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Research article

THE RELATIONSHIP BETWEEN FUNCTIONALABILITIES AND COMPETITIVE SUCCESS OF SELECTED JUDOKAS

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Abstract. *The aim of this study was to determine the relationship between functional abilities and competitive success on a selected sample of national-level judokas. The study was conducted two weeks before the national championship. The research protocol consisted of the Special Judo Fitness Test (SJFT) and the Multistage Fitness Test (MFT). The SJFT Index was non-significantly higher in non-medalists compared to medalists ($p = 0.12$, $ES = 0.85$, moderate). Estimated maximal oxygen consumption (VO_{2max}) was significantly higher in medalists than non-medalists ($p = 0.05$). SJFT Index ($p = 0.04$, $r = 0.48$, moderate) and VO_{2max} ($p = 0.03$ $r = 0.50$, large) significantly correlated with competitive success in judo athletes. There was no significant correlation between the SJFT Index and VO_{2max} ($p= 0.38$, $r = 0.24$, small). The main findings of this study were: I) medalists performed the SJFT (lower index) better and had a higher VO_{2max}; II) SJFT and VO_{2max} were related to the competitive success of judokas. The results of the study show that significantly higher values of VO_{2max} and moderately better results on the SPJT (lower values of the SJFT Index) are characteristic of judokas who won medals at national championships than those who failed. The results obtained may be a relatively reliable guideline in the future planning of a specific training process ahead of the most important competition during the competition season.*

Key words: *judo, fitness test, SJFT, VO_{2max}*

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1. INTRODUCTION

Judo is a dynamic and physically demanding sport characterized by high-intensity intermittent actions over a short period, five minutes for men's, and four for the women's match (Torres-Luque, Hernández-García, Escobar-Molina, Garatachea, & Nikolaidis, 2016). A large number of different variables (technical, tactical, functional and psychological) determine the competitive result in judo (Dopsaj, Todorov, Vuković, Radovanović, 2013). Over the past decade, several studies have been conducted to determine the demands judokas must meet in order to achieve a top score (Franchini, Del Vecchio, Matsushigue & Artioli, 2011; Pocecco, Faulhaber, Franchini & Burtscher, 2012; Casals, Huertas, Franchini et al., 2017). However, the physiological profile of a judoka and the relationship between aerobic and anaerobic metabolism during the match is still not clear, despite the progression of scientific research in this specific area (Drid, Casals, Mekic, Radjo, Stojanovic & Ostojic, 2015; Prieske, Chaabene, Gäbler, et al., 2020; Kostrzewa, Laskowski, Wilk, Błach, Ignatjeva, & Nitychoruk, 2020). This can be partly attributed to the fact that judokas are divided into weight categories, which creates differences in body mass and body composition, and in individual technical and tactical skills. Both parts of energy capacity, anaerobic and aerobic, are involved during a judo match. Anaerobic capacity enables high-intensity but short-term attacks, while aerobic capacity enables prolonged effort during the potential five-minute duration of the match. During judo matches, very short periods of anerobic-alactate-based maximum activity with short recovery periods are shifted, during which the level of activity is reduced only to the submaximal in preparation for the next technique (attack). Due to the necessity of performing the desired techniques despite the fatigue created, a high level of physical preparation is required.

The assessment of the physical and functional abilities of judokas over the past two decades has significantly developed from general fitness testing in laboratory conditions to sports-specific testing conducted in the training and competition environment. Judo professionals sought to develop specific tests that would provide as objective assessment as possible of the system and technical and tactical actions used during the match (Azevedo, Drigo, Carvalho, Oliveira, Nunes, Baldissera & Perez, 2007; Franchini, Miarka, Matheus & Del Vecchio, 2011; Almansba, Sterkowicz, Sterkowicz-Przybycień & Comtois, 2012; Pocecco, Gatterer, Ruedl, & Burtscher, 2012; Franchini, Schwartz &Takito, 2020).

The Special Judo Fitness Test (SJFT) is the most commonly used diagnostic test developed with the aim of periodic monitoring of specific judo preparation (Franchini, Vecchio & Sterkowicz, 2009; Agostinho, Junior, Stankovic, Escobar-Molina & Franchini, 2018). Simultaneous assessment of functional preparedness and judo-specific techniques through key elements such as maximum performance, technical execution, fatigue and recovery speed, made the SJFT a generally accepted test. In this regard, SJFT has been used for both diagnosis and evaluation of motor preparation in judokas at different competitive levels. However, limited research has examined the relationships between the SJFT, maximal oxygen consumption (VO_{2max}), and competitive success (medalists vs. non-medalists) in judokas. Reporting data relative to competitive success (medalists vs. non-medalists) provides useful insight regarding fitness attributes that are important for judoka selection. The aim of this research was to determine the relationship between functional abilities (SJFT and VO_{2max}) and competitive success on the selected sample of national-level judokas (competitors who qualified and competed at a national championship).

2. METHODS

2.1. Participants

The sample of participants consisted of a total of 22 male judokas competing in categories from 60 kg to 100 kg (mean age 20.2±4.3 years; training experience 9.8±1.9 years). The study was approved by the Institutional Review Board and conducted in accordance with the guidelines of the Declaration of Helsinki.

2.2. Procedures

The research was conducted two weeks before the national championship, as the most important competition of the season in the state. The research protocol consisted of the SJFT and the Multistage Fitness Test, which were performed on two different consecutive days, during the beginning part (immediately after the warm-up) of morning training during the final preparations for the national championship. The results of the study were compared to the competitive result achieved at a national championship. Judokas were previously familiarized with both test procedures, had voluntary fluid intake, and a light meal at least two hours prior to testing. The body weight and the fat content of the participants was not measured, considering that rapid weight loss is commonly practiced among judokas in the period of two weeks before the competition (Lakicevic, Roklicer, Bianco, Mani, Paoli, Trivic et al., 2020; Štangar, Štangar, Shtyrba, Cigić, & Benedik, 2022).

2.3. The Special Judo Fitness Test (SJFT)

The SJFT is divided into three periods separated by 10s intervals of passive rest (Sterkowicz, 1995; Sterkowicz-Przybycień, Fukuda, & Franchini, 2019). During each period, the judoka was evaluated for sprints and the number of throws each of the two judokas of similar height and body mass made using ippon-seoi-nage (the one-armed shoulder throw), as many times as possible. The judoka began the test 3m from the opponent. The final heart rate (HR) was the value (beats per minute or bpm) recorded immediately after the test; HR 1 min is the heart rate obtained 1 min after the test, and Throws is the number of throws completed during all three periods of the test. The SJFT index is calculated as follows: (Final HR + HR 1min) / Throws (N).

2.4. The Multistage Fitness Test

The multistage fitness test, 20m shuttle run test or the beep test (Ramsbottom, Brewer & Williams, 1988) is a continuous sub-maximal test that requires the judoka to perform continuous 20m shuttle runs, where the judoka must reach the opposite end of the 20m grid before the next beep sounds. The time between recorded beeps decreases every minute, forcing the judoka to increase their running speed. A protocol began with an initial running speed of 8.5 km/h, with an increase in speed by 0.5 km/h every minute thereafter.

2.5. Statistical analysis

Data analyses were performed using IBM SPSS software (version 25.0; IBM Corporation, Armonk, NY). The normality of all data was assessed with the Shapiro-Willk test. A difference in the judo fitness test (index) was determined between medalists and non-medalists using separate independent t-tests, while Mann-Whitney tests were used to examine differences in VO_{2max}. The magnitude of the difference between medalists and non-medalists was measured with effect size, Cohen's d and interpreted (only for normally distributed data) as follows (Hopkins et al., 2009): trivial ≤0.20; small = 0.2-0.59; moderate = 0.60-1.19; large = 1.20-1.99; very large ≥2.0. The association between the competing success (medalists and non-medalists) and outcome measures (judo fitness test and VO_{2max}) was studied in athletes using the Spearman correlation coefficient and interpreted as follows (Hopkins et al., 2009): trivial (.0-.0 9), small (.10-.29), moderate (.30-.49), large (.50-.69), very large (.70-.89), almost perfect (.90-.99), and perfect (1.0).

3. RESULTS

Mean ± SD values for the judo fitness test and VO_{2max} are presented in Table 1. The SJFT Index was non-significantly higher in non-medalists compared to medalists ($p = 0.12$, ES = 0.85, moderate). Participation in the study was voluntary, and four judokas decided not to participate in the SFJT protocol due to minor upper body injuries. On the other hand, all 22 judokas completed the multistage fitness test. VO_{2max} was significantly higher in medalists compared to non-medalists ($p = 0.05$). The SJFT Index ($p= 0.04$, $r = 0.48$, moderate) and VO_{2max} ($p = 0.03$ $r = 0.50$, large) significantly correlated with the competitive success of judokas. There was no significant correlation between the SJFT Index and VO_{2max} ($p= 0.38$, $r = 0.24$, small).

Table 1 Differences between medalists and non-medalists on the judo fitness test and VO_{2max}

Subgroups and outcome measures	mean ± SD	p values
SJFT Index		
medalists n = 13	11.14 ± 0.85	0.12
non-medalists n = 5	11.86 ± 0.83	
VO_{2max}		
medalists n = 12	41.9 ± 4.5	0.05
non-medalists n = 10	37.7 ± 4.9	

SD - standard deviation

4 DISCUSSION

The study was conducted with the aim of determining the relationship between functional abilities and competitive results on a selected sample of judokas. The main findings of this study were: I) medalists performed the SJFT (lower index) better and had higher VO_{2max}; II) SJFT and VO_{2max} are related to the competitive success of judokas.

The results obtained showed that all the tested judokas have SJFT Index values that are classified as good, compared to the last published classification criteria (Sterkowicz-Przybycień, Fukuda, & Franchini, 2019). As a lower value of the SJFT Index indicates a better overall result on the Special Judo Fitness Test, the results show that medal winners showed better results but without statistical significance. Since the judokas' anaerobic-alactic system mostly contributes to the technical actions performed in the match, the SJFT can be considered a useful tool for the evaluation of the anaerobic system of judokas due to the efforts performed during the test, and its intermittent nature (Franchini, Sterkowicz, Szmatlan-

Gabrys, Gabrys, & Garnys, 2011). A comparison of judokas in relation to age demonstrates a higher total number of throws (medium effect) and HR immediately after the SJFT (small effect), with limited differences observed for HR one minute after the SJFT (Sterkowicz-Przybycień, Fukuda & Franchini, 2019).

Analysis of VO_{2max} results showed statistically significant higher values among medal winners than those who did not win a medal. Higher VO_{2max} values can be important in competitions because judokas allow for faster recovery between consecutive matches on the same day. The Multistage Fitness Test (MFT) has previously been reported to be a valid and reliable test for predicting VO_{2max} for adults (Ramsbottom, Brewer & Williams, 1988) and has become one of the most widely used field tests, despite the fact that it underestimates VO_{2max} when compared to laboratory conditions (Cooper, Baker, Tong, Roberts & Hanford, 2005). Although VO_{2max} is considered relevant to judo performance, existing literature has not shown differences among judokas from different competitive levels (Franchini, Del Vecchio, Matsushigue & Artioli, 2011). Moreover, despite the similarities, the physiological demands of combat or fight practice (randori) are not as high as observed during real competitive matches (Franchini, Brito, Fukuda, & Artioli, 2014).

Our findings on both applied tests on the sample of national-level judokas showed that there is no statistically significant correlation between the SFJT and MFT. The findings suggest that the SJFT and the MFT can be used to some extent to assess judo preparedness ahead of the competition. However, the degree of impact of the judokas' functional abilities on their competitive success during combat remains an unresolved and under-examined issue, which requires further research.

5. Conclusion

The results of the research show that statistically significantly higher values of VO_{2max} and moderately better results on the Special Judo Fitness Test (lower values of the SJFT Index) are characterized by judokas who won medals at the national championship in comparison to those who failed. The results obtained may be a relatively reliable guideline in the future planning of a specific training process ahead of the most important competition during the competition season. However, it must not be forgotten that judo is a sport in which technique prevails, and that functional abilities are only the foundation on which judokas base their technique and tactics during the match. Future studies should be designed so that functional testing is associated with accurate match analysis, in an effort to establish an even stronger link between the functional and technical abilities of judokas.

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POVEZANOST FUNKCIONALNIH SPOSOBNOSTI SA TAKMIČARSKIM USPEHOM DŽUDISTA

Cilj ovog istraživanja bio je da se utvrdi odnos između funkcionalnih sposobnosti i takmičarskog uspeha na odabranom uzorku džudista nacionalnog nivoa. Istraživanje je sprovedeno dve nedelje pre državnog prvenstva. Protokol istraživanja sastojao se od specijalnog džud ofitnes testa (SJFT) i višestepenog fitnes testa (MFT). SJFT indeks bio je neznačajno viši kod džudista koji nisu osvojili medalje u poređenju sa onima koji su ih osvojili (p = 0,12, ES = 0,85, umereno). Procenjena maksimalna potrošnja kiseonika (VO_{2max}) bila je značajno veća kod osvajača medalja nego kod onih koji medalje nisu osvojili (p = 0,05). SJFT indeks (p = 0,04, r = 0,48, umeren) i VO_{2max} (p = 0,03 r = 0,50, veliki) bili su u značajnoj korelaciji sa takmičarskim uspehom džudista. Nije bilo značajne korelacije između SJFT indeksai VO_{2max} (p = 0,38, r = 0,24, mali). Glavni nalazi ovog istraživanja bili su: I) osvajači medalja su imali bolji učinak kod SJFT (niži indeks) i imali su veći VO_{2max}; II) SJFT i VO_{2max} bili su povezani sa takmičarskim uspehom džudista. Rezultati istraživanja pokazuju da značajno veće vrednosti VO_{2max} i umereno bolje rezultate na SJFT (niže vrednosti SJFT indeksa) karakterišu džudiste koji su osvajali medalje na državnom prvenstvu od onih koji to nisu uspeli. Dobijeni rezultati mogu biti relativno pouzdana smernica za buduće planiranje specifičnog dela trenažnog procesa uoči najvažnijeg takmičenja tokom takmičarske sezone.

