7 - 41.0	>41.0
20 – 29 (Male)	<33.0	33.0 - 36.4	36.5 - 42.4	42.5 - 46.4	46.5 - 52.4	>52.4

Source: Heyward 1998 (Zadarko et al., 2010).

Statistical analysis

The obtained results were processed by descriptive statistics using Microsoft Excel and its complementary data analysis version "Data Analysis". Statistical and substantive significance was evaluated using the statistical program Real Statistics. Non-parametric Mann-Whitney Test for Two Independent Samples was used to compare the aerobic performance of male and female UPJŠ students. To determine statistical significance at 1% ($p < 0.01$) and 5% ($p < 0.05$) levels, the resulting p value of two-tailed testing was assessed. The strength of the effect "effect size" was determined by the "Cohen's d" value.

Results

Impact of the COVID-19 pandemic on PA

Respondents´ answers in questionnaire about the changes in their PA impacted by COVID-19 pandemic are shown graphically in Figure 1. In our research, we have divided the respondents´ answers into three categories – the one where they did not pay attention to the change in their PA because of the pandemic; the second one where the pandemic had a negative effect on their PA; and the third one where the pandemic did not negatively affect their PA.

Around one in ten students reported that they have not paid the attention to the changes in their PA. A negative impact of the pandemic on PA was reported by almost a quarter of all the students. What pleasantly surprised us was that for 2/3 of the students, their PA was not negatively affected by the pandemic.

When detailed evaluating in terms of students' gender, we found that for females, slightly over 1/10 have not paid attention to this issue with no significant changes among the faculties (FA 12,8%, FM 11,9%, FS 10% and FL 9%). The negative effect of the pandemic on PA, in the form of reducing or even abandoning activity, was reported by almost one-quarter of the women. We observed a slightly increased negative impact in the FL (26,9%), FM (22,4%), FS (19,4%) and FA (18,1%). Responses with no negative impact of the pandemic on PA were reported by more than 2/3 of women with no significant changes between the faculties (FS 70,2%, FA 69,1%, FL 64,1%, FM 65,7%).

No more then 1/10 of men have not paid attention to this issue, over 1/4 of them described the negative effect of pandemia on their PA. Again, similar to women, almost 2/3 of men were not negatively affected by the COVID-19 pandemic on PA. However, compared to women, a larger group of men used other types of PA. However, it is interesting to compare individual responses between faculties. As many as 21.8% of FA students did not pay attention to the change in their PA after the pandemic (FS 6.6%, FL 6.1%, FM 5.7%). Only 9.1% of FL students reported a negative impact on PA (FS 36.7%, FM 27.6%, FA 21.7%). Up to 84.8% of FL students did not experience a negative impact of the pandemic on their PA (FM 66.7%, FS 56.7%, FA 56.5%). For both genders, we did not report the comparison between FPA and IPES due to the small number of students participating in the questionnaire.

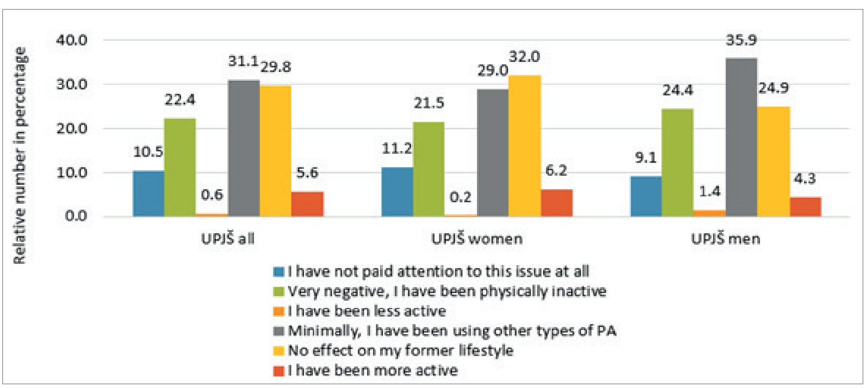

Figure 1. Impact of COVID-19 pandemic on physical activity of UPJŠ students (%)
Source: original research.

Level of aerobic performance of UPJŠ students in terms of gender

During the evaluation of women´s VO_2max (Table 2), we found that less than a quarter of them reached the average normative performance level. Less than 1/10 (8.9%) achieved VO_2max below the normalized average and more than 2/3 of women (67.4%) achieved it above the average. Based on the Heyward (1998) norms, the mean VO_2max of the entire group of women (Fig. 2) fell into the category of above-average "good" performance (according to Zadarko et al., 2010). The confidence interval (CI) of the whole group was 33.52–34.60 ml/kg/min (Confidence level 95% = 0.54; CL). Hence, with 95% probability, we can expect the mean VO_2max in the group of all women studying at UPJŠ to be within the CI level and thus within the "good" norm.

Table 2. Aerobic performance level of women (ml/kg/min)

Women	x_i	n_i	N_i	f_i	f_i (%)	*MEAN*	*MED*	*MOD*	*SD*	*v (%)*
Very poor	<23.6	1	1	0.003	0.3					
Poor	23.6 - 28.9	28	29	0.086	8.6					
Fair	29.0 - 32.9	77	106	0.237	23.7					
Good	33.0 - 36.9	166	272	0.511	51.1	34.06	33.24	33.24	4.91	14.41
Excellent	31.7 - 41.0	27	299	0.083	8.3					
Superior	>41.0	26	325	0.080	8.0					
	Total	325		1.000	100.0					

xi – interval norm; ni – absolut number; Ni – cumulative absolut number; fi – relative number; fi (%) – relative number in percentage; MEAN – arithemtic mean; MED – median; MOD – modus; SD – standard deviation; v (%) – variability in percentage.

The interquartile range, the 2nd and 3rd quartiles, includes 51.1% (166) of all tested women (Fig. 2).

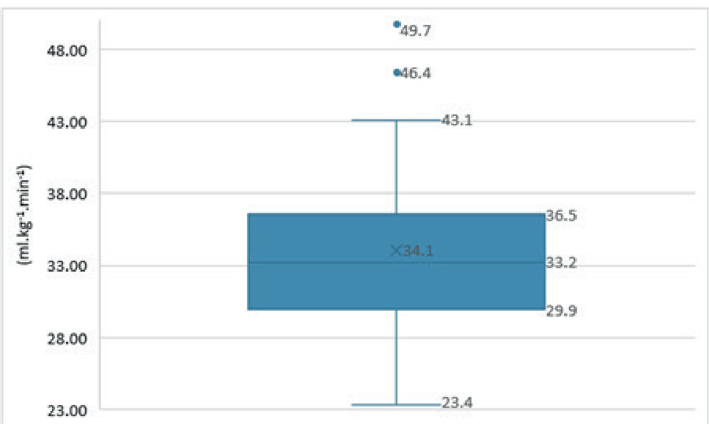

Figure 2. VO_2max in women of UPJŠ
Source: original research.

When evaluating the results of the men's VO_2max, the arithmetic mean (Mean) of the entire group was in the "fair" category. Less than 1/3 of the men achieved the "fair" level. Below average results were measured for less than 16% of the men and more than 1/2 of the men fell into the above average level (Table 3). The confidence interval of the whole group was at 40.82–42.95 ml/kg/min (CL 95% = 1.07).

With a probability of 95%, we conclude that the arithmetic mean (Mean) of VO_2max in all men studying at UPJŠ would be within the CI level and thus predominantly within the "fair" norm with performances extending into the "good" level.

Table 3. Aerobic performance level of men (ml/kg/min)

Men	x_i	n_i	N_i	f_i	f_i (%)	MEAN	MED	MOD	SD	v (%)
Very poor	<33.0	3	3	0.021	2.1					
Poor	33.0 - 36.4	19	22	0.136	13.6					
Fair	36.5 - 42.4	45	67	0.321	32.1					
Good	42.5 - 46.4	32	99	0.229	22.9	41.88	43.13	43.13	6.38	15.23
Excellent	46.5 - 52.4	29	128	0.207	20.7					
Superior	>52.4	12	140	0.086	8.6					
	Total	140		1.000	100.0					

xi – interval norm; ni – absolut number; Ni – cumulative absolut number; fi – relative number; fi (%) – relative number in percentage; MEAN – arithmetic mean; MED – median; MOD – modus; SD – standard deviation; v (%) – variability in percentage.

The interquartile range, the 2nd and 3rd quartiles, includes 54.3% (76) of all tested men (Fig. 3)

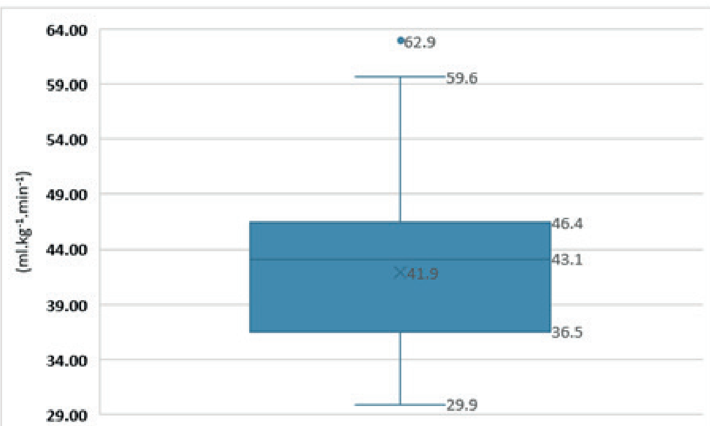

Figure 3. VO_2max in men of UPJŠ
Source: original research.

Students' aerobic performance in relation to their physical activity after pandemic

Comparing VO_2max performance in the groups of students with negative pandemic impact on PA (42) and students without negative pandemic impact on PA (84), we found a significant difference at the 1% level of statistical significance ($p < 0.01$) with a medium effect ($d = 0.62$). For females, we did not find a statistically significant difference in VO_2max ($p > 0.05$; $d = 0.29$) between the group with a negative effect of pandemic on PA and the group without a negative effect on PA (Table 4, Figs 4, 5).

Table 4. Difference in aerobic performance in groups of students according to the effect of pandemic on PA

Student groups	*Sex*	*n*	*Mean*	*SD*	*Min.*	*Max.*	*p*	*ES*
Negative impact on PA	*women*	74	33.2	4.15	26.7	49.7	**0.062[a]**	**0.29[d]**
No impact on PA	*women*	217	34.6	5.19	23.4	49.7		
Negative impact on PA	*men*	42	40,0	5.40	30,0	56.3	**0.003[a]**	**0.62[d]**
No impact on PA	*men*	84	43.7	6.41	30,0	62.9		

Mann-Whitney's U Test (a); Cohen's effect size (d); Mean = average; SD = standard deviation; Min. = minimum; Max. = maximum; p = „p" value; ES = Effect Size.

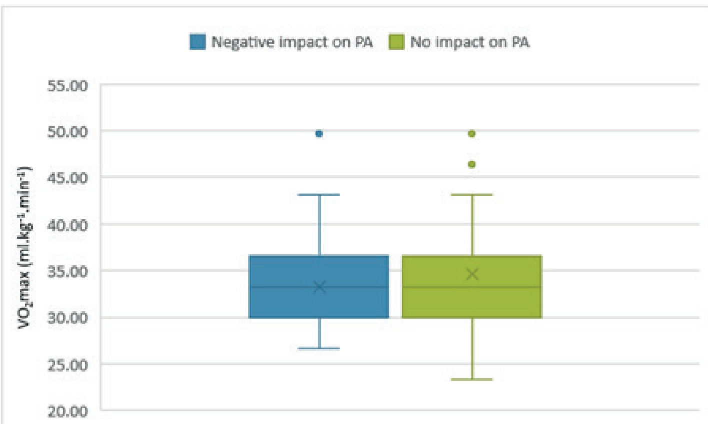

Figure 4. Variation in VO_2max in groups of women according to the effect of pandemic on their PA
Source: original research.

A similar research aimed at determining the VO_2max of students was carried out before the COVID-19 pandemic at selected universities from the Carpathian Euroregion, including students from Slovakia by Zadarko et al. (2010). Because we were partly involved in this research, we compared the published data with the results of our current research separately in the group of women and men (Tables 5, 6). In our research, for women in particular, we observed a significant decrease of VO_2max in the "excellent" norm (–11.9%) and in the "fair" norm (–6.3%). However, we found an increase in the "good" level (+24.4%).

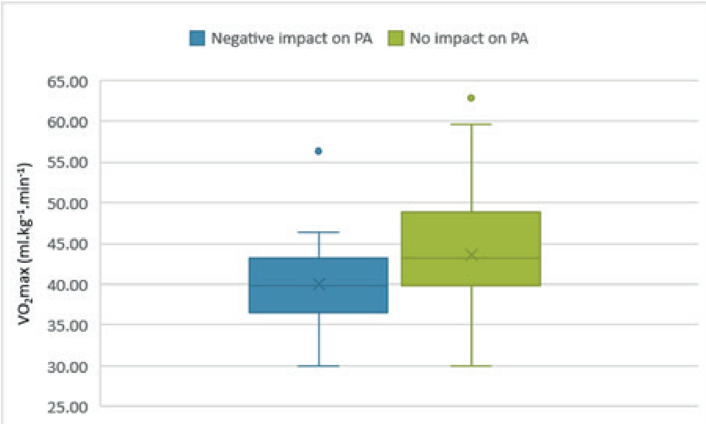

Figure 5. Variation in VO_2max in groups of men according to the effect of pandemic on their PA
Source: original research.