Ključne reči: *džudo, fitnes test, SJFT SJFT,* VO_{2max}

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Research article

RESEARCH OF PHYSICAL ACTIVITY AS A PART OF HEALTH-RELATED BEHAVIOR OF SCHOOL-AGE CHILDREN IN THE REPUBLIC OF SERBIA 2017/18

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Abstract. *Physical activity is defined as any bodily movement produced by skeletal muscles that requires energy expenditure. Reduced physical activity and unhealthy eating habits represent a significant risk to children's health and the formation of a negative attitude toward themselves. Our research aimed to examine how physically active children aged eleven, thirteen, and fifteen are in the Republic of Serbia. The paper used data from the Health Behavior Survey of school-age children in the Republic of Serbia in 2017. The standardized international protocol of the World Health Organization was used to collect data. 3933 schoolchildren aged eleven, thirteen, and fifteen were surveyed. Daily physical activity is statistically significantly different by region at the ages of eleven and fifteen, with a tendency to decrease with age (χ^2=39.84; dF=21; p=0.008), and at the age of fifteen (χ^2=42.77; dF =21; p=0.003). The most pronounced difference by region is in Belgrade, where the number of physically active children is significantly lower. At the age of fifteen, every fifth child has daily physical activity, while in other regions a third of them do. Children aged eleven are physically active all 7 days a week in Šumadija and Western Serbia (41.2%), in Vojvodina 40.5%, in Southern and Eastern Serbia 39.6%, and the least in Belgrade 37.9%. Based on the analyzed data, it can be concluded that children aged eleven, thirteen, and fifteen in the Republic of Serbia are insufficiently physically active. The results show that it is necessary to intensify health-educational programs and improve cooperation between families, schools, and health institutions in the field of preventive activities.*

Key words: *children, physical activity, prevention, adolescence*

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1. INTRODUCTION

Any body movement caused by skeletal muscles that involves energy consumption is referred to as physical activity (CDC, 2022; WHO, 2017). There are numerous ways to engage in physical activity, including walking, cycling, playing sports, and engaging in active leisure (dance, yoga, tai chi). If done regularly, for long enough, and with enough intensity, any type of physical activity can be beneficial to your health (WHO, 2018). A lower risk of cardiorespiratory and muscular fitness, cardiometabolic health, cognitive outcomes, and mental health are just a few of the well-known health benefits of exercise (WHO, 2020). Physical activity is a useful approach to enhance energy demands, reduce levels of body fat as well as provide metabolically active tissue during adolescence (Miletić et al., 2019). Additionally, exercise improves mental health and prevents the onset of dementia (Guthold et al., 2018). Workout intends to improve a person's overall and skill-specific talents through physical activity (Arsović et al., 2019).

Children spend less time than they should being active in the modern world because they spend so much time at school, watching television, using passive forms of transportation, and using computers and computers. Their physical health is greatly impacted by adopting such a sedentary lifestyle (Detels et al., 2022). At school, at home, on the bus, and in the neighborhood, they spend a lot of time in settings that discourage movement and necessitate extended sitting. Movement and muscle activity have been reduced in schools, households, and public settings. Children's behavior is impacted by these changes, causing them to move less and sit more. Obesity in children and adolescents has increased as a result of bad eating patterns and decreased physical activity, which poses serious health risks (Chaput et al., 2020). Boys are not in the best physical shape, according to Milanovic et al. (2019). Males are more likely than females to be overweight (24.8%), and boys are more likely to be obese (27%) than females. The prevalence of overweight (24.8%) is related to gender and the prevalence of obesity is higher in boys (27%) than in girls (22.4%) (Milanovic et al., 2019). Children now spend more time watching television, utilizing computers, or playing video games than they did twenty years ago (Detels et al., 2022). Young children are showing signs of these multi-year increasing tendencies slowing down (Detels et al., 2022).

Physical activity is linked to better long-term health, including benefits to the cardiovascular and musculoskeletal systems and a decrease in obesity. It is also linked to higher self-confidence (WHO, 2017). However, young people's levels of physical activity are declining, and the proportion of fat youngsters is rising (Detels et al., 2022). There is a complex and multifaceted relationship between physical activity, energy use, and health (Malm et al., 2019). Over the past few decades, the majority of wealthy nations have maintained very steady rates or slightly downward trends in leisure-time physical activity (Guthold et al., 2018). Females were substantially less likely than males to begin or continue physical activity as adolescents and young adults (WHO, 2020). Girls (85%) were less physically active than males (78%) among adolescents aged 11 to 17 who did not fulfill the WHO recommendations for moderate to high-intensity physical activity each day (WHO, 2020). Compared to those living in rural areas, urban residents are 26% more likely to be considered physically inactive (Castrillon et al., 2020). Regarding psychosocial aspects, it was discovered that selecting a sedentary lifestyle was almost three times more likely when one lacked knowledge about physical activity (Rodulfo, 2019). A 48% association between a sedentary lifestyle and a bad self-perception of health was also found (Rodulfo, 2019).

Every child should strive to lead an active lifestyle. Everyone can be physically active through recreational activities and non-competitive sports. The likelihood of choosing a physically active lifestyle is increased by the potential of frequent physical activity and the satisfaction it provides (CDC, 2022). Because the habit is thought to be formed and accepted in childhood, altering the level of physical activity can have long-term effects (Carson et al., 2019). Children and adolescents between the ages of 5 and 17 are advised by the WHO to engage in at least 60 minutes of aerobic activity, primarily at a moderate to vigorous level, each day. Then, they should engage in exercises that are both muscle and bone-strengthening and high-intensity aerobic at least three days a week. They ought to restrict the amount of time they spend sitting down, particularly when doing so leisurely in front of a screen (WHO, 2020).

The current study aimed to examine how physically active children aged eleven, thirteen, and fifteen are according to age, sex, and territorial distribution in the Republic of Serbia, and whether they meet the recommended level of daily and vigorous physical activity.

2. METHODS

2.1. Participants

According to the World Health Organization's approach, a defined international study procedure including a questionnaire was utilized to gather information on schoolchildren's health behavior (WHO, 2010). Students between the ages of 11 and 15 made up the target audience. Not included in the study were any schools in Kosovo or Metohija. Using a nationally representative sample of 1.500 children for each age group, the established worldwide methodology was modified for use in the Republic of Serbia. A sampling frame was created using a list of Serbian elementary and secondary schools along with student enrollment data broken down by age. The Probability Proportional to Size technique was used to choose the schools. A stratified multistage sampling design was adopted in the study, and separate samples were taken for each of the three age groups. For each age group, 64 schools took part in the study. One or two classes of one grade were surveyed in each of the chosen schools. For primary schools, the sample was chosen based on region, and for secondary schools, based on region and type. Geographical research areas were designated for four statistical regions: Belgrade, Vojvodina, Šumadija and Western Serbia, Southern Serbia, and Eastern Serbia. Eight primary schools and nine high schools participated in Belgrade, eleven primary schools and ten high schools in Vojvodina, twelve primary schools and eleven high schools in Šumadija and Western Serbia, and eight primary schools and eight high schools in Southern and Eastern Serbia.

2.2. Measures

Data from a cross-sectional study conducted in 2017 by the Institute for Public Health of Serbia "Dr. Milan Jovanović Batut," the Ministry of Health, and the Ministry of Education, Science and Technological Development was used. The study was titled "Investigation of health-related behavior of school-age children in the Republic of Serbia." The questionnaire was comprised of questions. Two surveys were created from the questions; one contained 68 questions and was geared toward primary school students between the ages of 11 and 13 and the other contained 79 questions and included additional questions about the use of psychoactive substances and reproductive health. Twelve groups of questions were created from the questionnaires. The groups of questions included sociodemographic information, a self-assessment of health, life satisfaction, the impact of family circumstances on health and health-related behavior, attitudes toward school, questions about friends (support and communication), eating patterns and nutrition, teeth brushing, use of psychoactive substances and alcohol, leisure activities, peer violence/abuse, injuries, reproductive health, and physical activity. Physical activity-related survey items were broken down into two categories: daily exercise for an hour in the week before the survey, and strenuous exercise three or more times.

2.3. Procedure

Forty professional interviewers were conducted in the field from May 3 to June 8, 2017, under the direction of the study team from the Institute of Public Health of Serbia, "Dr. Milan Jovanović Batut." The survey was voluntary and anonymous, with students completing the survey questionnaire themselves.

2.4. Statistical Analysis

The sample was divided into categories such as age, sex, geographic distribution, and physical activity. The χ^2 test was used to determine the significance of the variation in the frequency of the responses by area, within each age group. The level of significance of the difference was defined for a probability of 95%, i.e. $p<0.05$. For the variables under investigation the mean, median, standard deviation, minimum, maximum, distribution, and the standard error of the mean, measures of frequency and relative numbers, measures of central tendency, and data dispersion were computed. A standardized test of descriptive statistics was used to determine the normality of the data distribution. Post hoc testing with the Bonferroni correction was used to discover any partial differences between the designated subgroups. All data were statistically analyzed in the SPSS 22.0 program. The outcomes are shown graphically and in tabular form.

Consent for the implementation of the population survey was given by the Ethics Committee of the Institute for Public Health of Serbia "Dr. Milan Jovanović Batut", and the consent of the parents and respondents was also obtained. The Ethics Committee of the Institute for Public Health of Serbia "Dr. Milan Jovanović Batut" gave consent for the secondary research of the collected data.

3. Results

A total of 3933 school-aged children between the ages of 11 and 15 were polled. The majority of students, 1.180 (30%), were from Šumadija and Western Serbia, while 1.068 (27.2%) and 864 (22.0%) were from Vojvodina and Belgrade, respectively. The least number of students, 821 (20.9%), were from Southern and Eastern Serbia. In the sample under study, boys are disproportionately represented in Šumadija and Western Serbia (52.5%), whereas girls are disproportionately represented in Belgrade (55.2%). The gender distribution in the sample among the age groups demonstrates that there was a balanced representation across all age groups (Table 1).

Table 1 Distribution of the sample by gender and age groups

Age	Boys	Girls	Total
11 years	537 (49.7%)	589 (50.3%)	1126
13 years	610 (50.7%)	592 (49.3%)	1202
15 years	798 (47.7%)	807 (52.3%)	1605

The distribution of respondents by region in terms of age is shown in graph 1. In the region of Southern and Eastern Serbia, the most represented respondents are 13 years old (38.37%), while in other regions the most represented respondents are 15 years old (36.92-46.44%).

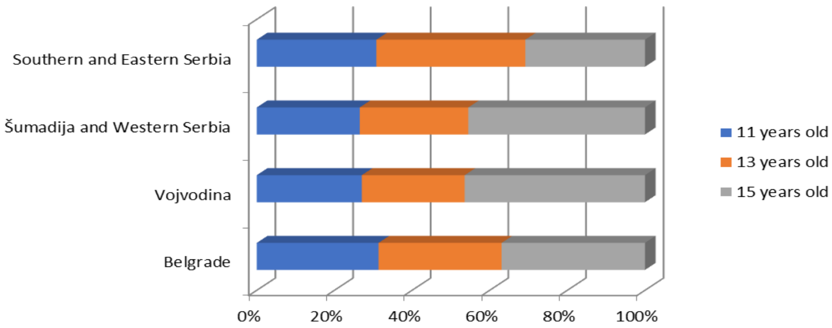

Fig. 1 Distribution of the sample by age groups across regions

At the age of 11, 13.1% of kids in Vojvodina, or 13.8% of kids in Southern and Eastern Serbia, exercised three days in the previous week, compared to 6.1% of kids in Belgrade and 7.6% of kids in Šumadija. A total of 9.1% of children in Vojvodina exercised five days in the week before the study, compared to 13.3% in Southern and Eastern Serbia, 16.3% in Šumadija, and 19.5% in Belgrade. The lowest percentage of children who exercised six days a week was found in Southern and Eastern Serbia (7.9%), while other regions saw rates as high as 10.9% in Vojvodina, 12.3% in Šumadija, and 13.8% in Belgrade. If we examine physical activity across all seven days of the week, children in Šumadija and Western Serbia engaged in regular physical activity at the highest rate (41.2%), followed by Vojvodina with 40.5%, Southern and Eastern Serbia with 39.6%, and Belgrade with 37.9%.

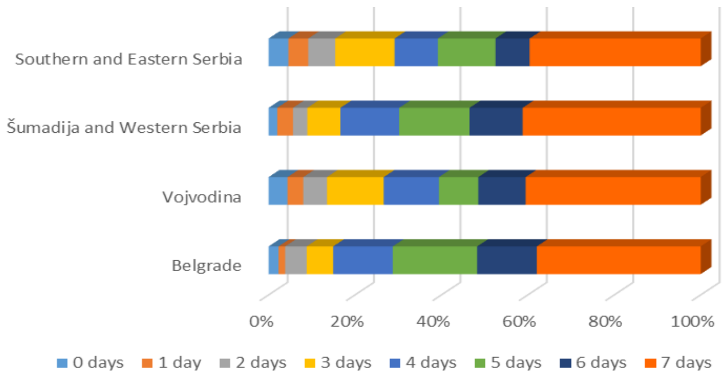

Fig. 2 Frequency of physical activity among children aged 11 by region

In Belgrade, 10.1% of 15-year-olds reported having exercised at least once over the previous seven days, compared to 4.0% in Southern and Eastern Serbia, 4.7% in Šumadija and Western Serbia, and 5.7% in Vojvodina. In Vojvodina, just 8.1% of children reported having exercised twice in the previous week, compared to 12.6% in Šumadija, 13.0% in Belgrade, and 13.5% in South and East Serbia. 4.7% of kids in Belgrade, 5.6% of kids in Southern and Eastern Serbia, 8.7% of kids in Šumadija, and 9.4% of kids in Vojvodina practiced for six days in the previous week. 15-year-old children exercised on 32.4% of days in Vojvodina, 30.3% of days in Southern and Eastern Serbia, 28.2% of days in Šumadija and Western Serbia, and 22.2% of days in Belgrade in the week before the survey.

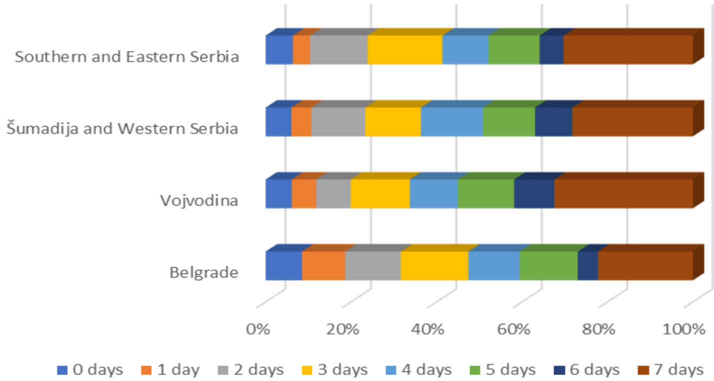

Fig. 3 Frequency of physical activity of children aged 15 by region (previous 7 days)

The representation of physical activity is statistically significantly different by region at the age of 11 (χ^2=39.84; dF=21; p=0.008) and 15 years (χ^2=42.77; dF=21; p=0.003). The Kruskal Wallis test showed a statistically significant difference between different ages in physical activity in the last seven days (.000). To see between which groups there is a statistically significant difference, we conducted the Mann-Whitney U test between pairs of groups and applied the Bonferroni alpha correction (0.05/3=0.017). A series of post hoc tests - Bonferroni tests between students aged 11 and 13 showed that there was a statistically significant difference (.001) in physical activity, between students aged 13 and 15 (.000), and a significant difference was obtained when we analyzed the age groups of 11 and 15 (.000). The obtained results are shown in Table 2.