Table 5. Comparison of aerobic performance of women

Women	x_i	n_i *Zadarko et al. (2010)*	n_i UPJŠ *(2023)*	f_i (%) *Zadarko et al. (2010)*	f_i (%) UPJŠ *(2023)*
Very poor	<23.6	16	1	0.8	0.3
Poor	23.6 - 28.9	263	28	12.5	8.6
Fair	29.0 - 32.9	628	77	**30**	**23.7**
Good	33.0 - 36.9	559	166	**26.7**	**51.1**
Excellent	31.7 - 41.0	423	27	**20.2**	**8.3**
Superior	>41.0	207	26	9.9	8.0
	Total	2096	325		

xi – interval norm; ni – absolut number; fi (%) – relative number in percentage.

Similarly to women, comparing the results of our research with those of Zadarko et al. (2010), we found a significant decrease in the level of VO_2max in the “superior” norm (–14.7%) and in the “excellent” norm (–9.3%) in men (Table 6). We observed an increase in the “fair” (+13.7%) and “poor” (+10.6%) levels.

Table 6. Comparison of aerobic performance of men

Men	x_i	n_i Zadarko et al. (2010)	n_i UPJŠ (2023)	f_i (%) Zadarko et al. (2010)	f_i (%) UPJŠ (2023)
Very poor	<33.0	27	3	2.8	2.1
Poor	33.0 - 36.4	29	19	**3**	**13.6**
Fair	36.5 - 42.4	179	45	**18.4**	**32.1**
Good	42.5 - 46.4	219	32	22.5	22.9
Excellent	46.5 - 52.4	292	29	**30**	**20.7**
Superior	>52.4	226	12	**23.3**	**8.6**
	Total	972	140		

xi – interval norm; ni – absolut number; fi (%) – relative number in percentage.

Discussion

The first finding of our study was information from questionnaire provided by probands regarding the decline in their PA due to the impact of the COVID-19 pandemic. Interestingly, and quite positively, we found a decrease in PA in only about one quarter of the UPJŠ undergraduates. This trend has also been observed by other studies conducted in the same period on students of other universities (Baceviciene & Jankauskiene, 2021). On the other hand, we are aware of data from other researches that speak of a far greater decline in PA. A large cross-sectional study by Rogowska et al. (2020) during the COVID-19 pandemic showed a significant decline in the number of students who adhered to the recommended level of PA, from more than 60% before the pandemic to less than half during the pandemic period. This decline is likely to have been closely related to global trends towards the introduction of restrictive measures limiting traditional PA practicing options. To substantiate these findings, further cross-sectional analyses quantitatively assessed changes in PA levels in different university settings during the pandemic. The results showed that less than 40% of university students are engaged in the recommended amount of PA during national lockdowns, which had a significant impact on their mental health and well-being (Talapko et al., 2021). Despite the general trend of reduced PA, the opposite has also been the case. Some students were able to maintain or even increase their activity levels by switching to other forms of exercise or incorporating PA into their daily regimens during the restrictions. This trend was also noted in the case of the UPJŠ students we observed.

The aerobic performance of the university students assessed in our research showed considerable variability, which appeared to be influenced by several factors, including lifestyle and pandemic-induced changes in PA. The results obtained confirmed the expected differences in aerobic performance between males and females. From a physiological perspective, it is natural and scientifically confirmed that women generally have a lower VO_2max compared to men (Diaz-Canestro & Montero, 2019). This difference is attributed to several biological factors, including lower hemoglobin levels, smaller heart size, and a higher percentage of body fat in women. These physiological characteristics mean that women often have a lower capacity to carry and utilise oxygen during vigorous physical activities, which directly affects their aerobic performance, therefore it is important to assess the results of measurements according to the current standards set for both sexes (Charkoudian & Joyner, 2004).

A number of prolonged studies provide the evidence that university students experienced a significant decline in PA and subsequently in their aerobic performance during the COVID-19 pandemic (Ahsan & Javed, 2021; Bielec & Omelan, 2022; Goncalves et al., 2021; Savage et al., 2020; Wilson et al., 2021). Previously active students also appear to have been unable to maintain their fitness levels due to pandemic-related disruption of their habits (Ahsan & Javed, 2021).

During the testing of the aerobic performance in men and women after pandemic, we found better VO_2max levels in the women's group compared to men within the gender-specific norms. Men achieved an average level of VO_2max and women a level of above average of VO_2max. Older research confirm that different modes and intensity of exercise can lead to improvement in aerobic capacity levels in different sexes (Sparling, 1980; Zoeller, 2008). Both the intensity and types of physical activities that men and women prefer may influence aerobic capacity. Studies have shown that men are more likely to engage in activities that combine a strength component with an aerobic component. Men prefer high-intensity strength training combined with aerobic activities with a focus on performance growth. Conversely, women prefer strength training at moderate intensity and aerobic activities with a focus on increasing self-esteem (Reading & LaRose, 2022). Decreased VO_2max may be related to reduced engagement in high-intensity physical activities. Students who maintained some form of routine PA, even if minimal, tended to have better aerobic performance (Olfert et al., 2022). These findings are consistent with other studies that similarly report a decline in physical fitness due to pandemic in demographically similar groups to the participants in our research (Anderson et al., 2022; Crombie et al., 2009; Heller et al., 2023).

One of the objectives of our research was to determine whether the claimed impact of the COVID-19 pandemic on performed PA would be reflected in the level of aerobic performance after its cessation. The results confirm that the association between the decline in PA levels during the pandemic and reduced VO_2max in the student population is evident. The data we analyzed revealed that the reduced PA of males due to the pandemic led to a significant decrease in aerobic fitness. Students who reduced their PA due to the impact of the pandemic experienced a reduced level of VO_2max. This may mainly reflect reduced engagement in high-intensity activities, which are essential for maintaining good aerobic fitness (Anderson et al., 2022). According to our findings, men, who typically engage more in collegiate high-intensity sports, showed a steeper decline in VO_2max compared to women, which could be associated with their higher pre-pandemic participation in these very activities (Keel et al., 2020; Wilson et al., 2019). Students who maintained some form of regular PA, albeit at a reduced rate or through other alternative approaches, demonstrated greater aerobic fitness. It has been shown that flexibility in exercise approaches can contribute significantly to maintaining fitness even during pandemic constraints (Romero-Blanco et al., 2020).

One of the ways to maintain aerobic performance in constrained conditions is reported by Čurgali et al. (2022), who describe a way of implementing a distance form of teaching sports activities at UPJŠ during the pandemic period, which can be an alternative for performing PA in difficult conditions.

Conclusion

The results of our research confirmed the predicted negative impact of the pandemic on PA undergraduates as a result of various society-wide measures. Similar limitations in the future may already have a more lasting impact on reducing the aerobic fitness of physically active people with potential long-term health consequences. Comparison of beep test results between women and men showed that women showed higher levels of VO_2max compared to men within the gender-specific norms. Women's achievement of higher levels of VO_2max compared to men may be influenced by their more effective engagement in performing PA even under constrained conditions. Women prefer aerobic activities, strength exercises in medium intensity with the focus on weight correction and body shaping. Men prefer strength exercises and collective sports games, more often associated with high intensity in their performance. The opportunities to perform team games and strength exercises were significantly limited during the pandemic period, which may have been one of the reasons for their lower aerobic performance.

The evidence of PA effect on health and aerobic fitness is now clearly established and validated. As PA decreases, the likelihood of long-term health risks increases. Performing adequate PA even during the period of university studies and establishing an exercise habit is important for building an active lifestyle, which contributes to consolidate health, reduce health risks and is generally an important preventive measure against civilisation-related diseases. It should be one of society's priorities to continually strive to build a system for providing sufficient opportunities for sport at all ages, with the long-term aim of improving physical education, sport and public health strategies.

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SELECTED TRAINING STRATEGIES TO IMPROVE PERFORMANCE IN MEN'S SPORTS SWIMMING

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Abstract The main aim of study was to identify effective strategies to increase the endurance and stamina of professional swimmers, thereby enhancing their overall performance in long-distance or endurance swimming competitions. The study included 21 participants from swimming clubs with a mean age of 17.34 ±2.51 years. The age range was 15 to 26 years, with varying height (172 cm to 196 cm) and weight (54 kg to 87 kg). The comprehensive study included anthropometric and isokinetic measurements, as well as training assessments analysed using statistical methods. Statistically significant changes were observed in the right arm (159.22% to 178.52%) and left arm (149.13% to 169.08% and 40.20%). There was a statistically significant improvement of 22.5 % in the left arm only straightening movement. The study's conclusions emphasise the importance of high-intensity exercises between 80% and 100% of maximum capacity to increase speed and power. These exercises should include significant resistance (70% to 90% of maximum load) and a limited range of repetitions (1 to 10). To develop strength and endurance, workouts should mirror the pace of a typical distance swim, incorporating moderate loads (45% to 80% of maximum body weight) and a greater range of repetitions (20 to 200).

Key words: swimming, endurance, strength, performance

Introduction

The development of swimming as a sport has been influenced by new swimming techniques, modern sports facilities and sports associations and unions, but also by successive record-breaking performances (Lipoński, 2006; Nadobnik & Wiażewicz, 2022), but the logistic curves provide evidence that swimming records experienced a period of "accelerated" growth during the 1960–1970s and are now beginning to plateau (Nevill et al., 2007). Sport swimming is a very demanding sport. Training sessions last 5 or even 7 days a week and often twice a day. The average daily training volume ranges from 6.000 m to 10.000 m and more (Feijen et al., 2020). It should be assumed that athletes make an average of 8 to 10 shoulder movements over a distance of 25 meters, this means that they make about 30.000 rotations of each shoulder joint per week. This puts a significant strain on the shoulder girdle (Heinlein & Cosgarea, 2010). Daily swimming training of many hours of about more than 1 million times per annual cycle (Johnson et al., 2003) may influence the pathogenesis of swimmer's shoulder caused by repetitive swimming movements (Struyf et al., 2017; Sein et al., 2010).

Swimming at a high professional sporting level requires athletes to have somatic predispositions, such as body composition and structure (Hibberd et al., 2016; Shimura et al., 2021). Studies highlight the importance of these physical characteristics in enhancing performance and reducing the risk of injury (Zwierzchowska et al. 2023; Czabański et al., 2003). Depending on the distance, athletes rely on different energy sources during the effort. The configuration of a swimmer's energy utilization pattern should be tailored to the specific race distance in which the athlete specializes, know how the different energy systems (aerobic, anaerobic, lactate threshold) are engaged depending on the intensity and duration of the swim. It is the job of coaches to adapt training to optimise energy use for specific race distances (Guignard et al., 2019; Lorens et al., 2011).

The selection of male athletes is based on factors such as body proportions, height and relatively low body mass, smooth musculature, fine bone structure, adequate length and width of hands and feet, compatible calendar and biological age, high level of motor coordination according to the Rohrer index and high vital lung capacity, large range of motion in the shoulder and ankle joints (Jurimae et al., 2007; Maszczyk et al., 2011; Swanik et al., 2002; Seifert & Chollet, 2009). Talent, interest in swimming, diligence and good health also play a huge Role (Wiażewicz, 2015). Therefore, it would be appropriate to ask what methods should be used to improve sports performance in men's swimming. In this article, the authors, by conducting scientific research, try to answer this research question.

Many researchers confirm the need to modify training programmes to achieve the best athletic

Performance (Batalha et al., 2015; Morouęo et al., 2011a). Not only training in water, but also training on land is very important because it can result in improved arm performance in athletes (Morouęo et al., 2011b; Alonso-Cortes et al., 2006). Such training leads to an even development of the body by athletes (Ikeda et al., 2002). In contrast, specialised strength training improves muscle balance around the shoulder joint (Rzepka, 2012). In the provided article, the research encompassed a comprehensive set of approaches, including a literature review, gathering and examining demographic data and swimming performance results, as well as conducting anthropometric and isokinetic measurements. Furthermore, the study involved assessing generated graphs, evaluating the efficacy of training interventions, and performing statistical analyses on the acquired data. Various research methods were employed, such as observation, examination of individual cases, experimental techniques, statistical analysis, document analysis, interviews, and measurements, as relevant to the specific research methods used. In order to make a more detailed inference about the force in the shoulder joints, an analysis of the straightening torque variation curves generated from the collected data was performed. Torque was analysed over the 180-0° movement range. The analysis of the torque distribution data in the righting movement at the shoulder joint follows (Ciosek et al., 2015; Łubkowska & Troszczyński, 2011; Biodex, 2018).

We hypothesised that in order to increase swimmers' speed and power, it is necessary to exercise at a level close to the athlete's maximum capacity with a limited number of exercise repetitions. In contrast, to increase strength and endurance, a moderate load is sufficient, but with an increased number of repetitions of training exercises.

Material and Methods

Prior to conducting the study, consent was sought from the Bioethics Committee of the Regional Medical Chamber in Szczecin Poland to conduct the study. The Commission gave such consent through its resolution No. 15/KB/V/2013. The study group consisted of 21 athletes of the Szczecin City Swimming Club (MKP), who held a sports class of the Polish Swimming Federation (PZP). In addition, they were to be at least 14 years old. Participants received dietary catering, which consisted of a personalised high-protein and high-carbohydrate diet to meet each athlete's specific nutritional requirements. The daily routine of the participants involved two training sessions, one in the morning and one in the afternoon. The lifestyle and nutrition of the subjects were comparable. The average age of the male participants was 17.34 ±2.51 years, with the oldest individual being 26 years old and the youngest six athletes aged 15 years. The average height of the athletes was 183.48 ±5.56 cm, ranging from the tallest at 196 cm to the shortest at 172 cm. The average weight of the subjects was 73.41 ±8.46 kg, with the highest recorded weight at 87 kg and the lowest at 54 kg. The mean training seniority was 10.34 ±2.8 years. The highest value of seniority was shown at 20 years, while the lowest value was 6 years. The athletes represented different classes. Among the athletes surveyed were world championships medalist; European championships finalist; European junior championships medalists, Polish championships participant, finalists and medalists; Polish junior championships finalists and medalists. The use of an isokinetic mode in the case of male athletes offered the possibility to control the speed of execution of a set movement. "Adjusting resistance" allowed the subject to increase the speed of the movement during the measurement, but no more than a preset value for the direction of movement (Moore at al., 2021). The flexion movement measurements encompassed the entire range of motion, starting from the position of maximum downward and backward extension of the joint and concluding at the point of maximum upward and backward flexion of the arm. Similarly, the measurements for straightening were conducted in the opposite direction. In total, each measurement generated 68 distinct strength parameter values for an individual, considering factors such as the limb's movement direction, the side of the body, and any disparities between the sides. A total of 4556 different values were collected during force measurements. The equipment utilized for this study was situated within the premises of the Biological Regeneration and Rehabilitation Centre at the Szczecin House of Sports (SDS) in Poland. An experimental approach was employed to assess the efficacy of an annual training program focused on strength training. These measurements were conducted on two occasions.

For the purposes of the study, the significance of the differences in the results of the individual strength parameters obtained in measurement one and two was analysed. An assessment of variable distributions was conducted. When the results of the Shapiro-Wilk test indicated that the distribution of variables in both measurements did not significantly deviate from normal (W > Critical value for 21 cases = 0.908 for men), a parametric Student's t-test for paired samples was employed. In cases where at least one parameter from either measurement significantly departed from a normal distribution (W < Critical value for 21 cases = 0.908 for men), the non-parametric Wilcoxon matched-pairs test was utilized. This test is the non-parametric equivalent of the Student's t-test for correlated variables. The presentation of results involved means ( ) and standard deviations (SD) or medians (Me) and interquartile ranges (R), contingent on the assessment of data distribution fitting normality (Łubkowska & Troszczyński, 2013; Skurvydas et al., 2008). For the statistical analysis of the variables, the differences between the sport score from measurement one and measurement two (AWS = WS2 – WS1) and the differences in the scores of the individual strength parameters between measurement two and measurement one (e.g. APT = PTII measurement – PTI measurement) were calculated. An analysis of the distributions of the variables was performed using the Shapiro-Wilk test. When the results of the Shapiro-Wilk test indicated that the distribution of both compared variables (differences) did not deviate significantly from the normal distribution (W > Critical value for 21 cases = 0.908 for men), r- Pearson correlation analysis was applied. In addition, the coefficient of determination (R^2) was calculated. If the result of the analysis of the distribution of at least one of the compared variables (differences) indicated that the distribution deviated significantly from the normal distribution (W critical value for 21 cases = 0.908 for men), rho-Spearman correlation analysis was performed (Wiażewicz, 2016).

Results

In the annual training plan, technical exercises were planned for an average of 246.73 km, but the actual performance was 222.53 km. Shoulder muscle strength exercises had an average load of 448.16 km, with a typical performance of 402.24 km. In the men's group, joint range of motion (ROM) increased in the second measurement for both arms, with more than a 3° increase in the average score of the right arm in the first measurement. The left arm also showed an increase from 228.00 ±12.40° to 237.70 ±18.10° in measurement two, although not statistically significant (Table 1).

Table 1. Parameter: Joint Range of Motion (ROM) of the arm in the tested athletes

			$W_{1\ x}$	$W_{2\ xxx}$	measurement I	measurement II	p
ROM	PR[1] (°)	(SD)	0.953	0.985	236.98 (15.76)	240.17 (20.30)	0.4160
	LR[2] (°)	Me (R)	0.961	0.862*	228.00 (12.40)	237.70 (18.10)	0.0582

ROM – parameter: joint range of motion; PR – right shoulder; LR – left shoulder; 1 – Wilcoxon's paired t-test was used. Student's t-test; 2 – Wilcoxon signed-rank test; $\bar{x}$ – arithmetic mean; SD – standard deviation; Me – median; R – quartile range; ° – degree, unit of measurement of plane angle; W1 – result of the Shapiro-Wilk test for the first measurement; W2 – result of the Shapiro-Wilk test for the second measurement; p – level of statistical significance; * – statistically significant result of the Shapiro-Wilk test, W < 0.908.

Men achieved a higher agonist:antagonist ratio (AG:AN) in measurement two, with a more than 2% increase for the right arm. There was also a trace increase of 0.1% in the AG:AN ratio for the left arm in the second measurement, but these changes were not statistically significant (Table 2).

Table 2. Parameter: Agonist to Antagonist Ratio (AG:AN) of the arm in the tested athletes

			W_1	W_2	measurement I	measurement II	p
AG:AN	PR[2] (%)	Me (R)	0.576*	0.435*	76.2 (25,8)	78.4 (8,5)	0.4140
LR[2] (%)	Me (R)	0.618*	0.413*	78.5 (24.3)	78.6 (9.5)	0.2971	

AG:AN – parameter: agonist to antagonist ratio; PR – right arm; LR – left arm; 2 – Wilcoxon matched pairs test applied; Me – median; R – quartile range; % – percentage; W1 – Shapiro-Wilk test result for measure one; W2 – Shapiro-Wilk test result for measure two; p – level of statistical significance; * – statistically significant result of the Shapiro-Wilk test, W < 0.908.

Peak torque (PT) increased in both arms for men in flexion and extension movements. In the right arm flexion movement, PT increased by almost 6 Nm ($P = 0.0073$), and in the right arm straightening movement, there was an increase from 74.32 ±19.46 Nm to 80.52 ±18.44 Nm ($P = 0.0415$). The left shoulder also showed an increase in PT in both movements, but these changes were not statistically significant (Table 3).

Table 3. Parameter: Peak Torque (PT) in flexion and extension movements of the of the arm in the tested athletes

				W_1	$W_{2\ xx}$	measurement I	measurement II	p
PT	bending	PR[1] (Nm)	(SD)	0.948	0.965	59.26 (12,67)	65.15 (15.55)	0.0073**
		LR[2] (Nm)	Me (R)	0.935	0.895*	58.00 (16.60)	60.20 (14.30)	0.1808
		scarcity[2] (%)	Me (R)	0.803*	0.848*	6.90 (8.80)	8.90 (7.70)	0.6143
	straightening	PR[1] (Nm)	(SD)	0.957	0.914	74.32 (19.46)	80.52 (18.44)	0.0415**
		LR[1] (Nm)	(SD)	0.933	0.941	71.74 (19.52)	75.92 (19.59)	0.2283
		scarcit [2] (%)	Me (R)	0.913	0.883*	7.60 (11.70)	6.30 (13.80)	0.9032

PT – parameter: peak torque; PR – right arm; LR – left arm; 1 – Student's t-test was used; 2 – Wilcoxon signed-rank test was used; $\bar{x}$ – arithmetic mean; SD – standard deviation; Me – median; R – quartile range; Nm – newton meter, unit of torque and torque unit; % – percentage value; W1 – Shapiro-Wilk test result for the first measurement; W2 – Shapiro-Wilk test result for the second measurement; p – level of statistical significance; * – statistically significant Shapiro-Wilk test result, W < 0.908; ** – statistically significant difference, p < 0.05.

Maximum repetition work (MRW) results were higher in measurement two, with a significant increase in the right arm flexion movement (almost 23 J, *P* = 0.0003) and the extensor movement (over 21 J, *P* = 0.0307). The left shoulder MRW in the flexion movement also increased significantly from 157.90 ±36.11 J in measurement one to 177.69 ±32.93 J in measurement two (*P* = 0.0026). In measurement two, athletes exhibited a slightly shorter time to peak torque (PT TIME) in the right arm flexion movement compared to measurement one. The left arm showed an almost twofold increase in PT TIME. A reduction in PT TIME during the straightening movement was observed for both arms, with statistical significance only for the left arm (*P* = 0.0015). The angle to peak torque attainment (PT ANGLE) in flexion was negative for both arms, while in extension, it was positive. In the straightening movement, the right arm showed a nonsignificant increase in PT ANGLE, whereas the left arm exhibited a significant 16° increase (*P* = .0091) in measurement two. Significant changes were noted in total work (TW) during flexion of both arms. The right arm had an almost 140 J improvement (*P* = 0.0031), and the left arm showed an almost 200 J improvement (*P* = 0.0125), leading to a decrease in the total work deficit (TW) between the test sides. Average power (AP) increased in both arms during flexion and extension movements in measurement two. The right arm's flexion movement score increased from 60.47 ±20.61 W in measurement one to 70.02 ±25.93 W in measurement two (*P* = 0.0018). Similarly, athletes in the left shoulder test demonstrated an increase from 59.04 ±20.33 W to 66.54 ±19.96 W (*P* = 0.0145) between the two measurements. In the second measurement, statistically significant changes occurred in average power (AP) during the straightening movement in both the right and left arms, with a negligible non-significant change in the average arm power deficit. Acceleration time (AT) changes were small and variable, with slightly higher values in the right arm flexion movement and a slight reduction in the left arm AT. Deceleration time (DT) in the flexion movement showed consistent results for the right arm and a slight increase in the left arm in measurement two. There was a trace reduction in DT during straightening movements for both arms. Average peak torque (APT) increased significantly in both flexion and extension movements for both arms. The right arm flexion movement showed a statistically significant change from 38.95 ±10.27 Nm in measurement one to 43.10 ±14.88 Nm in measurement two (*P* = 0.0180). Results for peak torque to body weight (PT/BW) ratio were higher in the second measurement, with a significant improvement in the right arm for both movements. Athletes achieved a significant increase in PT/BW ratio, from 81.50 ±14.40% to 89.10 ±16.56% in the right arm, and from 102.27 ±23.04% to 110.97 ±22.70% in the left arm, in measurement two. The left arm showed a slight improvement in the peak torque to body weight (PT/BW) ratio in both flexion and extension movements, but these changes were not statistically significant. In the work to body weight (W/BW) ratio measurement, athletes achieved overall increases, with significant changes observed in the right arm (from 159.22 ±41.49% to 178.52 ±48.88%) and the left arm (from 149.13 ±39.71% to 169.08 ±40.20%). Fatigue factor (WF) scores were higher in the second measurement for the right arm, but lower for the left arm. The athletes in the second measurement of the right arm scored a few per cent higher than in the first measurement. This was true for movements in both directions, but a statistically significant change only occurred for right shoulder extension: in measurement one, the value of the factor in question was 0.4 ±72.2 per cent, while in measurement two it was already 7.1 ±59.4 per cent ($P = 0.0129$). A slight reduction in the fatigue factor (WF) value for men was observed in the left arm test, both in flexion and extension movements.

Discussion and implication

It was noted that almost all isokinetic variables obtained in the presented studies were higher in shoulder straightening movements than in flexion movements for both sides and speed. This is corroborated by data obtained among sports subjects, as well as the results of non-training subjects. Shoulder joint range of motion (ROM) among the male participants was greater than the normal value of 208–218°. The biomechanical characteristics of upper limb movements during swimming require significant mobility in the shoulder joint. However, hypermobility in the shoulder joint can also cause strength deficits and accelerated fatigue in internal rotation, which increases the risk of shoulder injury. The agonist-to-antagonist ratio (AG:AN) in study one was similar to the average value of 88–89% obtained in studies of Masters category swimmers.