Table 2 Physical activity in the last seven days in terms of age

Physical activity in the last seven days	N	Mean Rank	Mean	Std. Deviation	Med.	p
11 years	1076	2128.65	5.14	2.003	6.00	.000
13 years	1169	1980.07	4.86	2.053	5.00	.001
15 years	1589	1728.49	4.32	2.260	4.00	.000
Total	3834		4.72	2.156	5.00	

There is a very small statistically significant negative correlation concerning age and a small negative correlation concerning female gender which is statistically significant (Table 3).

Table 3 Correlation (Spearman) of age, gender, and physical activity

Spearman's rho			Physical activity in the last seven days	Gender
Age	Correlation Coefficient	1.000	-.156**	-.014
	Sig. (2-tailed)	.	.000	.384
	N	3933	3834	3933
Physical activity in the last seven days	Correlation Coefficient	-.156**	1.000	-.218**
	Sig. (2-tailed)	.000	.	.000
	N	3834	3834	3834
Gender	Correlation Coefficient	-.014	-.218**	1.000
	Sig. (2-tailed)	.384	.000	.
	N	3933	3834	3933

We analyzed the total frequency of vigorous physical activity. Concerning the total number and percentage, the answers are shown in table 4.

Table 4 The total frequency of vigorous physical activity

	Vigorous physical activity	N	%
	Daily	1116	28.4
	4-6 times a week	860	21.9
	2-3 times a week	886	22.5
	Once a week	385	9.8
	Once a month	169	4.3
	Less than 1 per month	222	5.6
	Never	231	5.9
	In total	3869	98.4
	Missing data	64	1.6
Total		3933	100.0

Some 2862 (72.7%) school children participated in vigorous physical activity three or more times a week out of a total of 3869 (97.6%) who answered this question. The Kruskal Wallis test showed a statistically significant difference between different ages in vigorous physical activity (.000). To see between which groups there is a statistically significant difference, we conducted the Mann-Whitney U test between pairs of groups and applied the Bonferroni alpha correction (0.05/3=0.017). A series of post hoc tests - Bonferroni tests between students aged 11 and 13 showed that there is a statistically significant difference (.029) in vigorous physical activity between students aged 13 and 15 (.022), and we obtained a statistically significant difference when we analyzed the groups aged 11 and 15 (.017). The obtained results are shown in Table 5.

Table 5 Vigorous physical activity in terms of age

Vigorous physical activity	N	Mean Rank	Mean	Std. Deviation	Med.	p
11 years	1084	1731.33	2.47	1.585	2.00	.017
13 years	1187	1890.63	2.71	1.670	2.00	.029
15 years	1598	2106.12	3.09	1.877	3.00	.022
Total	3869		2.80	1.756	2.00	

Children aged 15 have statistically significantly more energetic physical activity compared to school children aged 11, observed in the total sample (.017). This type of activity intensifies as age increases. The correlation between age and gender is shown in Table 6.

Table 6 Correlation between age, gender, and vigorous physical activity

Spearman's rho			Gender	Vigorous physical activity
Age	Correlation Coefficient	1.000	-.014	.143**
	Sig. (2-tailed)	.	.384	.000
	N	3933	3933	3869
Gender	Correlation Coefficient	-.014	1.000	.227**
	Sig. (2-tailed)	.384	.	.000
	N	3933	3933	3869
Vigorous physical activity	Correlation Coefficient	.143**	.227**	1.000
	Sig. (2-tailed)	.000	.000	.
	N	3869	3869	3869

There is a small significant positive correlation between age and vigorous physical activity, as well as a small correlation between gender and that type of activity, statistically significant, according to Cohen's criteria, in favor of male children.

4. DISCUSSION

Improved physical fitness (cardiorespiratory and muscular), cardio-metabolic health (blood pressure, dyslipidemia, glucose intolerance, and insulin resistance), bone health, cognitive outcomes (academic performance), mental health (reduced depressive symptoms), and decreased adiposity are all health outcomes of physical activity in children and adolescents (Chaput et al., 2020). Parallel to this shift, research has shown that extended sitting, unrelated to exercise time, is a new risk factor for cardio-metabolic disease and elevated all-cause mortality. Play, sports, organized exercise, physical education in the classroom, alternate modes of transportation (wheeling, rollerblading, walking, and cycling), or household chores are all advised. Young people's physical, mental, and social well-being can be improved by moderate physical activity and enjoyment.

Data from 1.6 million schoolchildren in 164 countries throughout the world showed that in 2016, 80% of teenagers aged 11 to 17 did not meet the current requirements for daily physical activity, with girls being less physically active, which is consistent with the findings of our study (Guthold et al., 2018). The findings of Radisavljević Janić et al. (2020) also revealed that boys in Serbia are more physically active than girls and that younger adolescents in Serbia are moderately active. The results of the research by Radisavljević Janić et al. (2020) also showed that in Serbia, younger adolescents are moderately physically active and that boys have a higher level of physical activity compared to girls.

The findings of our study are consistent with a recent Italian study of a similar nature, showing that children's daily physical activity declines with age, while their frequency of vigorous physical activity increases (graphs 4 and 5) (Stival et al., 2022).

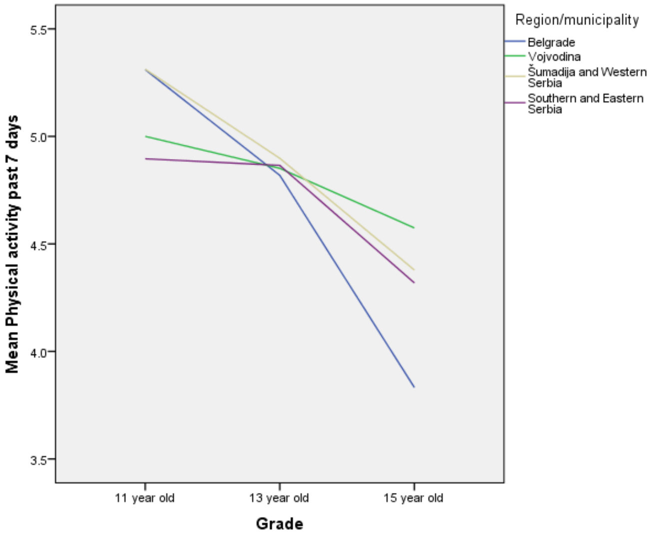

Fig. 4 Frequency of daily physical activity by age and region

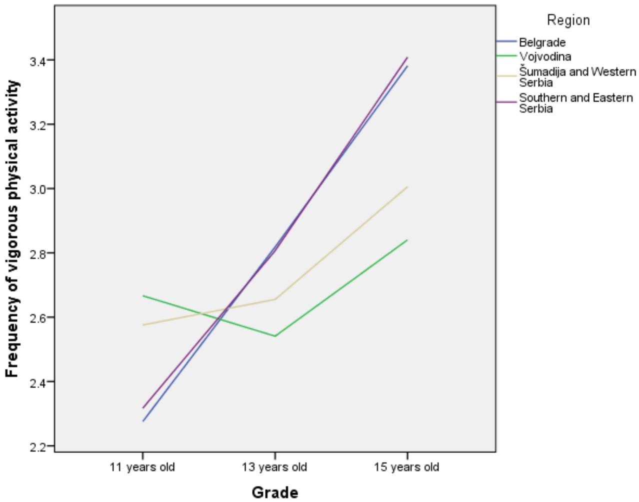

Fig. 5 Frequency of vigorous physical activity by age and region

Boys in the Republic of Serbia are more physically active, as in the study by Biadgilign et al. (2022). Quality of life and contentment with one's appearance is much higher for kids and teenagers who engage in more vigorous physical activity (Finne et al., 2013). Obesity in children and adolescents is linked to the emergence and maintenance of physical inactivity (Wu et al., 2017). The current focus on childhood overweight is justified, despite limited data on economic benefits. Nikolic et al. (2020) also showed higher values of intensive and moderate physical activity scores compared to females, in a representative sample of adolescents from one area in Serbia (Pančevo).

The majority of those surveyed completed at least 30 minutes of moderate exercise or 1.5 hours of strenuous exercise five days each week (Nikolic et al., 2020). Only about 19% of Serbian teenagers engage in intense physical activity. Serbian urban youth do not participate in enough physical activity (Nikolic et al., 2020).

The Republic of Serbia's school-aged population is physically active, but not enough. Two to three times per week, 22.5% of the responders engage in the advised strenuous physical exercise. In a comparable study, only roughly 19% of Serbian adolescents exhibited high levels of physical activity. According to Nikolic et al., Serbian urban youths do not exercise enough. Increasing physical activity requires a system-based approach. Since policies that encourage more physical activity can help health, local economies, community well-being, and environmental sustainability, cross-sectoral cooperation could result in major advantages (Guthold et al., 2018). From an early age, active play and recreation are crucial for children's and teenagers' healthy growth and development. The health literacy required for a long-term healthy and active lifestyle can be provided via quality physical education and supportive learning environments in schools (WHO, 2018). Sports organizations and youth groups are crucial places for social interaction and health, and communities in particular should support them (Chaput et al., 2020).

Evidence from a recently published systematic review of the literature shows that several types of physical activity, including aerobic exercise and activities that strengthen muscles and bones, are linked to better health outcomes (Chaput et al., 2020). Physical activity can be done as part of play, leisure, and recreation for kids and teenagers. The WHO has set a target of lowering the rate of obesity among adults and adolescents from its current rate, which can be accurately accomplished by boosting physical activity (WHO, 2017). In 2020, the World Health Organization (WHO) published updated global guidelines on physical activity and sedentary behavior for children and adolescents (Table 7).

Table 7 WHO guidelines for physical activity of children and adolescents (5–17 years)

It is recommended that:
▪ During the week, children and adolescents should engage in an average of 60 minutes per day of cardiovascular exercise at a moderate to an intense level.
▪ High-intensity aerobic exercise, as well as exercises that build bones and muscles, should be incorporated at least three days a week.
Good practice recommendations:
▪ It is preferable to engage in some physical activity than none at all.
▪ Children and teenagers will benefit from physical activity for their health if they follow the suggestions.
▪ Children and teenagers should begin with low-intensity exercise and gradually increase the frequency, intensity, and duration of their physical activity.
▪ It is crucial to give all kids and teenagers safe, equal chances to engage in physical activity, as well as encouragement to do so. These activities should be fun, diverse, and appropriate for their age and skills.

Source: WHO guidelines on physical activity and sedentary behavior for children and adolescents aged 5–17 years: summary of the evidence 2020. (Chaput et al., 2020)

The wealthy population has become less active over the past few decades. There is proof that differences in physical activity may be influenced by industrialization and globalization processes (Goryakin et al., 2015). On the other hand, local factors play a significantly larger role in explaining why some people remain slender while others gain weight than global ones (de Soysa & de Soysa, 2018).

The analysis of personality traits as a significant role in the practice of preventative forms of healthy behavior may be a suggestion for future research. Further research into the disparities between children's attitudes toward physical activity in urban and rural areas is necessary to comprehend the causes of insufficient physical exercise. Analyzing the social settings and attitudes of overweight children toward physical activity may also help us understand the causes of unhealthy lifestyles. School-aged children are a suitable choice if policymakers want to target a particular social group because they can be reached in most nations through school-mediated activities (Detels et al., 2022).

CONCLUSIONS

Our findings demonstrate that between the ages of eleven and fifteen, regular physical activity differs statistically significantly by region, with a tendency to decline with age. The disparity between the regions was most evident in Belgrade, where there are much fewer youngsters who are physically active, especially when one considers the availability and opportunity for doing so. Thus, only every fifth child in Belgrade of the age of fifteen engages in daily physical exercise, compared to a third of children in Southern Serbia, Šumadija, and Vojvodina. However, strenuous physical activity should be more common, especially among girls, even though it gets stronger with age. It is evident from the data analysis that youngsters in the Republic of Serbia who are eleven, thirteen, and fifteen years old are not sufficiently physically active enough.

The implementation of new health and educational programs tailored to the needs of schoolchildren; creative health and educational approaches relating to changes in physical activity habits; enhancing the health of school-aged children by including health-educational content in the regular Work Plans; and operational cooperation between the education and health sectors within the framework of health-educational programs are all possible ways to increase physical activity among school-aged children.

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FIZIČKA AKTIVNOST DECE ŠKOLSKOG UZRASTA – ISTRAŽIVANJE PONAŠANJA U VEZI SA ZDRAVLJEM DECE ŠKOLSKOG UZRASTA U REPUBLICI SRBIJI U 2017. GODINI

Fizička aktivnost se definiše kao svaki telesni pokret koji proizvode skeletni mišići a koji zahteva utrošak energije. Smanjena fizička aktivnost i nezdrave navike u ishrani predstavljaju značajan rizik po zdravlje dece i formiranje negativnog stava prema sebi. Cilj našeg istraživanja bio je ispitati koliko su fizički aktivna deca uzrasta jedanaest, trinaest i petnaest godina u Republici Srbiji. U radu su korišćeni podaci iz Istraživanja ponašanja u vezi sa zdravljem dece školskog uzrasta u Republici Srbiji 2017. Za prikupljanje podataka korišćen je standardizovani međunarodni protokol Svetske zdravstvene organizacije. Anketirano je 3933 školske dece uzrasta jedanaest, trinaest i petnaest godina. Svakodnevna fizička aktivnost je statistički značajno različita po regionima u uzrastu od jedanaest i petnaest godina, sa tendencijom opadanja sa odrastanjem (χ^2=39,84; dF=21; p=0,008) i u uzrastu 15 godina (χ^2=42,77; dF=21; p=0,003). Najizraženija razlika po regionima je u Beogradu gde je broj fizički aktivne dece značajno manji. U uzrastu od petnaest godina svako peto dete u ima svakodnevnu fizičku aktivnost, dok u ostalim regionima njih trećina. Fizičku aktivnost deca uzrasta 11 godina, svih 7 dana u nedelji, imaju u Šumadiji i Zapadnoj Srbiji (41,2%), u Vojvodini 40,5%, Južnoj i Istočnoj Srbiji 39,6% i najmanje u Beogradu 37,9%. Na osnovu analiziranih podataka može se zaključiti da su deca uzrasta jedanaest, trinaest i petnaest godina u Republici Srbiji nedovoljno fizički aktivna. Rezultati pokazuju da treba intenzivirati zdravstveno-edukativne programe i poboljšati saradnju između porodice, škole i zdravstvenih ustanova u oblasti preventivnih aktivnosti.

Ključne reči: *deca, fizička aktivnost, prevencija, adolescencija*

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Research article

INFLUENCE OF BODY COMPOSITION PARAMETERS ON EXPLOSIVE POWER PERFORMANCE IN FEMALE ADOLESCENT FOOTBALL PLAYERS

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Abstract. *The primary aim of this study was to quantify the relationship between body composition variables and explosive power performance in female adolescent football players. A secondary aim was mesure the influence of body composition on explosive power in female adolescent football players. A cross-sectional study included sixteen female adolescent football players (age: 14.5 ± 0.97 years; height: 170.06 ± 4.39 cm; weight: 61.35 ± 11.25 kg) competing as part of the Serbia Development League. The body composition parameters were: muscle mass in percentage (MM), body fat mass in kg (BFM), body fat mass in percentage (PBF), while explosive power parameters were: CMJ Jump Height in cm (CMJHeight), CMJ Relative maximal F (CMJF), CMJ Relative maximal P (CMJP), SJ Jump Height in cm (SJHeight), SJ Relative maximal F (SJF), SJ Relative maximal P (SJP). Pearson's correlation coefficient was used to determine the correlation between all tests and a simple linear regression analysis was applied to determine the influence between body composition and explosive power performance. Significant regressions were found between MM and CMJHeight ($r = 0.50$, $p \leq 0.05$, R2 = 0.25) and MM and SJHeight ($r = 0.69$, $p \leq 0.003$, R2 = 0.47). Also, regression analyses were found between PBF and CMJHeight ($r = 0.58$, $p \leq 0.02$, R2 = 0.33) and PBF and SJHeight ($r = 0.72$, $p \leq 0.002$, R2 = 0.51). Lower values of body fat mass and body fat mass in percentage and higher values of muscle mass lead to better results in explosive power performance.*

Key words: *strength, force, squat jump, countermovement jump*

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INTRODUCTION

Women's professional, semi-professional, and community football are some of the fastest growing sports worldwide (Martínez-Lagunas, Niessen, & Hartmann, 2014; Crossley et al., 2020). Identifying and developing young talent in early adolescence are a priority in youth soccer and have grown quickly over recent years (Reilly, Richardson, Stratton, & Williams, 2004). Football clubs are becoming increasingly aware of the importance of identifying talented youth soccer players at early ages or in adolescence and including them in sports club and football youth categories (Dodd, & Newans, 2018). Implementing tests to estimate physical performance plays an important role in the monitoring and development of football players. (Williams, & Reilly, 2000; Reilly, Bangsbo, & Franks, 2000). Over recent years, researchers have tried to identify factors that influence player success in soccer with attention being paid to anthropometric and physical performance (Gil, Ruiz, Irazusta, Gil, & Irazusta, 2007). Body composition and physical performance are an important element in player scouting at young ages (Vaeyens, et al., 2006; Carling, Le Gall, Reilly, & Williams, 2009; Murr, Raabe, & Höner, 2018; Barnes, Archer, Hogg, Bush, & Bradley, 2014; Bradley, Di Mascio, Peart, Olsen, & Sheldon, 2010).

Training is one of the factors which affect the development of physical performance in pre-adolescence and adolescence ages. In football, explosive power has been used to monitor physical performance (Ronnestad, Kvamme, Sunde, & Raastad, 2008), compare training loads (Andersson, et al., 2008; Alves, Rebelo, Abrantes, & Sampaio, 2010), and to prevent injuries (Menzel, et al., 2013), though for young players, it has mostly been used to identify talented athletes (Unnithan, White, Georgiou, Iga, & Drust, 2012). Furthermore, squat jump (SJ) and counter-movement jump (CMJ) height correlate with performance success in this sport (Arnason, et al., 2004; Helgerud, Rodas, Kemi, & Hoff, 2011). Body composition is important because it is among the factors that can determine sports potential and the possibility of success in sport, in combination with technical skills and tactical abilities, physical, functional, and psychosocial factors (Gil, Gil, Ruiz, Irazusta, & Irazusta, 2007). Muscular strength is a very important factor which can influence body composition parameters that support development and maintain the physical performance of players. (Cinita, et al., 2022). Muscular strength correlates with enhanced force-time characteristics, which influences performance. Great muscular strength correlateds with improvement in player performance in jumping, sprinting, and change of direction (Styles, Matthews, & Comfort, 2016; Thomas, Comfort, Chiang, & Jones, 2015). Low fat percentage correlates to sprinting, acceleration, change of direction times, and jumping performance (Dodd, & Newans, 2018). Body fat, lean mass, and muscle mass should be monitored because inappropriate training loads (intensity, frequency...) can lead to undesirable changes in physique, which could influence performance factors such as speed, strength, power, and risk of injury (Collins, & Rollo, 2014; Sutton, Scott, Wallace, & Reilly, 2009). An inappropriate body mass index could be responsible for inconsistent performance over a session (Lesinski, Prieske, Helm, & Granacher, 2017). Nikolaidis (2014) argued that physical fitness and physical performance correlate with the body mass index of female soccer players ($r = 0.27$ to 0.51) (Nikolaidis, 2014). Adolescent sports players, boys and girls, showed a statistically significant correlation between body composition and the standing broad jump ($r = -0.23$ to -0.62) (Agata, & Monyeki, 2018). Pérez-López, Sinovas, Álvarez-Valverde, & Valades (2015) showed similar results in Spanish male adolescent football players, where parameters of body composition were fat mass in percentage, and kilograms were in a negative correlation with height CMJ and SJ (r = -0.21 to -0.34), while correlation values for fat free mass and skeletal muscle mass with height CMJ and SJ were (r = 0.07 to 0.37). However, the results of body composition in young male football players showed a non-significant correlation with CMJ and SJ (Atakan, Unver, Demirci, Bulut, & Turnagol, 2017). In contrast, no equivalent research has ever been conducted in adolescent female football players. Therefore, the precise influence of body composition on explosive power performance remains unclear, with no reference data available for adolescent players or female adolescent football players. Due to that shortage of related studies, normative data for female adolescent football players should be established to help coaches identify and develop young talent in early adolescence.

The primary aim of this study was to quantify the relationship between body composition variables and explosive power performance in female adolescent football players. A secondary aim was to measure the influence of body composition on explosive power in female adolescent football players.

METHODS

Participants

Sixteen female adolescent football players (age: 14.5 ± 0.97 years; height: 170.06 ± 4.39 cm; weight: 61.35 ± 11.25 kg) took part in the study. The players were competing as part of the Serbia Development League. Procedure and testing were at the end of the preseason phase. All female adolescent football players were registered with the same team and had played at least one half-season before testing. Adolescent players who were in the recovery phase from some form of acute or chronic injuries and players in the process of rehabilitation were excluded.

All of the adolescent football players were first informed about the study. The purpose and aim of the study were explained to them, along with any possible consequences. In addition, the players were also informed about the procedure and course of the testing itself.

Procedures

Before testing, all players were familiarized with the testing procedures. Familiarization involved a verbal explanation and demonstration of each test by the same member of the research team. Height was measured using an anthropometer (Seca 220; Seca Corporation, Hamburg, Germany) to the nearest 0,1 cm, while body composition was measured using a digital Inbody 770 (Brewer et al., 2021) scale to the nearest 0.1 kg (InBody 770; Biospace Co. Ltd, Seoul, Korea). Body composition was estimated in the morning hours. One day prior to body composition testing, the players had to adhere to a protocol which included a minimum of eight hours of not consuming food, caffeine, or alcohol until testing the following morning (Brewer et al., 2021). Players completed a battery of explosive power tests indoors. A standardized 10-minute warm-up consisting of jogging and multi-way dynamic stretching, was used for all players before testing. The players completed 3 trials of each test, each separated by 3 minutes of passive standing rest. The best performance was recorded as the outcome measure.

Body composition

The evaluation of body composition was carried out in an indoor facility using multi-frequency bioelectrical impedance (Inbody 770; Biospace Co. Ltd, Seoul, Korea) as per Brewer et al. (2021), at frequencies of 1, 5, 50, 250, 500 and 1000 kHz under controlled temperature conditions of 23-28 °C. The measuring instrument used a tetrapolar system of tactile electrodes with eight points (four are attached to the palm and thumb, and the remaining four to the feet), which independently measure the impedance of the arms, torso, and legs. Body composition measures that were measured are: muscle mass in % (MM), body fat mass in kg (BFM), body fat mass in % (PBF).

Explosive power

The jumps were assessed by using the squat and countermovement jumps. The squat jump (SJ) consisted of a standing position with knees flexed at 90 degrees, hands on the waist. With no help of the upper limbs, the player should jump and extend the legs, falling in the same place. The players waited 3s in the squat position before each jump. The countermovement jump (CMJ) started in a standing position with hands on the waist, realized with flexion of the legs and simultaneously with the jump, legs extended and falling in the same place. The SJ and CMJ were tested with a portable force plate designed for field testing (Quattro Jump, Type 9290 AD, Kistler, Switzerland). This device records only the vertical ground reaction force at a sampling frequency of 500 Hz, and jump height is automatically calculated by the Quattro jump software using double integration of the force signal using Simpson's rule of integration (Buckthorpe, Morris, & Folland, 2012). Explosive power measures that were measured are: CMJ Jump Height from Take Off V in cm (CMJHeight), CMJ Relative maximal F (%BW) (CMJF), CMJ Relative maximal P (W/kg) (CMJP), SJ Jump Height from Take Off V in cm (SJHeight), SJ Relative maximal F (%BW) (SJF), and SJ Relative maximal P (W/kg) (SJP).

Statistical analysis

The data were processed by the Statistical Package for Social Sciences SPSS (v19.0, SPSS Inc., Chicago, IL, USA). The Shapiro-Wilk test confirmed normality in all measures for use of parametric analyses ($p \geq 0.05$). Levene's test was used to assess the equality of variance in all measures. The mean ± standard deviation with 95% confidence intervals was calculated for each outcome measure. Pearson's correlation coefficient was used to determine the correlation between all tests with 95% confidence intervals. The magnitude of the correlations was interpreted using the following criteria: <; 0.1, trivial; 0.1–0.3, small; 0.3–0.5, moderate; 0.5–0.7, large; 0.7–0.9, very large; and > 0.9 almost perfect (Hopkins, 2002). The level of significance for the correlation analysis was set at $p<0.05$ (Hopkins, 2002). Simple linear regression analyses were also conducted to assess the shared variance (R2) between body composition and explosive power performance.

RESULTS

Descriptive statistics, the mean ± standard deviation for each outcome measure is presented in Table 1.

Table 1 Mean ± standard deviation performance times with 95% confidence intervals (CI) for body composition and explosive power

Outcomes	Mean ± SD	95% CI
MM	43.1 ± 3.42	41.28 ± 44.92
BFM	14.32 ± 6.00	11.12 ± 17.52
PBF	21.06 ± 6.50	17.60 ± 24.53
CMJHeight	21.69 ± 3.81	19.66 ± 23.73
CMJF	203.59 ± 13.90	196.19 ± 210.99
CMJP	36.89 ± 3.73	34.91 ± 38.88
SJHeight	18.82 ± 4.35	16.50 ± 21.14
SJF	193.06 ± 7.58	189.03 ± 197.09
SJP	42.89 ± 9.05	38.07 ± 47.71

Pearson correlation coefficients and regression statistics between body composition parameters and all other explosive power outcomes are presented in Table 2.

Table 2 Associations between body composition and explosive power outcomes in female adolescent football players (N=16)

	r (95% CI)	Magnitude	SEE	p
MM				
CMJHeight	0.50 (0.004 to 0.997)	moderate	0.89	**< 0.05**
CMJF	0.61 (0.149 to 1.062)	large	0.82	**0.01**
CMJP	0.24 (-0.317 to 0.796)	small	1.0	0.37
SJHeight	0.69 (0.272 to 1.104)	large	0.75	**0.003**
SJF	0.28 (-0.270 to 0.830)	small	0.99	0.29
SJP	0.61 (0.160 to 1.066)	large	0.81	**0.01**
BFM				
CMJHeight	-0.65 (-1.086 to -0.216)	large	0.79	**0.006**
CMJF	-0.51 (-1.005 to -0.020)	large	0.89	**0.04**
CMJP	-0.52 (-1.011 to -0.034)	large	0.88	**0.03**
SJHeight	-0.62 (-1.072 to -0.177)	large	0.81	**0.01**
SJF	-0.29 (-0.840 to 0.257)	small	0.99	0.27
SJP	-0.66 (-1.092 to -0.232)	large	0.78	**0.005**
PBF				
CMJHeight	-0.58 (-1.045 to -0.107)	large	0.85	**0.02**
CMJF	-0.58 (-1.045 to -0.108)	large	0.84	**0.01**
CMJP	-0.32 (-0.859 to 0.229)	moderate	0.98	0.23
SJHeight	-0.72 (-1.116 to -0.315)	very large	0.72	**0.002**
SJF	-0.32 (-0.861 to 0.277)	moderate	0.98	0.23
SJP	-0.65 (-1.085 to -0.214)	large	0.79	**0.006**

Legend: r - Pearson correlation coefficient with 95% confidence intervals (CI);
SEE - standard error of the estimate; p - statistically significant association

The largest associations ($r = 0.61$, $p \leq 0.01$) were between MM and CMJF and between MM and SJP. The correlation between BFM and SJHeight was ($r = 0.81$, $p \leq 0.01$, large) and between PBF and CMJF was ($r = 0.84$, $p \leq 0.01$, large), as shown in Table 2.