Among swimmers, the mean values of this parameter were several to several per cent lower. Agonist to antagonist (AG:AN) ratios among athletes with dominant shoulder straightening movements, during training and during athletic competition, were reported to be 50% in baseball pitchers. In young players, the coefficient in question took on values of 88–92%. It should be borne in mind that increased joint stability is influenced by the maintenance of appropriate proportions of the strength of individual muscle groups. Peak torque (PT) values of the arms in both measurements, among the tested athletes, showed higher values, from a few to even several Nm in bending and in extending, about 48 Nm for bending and about 67 Nm for extending. This was the average for male, exclusively swimming sprinters. This confirmed the thesis of higher strength demands placed on sprinters. The value of the torque was able to change with the change of the preset angular velocity. The lower the preset angular velocity, the more torque could be produced in concentric contraction. Although many authors base their studies solely on the analysis of peak torque (PT) of the arm muscles, the inference should be extended to include the results of other strength parameters obtained by isokinetic measurement. Describing shoulder muscle characteristics solely by peak torque (PT) values may not be exhaustive. Acceleration time (AT) and deceleration time (DT) were the values of the time it took the subjects to reach the set angular velocity and to stop ($v = 0$) from the angular velocity. In this way, the neuromuscular abilities of the subjects to induce movement and to eccentrically control at the end of the range of motion were assessed. The lower the values of these parameters, the higher the neuromuscular abilities of the subject. The values of acceleration time (AT) and deceleration time (DT) of the athletes varied. Average peak torque (APT) is the quotient of the sum of the peak torque values of all repetitions performed during the test and the number of these repetitions. This parameter provided an opportunity to assess the ability of the muscles to maintain a high level of peak torque for all repetitions in the test. The peak torque to body weight (PT/BW) ratio in the men's group for the flexion movement took an average value at the lower limit of the norm, and for the extensor movement at its middle range. It should be added that these norms were created based on the results of non-trained individuals. The acceptable coefficient of variation (COV) for large muscle groups, which include the shoulder, is 15%. For male swimmers, the value of this variable was within normal limits and the results were similar to those of young swimmers – 10–12%, in a study on young swimmers, showed several percent higher values of this parameter for shoulder flexion – 24–25% and a negative value in the straightening movement, from about –8% to about –17%, compared to the results in the presented article.

Conclusion

To improve speed and power, it is necessary to perform exercises at between 80% and 100% of the athlete's maximum capacity. Workouts should include significant resistance between 70% and 90% of maximum body weight and a maximum of 10 repetitions.

When focusing on building strength and endurance, it is necessary to match the pace to a typical swimming distance. This includes working with a moderate load, usually in the range of 45% to 80% of your maximum body weight and covering a number of repetitions between 20 and 200.

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EFFECT OF CORRECTIVE EXERCISE STRATEGIES ON TAPPING SKILL AMONG UNIVERSITY LEVEL KHO KHO PLAYERS WITH OVERPRONATED FOOT

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[A]Study Design; [B]Data Collection; [C]Statistical Analysis; [D]Manuscript Preparation

Abstract One of the key abilities in the game Kho Kho is tapping. Control of running speed, along with appropriate body balance and suppleness, are necessary for this tapping skill. Research and clinical practice have focused a lot of attention on foot pronation as a possible risk factor for lower extremity overuse injuries. The aim of the article is to determine the effectiveness of corrective exercise strategies on tapping skill among university level kho kho players with overpronated foot. In this randomized controlled trial, total of 30 university level kho kho players in Saveetha school of physical education were selected according to the inclusion and exclusion criteria. 30 players were equally randomized into two groups. One group received corrective exercise strategies protocol and the other group received general strength training for a period of 8 weeks. Navicular drop test and tapping skill test were used as outcome measures. This study concluded that the corrective exercise strategies were effective in improving tapping skill among university level kho kho players with overpronated foot when compared to regular strength training where the p value was <0.0001.

Key words: overpronation, corrective exercise strategies, kho kho players, navicular drop test, tapping skill test

Introduction

An traditional Indian tag game between two teams is called Kho Kho. A rectangular field that is normally 27 meters long and 16 meters broad is used for the game. The game offers a special blend of strategy, agility, and speed. There are twelve players on each team, but only nine of them are ever on the field at once. Within a set amount of time, the "chaser" team's goal is to tag as many players on the "defending" team as possible.

To rule the game of Kho Kho, one must possess both offensive and defensive abilities. One of the key abilities in the game Kho Kho is tapping. Control of running speed, along with appropriate body balance and suppleness, are necessary for this tapping skill (Tiwari & Venugopal, 2015). It also demands a certain level of skill from the players. The game is an excellent way to test one's strength, speed, stamina, and physical fitness. This game requires quick reflexes and forceful, fast motions of the entire body, which frequently leads to injuries. These injuries are caused by mishaps, subpar instruction, subpar facilities, inadequate conditioning, or inadequate stretching and warm-up. As diverse as the players are, equally varied are the quantity and kinds of injuries. Any complaint or injury sustained by a player that results in tissue damage, results in lost time, and requires medical attention is considered a sports injury (Patil & Dnyanesh, 2019).

Research and clinical practice have focused a lot of attention on foot pronation as a possible higher probability of injuries sustained during overuse of the lower body. Foot mechanics is thought to have a role in lower extremity malalignment and condition close to the foot through joint coupling with the tibial internal rotation (Dabholkar et al., 2017). Foot abnormalities can alter the lower limb's range of motion and occasionally raise the risk of injury. The connection between foot abnormalities and enhancing the possibility of lower extremity injuries originates from atypical muscular contractions. For instance, it is pointed out that people with flat feet showed higher or reduced lower limb activity as a result of neuromuscular reflect adjustments to reduce the strain generated by the foot abnormality while moving (Khodaveisi et al., 2016).

A hypermobile midfoot and a flattening of the medial arch are characteristics of excessive pronation, which can also put more strain on the neuromuscular mechanism that keeps the foot stable and upright posture. Foot type influences postural stability in both static and dynamic scenarios. It seems that these variations are connected to structural variations as opposed to variations in supplemental information (Cote et al., 2005).

Researchers have investigated the corrective exercise on overpronation foot and changes in the foot were found (Yalfani et al., 2023). For example, (Golchini & Rahnama, 2020) examined twelve weeks of systematic and functional corrective exercises using FMS. The result concluded that the body posture improved. Goo et al. (2016) showed that the strengthening of gluteus maximus helped to improve the flatfoot. Kazemi Pakdel et al. (2022) investigated the comprehensive corrective exercise on function and joint position sense with pronated foot concludes improvement in the flatfoot.

Prevalence showed that it is necessary to evaluate the foot posture of Kho Kho players (Dabholkar et al., 2017). Numerous research have included corrective exercise on balance, proprioception, changes in arch of foot (Yalfani et al., 2023), body posture (Golchini & Rahnama, 2020), muscle activity (Goo et al., 2016), function, joint position sense (Kazemi et al., 2022) with overpronated foot. The literature indicates that no research has yet demonstrated the effect of corrective exercises on tapping skill. Hence, the intent of this study was to look at the efficiency of corrective exercise on tapping skill among university level Kho Kho players with overpronated foot.

Material and Methods

The study received approval from the Institutional review board of Saveetha University. [01/037/2023/ISRB/PGSR/SCPT]

Design

We carried out single blinded randomized controlled trial to demonstrate the effectiveness of corrective exercise strategies on tapping skill among university level Kho Kho players with overpronated foot. All the players were signed in the informed consent form.

Participants

From Saveetha College of Physiotherapy, we have taken Kho Kho players and analyzed the foot posture using navicular drop test. We included players who had participated at the university level, practicing Kho Kho for the past one year at the competitive level, age group of 18 to 26. We excluded players if they had recent ankle injuries, lower limb fractures. Among 98 university level Kho Kho players, 30 players were overpronated (more than 10mm of navicular drop) and fulfilled the inclusion criteria. They were randomly divided into 2 groups. One group received corrective exercise strategies, and the other group continued their regular strength training.

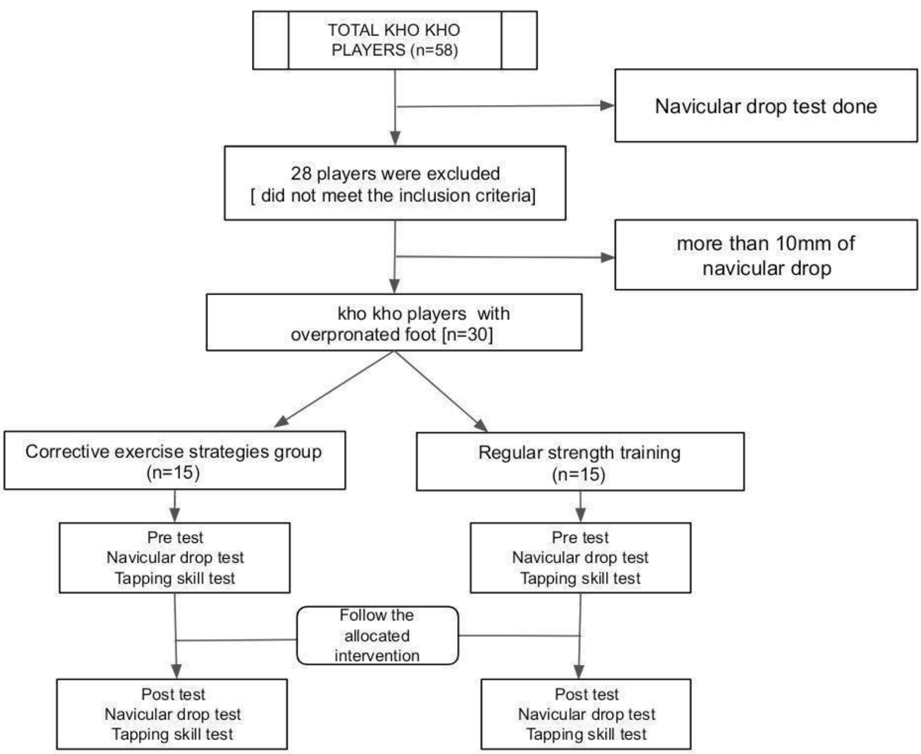

Figure 1. Shows Flowchart on Methodology

Procedures

For one session, the players commuted to the sports medicine gym. We took the players' navicular drop measurement at the beginning of the session. Next, the players performed the tapping skill test on the Kho Kho ground. Following the baseline evaluation, players were randomly assigned into two groups and performed the intervention that was assigned to them, as detailed in this section. After eight weeks, the same assessments (posttest) were completed by the players following the intervention. Both tests were completed by the players three times, and the three trials average was used to examine the data.

Outcome measure

Navicular drop test:

The degree of subtalar pronation was measured using the navicular-drop test, which we utilized to screen patients for foot type (Adhikari et al., 2014; Chandan et al., 2018). The individual was placed in a weight-bearing position and the navicular drop was assessed by altered version of the Brody method. The individual was instructed to stand on a four inch (10.16-cm) box barefoot, with one foot lightly resting on the box and all weight applied to the foot that was being measured. The therapist palpated the medial and lateral part of the talar dome with the thumb and index finger, which can be found exactly in front of the anterior aspect of the fibula as well as anterior and inferior to the medial malleolus. The player gradually turned over and everted their ankle and hindfoot until the therapist's thumb and index finger felt the depressions. The therapist positioned the foot in this neutral subtalar position and calculated the distance in millimeters between the floor and the navicular tubercle by a length of ruler. Therapist asked the player to allow the ankle into full weight bearing, and then we used a ruler to measure the player's navicular position. Noted the difference between the player's navicular drop score and its last weight-bearing. The navicular drop was measured three times, and the players were divided into two groups randomly. After 8 weeks of intervention, players were asked to perform the navicular drop test for the post test.

Tapping skill test:

Stopwatch, measuring tape, whistle, four cones were used as tools. Kho Kho ground which was twenty three meters & four meters, pole to first block two meters, second block to seventh block two meters, eighth to second pole two meters, and square box three by three centimeters.

In the space between the seated blocks, four cones were positioned. Square cones were arranged as follows: the first cone placed between the 1st and 2nd seated blocks, the 2nd cone between the 3rd and 4th seated blocks, the 3rd between the 5th and 6th seated blocks, and the 4th cone between the 7th and 9th seated blocks. A player begins running from the starting line when the whistle sounds. He touches the 1st cone with the right hand while facing forward and bending his right knee. Then, the player runs to the second pole and meets the third cone in the same way. Finally, finishes the run by running to the second pole and touching the fourth and second cones in the same way (Figure 2). A player received three chances, and the best attempt was noted (Patil & Dnyanesh, 2019). This test was performed before and after 8 weeks of intervention.

For eight weeks, the corrective exercise group (Group A) underwent a corrective exercise strategies while the regular strength training group (Group B) carried on with their regular strength training.