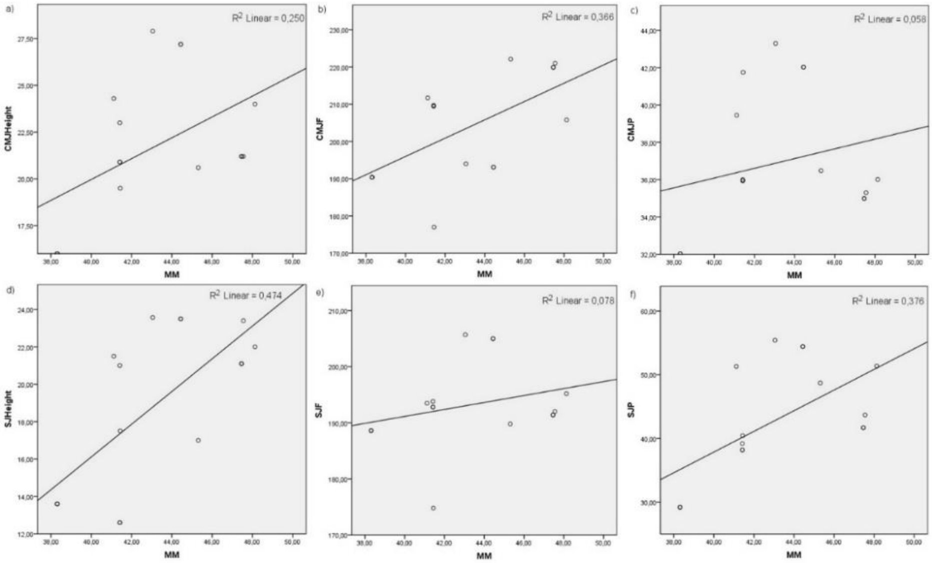

Fig. 1 Scatterplots showing the relationships between MM and a) CMJHeight b) CMJF, c) CMJP, d) SJHeight, e) SJF, f) SJP in female adolescent football players

Significant regressions were found between MM and CMJHeight ($r = 0.50$, $p \leq 0.05$, moderate, $R^2 = 0.25$) and MM and CMJF ($r = 0.61$, $p \leq 0.01$, large, $R^2 = 0.36$) and MM and SJHeight ($r = 0.69$, $p \leq 0.003$, large, $R^2 = 0.47$) and MM and SJP ($r = 0.61$, $p \leq 0.01$, large, $R^2 = 0.42$)

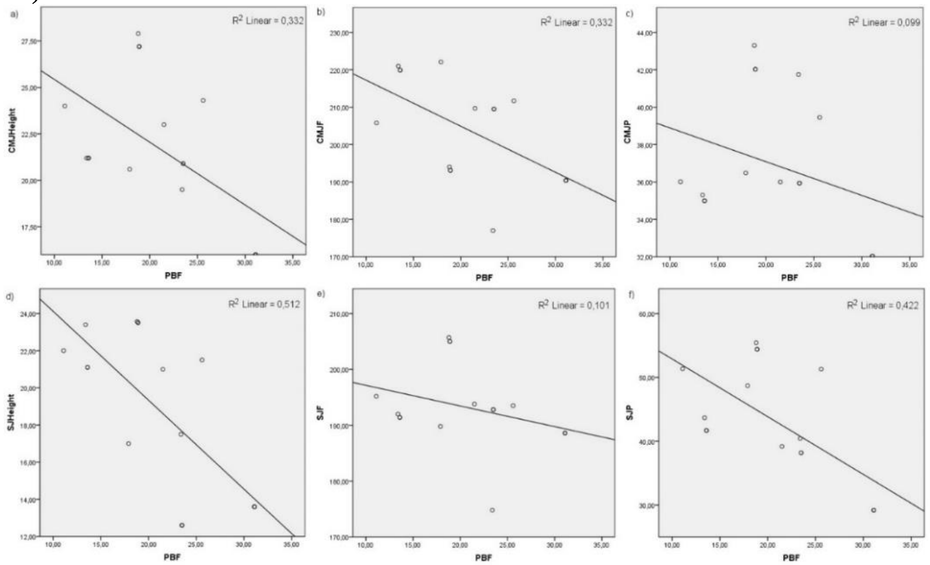

Fig. 2 Scatterplots showing the relationships between PBF and a) CMJHeight b) CMJF, c) CMJP, d) SJHeight, e) SJF, f) SJP in female adolescent football players

Regression analyses in Figure 2 were found between PBF and CMJHeight (r = 0.58, p ≤ 0.02, large, R^2 = 0.33) and PBF and SJHeight (r = 0.72, p ≤ 0.002, very large, R^2 = 0.51), and PBF and SJP (r = 0.65, p ≤ 0.006, large, R^2 = 0.42).

DISCUSSION

The primary aim of the present study was to quantify the relationship between body composition variables such as muscle mass, body fat mass in kilograms and percentage, and explosive power performance parameters in female adolescent football players. A secondary aim was to measure the influence of body composition on explosive power in female adolescent football players. Body composition parameters were correlated with a range of explosive power in female adolescent football players. Specifically, jump height, relative maximal force and relative maximal power depend on body composition parameters. The results of this study suggest that the body composition parameters and explosive power are associated and that muscle mass and body fat mass in percentage can have an on jump height and relative maximal power values in particular.

Estimate of body composition parameters is a significant indicator of vertical jumping performance in adolescent male football players (Cinita, et al., 2022). Cinita et al. (2022) reported a body mass significant correlation with CMJ height (r = 0.25) and SJ height (r = 0.19), while values of PBF were in a negative correlation with CMJ (p ≤ 0.01, r = -0.47) and SJ (p ≤ 0.01, r = -0.57). The regression analysis showed a significant influence of body mass and PBF on CMJ height (p ≤ 0.01, R^2 = 0.39) and SJ height (p ≤ 0.01, R^2 = 0.45) in children aged 17, while in children aged 15 it was (p ≤ 0.01, R^2 = 0.46) for CMJ height and (p ≤ 0.01, R^2 = 0.52) for SJ height (Cinita, et al., 2022). Other body composition parameters also showed a significant correlation among Spanish adolescent male football players with CMJ and SJ height such as fat free mass (p ≤ 0.01, r = 0.36 to 0.37) and skeletal muscle mass (p ≤ 0.05, r = 0.07 to 0.09), while PBF (p ≤ 0.01, r = -0.33 to -0.34) and fat mass in kilograms (p ≤ 0.01, r = -0.21 to -0.23) had a negative correlation (Pérez-López, et al., 2015). Central defenders and forwards players perform better on the vertical jump than midfielders (Rampinini, Coutts, Castagna, Sassi, & Impellizzeri, 2007). This should be related to the fact that defenders and forwards players have more physical contact and jumping in the match (Rebelo, et al., 2013). This was also confirmed by Aurélio et al. (2016) who reported that height has significant influence on CMJ (R^2 = 0.91). Atakan et al. (2017) presented different results in adolescent male football players. In seventeen adolescent male football players, no significant correlations for PBF, fat mass, fat mass index, lean mass and lean mas index and parameters of CMJ and SJ (Atakan, et al., 2017) were found. In other sports, for male adolescent handball players 14 years old CMJ height and SJ height showed correlations with the body mass index and PBF (p≤ 0.05, r = -0.616 to -0.777), while only lean mass showed a non-statistically significant correlation (Molina-López, Barea Zarzuela, Sáez-Padilla, Tornero-Quiñones, & Planells, 2020). CMJ and SJ power presented a large positive correlation (p≤ 0.05, r = 0.703 to 0.904) with the body mass index, lean mass, and PBF (Molina-López, et al., 2020). Older handball players who are 16 years old presented different results for CMJ and SJ height, showing a non-significant correlation with body composition parameters, while CMJ and SJ power showed a positive relationship only with the body mass index and lean mass (Molina-López, et al., 2020). Different results were determined between athlete adolescents and non-sport athlete adolescents. Sport participation in adolescents showed a relationship between the standing broad jump and body mass index and PBF ($p \leq 0.01$, $r = -0.23$ to -0.62), while non-athlete adolescents showed non-significant results with body mass index (Agata, & Monyeki, 2018).

It should be noted the studies which included male adolescent football players (Cinita et al., 2022; Pérez-López et al., 2015; Aurélio et al., 2016) presented results that match those of our study, stressing the multifaceted influence of PBF on CMJ and SJ height (Cinita, et al., 2022). Consequently, parameters of explosive power performance may be more influenced by body composition parameters, specifically PBF and MM. A negative correlation presented that lower PBF values may have a positive influence on CMJ and SJ height, while increasing MM may be also increase CMJ and SJ height. During adolescence in boys, there is an increase in the hormone testosterone, which is responsible for the development of muscle mass (Haff, & Triplett, 2015). Pérez-López et al. (2015) reported increased muscle mass, there is also an improvement in the height of reflection in the CMJ and SJ. In adolescent girls, the hormone estrogen increases the appearance of adipose tissue (Haff, & Triplett, 2015), and accordingly can lead to reduced performance values. However, our results showed that girls who play football also show that increasing MM increases values of CMJ and SJ height ($r = 0.50$ to 0.69) and that PBF and MM have a strong influence on height but also on the power produced during the jump. A study which included fewer male football players aged seventeen did not find a significant correlation with body composition parameters and explosive power parameters (Atakan, et al., 2017). However, the limited contribution of studies involving female adolescent football players should be noted.

The limitations of our study included the recruitment of state-level adolescent female football players. Our findings may not easily transfer to other sports or non-sport populations and explosive power parameters can differ according to sex, sports, playing level, and playing year. We included fewer adolescent female football players which warrants further investigation across a broad range of football player samples. Also, other studies should consider the biological and chronological age of female athletes. In order to expand the knowledge about the influence of body composition on sports performance in adolescent female football players, it is necessary to include other tests for evaluating explosive power, as well as to monitor the changes that occur in female athletes for a certain period of time.

CONCLUSION

Our study provides a comprehensive analysis of the body composition parameters and explosive power parameters and is the first to identify the contribution of their correlation and influence in adolescent female football players. Muscle mass, body fat mass, and body fat mass in percentage were indicators of a correlation with explosive power. Lower values of body fat mass and body fat mass in percentage showed a better performance in CMJ and SJ height, relative maximal force, and relative maximal power. Higher values of muscle mass lead to better results in CMJ and SJ height. Our results suggest the influence of body composition on explosive power parameters in adolescent female football players.

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UTICAJ PARAMETRA TELESNE KOMPOZICIJE NA EKSPLOZIVNE SNAGE KOD FUDBALERKI U PERIODU ADOLESCENCIJE

Cilj ove studije bio je da se kvantifikuje odnos između varijabli telesne kompozicije i eksplozivne snage kod fudbalerki u period adolescencije. Sekundarni cilj je bio uticaj telesne kompozicije na eksplozivnu snagu kod kod fudbalerki u period adolescencije. Transverzalna studija obuhvatila je *šesnaest fudbalerki (godine: 14,5 ± 0,97; visina: 170,06 ± 4,39; težina: 61,35 ± 11,25) koje su se takmičile u okviru Razvojne lige Srbije. Parametri telesne kompozicije su bili: mišićna masa u procentima (MM), masa telesne masti u kg (BFM), masa telesne masti u procentima (PBF), dok su parametar eksplozivne snage bili: CMJ Visina skoka u cm (CMJHeight), CMJ Relativni maksimalni sila (CMJF), CMJ Relativni maksimalni snaga (CMJP), SJ Visina skoka u cm (SJHeight), SJ Relativna maksimalna sila (SJF), SJ Relativna maksimalna snaga (SJP). Pirsonov koeficijent korelacije je korišćen za određivanje korelacije između svih testova, a analiza linearne regresije su primenjene da bi se utvrdio uticaj između sastava tela i performansi eksplozivne snage. Pronađene su značajne regresije između MM i CMJHeight ($r = 0,50$, $p \leq 0,05$, $R^2 = 0,25$) i MM i SJHeight ($r = 0,69$, $p \leq 0,003$, $R2 = 0,47$). Takođe, pronađene su regresione analize između PBF i CMJHeight ($r = 0,58$, $p \leq 0,02$, $R^2 = 0,33$) i PBF i SJHeight ($r = 0,72$, $p \leq 0,002$, $R^2 = 0,51$). Manje vrednosti mase telesne masti i mase telesne masti u procentima i veće vrednosti mišićne mase utiču na bolje rezultate u performansama eksplozivne snage.*

Ključne reči: *snaga, sila, skok iz čučnja, skok protiv pokreta*

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Research article

THE INFLUENCE OF INSTRUCTIONS ON REACTION TIME AND DEFENSIVE EFFICIENCY IN FOOTBALL

UDC 796.332.012.13

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Abstract. *Any delay in making a decision in games greatly reduces the efficiency of football players during competitive activities. The aim of this research was to examine the impact of instructions on defensive efficiency. Defensive efficiency was assessed based on the achieved reaction time of the participants in quasi-specific football situations in one-on-one games, using video-based methods. The sample consisted of 20 males, divided into two equal groups: top football players and students. The results of the study have shown that top footballers have a more efficient defensive strategy compared to students, with significant differences observed when presented with stimuli without a fake move ($F = 7,190$, $p = 0.015$). The differences were not significant after the response to the stimuli with a fake move ($F = 0.348$, $p = 0.563$), but it should be noted that in three out of four cases, the players had a slightly shorter average reaction time. Still, the results have shown that experimental instructions had no effect on defensive efficiency when presenting simple stimuli ($F = 2.281$, $p = 0.148$), as well as when presenting more complex stimuli with a fake move ($F = 1.170$, $p = 0.294$). Instructions have an important place in young players' training, but defensive efficiency of top players is affected by how well-trained they are, which is manifested through the adopted mechanisms as a result of training. Therefore, it can be concluded that giving instructions must be a part of the individual approach depending on the skill level of the person whom it is communicated to.*

Key words: *motor control, reaction speed, video-based method, dribbling*

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1. Introduction

Conditions for performing in modern elite sports require athletes to be fast in making adequate decisions when resolving complex competitive situations. Shorter reaction time can significantly affect performance efficiency in most sports (Ric et al., 2017). Bearing in mind that football players encounter complex situations during the games when it is important to pay attention to several factors (Ruschel et al., 2011), the ability to react quickly has a huge impact on the player's performance during competitive activities.

The introduction of new rules, improvement of playing conditions and use of modified modern training technology have led to an increase in modern football dynamics. Observed differences between the technical and tactical performance of the players who play in different ranks clearly indicate that better players are prepared through training for playing fast with a high degree of ball control (Leontijević, Janković & Tomić, 2018). Due to tactical ideas of football experts, the density of players in the area around the ball has increased, causing a higher frequency of passes by 35% and a higher ball speed by 15% (Wallace & Norton, 2014). In addition, the number of contacts with the ball decreases and ranges from 1.87 to 2.23 contacts by individual possession depending on the position of the player (Dellal, Wong, Moalla & Chamari, 2010). It is clear that current trends are forcing footballers to use rational and simple solutions in the game, that is, to quickly make decisions with and without the ball in complex game conditions (Janković & Leontijević, 2016). Any delay in making a decision during games can significantly impair football players' efficiency (Schmidt & Wrisberg, 2000), so the assessment of sensory and motor abilities of players is of great importance for the scientific and professional population.