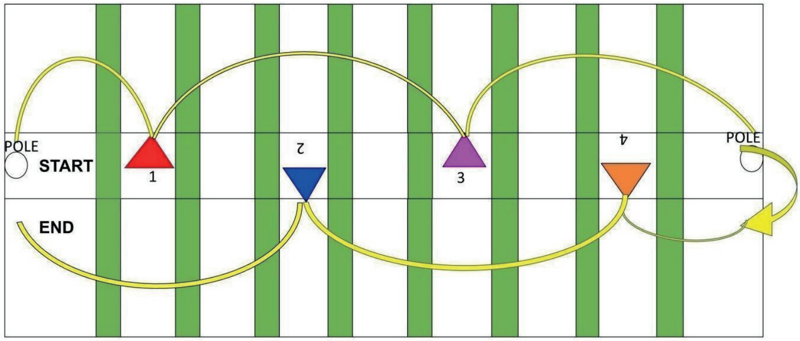

Figure 2. Shows Tapping Skill Test Ground

Corrective exercise strategies:

The methodical process of diagnosing a neuromuscular skeletal problem, creating a plan of action, and putting an integrated corrective strategy into practice is referred to as "corrective exercise." Exercise technique, the formulation of a correction program, and knowledge of the integrated assessment process are required for this process. A methodical strategy for handling this process has been devised by the National Academy of Sports Medicine (NASM) (Clark & Lucett, 2010). The four main phases of the NASM corrective exercise continuum are:

1. Phase of Inhibition: In order to relieve tension or lower the activity of the body's hyperactive neuromyofascial tissues, the inhibition phase applies inhibitory strategies. Foam rollers and other self-myofascial release techniques are frequently utilized to accomplish this.
2. Phase of Lengthening: Static stretching and neuromuscular stretching are two lengthening procedures used in the lengthening phase to improve extensibility.
3. Phase of Activation: Reeducating underactive tissues and boosting activation are the goals of the activation phase. Positional isometrics and individual strengthening exercises can be used to achieve this.
4. Phase of Integration: The goal of the integration phase is to conduct integrated dynamic motions in order to functionally progress and retrain all muscles and muscular subsystems to function in unison. Health and fitness experts can address muscular imbalances, reduce injuries, and aid to restore functional movement patterns with the help of corrective exercise methodologies like NASM's Corrective Exercise Continuum.

One day following the pretest, the eight weeks training regimen with the therapist began individually for each player (three sessions a week). Corrective exercises comprised 24 sixty-minute sessions, 10 min for the initial warm-up, 5 min for the constraint workouts, 35 min for the stretching, strengthening, and integrative activities, and 10 min for the cool-down. (Clark & Lucett, 2010) (Table 1).

Table 1. Corrective exercise strategies

Indicators Exercise	Exercise	Sets	Reps
Inhibit exercise	Gastrocnemius/soleus	1	1
(myofascial release/ foam roll)	Biceps femoris	1	1
Duration – 30 s	Iliotibial band	1	1
	Adductors/hip flexors	1	1
	peroneals	1	1
Lengthen exercise	Gastrocnemius	1	1
(static stretching)	Soleus	1	1
Duration – 30 s	Biceps femoris	1	1
	Iliotibial band	1	1
	Adductors/hip flexors	1	1
	peroneals	1	1
Activation exercises	Ankle dorsiflexion against resistance.	1–2	10–15
Isolated strengthening exercises	Plantar flexion and inverting against resistance	1–2	10–15
	Raise the heel of one foot	1–2	10–15
	Bending knee against resistance with internal rotation	1–2	10–15
	Towel scrunches and shorten the leg without flexing fingers	1–2	10–15
	Abduction and external rotation of hip against resistance .	1–2	10–15
Positional isometrics techniques	Supine position with knees bend at 90 degree against hand resistance	1	4
	Supine position with straight knees, plantarand inversion foot against hand resistance	1	4
	Supine position with straight knees against hand resistance dorsiflexion foot	1	4
Integrate exercises	Single leg balance reach (in several directions)	1–2	10–15
(integrated dynamic movement)	Step ups	1–2	10–15
	Lunges	1–2	10–15
	Single leg squat	1–2	10–15

Table 1 shows corrective exercise strategies protocol.

Statistical analysis

Data Collection: Data were collected using the navicular drop test and tapping skill test from a total of thirty players, divided into two groups: Group A (corrective exercise) and Group B (regular strength training).

Paired t-test: The paired t-test was used to analyze the pretest and posttest values within each group (Group A and Group B) separately for both the navicular drop test and tapping skill test. This test helps to determine the significant changes within each group after the intervention.

Unpaired t-test: The unpaired t-test was employed to compare the posttest values between Group A and Group B for both the navicular drop test and tapping skill test. This test helps to assess the significant differences in outcomes between the two groups after the intervention.

Table 2. Pre test and post test values of Group A using paired t test

S NO	OUTCOME	EXPERIMENTAL GROUP		T VALUE	P VALUE
		Pre test (mean ±SD)	Post test (mean ±SD)		
1	Navicular drop test	12.50 ±1.28	9.92±0.85	14.9173	p < 0.0001
2	Tapping skill test	11.97 ±1.30	10.47±0.72	6.4078	p < 0.0001

Table 3. Pre test and post test values of Group B using paired t test

S NO	OUTCOME	CONTROL GROUP		T VALUE	P VALUE
		Pre test (mean ±SD)	Post test (mean ±SD)		
1	Navicular drop test	12.63 ±1.49	12.52 ±1.50	5.9059	p < 0.0001
2	Tapping skill test	11.94 ±1.21	11.68 ±1.28	4.3752	p < 0.0001

Table 4. Post test values of Group A and Group B using unpaired t test

S NO	OUTCOME	Experimental group (mean ±SD)	control group (mean ±SD]	T VALUE	P VALUE
1	Navicular drop test	2.573 ±0.66	0.12 ±0.68	14.1494	p < 0.0001
2	Tapping skill test	1.503 ±0.90	0.263 ±0.23	5.1196	p < 0.0001

Results

Before interventions as pretest values and after interventions as posttest values, data was collected using the navicular drop test and tapping skill test. The results were statistically analyzed. The values from the tapping skill test and the navicular drop test were evaluated using paired t tests for the Corrective exercise Group and the Regular strength training group. The unpaired t test was used to assess the post-test results for both groups.

Tapping skill has significantly increased for the corrective exercise group, as seen by pre- and posttest results from the navicular drop test and tapping skill test values assessed using paired t tests. The corrective exercise group was evaluated using the tapping skill test and the navicular drop test, which are shown in Table 2. The pretest mean value of the navicular drop test was 12.50, SD 1.28, and p value <0.0001, while the posttest mean value was 9.92, SD 0.85, and p value <0.0001. The pretest mean value of the tapping skill test was 11.9740, SD 1.3008, and p value <0.0001, while the posttest mean value was 10.4707, SD 0.7245, and p value <0.0001. A noteworthy distinction [P < 0.0001] exists in the group's post-treatment enhancements and the changes that would have happened by chance. Following corrective exercise measures, it was found that scores on the tapping skill test and the navicular drop test improved significantly.

Table 3 presents the results of the navicular drop test and tapping skill test administered to the regular training group. The pretest mean value of the tapping skill test was 11.94, SD 1.21 and p value <0.0001 whereas the posttest mean value was 11.68, SD 1.28, and p value <0.0001. The pretest mean of the navicular drop test was 12.63, SD 1.49, and p value <0.0001, while posttest mean was 12.52, SD 1.50, and p value <0.0001. A noteworthy distinction [P < 0.0001] exists in the group's post-treatment enhancements. and the changes that would have happened by chance. It was discovered that using the conventional approach considerably increased the results of the tapping skill test and the navicular drop test.

The results of the corrective exercise group and regular strength training post-test for tapping skill test and navicular drop test, when examined using the unpaired t test, reveal a significant difference. Table 4 showed the posttest results for the corrective exercise group and regular training group based on the tapping skill test and navicular drop test. The posttest results for the navicular drop test in the corrective exercise group were mean value 2.573 SD 0.66, p value <0.0001. The post-test results for the Navicular drop test in the Group B were mean value 0.12, SD 0.68, p value <0.0001. The posttest mean, SD, and p values for the tapping skill test for the corrective exercise group were 1.503, 0.90, and <0.0001. Posttest mean, SD, and P values for the tapping skill test for the regular training group were 0.263, 0.23, and <0.0001.

After eight weeks, tapping skill improved significantly with the use of corrective exercise programs (p < 0.001). Using the navicular drop test and tapping skill test, corrective exercise strategies significantly improved the navicular drop among university-level Kho Kho players with overpronated foot during 8-week protocol, despite improvements being seen in both groups.

Discussion

This study's goal was to determine the impact of corrective exercise strategies on tapping skill among university level Kho Kho players with overpronated foot. According to the study's conclusions, corrective exercise group who received corrective exercise strategies to evaluate navicular drop and tapping skill using navicular drop test and tapping skill test performed better than regular strength group. Furthermore, there is a lower chance of improvement in the tapping skill and navicular drop for regular strength training. Given that there was a 1.8 point average difference in the posttest scores in the tapping skill test, the difference was significant. The navicular drop test showed a 2.5 mm difference in scores from the posttests of corrective exercise group, with an average difference that was statistically significant. These findings showed that the corrective exercise group average scores were higher than the regular training group, and there were noticeable variations. It is noteworthy to notice that, although not statistically significant, there was a difference in the regular strength training group posttest and pretest average scores for the variables mentioned above.

Poor circumstances brought on by external stimuli, reduced motor function, and improper muscle and joint function are known as musculoskeletal abnormalities. The likelihood of injury and physical abnormalities rises if there is improper coordination among the opposing muscles on the joint's two sides.

The outcomes are consistent with research conducted by (Yalfani et al., 2023; Golchini & Rahnama, 2020; Goo et al., 2016; Kazemi Pakdel & Sedaghati, 2022) about corrective exercise strategies. This compatibility makes sense because the corrective exercise utilized in this research and the subjects were comparable to each other. Researchers and therapists take into account the muscle groups respective strengths, when evaluating the avoidance of injury and the treatment of physical deformities, and of course when monitoring the development of therapy and rehabilitation. The identification of simultaneous muscle groups has been found to be a significant factor in joint integrity (Golchini & Rahnama, 2020). The tibialis posterior tendon absorbs energy during early stance when the subtalar joint pronates during human walking. (Maharaj et al., 2017; Khayambashi et al., 2012) conducted study in females with patellofemoral pain, isolated hip abductor and external rotator strengthening proved beneficial in reducing pain and increasing health. According to the study's findings, bilateral foot pronation was associated with greater thoracic kyphosis, sacral position, pelvic tilt, and lumbar lordosis. Actually, every single one of them is a compensatory occurrence (Ghasemi et al., 2016).

Given that overpronation is associated with increased risk of lower extremity injuries, the effectiveness of corrective exercise strategies in addressing this issue has significant implications for injury prevention among kho kho players. By improving foot mechanics and stability through targeted exercises, players may experience reduced strain on the lower limbs during gameplay, ultimately lowering the incidence of injuries such as sprains and strains. The results of this investigation align with earlier studies that have looked at the impacts of corrective exercises on foot posture and function in various athletic populations. Studies investigating similar interventions have reported improvements in body posture, muscle activation patterns, and joint position sense following corrective exercise programs. The current study contributes to this body of literature by specifically focusing on tapping skill enhancement in kho kho players with overpronated foot.

Based on the current study's statistical analysis, Kho Kho players with overpronated foot who received corrective exercise strategies reported a notable improvement in their navicular drop and tapping skill.

Limitations

The Limitation of the study was inability to regulate the players' psychological component and motivation level, as well as its lack of control over the players' food and sleep. In this study, university level Kho Kho players were included. For future studies, state level kho kho players can be used.

Conclusion

The study's conclusion supports the effectiveness of corrective exercise strategies in improving tapping skill and addressing overpronation among university-level Kho Kho players. By targeting foot mechanics and stability, these interventions have the potential to reduce the risk of lower extremity injuries and enhance overall gameplay performance. Incorporating corrective exercises into training programs for Kho Kho players may therefore be beneficial in optimizing their athletic abilities and promoting long-term musculoskeletal health.

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EFFECTS OF STATIC AND DYNAMIC STRETCHING ON JOINT POSITION SENSE IN ARTISTIC GYMNASTS

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Abstract This study aimed to examine the effects of static and dynamic stretching as part of warm up routines on shoulder and knee joint position sense in artistic gymnasts. A randomized crossover design was employed, involving twenty-six artistic gymnastics athletes (age = 8.94 ±1.11 yr.), who performed on three separate days the following protocols: (a) 3 min of jogging followed by dynamic stretching, (b) 3 min of jogging followed by static stretching, and (c) 3 min of jogging without stretching. After the 3 protocols the athletes performed the active angle reproduction test for shoulder and knee joint position sense. The repeated measures ANOVA revealed no significant differences between static and dynamic stretching concerning shoulder and knee joint position sense. Gymnasts devote much of their training to stretching routines, resulting in exceptional flexibility compared to other athletes. Thus, warm-up stretching may not significantly alter young gymnasts' musculotendinous units, leaving their joint position sense unaffected. Moreover, the study sample consisted of young athletes, who have lower musculotendinous stiffness than adults, possibly making their joint position sense less affected by stretching due to their inherent lower stiffness. This study's findings indicate that 30-second warm-up static stretching does not adversely affect shoulder and knee joint position sense in gymnasts.

Key words: joint position sense, proprioception, gymnastics, stretching, children

Introduction

Traditionally, stretching exercises are performed during warm-up in gymnastics because they are considered to protect against injuries and enhance performance (Behm & Chaouachi, 2011; D'Anna & Gomez Paloma, 2015). However, recent literature provided evidence that pre-exercise static stretching (SS) might impair athletic performance, especially in sport activities related to maximal strength, jumping, and speed (Trajano et al., 2017).