Footballers must have a high level of visual and perceptual skills in order to be trained to collect and process information in the shortest possible time, and then select effective motor responses based on the analysis of a large number of factors (Williams, 2000). The analysis of the results of previous research showed that football players have shorter response time than recreational players (Ando, Kida & Oda, 2001), but it was noticed that there is inconsistency in the results when comparing reaction times of different quality footballers. By using a complex and expensive system, such as virtual technology, which is not available to many researchers, Wood et al. (2020) showed that there are differences between professional football players, players from the academy, and beginners, while in other studies there were no differences between players at different levels (Ruschel et al., 2011; Ricotti, Rigosa, Niosi & Menciassi, 2013). Yet, the results presented in studies where no differences were found are limited in value when generalizing conclusions because of the method used (computer – finger) to estimate the reaction time (Peiyong & Inomata, 2012). In addition, the basic video-based method for assessing sensory and motor abilities of athletes stood out as a reliable, sensitive and accessible method for estimating reaction time. Using this method, which makes it possible to ensure a high level of ecological validity of the test, the research results showed that top athletes, in samples of karate, fencing and football athletes, achieve shorter reaction time compared to students (Mudrić, Ćuk, Janićijević, Nedeljković & Jarić, 2015; Milić, Nedeljković, Ćuk, Mudrić & Garcia-Ramos, 2019; Tomić, Janićijević, Nedeljković & Leontijević, 2021).

Theorists agree that success in performing motor activities largely depends on attention, and attention is influenced by various pieces of information that reache the human system from different sources in the environment (Cattel, 1893; Bernstein, 1996; Schmidt & Lee, 2005). In sports, verbal instructions are one of the most important sources of information and is an indispensable method of training when giving targeted information relevant to motor activities performance. It has a special contribution during the training of players (Aleksić & Janković, 2006). In addition to the mentioned research in which football players' sensory and motor abilities were examined, scientists were interested in detecting more efficient visual strategies for solving various offensive and defensive activities of players by estimating reaction times (Vaeyens, Lenoir, Williams & Philippaerts, 2007; Krzepota, Stepinski & Zwierko, 2016). The players who successfully solve one-on-one situations in offensive and defensive terms are of special importance in football. The results of previous research confirmed that top players have a more efficient strategy due to the defensive activities reflected in a shorter time interval from the appearance of the stimulus to the beginning of the adequate response (Krzepota et al., 2016). Professional literature suggests that defensive players in one-on-one situations should focus on the ball (Luongo, 2000; Harrison, 2003), to avoid responding to attackers' fake moves. However, the analysis of other results (Williams & Davids, 1998; Nagano, Kato & Fukuda, 2004) concludes that a certain group of authors emphasises hips and knees as important regions for predicting the movement activities of players with a ball. These observations leave room for further discussion when it comes to detecting more efficient strategies in football players' individual defense.

Based on previous research, we can expect that the participants in our study will achieve a shorter reaction time after the verbal instructions directing the visual focus towards the ball compared to the instructions directing the visual focus towards the knee. The aim of this study was to examine the impact of instructions on defensive efficiency in quasi-specific football situations, by using the basic video-based method and assessing reaction times. The results obtained could affect improving the methodology for training young players in terms of clearer instructions on taking a defensive position towards the attacker with the ball.

2. METHODS

2.1. Sample

The sample consisted of 20 males, divided into two equal groups. One group consisted of top football players (N = 10, age: 20.9 ± 3.6 years; weight: 75.4 ± 6.5 kg; height: 1.82 ± 0.05m), represented by players of the senior squad of FK Partizan Belgrade. The other group included students (N = 10, age: 23.4 ± 0.5 years; weight: 86.0 ± 10.2 kg; height: 1.84 ± 0.03m) from the Faculty of Sport and Physical Education. For both groups of participants, there were clear inclusion criteria. The football players had to meet the requirement that they had been actively training football for at least 10 years and that they were playing in a professional football club at the time of testing. The basic criterion for the students was that they gained the experience of playing football exclusively during their Football course, and that they had not had previous training experience with similar ball sports. Just one participant from the total sample indicated the left leg as dominant. The entire testing protocol was approved by the Ethics Committee of the Faculty of Sport and Physical Education, University of Belgrade (02 - 462 / 20-1), and was designed in accordance with the Declaration of Helsinki.

2.2. Instruments

The following instruments were used during the experiment:

- A video camera (Basler BIP2, Ahrensburg, Germany) for recording a model's offensives activities used as a stimulus during the testing;
- Two force platforms (AMTI BP600400, Advanced Mechanical Technology, Inc. Watertown, MA 02472-4800 USA) to identify relevant points that marked the beginning of the models' and participants' movement (Mudrić et al., 2015; Milić et al., 2019; Tomić et al., 2021);
- A projector and a screen for showing the stimuli to the participants;
- A football;
- A trigger for a synchronized start of the camera and force platforms during the model's recording, as well as the projector and force platforms during the participants' testing;

2.3. Design

The experimental protocol was conducted in the laboratory of the Faculty of Sport and Physical Education in Belgrade and consisted of two separate activities. The conditions in the laboratory were optimal and the room was slightly darkened for a clearer presentation of the video stimuli. The first step involved recording the offensive activities of the model, which was later used for stimuli during testing. After selecting and preparing a video presentation, the participants were tested on a separate occasion.

2.3.1. Offensive actions - "stimulus" recording

By analysing the application of dribbling in football (Janković & Leontijević, 2008) it was decided that offensive actions consist of basic external dribbling and skipping sideways (Fig. 1). The role of the model was played by a top football player who was not in the sample of participants. By taking a parallel position on the two synchronised force platforms, the model was placed at a distance of 2m from the camera used to record the stimuli (Figure 2A). After positioning the model, the first instruction "READY" ensued, after which the model remained still for the next 6 seconds. This was followed by the instruction "GO" after which the model performed the previously agreed offensive action.

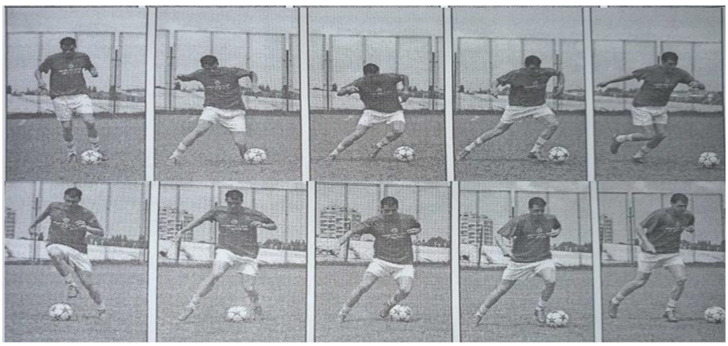

Fig. 1 Offensive actions of the model - basic external drilling (row I), skipping sideways (row II). (adapted from Aleksić & Janković, 2006)

2.3.2. Defensive actions - "response" recording

During the tests, the participants took an optimal defensive position by placing the feet parallel on the force platforms (Figure 2B). The participants' response meant tackling by stepping forward (Janković & Leontijević, 2016). When applying the stimulus with a fake move (skipping sideways), the participants ended the response by stepping to the side to which the model carried away the ball, no matter whether the wrong response was initially initiated under the influence of the feint of the model.

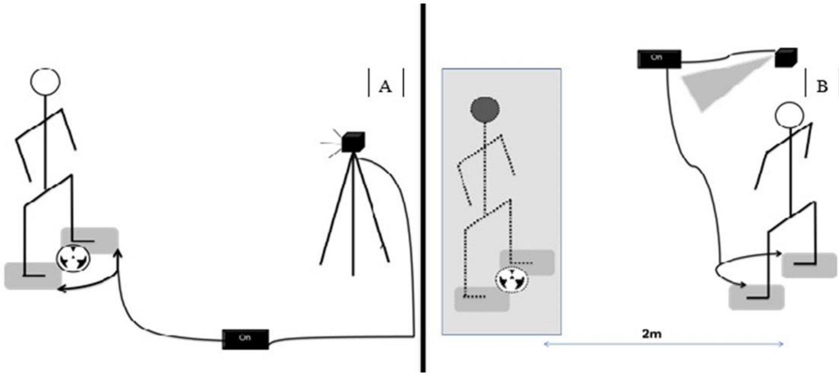

Fig. 2 Experimental design, A - stimulus recording, B - participant testing.

2.4. Testing Procedure

The experimental condition of the research was the verbal instruction given by the researcher to the participant immediately before each experimental attempt. The instruction was “ball” or “knee”, and based on it, the participant was supposed to direct his visual focus on the designated model space when responding. Complex reaction time was assessed in the research, bearing in mind that the participant could expect one of four different offensive actions after each instruction.

The expected testing duration depended on the individual arrival of each participant according to a pre-arranged schedule. Bearing in mind that the testing was conducted during the season of the National Football Championship in Serbia, and due to frequent professional obligations of the participants from the professional players group, the testing procedure differed between the groups of participants in terms of the number of experimental attempts. Participants from the group of students had 24 experimental attempts each (3 attempts x 4 stimuli x 2 instructions), and from the top football players’ group, 16 experimental attempts (2 attempts x 4 stimuli x 2 instructions).

Prior to the test itself, the participants could perform a basic warm up on their own - dynamic stretching, and then a specific warm up – trial attempts (2 attempts on each stimulus and experimental condition). Testing ensued upon completion of the warm up. After the experimental instructions (ball or knee), followed by the first instruction "READY" - the participant placed himself on the force platforms and took the optimal defensive position (Figure 3). This was followed by the second instruction "GO" - which meant that at that moment the trigger was used to start the presentation of the offensive stimulus on the screen.

At the end of the experimental attempt, the participant left the platforms only after the video ended. In order to prevent the participants from being able to predict the stimulus that awaited them in the next experimental attempt, they were presented with experimental attempts in random order. In addition, the duration of offensive actions recording, from the announcement of the second instruction by the researcher to the beginning of the dribbling, varied from 1 to 5 seconds. Also, compared to the total number of experimental attempts, there were 20% "fake specimens" of stimuli during which the model did not perform any movement. In case of a wrong response, the attempt was repeated later during the testing. The entire testing was conducted in line with the previously prepared protocols in the presence of the same researcher.

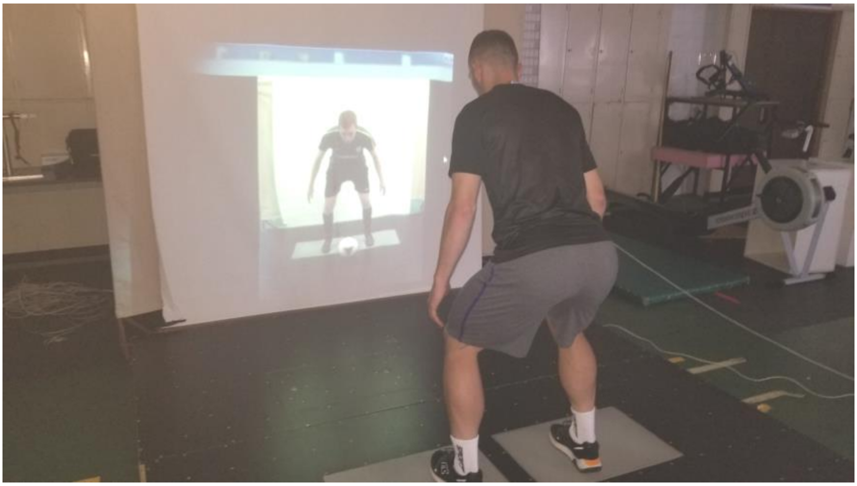

Fig. 3 Experimental setup.

2.5. Data Analysis

Specialized software (National Instruments LabView Student Edition 2007, Austin, TX, USA) was designed for this research. The software processed all the signals recorded by the force platforms when performing offensive activities by the model and later responses by the participants during the testing. The developed software enabled the discovery of relevant points for determining the beginning of the activity of the model and the participants in the experiment (Figure 4). Depending on the type of stimulus, it was necessary to determine the following points for both the models and the participants:

- The beginning of the movement - this point is sought in all offensive stimuli and it represented the first change of force greater than 5% compared to the maximum values of rate of force development (RFD), with either foot.
- The beginning of the real movement - this point had to be found when presenting offensive stimuli with the feint, or skipping the ball. For the model, it represented the peak of force achieved by the foot which the model stepped on after the feint and began removing the ball to the real side. In the case of the participants, the beginning of the real movement was the peak of force exerted by the foot which they stepped on at the moment of initiating the response on the correct side when removing the ball.

Fig. 4 Processed force platform signal in LabView software.

After finding the necessary points, to assess the efficiency of the defense the following intervals were observed:

- When presenting offensive actions without fake moves, the difference noticed between the participants and the model for the point "beginning of the movement" is defined as the "***initial reaction time***" interval.
- When presenting offensive actions with a fake move, the difference between the "beginning of the movement" of the model and the "beginning of the real movement" of the participant was defined as the "***total reaction time***" interval.

2.6. Statistical Analyses

The lowest achieved participants' values were used for statistical data processing. A mixed analysis of variance ("between groups – within groups" ANOVA) was used to detect the differences for each of the four offensive stimuli and two instructions as a factor within groups. As a factor between the groups, the results were compared between the students and the top football players. When significant differences were determined, the Bonferroni post-hoc test was applied for the main factors. Statistical analysis was performed using Microsoft Office Excel 2010 (Microsoft Corporation, Redmond, WA, USA) and SPSS 22.0 (Inc., Chicago, IL), while the level of statistical significance was set at $p < 0.05$.

3. Results

In situations when the participants were presented with a stimulus without a fake move (Figure 5) the results showed significant differences between the group of participants ($F = 7.190$, $p = 0.015$) and versions of offensive actions ($F = 12.247$, $p = 0.003$), but not when it comes to instructions ($F = 2.281$, $p = 0.148$). The interaction between the factors 'offensive action*instruction' turned out to be significant ($F = 5.736$, $p = 0.028$) and it was found that the differences in the initial reaction times were smaller during offensive actions when the participants' focus was on the knees. For other factors, there were no significant interactions, 'offensive action*group' ($F = 0.357$, $p = 0.557$), 'group* instruction' ($F = 0.013$, $p = 0.909$), as well 'offensive action*instruction*group' ($F = 3.309$, $p = 0.086$).