The static stretch-induced decreases in strength and power parameters have been attributed to two mechanisms: (a) alterations in the musculotendinous unit (decreased muscle–tendon unit stiffness), and (b) disruptions in neural output, including decreased activation of motor units and changes in reflex sensitivity (Jelmini et al., 2018; Zaggelidou et al., 2023). Considering that stretching affects both extrafusal fibers and muscle spindle fibers (Guissard & Duchateau, 2004), it is reasonable to hypothesize that SS may also impair the function of muscle spindles (i.e. proprioceptive acuity) (Shah et al., 2023). Muscle spindles are intramuscular sensors that provide information about muscle length and velocity at which a muscle is stretched or contracted (Kröger & Watkins, 2021). They lie parallel to the main muscle and undergo stretching as the muscle lengthens, while they contract when the muscle shortens (Abbott et al., 2024). Therefore, alterations in the structure of muscle spindles, due to stretching, may also lead to impairments in sensory information related to the joint proprioceptive acuity (joint position sense).

Sensory information regarding joint positions plays a crucial role in enabling individuals to coordinate the movement of their body parts with respect to each other and their overall spatial orientation. A decrease in the acuity of joint position sense (afferent information from muscle spindles) could potentially lead to decreased performance (uncoordinated movements) and an increased risk of injury (Vasconcelos et al., 2018). It is widely recognized that acute SS has a short-term negative effect on extrafusal muscle fibers properties, such as muscle tendon stiffness and tendon tap reflex (T-reflex) (Behm et al., 2021; Murakami et al., 2024). However, the effects of acute SS on intrafusal muscle fibers (muscle spindles) remain relatively understudied.

A few studies investigated the impact of acute SS on joint position sense and their results have been inconclusive. Oskouei et al. (2021) reported that SS of the hamstrings affected negatively the knee joint position sense in football players. Whereas Ghaffarinejad et al. (2007) reported enhanced knee joint position sense in university students (25.6 ±1.2 years) after SS. On the contrary, Larsen et al. (2005) with a sample of university students (median age 25 years) and Torres et al. (2012) with a sample of healthy men (age: 22.1 ±2.7 years*)* reported that SS exercises have no effect on knee joint position sense. All those studies were conducted on the lower limbs; thus, their findings are limited to that specific body region. However, the performance in gymnastics depends not only on the precision of movement in the lower limbs but also in the upper limbs (Williams, 2023). To our knowledge, no study examined the effects of SS on shoulder position sense in gymnastics. Furthermore, the participants in studies examining the influence of SS on joint position sense (JPS) were adults. As far as we know, no study has compared the effects of SS and dynamic stretching (DS) on JPS in children. Children's musculotendinous units have greater compliance compared to adults, and they exhibit smaller stretch reflexes. Consequently, children may respond differently to stretching protocols compared to adults.

The purpose of the present study was to compare the effects of static and dynamic stretching on knee and shoulder position sense in young gymnasts. Since intrafusal fibers of muscle spindles exhibit thixotropic properties (Proske & Gandevia, 2012), it was hypothesized that SS might potentially modify the sensitivity of muscle spindle feedback, resulting in reduced accuracy of JPS. On the contrary, DS has been shown to increase muscle temperature and stimulate the nervous system (Herda et al., 2013), factors that are assumed to enhance the sensitivity of mechanoreceptors and potentially improve joint position sense (Sayyadi et al., 2024).

Methods

Participants

The sample size of the study was determined using G*Power (version 3.1) (Faul et al., 2007). The calculation parameters included an effect size (f) of 0.25, an alpha (α) of 0.05, and a power of 0.8. Based on G*Power's calculations, the optimal sample size is 28 children. Thirty-one guardians and children expressed interest in participating in the research (8.94 ±1.11 years old). However, the final sample consisted of 26 children because 5 children did not take part in all the procedures. The inclusion criteria for participation in the study were: (a) regular participation in artistic gymnastics training, at least 3 times per week, for a minimum duration of one year and (b) absence of acute musculoskeletal injuries, as reported by guardians.

The research adhered to the ethical guidelines of the local university. Informed consent was obtained from the children's guardians, and the children provided their oral assent. All procedures were conducted in accordance with the declaration of Helsinki.

Procedures

The participants attended an orientation session one week before the experimental protocols were performed. During this session, they were familiarized with both the stretching routines and the measures.

The study employed a randomized crossover design, comprising three experimental protocols. The three protocols were performed at the same time of the day (17:00–19:00 hr), with a period of 3–4 days between them. The order of the protocols and the tests was counterbalanced for each participant and each day to avoid carry-over effects.

Each protocol started with a 3-minute jogging at a self-selected moderate intensity (approximately 400m). After the 3-minute jogging, participants engaged in one of the three protocols: (a) 7 min SS, (b) 7 min DS or (c) sitting quietly for 7 min.

Stretching protocols

The stretching exercises targeted the main muscle groups relevant to the study's measurements. (shoulder and knee flexion): quadriceps, hamstrings, anterior deltoid, and pectoralis major (Figure 1). The typical duration of static stretching in gymnastics warm-up routines ranges between 15–30´´ per muscle group, and several studies reported that this duration is sufficient to achieve an increased range of motion (Chatzopoulos et al., 2019; Katsanis et al., 2021; Melocchi et al., 2021). Static stretching of the muscles was held for 30 s at a point of mild discomfort.

After a 10–15 s interval, the contralateral muscle group was stretched. The total duration of SS was approximately 7 min (±1 min).

The DS protocol comprised exercises that stretch the same muscle groups as in the SS protocol (Figure 1). The DS exercises lasted 30 s with a rate of approximately one stretch cycle every 2 s. The duration varied depending on the diverse range of movements performed by each participant. Each exercise consisted of 5 slow repetitions, followed by 10 repetitions performed as quickly as possible, all executed in a controlled manner without bouncing (Antonopoulos et al., 2014; Chatzopoulos et al., 2015). A similar 10–15 s rest period was provided between exercises, in accordance with the rest period in the SS protocol. The total duration of the DS was equivalent to that of the SS (7 ±1 min).

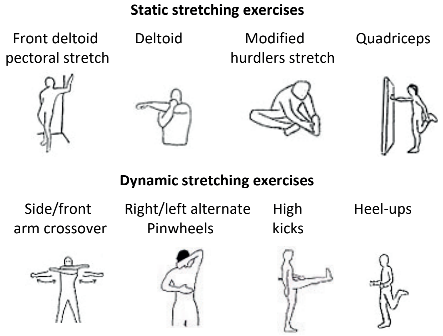

Fig. 1. Static and dynamic stretching exercises

Measurements

Shoulder and knee flexion was measured with KFORCE Sens® electrogoniometer, which offers real-time feedback of the angle on the tablet screen (measurement accuracy 1°, sampling rate 75Hz, Kinvent, France) (Tekin et al., 2022). Only the dominant arm and leg was measured. Arm dominance was determined with the question "Which hand do you use for eating?". Leg dominance was determined through the test of kicking a ball. The participants wore comfortable gymnastic clothes and shoes during the measurements to standardize proprioceptive input.

Standing shoulder flexion test

The KFORCE Sens® device was attached with Velcro fasteners perpendicular to the humeral shaft, positioned below the deltoid tuberosity (Figure 2). The participants were instructed to execute a forward flexion arm movement in the frontal plane with full elbow extension and maintaining neutral wrist flexion/extension.

Fig. 2. Standing shoulder flexion test

From a standing position with the arms relaxed at their sides, the participants were instructed to gradually flex their tested shoulder until reaching an angle of 30°, which was displayed on the tablet screen (the device provides real time feedback). After reaching the 30° angle, participants were instructed to maintain this position for 5 s and remember it. Subsequently, participants returned to the initial position with their arms relaxed at their sides. After a 5-second interval, they were asked to reproduce the memorized angle with closed eyes (blindfolded). Upon reaching what they perceived as the memorized reference position, they indicated to the examiner by saying "here," and their angle was recorded. After one practice trial, participants performed 3 trials with a resting period of 3 s. The mean of the 3 absolute differences between the 30° angle and the reproduced angle (blindfolded) was used for data analysis.

Standing knee flexion test

The KFORCE Sens® device was attached by Velcro fasteners above the lateral malleolus. The participants stood on a wooden platform (15 cm high) on their non-dominant leg, while their dominant leg hung freely beside the platform (Figure 3). The opposite hand of their dominant leg was attached to the wall to maintain their balance (Chatzopoulos, 2019).

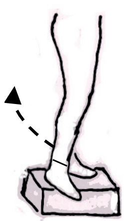

Fig. 3. Standing knee flexion test

The participants were instructed to flex their dominant knee until reaching the angle of 30°. The angle was displayed on the tablet screen (the application provides real time feedback). Once the leg had reached the 30° angle, the participants were instructed to stop there and remember this knee angle (position) for about 5 s. Then, the participants returned to the starting position, and after 5 s they were asked to reproduce the memorized knee angle without screen feedback (the screen was removed from their field of vision). When the participants felt they had reached the memorized angle position, they notified the examiner by saying "here," and the angle was recorded. After one practice trial participants underwent three trials with a restin°g period of 3 s. For data analysis, the mean of the three absolute differences between the 30° angle and the reproduced angle (without feedback) was calculated.

Statistical analysis

The differences among the three protocols were analyzed using one-way Analysis of Variance (ANOVA) repeated measures. In case the assumption of sphericity was violated, the Greenhouse-Geisser correction was applied. Effect sizes of ANOVA are presented as partial eta square values (η_p^2 small effect: 0.02; medium effect: 0.13; and large effect: 0.26). Post hoc analyses were conducted using the Holm-Sidak method for multiple comparisons.

Reliability was assessed using a two-way, random-effects, single measure Intraclass Correlation Coefficient (ICC 2,1). The ICC values were interpreted according to the guidelines of Hallgren (2012), that is, ICCs < 0.40 were labelled “poor”, 0.40–0.74 “fair to good”, >0.75 “excellent”. All statistical analyses were carried out employing SPSS (version 28). Statistical significance was set at $p \leq 0.05$.

Results

The descriptive statistics for the dependent variables are presented in Table 1.

Table 1. Descriptive data of shoulder and knee JPS tests

Joint position sense test	No stretching	Static stretching	Dynamic stretching
Shoulder (°)	2.79 ±1.60	3.76 ±2.03	3.09 ±1.70
Knee (°)	3.85 ±2.17	4.17 ±2.04	4.03 ±2.24

Shoulder joint position sense

There was no significant difference between the three protocols ($F = 2.08$, $p = 0.135$, partial eta squared $\eta_p^2 = 0.077$). Specifically, there was no significant difference between NS and SS ($p = 0.100$), NS and DS ($p = 0.926$) and between SS and DS ($p = 0.451$).

Knee joint position sense

Mauchly’s Test of Sphericity indicated a violation of the assumption of sphericity ($\chi^2 = 6.756$, $p = 0.034$), and a Greenhouse-Geisser correction was applied. There was no significant difference between the three protocols ($F = 2.07$, $p = 0.766$, $\eta_p^2 = 0.008$). Specifically, there was no significant difference between NS and SS ($p = 0.772$), NS and DS ($p = 0.986$) and between SS and DS ($p = 0.991$).

Reliability of the measurements

The reliability of the shoulder and knee flexion tests was assessed using the test–retest method in a pilot study involving 10 children (aged 9–10 years), conducted one week prior to the main study. The children underwent a retest 48 hours following the initial assessment, and the intraclass reliability coefficients were satisfactory (knee ICC2,1 = 0.615, shoulder ICC2,1 = 0.64). The children involved in the reliability measurements were not included in the main study.

Discussion

The aim of this study was to investigate the acute effects of static and dynamic stretching on joint position sense (JPS) in the upper and lower limbs of young gymnasts. Contrary to the hypothesis, the results did not indicate that static stretching (SS) would result in a reduction in knee and shoulder JPS of young gymnasts. Moreover, the findings did not support the hypothesis of an increase in JPS following dynamic stretching (DS).

The finding of the present study that SS does not affect JPS agree with the results of Torres et al. (2012) and Larsen et al. (2005). Indeed, Torres et al. (2012) reported no effects on knee JPS after 10 passive stretches lasting 30 s each (sample age: 22.1 ±2.7 years), and Larsen et al. (2005) no effects on knee JPS after 3 × 30 s SS (sample median age 25 years, range 21–31). Thus, it could be concluded that the results of this studies do not support the hypothesis that SS affects the viscoelastic properties of the muscle spindles and alters their proprioceptive sensitivity. However, another possible explanation for the no significant findings could be that sensory inputs are not restricted to muscle spindles (Riemann & Lephart, 2002). Proprioceptive input originates from various receptor submodalities situated in distinct tissues (e.g. muscle, tendon, skin ligamentous) (Cordo et al., 2011). It is quite probable that the relative importance of each receptor varies depending on the task. For instance, studies have demonstrated that skin receptors fire reliably in relation to the position and movement of adjacent joints (Cordo et al., 2011). In addition, articular afferents also convey information regarding position and movement in an additive manner with muscle and skin afferents. The cumulative nature of these signals, whether proportional or not, suggests that the sum of these afferent responds dictates the magnitude of sensation (Collins et al., 2005). Consequently, it seems that the descending commands from the central nervous system depend on the comprehensive processing of information originating from various receptors, and not exclusively from muscle spindles (Proske & Gandevia, 2012).