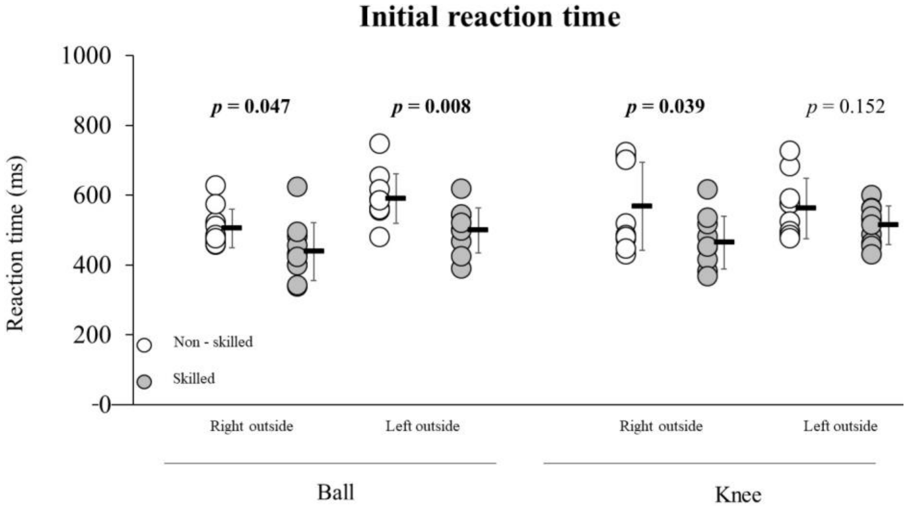

Fig. 5 Response time between students (clear circles) and football players (dark circles) in relation to different instructions (ball or knee) for offensive actions without a feint.

The results for the total reaction time (Figure 6) showed significant differences for the factor stimulus (F = 10.848, p = 0.004). The participants would start the correct response earlier when presented with a stimulus in which the model started the feint by skipping the ball to the right, and carried the ball to the left. However, the three-factor ANOVA did not show significant differences between instructions (F = 1.170, p = 0.294) and groups (F = 0.348, p = 0.563). In addition, the interaction between the main factors did not show statistical significance, 'offensive action*group' (F = 0.505, p = 0.486), 'group* instruction' (F = 2.019, p = 0.172), 'instruction*offensive action'(F = 0.201, p = 0.659) and 'offensive action*focus*group'(F = 0.080, p = 0.781).

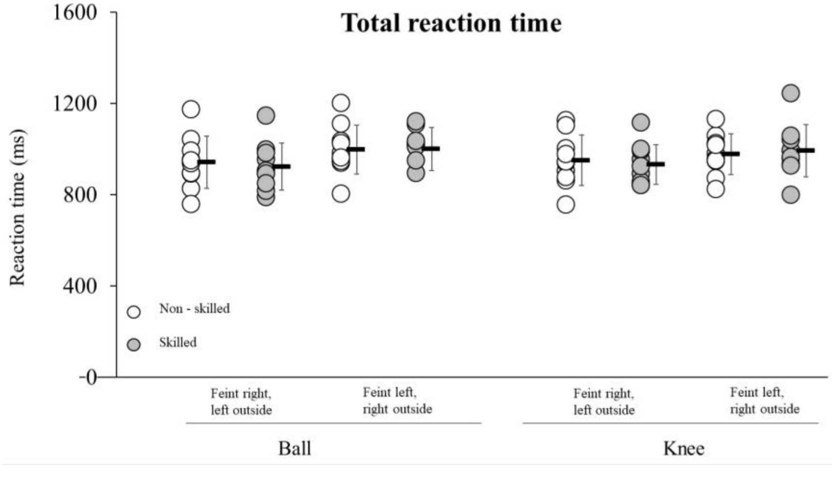

Fig. 6 Reaction time between students (clear circles) and football players (dark circles) in relation to different instructions (ball or knee) for offensive actions with a feint.

4. DISCUSSION

The aim of this research was to examine the impact of instructions on defensive efficiency. The efficiency of the defense was assessed based on the participants' reaction time in quasi-specific football situations, using a reliable and sensitive test – a video-based method (Tomić et al., 2021). Any delay in decision-making in a game greatly reduces football players' efficiency during competitive activities. The results indicate that the experimental instructions (ball or knee) had no effect on the defensive efficiency as no differences were observed in the participants' reactions. Also, the analysis of the results shows that top footballers have a more efficient defensive strategy compared to students. They achieved a significantly shorter initial reaction time (the response to the stimuli without feints). For the total reaction time (the response to stimuli with feints) no differences were observed between the groups, although in three out of the four cases the players had a slightly shorter average reaction time.

The fact that the participants are well-trained presents a significant factor in the reaction speed in a variety of situations (Schmidt & Lee, 2005). Perceptual abilities represent a significant criterion for participation in football, and the results of previous research show that the perceptual abilities of the players clearly make a difference in quality between footballers (Williams, 2000). Also, the results indicate that there is a positive correlation between the developed visual skill and players' tactical efficiency (Assis, Costa, Casanova, Cardoso & Teoldo, 2020). Somewhat different visual strategies have an impact on faster responses of better football players. It has been concluded that top player's visual focus is directed towards fewer specific regions of the opponent with a longer time interval dedicated to each region compared to beginners (Krzepota et al., 2016). Based on their experience, top athletes have mechanisms that allow them to perceive crucial information and thus predict subsequent opponent's activities (Shim, Carlton, Chow & Chae, 2005). This shortens the decision-making phase when processing information from the external environment and results in a shorter reaction time. Bearing in mind that the top football players in our study had a shorter reaction time compared to students, it is clear that the results of our research confirm the previous research. However, in our study, the football players did not achieve shorter reaction time when presented with more complex stimuli with feints. A study by Ando et al. (2001) concluded that footballers had shorter premotor reaction time compared to recreational players. In addition, it is known that frequent strength training, which is implied in the preparation of top footballers, has a positive effect on the rate of force increase (Pelton, Walker, Lahitie, Hakkinen & Avela, 2018). Bearing in mind the method for determining reaction times in our study, it can be said that, when presented with more complex stimuli, football players had more time to perceive important information about the stimuli before they started, and quickly performed a defensive action, as was also the case in the Craig (2014) study.

Resolving situations in an efficient way when playing one-on-one in football is a core component in the attack and defense phase (Harrison, 2003). Professional literature recommends focusing attention on the ball in defensive actions (Luongo, 2000; Harrison, 2003), with particular emphasis on the importance of instructions during players' training. The interpretation of the influence of instructions on focusing attention on crucial information processing when performing motor activities has long been present in science theory (Bernstein, 1996). However, a small number of studies have investigated the influence of verbal instructions on football players' performance (Beilock & Carr, 2002; Ford, Hodges & Williams, 2005). The results of our study have not shown that verbal instructions for directing external focus has an impact on the participants' defensive efficiency. The results of the research conducted on a sample of golfers and football players showed that verbal instructions which affects the inner focus has a greater impact on beginners, while for more successful athletes, the instructions for directing external focus is more significant (Ford et al., 2005; Perkins-Ceccato, Passmore & Lee, 2003). Bearing in mind that in our research the instructions in both cases was meant to direct the external focus, it is clear why the instructions did not affect the defensive efficiency of the student group of participants. When examining the visual strategies of footballers, Nagano et al. (2004) emphasised that top players have a more open pattern that is manifested by directing attention to a wider space towards the opponent, encompassing the knees and hips besides the ball. Therefore, the results of our study for the group of footballers can be interpreted as a consequence of their already adopted strategy. Top players in defensive situations focus on 2-3 regions of the opponent, in order to collect as much necessary information as possible for starting the defense activity (Krzepota et al., 2016), and not on individual ones as was the case in our study.

5. Conclusion

It can be concluded that the conducted study confirms that top footballers have a more efficient strategy compared to students when making decisions in individual defensive actions. Therefore, the test used in this study can be implemented in the assessment of the sensory-motor abilities of players in separate quasi-specific football situations. It can also be used to identify talented players in younger categories (Savelsbergh, Haans, Kooijman & Kampen, 2010). However, the results of our study have not shown that verbal instructions for directing external focus had an impact on the participants' defensive efficiency. It can be concluded that defensive efficiency is influenced by several factors, but also, that, when giving verbal instructions, an individual approach is very important in terms of the skill level of the person being instructed.

Several limitations were noticed in the conducted study. Taking into account the sensitivity of the variable being assessed (reaction time), it can be said that a relatively small number of participants (because of the criteria for selecting top football players and students) was tested. Also, as a consequence of a large number of top players' professional obligations in the competition season, a slightly smaller number of attempts performed by the top players could have negatively affected the obtained research results. Further research should examine the impact of instructions on football players based on their positions in the team, i.e. compare defensive players to attackers, bearing in mind that in our research it was not a criterion for selecting top players.

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UTICAJ INSTRUKCIJE NA REAKCIONO VREME I EFIKASNOST U DEFANZIVI U FUDBALU

Svako kašnjenje prilikom donošenja rešenja u igri, u velikoj meri umanjuje efikasnost fudbalera prilikom takmičarskih aktivnosti. Cilj ovog istraživanja je da se ispita uticaj instrukcija na efikasnost odbrane. Efikasnost odbrane je procenjivana ostvarenim vremenom reagovanja ispitanika u kvazi - specifičnim fudbalskim situacijama igre 1vs1, upotrebom video metoda. Uzorak ispitanika je činilo 20 osoba muškog pola, podeljenih u dve jednake grupe vrhunskih fudbalera i studenata. Rezultati istraživanja su pokazali da vrhunski fudbaleri imaju efikasniju odbrambenu strategiju u odnosu na studente uz značajne razlike uočene prilikom prezentovanja stimulusa bez fintirajućeg pokreta (F=7,190, p=0,015). Razlike nisu bile značajne nakon odgovora na stimulus sa fintirajućim pokretom (F=0,348, p =0,563), ali treba napomenuti da su u tri od četiri slučaja fudbaleri imali neznatno kraće prosečno vreme reakcije. Ipak rezultati istraživanja su pokazali da eksperimentalna instrukcija nije imala uticaja na efikasnost odbrane prilikom prezentovnja jednostavnih stimulusa (F=2,281, p=0,148), kao ni prilikom prikazivanja složenijih stumulusa sa finitrajućim pokretom (F=1,170, p=0,294). Instrukcija ima značjano mesto u obuci mladih igrača, ali na efikasnost odbrne vrhunskih igrača utiče utreniranost koja se ispoljava usvojenim mehanizmima usled treninga. Prema tome, zaključuje se da davanje instrukcija mora biti u sklopu individualnog pristupa u odnosu na nivo veština osobe kojoj se saopštava.

Ključne reči: *motorna kontrola, brzina reagovanja, video metod, dribbling*

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Research article

THE EFFECTS OF A 4-WEEK STRENGTH AND CONDITIONING PROGRAM ON STRENGTH, POWER, AND THROWING VELOCITY FOR JUNIOR VARSITY AND VARSITY HIGH SCHOOL WATER POLO PLAYERS

UDC 796.253.015.52

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Abstract. *This study investigated the effects of a 4-week strength and conditioning program on the strength, power, and throwing velocity of male junior varsity and varsity high school athletes. Six junior varsity and eight varsity water polo players were recruited. Pre- and post-testing included isometric grip and leg/back strength; vertical jump (VJ); 2-kg medicine ball throw; and maximum throwing velocity with a water polo ball. All participants completed a 4-week strength and conditioning program designed to enhance base levels of strength. Data was analyzed via a two-way repeated measures ANOVA ($p<0.05$), including groups as a between-subjects factor measured at two levels (junior varsity, varsity). The within-subject factor (time) represented pre- and post-training measures. Change scores were calculated for each variable; independent samples t-tests ($p<0.05$) compared change scores between groups. There were significant time interactions for grip strength, leg/back strength, VJ, and throwing velocity ($p\leq0.031$). Post hoc analyses showed that the junior varsity group significantly improved grip strength, leg/back strength, and VJ ($p\leq0.019$). The varsity group improved grip strength and throwing velocity ($p\leq0.005$). There were no significant time*group interactions ($p=0.068$-0.156), or significant between-group differences in change scores ($p=0.134$-0.756). Thus, rate of improvement was not different between groups. Nonetheless, a greater adaptive reserve may have existed in the junior varsity group such that they experienced grip strength, leg/back strength, and VJ improvements after a short-term training program. A longer program may be required for varsity athletes to experience pronounced changes in strength and power. Nevertheless, these adaptations could translate into greater throwing velocity.*

Key words: *adolescent, isometric strength, lower-body power, motor skill, vertical jump*

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INTRODUCTION

Sports participation can be critical in the physical development of high school students, and depending on the school, a range of sports may be available. Survey data provided by the National Federation of State High School Associations indicated that 4,534,758 boys and 3,402,733 girls participated in structured high school sports programs (National Federation of State High School Associations, 2019). Regardless of the sport, high school athletes would also benefit from effective strength training and conditioning. Strength and conditioning programs are generally designed to enhance the physical performance and reduce the injury risk of athletes (Howe, Waldron, & Read, 2017), including high school-aged individuals. Resistance training is a common focus for the high school strength and conditioning coach (Duehring, Feldmann, & Ebben, 2009; Reynolds et al., 2012), and the position stand from the National Strength and Conditioning Association highlights a range of potential benefits associated with resistance training for young athletes (Faigenbaum et al., 2009).

There has been some research analyzing the effects of resistance training on high school-aged athletes. For example, Coutts, Murphy, & Dascombe (2004) found that a 12-week resistance training program in teenage rugby league players led to increased muscular strength (measured by the three-repetition maximum [3RM] bench press and back squat), lower-body power (vertical jump), and 20-m sprint speed. Channell & Barfield (2008) documented that 8 weeks of either Olympic lifting or traditional resistance training could improve vertical jump performance in high school football players. A 6-week whole-body resistance training program completed by female high school soccer players led to improvements in 3RM back squat, 3RM hip thrust, vertical and standing broad jump, and the pro-agility shuttle (Millar et al., 2020). In addition to improved muscular strength, power, and resistance to injury, other advantages could include enhanced performance of motor skills (Faigenbaum et al., 2009). Indeed, Millar et al. (2020) also found a 13.2% increase in ball kicking distance in their sample of female high school soccer players. This is especially important given that physical activity and exposure to different motor skills (such as resistance training exercises) during an individual's formative years could influence what they do in their sport. This could be especially useful for younger athletes (i.e., junior varsity athletes) as they generally have less experience than their older counterparts (i.e., varsity athletes).