In contrast to our neutral findings, Walsh (2017) documented enhancements in knee JPS among 10 athletes competing in various sports (rugby, soccer and tennis) following SS (90 s duration). On the contrary, Oskouei et al. (2021) demonstrated that the SS of the hamstrings had an adverse impact on knee joint position sense in a sample of 12 adult football players (3 × 30 s). Apart from the variations in stretching procedures (e.g. pre-stretching aerobic activity, stretching duration, intensity), one significant difference between the previous studies and ours lies in the composition of the sample. The samples in the previous studies comprised athletes participating in sports with low flexibility demands (e.g. soccer, basketball), while ours consisted of gymnastics athletes. In gymnastics the level of technical and artistic perfection is determined by the range of motion (RoM) an athlete can achieve during the execution of these movements (Batista et al., 2019). For this reason, stretching exercises play a substantial role in daily gymnastics training, resulting in exceptionally high levels of flexibility compared to athletes in other sports (e.g., soccer, basketball, track and field) (Vernetta et al., 2022). Thus, it is possible that the stretching exercises of our study may not induce significant alterations in the musculotendinous unit of the gymnastics athletes, and consequently their JPS was not affected. Future research comparing samples with different levels of flexibility may help clarify this issue.

Regarding DS, the results of the present study showed no significant difference with NS (only jogging, without stretching), neither a difference compared to SS. The results of the current study agree with Younis et al. (2018) who reported no significant improvements in knee JPS after DS and proprioceptive neuromuscular facilitation (PNF) stretching (6 × 10 s contraction followed by 20 s of stretching). In addition, Romero-Franco et al. (2020) reported no differences between the SS group (5 min of running followed by 20 s SS) and the DS group (20 repetitions each muscle, gastrocnemius, hamstrings and quadriceps) in knee JPS. On the contrary Pamboris et al. (2019) reported that slow DS resulted in a better performance compared to pretesting (adult participants). Whereas Chen et al. (2018) reported decreased accuracy of knee JPS after DS (6 × 8 repetitions per set, total 48 repetitions). The divergent findings could be attributed to various factors, including muscle groups, stretching velocity, level of physical conditioning, and the testing protocol employed (e.g., passive repositioning test versus active).

Previous studies have suggested that active repositioning tests may provide a more precise evaluation of joint performance compared to passive tests (Benjaminse et al., 2009; Sayyadi et al., 2024). During active repositioning tests, participants can adjust the angle, while in passive repositioning, participants can only stop the movement at a point without adjustment (Ghanbari et al, 2014). In our study the active repositioning test was applied, and the participants showed high repositioning performance (the absolute difference was only a few degrees). Therefore, perhaps it was difficult to enhance this already high level of repositioning performance any further.

To our knowledge this is the first study that examined the effects of stretching on young children's JPS. Hence, comparisons between the results of previous studies and the present one should be approached with caution, considering the different viscoelastic properties of the muscle-tendon units between children and adults (Kubo et al., 2001). Children display lower musculotendinous stiffness compared to adults and their JPS may therefore be less affected by stretching. Future studies could explore whether children's JPS responds differently to stretching compared to adults.

The limitation of the study pertains to the characteristics of the sample (young gymnasts with high level of flexibility). Thus, the findings might not be applicable to other athletic populations. Another limitation refers to the subjective stretching in SS and DS. Despite instructing participants during SS to stretch "at a point of mild discomfort" and during DS to stretch "as high as possible," it was not possible to ascertain whether they exerted their maximum effort.

Conclusions

The successful execution of the technical elements in artistic gymnastics demands extreme flexibility levels (Di Cagno et al., 2014). For this reason, SS are an integral part of the warm-up routines in gymnastics. The findings of the present study suggest that a practical duration of warm-up SS of 30 s has no detrimental effects on shoulder and knee JPS.

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EFFECT OF CREATINE AND CAFFEINE SUPPLEMENTATION TOGETHER AND SEPARATELY ON SERUM LACTATE LEVELES AND PERFORMANCE OF MALE WRESTLERS

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Abstract Supplementation is widely used by athletes to enhance physical capabilities, improve exercise performance, and achieve other ergogenic effects. These practices promote adaptability, recovery, and the ability to train and compete. The aim of this study was to investigate the effects of caffeine, creatine, and their combination on performance and blood lactate levels in semi-professional male wrestlers. A total of twenty wrestlers participated in a double-blind, crossover, randomized placebo-controlled study, which included five experimental treatments: creatine (Cr), caffeine (CAF), creatine + caffeine (Cr+CAF), control (Con), and placebo (PLA). The participants, with an average age of 19.43 ±1.75 and a body mass index of 23.11 ±3.34, were selected voluntarily. Creatine and caffeine powder were mixed in water and consumed 60 minutes prior to each evaluation session. Performance and blood lactate values were measured before and immediately after the Dummy throw test. The results showed that performance significantly improved following the Cr+CAF and Cr conditions ($p \leq 0.05$). Additionally, blood lactate values immediately after the Dummy throw test were significantly lower in the Cr condition ($P = 0.04$) compared to PLA and CON. However, although blood lactate values decreased in the Cr+CAF condition, the difference was not statistically significant ($P > 0.05$). In conclusion, male wrestlers may benefit from the ergogenic effects of creatine and caffeine when consumed separately or in combination.

Key words: caffeine, creatine, sport performance, sports nutrition, wrestling

Introduction

Wrestling, an ancient combat sport with its origins traced back to the Ancient Greek Olympics, continues to hold a significant position as a discipline of great prominence within the contemporary Olympic Games (Barbas et al., 2011; Demirkan et al., 2015). It involves physical competition between two opponents of equal body mass, aiming to gain and maintain an advantage over the other. The sport incorporates various grappling techniques, including clinch combat, throws, takedowns, joint locks, pins, and other grappling positions, all performed on a matted area (Chaabene et al., 2017). Supplementation is widely utilized by athletes to enhance physical capabilities, improve exercise performance, and gain other ergogenic effects. These practices promote adaptability, recovery, and the ability to train and compete (Maughan et al., 2018). According to the consensus statement from the International Olympic Committee (Maughan et al., 2018), only a few supplements have sufficient evidence to support their efficacy in enhancing physical performance and athletic capabilities (Durkalec-Michalski et al., 2019). The ergogenic supplement widely recognized for its effectiveness in enhancing lean body mass and augmenting anaerobic performance is commonly acknowledged to be creatine monohydrate (Aedma et al., 2015). A commonly recommended protocol for creatine supplementation involves an initial loading phase of 20–25 grams per day for a duration of 2–7 days, followed by a maintenance phase of 2–5 grams per day (Cooper et al., 2012; Burke et al., 2006). A meta-analysis of 96 published studies, encompassing 1847 individuals, demonstrated that creatine supplementation had a greater impact on repetitive-bout exercises than on single-bout exercises and was more effective in upper-body performance tasks compared to lower-body performance activities (Branch, 2003). Furthermore, Koçak and Karli (2003) reported significant improvements in mean power and peak power achieved during a 30-second Wingate test in professional male wrestlers following creatine supplementation. Oopik et al. (2002) discovered that administering creatine to well-trained wrestlers during a 17-hour recovery period from rapid body mass loss facilitated the restoration of physical functioning abilities as assessed in a performance test simulating a wrestling competition.

Caffeine (CAF) (1,3,7-trimethylxanthine) is a stimulant present in coffee, tea, energy drinks, chocolate, guarana, kola, and bissey nut supplements (Durkalec-Michalski et al., 2019). CAF is typically consumed orally and metabolized by the liver (Magkos & Kavouras, 2005). After intake, blood CAF concentrations start to rise within approximately 15–45 min and reach a peak around 60 min (with a range of 15–120 min) (López-González et al., 2018). CAF has a half-life of 2.5–10 hours when taken in dosages below 10 mg/kg (Magkos & Kavouras, 2005). The effects of caffeine (CAF) supplementation on sports performance have been attributed to multiple proposed mechanisms (van Duinen et al., 2005). These mechanisms include its role as an adenosine receptor antagonist (Fredholm et al., 1999; Spriet & Gibala, 2004), modulation of central nervous system (CNS) activity (Sökmen et al., 2008), influence on muscle excitation-contraction coupling (Tarnopolsky, 2008), and recruitment of motor units (Cornish et al., 2015). CAF also promotes glycolytic activity and enhances muscular energy generation by increasing blood catecholamine levels (Van Soeren et al., 1993). The International Society of Sports Nutrition recommends consuming 3–6 mg/kg of CAF approximately 15–30 min before physical activity. Doses exceeding 9 mg/kg may not provide additional benefits (Goldstein et al., 2010).

Both creatine and caffeine are recognized as useful ergogenic aids for improving aerobic and anaerobic performance (Aaserud et al., 1998; Ahmun et al., 2005; Bemben & Lamont, 2005; Graef et al., 2009; Schneiker et al., 2006). It is necessary to research the effects of combined supplementation so that active individuals can gain more confidence in their knowledge of the effects of the supplements they choose to consume for performance improvement. Specifically, considering the research on the effects of caffeine and creatine supplementation on wrestlers and the sport's popularity worldwide, it is important to study the effects of combining creatine and caffeine on wrestlers. Therefore, this research aims to determine the effect of creatine and caffeine supplementation, both separately and together, on serum lactate levels and the performance of male wrestlers. This research hypothesis suggests that when creatine and caffeine are combined, performance will be at a greater level than when used alone.

Methods

Ethics approval and consent to participate

This study was approved by the Human Ethics Research Committee of Sport Sciences Research Institute of Iran according to the compliance with Ethical Standards in Research of the Ministry of Science, Research and Technology, with the code SSRI.REC-2206-1708 (R1) (date of registration: 22/08/2022), as well as operating in accordance with the Declaration of Helsinki. Before participating in the study, wrestlers signed informed consent.

Particpants

Sixteen male wrestlers completed the entire research procedure and were included in the analyses (Figure 1, Table 1). The participants consisted of members from the Ebrahim Hadi wrestling gym, including top wrestlers who had participated in league events. To qualify for participation in the study, athletes were required to meet several eligibility criteria, including being in excellent health, presenting a valid and current medical certificate certifying their capability to engage in sports activities, possessing a minimum of three years of training experience, and actively participating in four weekly exercise sessions that specifically focused on combat sports. Any individuals with current injuries, health-related contraindications, a reported overall feeling of unwellness, or those unwilling to comply with the research protocol were excluded (Figure 1). The research was conducted during the five-week preparatory period of the annual training program. During this transition phase, the wrestlers trained five times per week, which included five wrestling-specific sessions incorporating resistance, endurance, and power training.

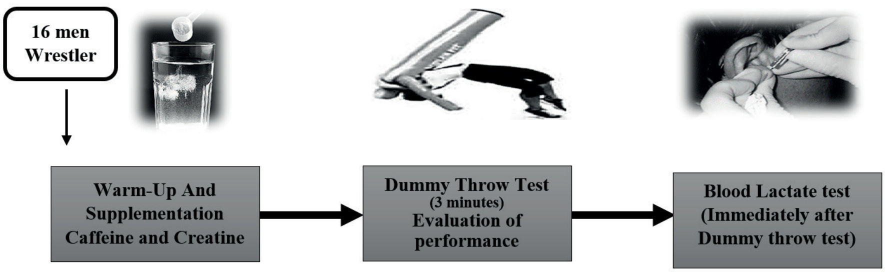

Figure 1. Schematic of research plan.

Table 1. Descriptive statistics of performance and Blood lactate variables in five supplementation conditions (Mean ± SD).

Condition	Performance (Repetition)	Shapiro-Wilk (P value)	Blood Lactate (mmol.L^{-1})	Shapiro-Wilk (P value)
CAF+PLA	13.93 ±2.01	0.69	12.14 ±2.66	0.74
Cr+PLA	14.18 ±1.86	0.35	9.46 ±2.02	0.13
Cr+ CAF	16.18 ±1.86	0.18	10.51 ±1.78	0.15
PLA+PLA	12.75 ±2.01	0.14	11.42 ±1.40	0.93
CON	12.18 ±1.79	0.14	11.35 ±1.29	0.68

* CAF; Caffeine, Cr; Creatine, PLA; Placebo, CON; Control.

Experimental design

The present study was designed as a randomized, double-blind, crossover, placebo-controlled experiment. To ensure blinding for both researchers and participants, an independent pharmacist produced and provided all the supplements. Anthropometric measurements were taken during the preliminary visit. After two familiarization sessions with the training protocol, participants were randomly assigned to one of five conditions: Creatine (Cr), Caffeine (CAF), a combination of Cr and CAF, placebo (PLA), and control (CON). To account for potential training effects, each participant randomly determined the sequence of these conditions. The data from the CON session were used as a baseline for comparative analysis. A washout period of seven days was implemented between sessions.

Supplementation protocol

The supplements and PLA (Maltodextrin as a placebo for creatine monohydrate and Cellulose as a placebo for caffeine anhydrous) were packed in identical Gelatin Capsules (China Gelatin Capsule Co., China), ensuring that participants could not discern the contents of the capsules. Supplementation was administered on evaluation days as follows: Creatine monohydrate powder (0.1 g/Kg-1 .d-1 [Creapure AlzChem Trostberg GmbH, Germany] + 3 mg/Kg-1 .d-1 caffeine placebo), Caffeine anhydrous (3 mg/Kg-1 .d-1 [CSPC Innovation Pharmaceutical, China] + 0.1 g/Kg-1 .d-1 Creatine monohydrate placebo), Creatine monohydrate + Caffeine anhydrous (0.1 g/Kg-1 .d-1 + 3 mg/Kg-1 .d-1), or PLA (0.1 g/Kg-1 .d-1 Maltodextrin + 3 mg/Kg-1 .d-1 Cellulose). Participants mixed their supplement powder with water on evaluation days and consumed the solution 60 min before exercising. The duration of 60 min was selected based on the approximate time to reach peak plasma caffeine concentrations after caffeine consumption (Graham, 2001), and pre-exercise creatine supplementation enhances muscle growth and performance. In order to specifically evaluate the effects of pre-exercise creatine and caffeine supplementation, participants in the study were instructed to refrain from supplementing on non-training days. Additionally, they were advised to avoid consuming other sources of caffeine for a period of three hours prior to taking their supplement. This precaution was implemented to ensure an accurate assessment of the impact of caffeine supplementation on muscle.

Diet

To evaluate changes in total energy intake and macronutrient composition between groups over the course of the supplementation and evaluation period, participants' dietary intake was documented during the initial and final weeks. A 3-day food booklet was utilized by participants to record their food consumption for two weekdays, which could be consecutive or non-consecutive, as well as one weekend day. The food records were analyzed using MyFitnessPal (Under Armour, Inc.), a reliable tool for dietary analysis (Teixeira et al., 2018).

Anthropometric measurements

Anthropometric measurements were obtained during the initial visit to the laboratory in the early hours of the day, with the subjects in a fasted state. Body mass and height were measured using a stadiometer and a professional medical scale (WPT 60/150 OW, RADWAG®, Radom, Poland). The stadiometer provided height measurements with an accuracy of 0.1 cm, while the medical scale provided body mass measurements with an accuracy of 0.1 kg.

Training protocol and Performance evaluation

The capacity for wrestling-specific performance was assessed using a modified dummy throw test designed to simulate wrestling conflict (Anioł-Strzyżewska & Starosta, 2012). The test was conducted in two modes:

- slow mode—four compulsory suplex throws in 30 s
- quick mode—as many suplex throws as possible in 15 s

For three minutes, the modes were alternated in one round. Each round consisted of four slow mode parts and four quick mode parts. The score for the test was determined by the number of correctly completed throws made during the quick mode parts. Athletes were given the necessary instructions before starting the test. The size of the dummy was adjusted to match the athlete's body weight and height.

Blood samples Analysis

The blood lactate (BL) samples were obtained from wrestlers' earlobe before warm-up and immediately after the training protocol. The concentration of BL (mmol/L) was measured using the photometric method with a portable analyzer (Lactate Scout+ analyzer, SensLab GmbH, Germany).

Statical Analysis

The statistical analysis was performed using a statistical software package (IBM SPSS Statistics 23.0, Armonk, NY: IBM Corp.), and the results are reported as mean and standard deviation (SD). After ensuring normality (i.e., Shapiro-Wilk) and variance (i.e., Levene), a one-way repeated-measures analysis of variance (ANOVA) was performed to examine the impact of various supplements on performance and blood lactate (BL) after each training regimen. When significant differences across conditions were discovered, a Bonferroni posthoc analysis was used to determine the differences.

Results

Performance (Dummy throw test)

The results showed a significant effect of supplementation on performance in male wrestlers during the Dummy throw test (Table 1), F [4, 75] = 10.41, P = 0.001, η_P^2 = 0.35. Pairwise comparisons revealed that the number of repetitions during the 3-minute Dummy throw test was significantly greater in the Cr+CAF condition (16.18 ±1.86, P < 0.01) and the Cr condition (14.18 ±1.86, P = 0.04) compared to the PLA condition (12.75 ±2.01) and the CON condition (12.18 ±1.79). However, a non-significant effect of CAF supplementation alone (13.93 ±2.01, P = 0.11) was observed on performance compared to the PLA condition (12.75 ±2.01) and the CON condition (12.18 ±1.79). Furthermore, a significant difference was observed between CAF and Cr+CAF (P = 0.01), indicating a greater effect of the combination of CAF and Cr on performance during the Dummy throw test in male wrestlers.

Blood Lactate

A significant difference was also observed in BL levels following the Dummy throw test, F [1, 75] = 4.69, P = 0.002, η_P^2 = 0.2. Pairwise comparisons revealed that BL levels immediately after the Dummy throw test were significantly lower in the Cr condition (9.46 ±2.02, P = 0.04) compared to the PLA condition (11.42 ±1.40) and the CON condition (11.41 ±1.29). However, no significant differences were observed between the CAF condition (12.14 ±2.66, P ≥ 0.05) and the Cr+CAF condition (10.51 ±1.78, P ≥ 0.05) compared to the PLA condition (11.42 ±1.40) and the CON condition (11.41 ±1.29).

Discussion

The present study was the first to examine the effects of creatine and caffeine supplementation on male wrestlers. It was hypothesized that the co-ingestion of creatine and caffeine would have a superior effect compared to creatine and caffeine supplementation alone in improving performance and reducing blood lactate levels in male wrestlers. The results demonstrated that the combination of creatine and caffeine supplementation, as well as creatine alone, significantly affected performance during the Dummy throwing test in male wrestlers. Additionally, the creatine alone condition resulted in significantly lower blood lactate values.

Creatine and caffeine are two of the most commonly used nutritional ergogenic aids, and numerous studies have demonstrated that both supplements offer ergogenic advantages in terms of strength and sprint performance. Furthermore, both ingredients are generally regarded as safe for consumption. (Nawrot et al., 2003; Persky & Rawson, 2007), they have independent mechanisms of action on performance, and there are no apparent pharmacokinetic interactions when they are taken together (Vanakoski et al., 1998). As a result, they are an attractive choice for combined supplementation among athletes involved in high-intensity exercise.

Individuals supplemented with creatine alone experienced an improvement in performance during the Dummy throw test. Harris et al. (1992) were the first to show that creatine supplementation with creatine monohydrate enhanced muscle creatine concentrations by 20%. Creatine supplementation has been shown to improve lean body mass, strength, power, and performance in high-intensity, short-duration workouts (Greydanus & Patel, 2010). These ergogenic benefits have been extensively studied in the gym and the laboratory, with limited research conducted in actual gameplay situations. In contrast to our findings, Hespel et al. (2002) conducted a study in which they discovered that the inclusion of caffeine at a dosage of 5 mg/kg, administered during a three-day period of creatine supplementation at a dosage of 20 g/day, led to a reduction in muscular relaxation time compared to individuals who solely underwent creatine supplementation. This finding was observed in a group of young, healthy males. Additionally, Vandenberghe et al. (1996) conducted research that revealed the consumption of caffeine at a dosage of 5 mg/kg for three days during a creatine loading phase (0.5 mg/kg for six days) prevented young adults from experiencing an increase in muscle torque subsequent to creatine supplementation. The contradictions in the results are likely due to differences in supplement dosage and supplementation protocols. However, Gonzalez et al. (2011) and Ratamess et al. (2007) demonstrated that acute supplementation of creatine and caffeine together, 10 to 20 min before exercise, improved power, training volume, and endurance. Vanakoski et al. (1998) discovered that although creatine did not impair the ergogenic effects of caffeine, it did not enhance aerobic or anaerobic performance when combined with caffeine.

Furthermore, a recent study by Pakulak et al. (2021) showed a non-significant effect of combining caffeine and creatine on resistance training performance. This discrepancy may be attributed to differences in the type of training protocol employed. Consistent with the present study's findings, multiple investigations have demonstrated that multi-ingredient supplements incorporating both creatine and caffeine have the capacity to enhance strength, power, and lean mass. Notably, these beneficial effects have been observed under both acute and chronic consumption conditions (Fukuda et al., 2010; Hoffman et al., 2008; Kedia et al., 2014; Kendall et al., 2014; Kraemer et al., 2007; Lowery et al., 2013; Ormsbee et al., 2012; Shelmadine et al., 2009; Smith et al., 2010; Spillane et al., 2011; Spradley et al., 2012).

The combination of creatine and caffeine did not significantly alter blood lactate values compared to the placebo and control conditions in male wrestlers. However, the creatine alone condition resulted in a significant decrease in blood lactate values. Consistent with our findings, previous studies by Balsom et al. (1993, 1995) using sprints of 10 seconds or longer also reported lower lactate levels following creatine supplementation, which may be associated with increased AMPK activation in vitro (Ceddia & Sweeney, 2004). During intense exercise such as running, glycolysis is initiated, and within 6–10 s, it becomes the primary source of ATP production (Bogdanis et al., 1996). For instance, during a 10-second sprint, glycolysis contributes to approximately 44% of total ATP synthesis (Bangsbo, 2003). The absence of changes or reductions in blood lactate levels suggests that the increased muscle phosphocreatine (PCr) in the creatine group contributed to higher ATP generation during the final sprints of the session in our study. Additionally, caffeine had a significant impact on blood lactate during incremental exercise, independent of exercise intensity (Glaister et al., 2016). However, caffeine does not affect blood lactate at rest, indicating that some mechanical stress is required to elicit this response. Furthermore, the lack of caffeine's effect on blood lactate clearance rate after recovery suggests that the increase in blood lactate was likely due to enhanced lactate efflux from the active muscles, supporting the caffeine-induced increase in glycolysis (Glaister et al., 2016). While these findings contradict the results of Graham et al. (2000), it is important to note that Graham et al.'s methodologies may have lacked the sensitivity to detect the magnitude of alterations reported in our study, despite being substantial. Additionally, studies by Tarnopolsky et al. (1989) and Wiles et al. (1992) reported a higher mean blood lactate response with caffeine, indicating discrepancies in exercise intensity, blood lactate measurement methodologies, dosage, and supplementation protocols among previous studies. Our findings also revealed that blood lactate in the creatine plus caffeine (Cr+CAF) condition was lower than in the placebo (PLA) and control (CON) conditions but higher than in the creatine alone (Cr) group. This can be attributed to increased blood lactate resulting from caffeine supplementation and decreased blood lactate due to the mechanism of creatine supplementation described earlier.

This study has several limitations: Firstly, we were unable to measure blood lactate levels more accurately by obtaining blood samples and conducting laboratory measurements. Secondly, due to limited laboratory equipment and the absence of ergometer wheels at the test site, we were unable to measure other functional factors. Additionally, the limited time available for subjects to participate in the test further restricted our ability to gather additional data.

In conclusion, this study examined the impact of acute creatine and caffeine supplementation, both individually and in combination, on performance during the Dummy throwing test and blood lactate levels in male wrestlers. This study is the first to investigate the effects of combining creatine and caffeine on the performance and blood lactate response of male wrestlers. The findings revealed that both creatine and creatine plus caffeine supplementation improved performance during the Dummy throwing test, while creatine supplementation alone significantly decreased blood lactate levels. These results suggest that male wrestlers can benefit from the ergogenic effects of creatine and caffeine when consumed separately or in combination.

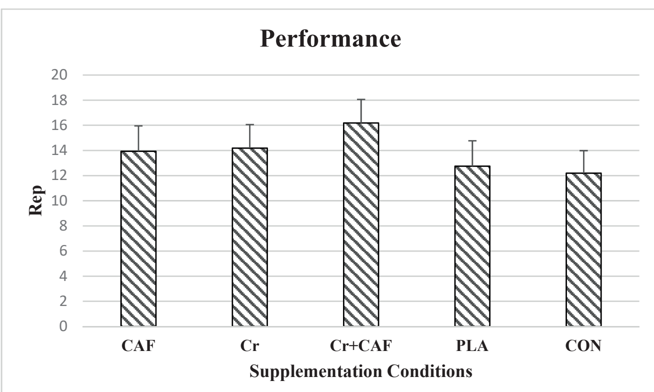

Figure 2. A comparison of performance scores between supplementations conditions, PLA and CON during Dummy throw test.

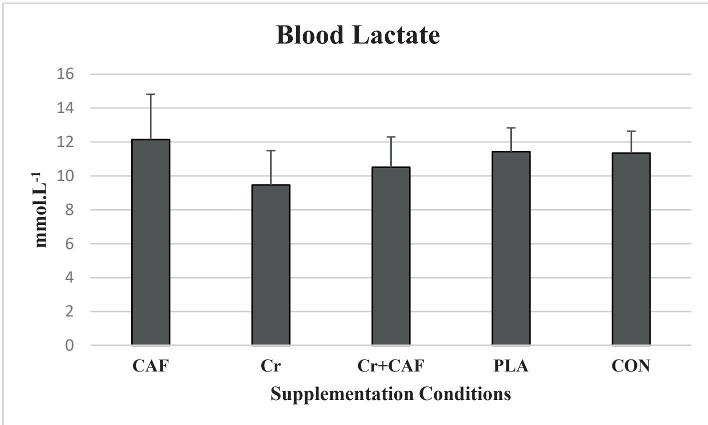

Figure 3. A comparison of performance scores between supplementations conditions, PLA and CON during Dummy throw test.

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