However, the provision of strength and conditioning for the high school athlete can be variable in its delivery and its quality. There are some schools who will hire strength and conditioning coaches with specific, nationally recognized credentials (e.g., Certified Strength and Conditioning Specialists; CSCS), while others may not take this approach (Duehring et al., 2009). This is notable; as an example, a coach who has a CSCS is expected to follow established guidelines in their practice as it relates to designing safe and effective strength training programs (National Strength and Conditioning Association, 2017). Despite these potential benefits, some schools may not employ a certified strength and conditioning coach; instead, they may use sport coaches or physical education teachers (Reynolds et al., 2012). There are also sport coaches who may not require their athletes to participate in resistance training programs, even if they are available and designed by a certified strength and conditioning coach (Reynolds et al., 2012). Inappropriate application of strength and conditioning programs (or a lack of availability of these programs) could have negative downstream effects for high school athletes. In a survey conducted by Wade, Pope, & Simonson (2014), collegiate strength and conditioning coaches stated that incoming freshmen athletes from high school lacked lower extremity and core strength, flexibility, proper lifting technique, and mental toughness. Wade et al. (2014) suggested that these data collectively showed a lack of collegiate training and sport preparedness of high school athletes. Moreover, strength and conditioning for high school athletes could be even more important given current population trends of reduced physical activity and the impacts on motor skill and movement competency (Robinson et al., 2015; Stodden, Langendorfer, & Roberton, 2009).

One of the barriers for why sport coaches may not have their athletes participate in strength and conditioning programs is a perception of lack of time to train (Duehring et al., 2009; Reynolds et al., 2012). This is despite the potential benefits to numerous aspects of athletic performance (Faigenbaum et al., 2009). Therefore, more research is needed to analyze the general effectiveness of high school strength and conditioning programs administered by an appropriately educated coach. In addition to this, research in high school-aged athletes tends to focus on training programs ranging from 6 weeks (Millar et al., 2020; Noyes et al., 2012) to 12 weeks (Coutts et al., 2004). However, previous research in high school-aged athletes has shown that 4 weeks is enough time for an appropriate training program to lead to improved squat technique (Dobbs et al., 2021), the Functional Movement Screen (Boucher et al., 2021), and 36.6-m sprint times (Hammett & Hey, 2003). However, there is no research that has documented whether a 4-week strength and conditioning program can improve traditional measures of strength, power, and motor skill in high school athletes. It would be useful to demonstrate whether sport-specific fitness and skill performance could improve with a short-term training program. This would document that even the provision of 4 weeks of specific strength and conditioning could be beneficial for the high school athlete. Further, it would be beneficial to note whether junior varsity and varsity athletes respond different to short-term structured strength and conditioning programs. This would be beneficial considering that an appropriate strength and conditioning program could not only influence qualities such as strength and power, but motor skill performance as well (Millar et al., 2020).

Therefore, this study investigated the effects of a 4-week strength and conditioning program administered by a certified strength and conditioning coach on the strength, power, and throwing velocity of junior varsity and varsity male high school water polo players. This was a convenience sample of athletes who were available for pre- and post-testing prior to their competition season. The researchers were not involved in the design of the training program but administered the pre- and post-testing sessions. It was hypothesized that there would be improvements in strength, power, and throwing velocity for both the junior varsity and varsity groups. However, the improvements would be greater for the junior varsity group.

METHODS

Participants

Participants were recruited from the junior varsity and varsity water polo teams from one high school in southern California. This was a sample of convenience from this high school relative to access and availability of athletes during the pre-season period from March-May 2022. Twenty-one water polo players were available for this study. All participants received a clear explanation of the study, including the risks and benefits of participation. Following this, consent and assent forms were given to potential participants to take home to their parents/guardians. Parents/guardians were provided contact details for the researchers to have any questions they may have answered. A parent/guardian completed the consent form, while the participant completed the assent form. Fifteen players returned consent and assent forms and were included in this study. However, participants were excluded if they did not complete the pre- and post-testing sessions, and one participant did not complete post-testing. The results in final sample of 14 participants (age: 15.57 ± 0.94 years; height: 177.26 ± 6.60 cm; 77.06 ± 16.18 kg); 6 in the junior varsity group (age: 14.83 ± 0.41 years; height: 177.38 ± 6.31 cm; 79.48 ± 20.14 kg), and 8 in the varsity group (age: 16.13 ± 0.84 years; height: 177.16 ± 7.25 cm; 75.24 ± 13.70 kg). The sample size in each of the groups was similar to previous training studies (Lockie, Murphy, Callaghan, & Jeffriess, 2014a; Lockie et al., 2012; Millar et al., 2020). G*Power software (v3.1.9.2, Universität Kiel, Germany) was used to confirm post hoc that the sample size of 14 (with groups of 8 and 6 participants) was sufficient for a repeated measures analysis of variance (ANOVA) with within-between interactions such that data could be interpreted with a small effect level of 0.35 (Hopkins, 2004), and a power level of 0.90 when significance was set at 0.05 (Faul, Erdfelder, Lang, & Buchner, 2007). The methodology and procedures used in this study were approved by the institutional ethics committee (HSR-19-20-511). The research was conducted in agreement with the recommendations of the Declaration of Helsinki.

Procedures

Approximately one week before the two days of testing, players had an informal familiarization testing day to understand what was expected of them for each test and for the testing administrators to make sure equipment was working properly. Testing was conducted within two approximate 60-minute sessions during the pre-season at a southern California high school; pre-testing in the week prior to the training intervention, and post-testing in the week after the intervention. Both testing sessions were conducted at approximately 4 p.m. in the weight room at the high school. Test selection and order were conducted in collaboration with the school's strength and conditioning director and coaches, with consideration given to time constraints and sport coach priorities. Prior to data collection, the participant's age, height, and mass were recorded. Height was measured using a stadiometer (Health O Meter, Ontario, Canada); body mass was recorded using electronic digital scales (Tanita Corporation of America, Inc., Illinois, USA). The head coach took the participants through their standard warm-up prior to testing. The participants were placed in two groups, and either completed the grip strength and leg/back dynamometer tests (strength station), or the vertical jump (VJ) and seated medicine ball throw (MBT) tests (power station). Following completion of both tests, participants switched to the other station. Participants rotated through in the same order for both stations, which ensured sufficient recovery periods for each participant. Testing circuits have been used in previous research (Collins et al., 2022; Lockie et al., 2021; Lockie et al., 2020a; Lockie et al., 2018a; Lockie et al., 2020d). Furthermore, all the tests conducted in this study were short-duration assessments. After completing the strength and power stations, the participants completed the maximum throwing velocity test outside the weight room. For each test in this study, three trials were completed with the average used for analysis. The procedures for the individual tests will be detailed hereafter.

Grip Strength

Grip strength provided a measure of upper-body strength (Ruprai, Tajpuriya, & Mishra, 2016), and has been used previously to assess strength in adolescents (Hager-Ross & Rosblad, 2002). A hand grip dynamometer (Takei Scientific Instruments, Niigata City, Japan) measured strength in each hand with procedures adapted from the literature (Lockie et al., 2021; Lockie et al., 2020c; Lockie et al., 2020d). Participants kept their testing arm by their side and squeezed the handle as hard as possible for approximately 2 s. The left hand was tested first for all participants. The average for both hands were summed together to provide the grip strength metric.

Isometric Leg/Back Strength

Leg and back isometric strength were measured by a leg/back dynamometer (Fabrication Enterprises, Inc., New York, USA) (Dawes et al., 2019; Dawes et al., 2017; Lockie et al., 2020b; Lockie et al., 2020c). The participant was positioned on the dynamometer so their arms were extended and both hands were on the handle placed at the mid-thigh (knee angle of ~110°) (Dawes et al., 2019; Dawes et al., 2017; Lockie et al., 2020b; Lockie et al., 2020c). From here, while maintaining proper spinal alignment and their feet flat on the base, participants pulled the handle upward as hard as possible by attempting to extend the hips and knees.

Vertical Jump (VJ)

The VJ was used to indirectly measure lower-body power via a jump mat (Just Jump, Probotics Inc., Huntsville, USA) (Lockie et al., 2016; Lockie et al., 2018b; McFarland, Dawes, Elder, & Lockie, 2016). The participant stood on the jump mat, before completing a countermovement and jumping as high as possible. No preparatory step was used, and no restrictions was placed on the countermovement range of movement or arm swing used. Participants were to maintain extended legs during flight, before landing on both feet. Within the jump mat software, VJ height was calculated in inches before being converted to cm for this study.

Seated Medicine Ball Throw (MBT)

The seated MBT indirectly measured upper-body power (Lockie et al., 2021; Lockie et al., 2018a; Lockie et al., 2020d). Participants sat with their head, shoulders, and lower back against a concrete wall, and projected a 2-kg medicine ball (Champion Barbell, Dallas, USA) as far as possible using a two-handed chest pass (Lockie et al., 2021; Lockie et al., 2018a; Lockie et al., 2020d). The perpendicular distance from the wall to the where the ball first contacted the ground was taken using a standard tape measure (Apex Tool Group, Sparks, USA).

Throwing Velocity

Throwing velocity was included because it has been used to measure motor skill competence (Stodden et al., 2009) and is an essential skill for water polo (Botonis, Toubekis, & Platanou, 2019; McCluskey et al., 2010; Smith, 1998; Vila et al., 2009). There are few studies that have investigated the effects of resistance training programs on motor skill performance in teenage athletes (Millar et al., 2020). Throwing trials were performed outdoors, and velocity was measured by a radar gun (Stalker Sport 2, Stalker/Applied Concepts, Texas, USA). An adaptation was made for this study whereby the participants threw a standard water polo ball (Hydro Grip Size 5, KAP 7 International, Inc., Irvine, USA) as fast as possible with the dominant hand from behind a start line, with one stride towards the target (Freeston et al., 2016). A researcher was positioned approximately 40 feet (12.19 m) in front of the participant with the radar gun to measure throwing velocity in kilometers per hour (km/hr). The radar gun was aimed at the ball release point, and this positioning was similar to previously published research (Callaghan et al., 2021; Callaghan et al., 2019).

Training Program

The program completed by the two groups is shown in Table 1. All athletes completed the same program, with individual modifications made relative to the loading used for different exercises. The strength and conditioning coach who designed the programs for the junior varsity and varsity athletes had an accredited certification with a national organization. Accordingly, they were required to adhere to codes of practice relative to the safe and effective design of resistance training programs (National Strength and Conditioning Association, 2017). The program followed traditional periodization principles (Haff, 2016), whereby the primary goal was to develop a foundation of strength and set-up the athletes for future phases of training (e.g., power development). Due to circumstances outside the control of the strength and conditioning coach (Spring break and the coach had jury duty), there was a 2-week break in-between the first 2 weeks and last 2 weeks of the program. Nonetheless, this program provides a real-world example of strength and conditioning at the high school level. Three sessions were completed in the first three weeks of the program (Monday, Tuesday, and Thursday). In the fourth week, only two sessions were completed (Tuesday and Thursday). Each training session was approximately 45-60 minutes and was a mix of compound and isolation exercises. Supersets and circuits were featured throughout the program. As previously noted, the researchers did not have input into the design of the program; exercise selection and program design were entirely up to the discretion of the strength and conditioning coach.

Table 1 Training program completed by the junior varsity and varsity groups. The letters and numbers indicate whether exercises were completed as part of a superset, tri-set, or circuit. LWP: Linear weight progression. 1RM: One-repetition maximum.

Week 1					
Session 1 (Monday)		Session 2 (Tuesday)		Session 3 (Thursday)	
Exercise	Sets x Repetitions	Exercise	Sets x Repetitions	Exercise	Sets x Repetitions
A1. Prone Y’s, T’s	2 x 8	A1. Low Pogo Jumps	1 x 20 @ 10 lbs	A1. Superman	2 x 8
A2. Quadruped T-Spine Rotations	2 x 8	A2. Goblet Squat	1 x 10 @ 10 lbs	A2. Shoulder Taps	2 x 8
A3. Fire Hydrant	2 x 8	A3. Single Leg Pogo	1 x 10 @ 10 lbs	A3. Push-up	2 x 5

B1. Front Squat	8, 6, 4, LWP+0	A4. Plate Overhead Lunge	1 x 10	B1. Bench Press	8, 6, 4, 2 @ 65%, 75%, 80%, 83% 1RM
B2. Bird Dog Row	3 x 8	A5. Romanian Deadlift to Goblet Squat	1 x 10	B2. Hamstring Marches	3 x 12
C. Front Squat	1 x 5	B1. Trap Bar Deadlift	3 x 5 @ 45, _, _ lb	C. Bench Press	1 x 5 @ 85% 1RM
D1. Wide-grip Pull-ups	3 x 5	B2. Plank	3 x 1 @ 50 seconds	D1. Band Hamstring Curl	3 x 12
D2. In-Outs	3 x 10 @ 25 lbs	C1. Trap Bar Deadlift	3 x 5	D2. Banded Triceps Pushdown	3 x 20
E1. Half-kneeling Dumbbell Shoulder Press	3 x 6	C2. Inverted Row	3 x 5	D3. Pull-up	3 x Maximum
E2. Dumbbell Bicep Curls	3 x 15 LWP+5	D1. Trap Bar Deadlift	3 x 8	E1. Incline Triceps Extension	15, 12, 10, @ 25, _, _ lbs
		D2. Barbell Shrug	3 x 1	E2. Dumbbell Half-kneeling Low-to-High Chop	10, 8, 6 @ 15, _, _ lbs
		E1. Band W's	3 x 10	E3. Band Pull-apart	3 x 20
		E2. Leg Raises	3 x 10		
Week 2					
Session 1 (Monday)		Session 2 (Tuesday)		Session 3 (Thursday)	
A1. YTW	2 x 8	A1. Thoracic Rotations (Side Lying)	2 x 6	A1. Cossack Squat	3 x 10 @ 25 lbs
A2. ATG Split-squat	2 x 6 @ 5 lbs	A2. Shoulder Taps	2 x 6	A2. Band W's	3 x 10
A3. Single-leg Pogo	2 x 10	A3. Band Pull-apart	2 x 8	A3. Copenhagen Plank	3 x 8 @ 3 seconds
B1. Front Squat	3 x 8 @ 50, 60, 65% 1RM	A4. Pallof Press	2 x 8	B1. Inverted Row	3 x 8
B2. Half-kneeling Dumbbell Shoulder Press	3 x 8	B1. Bench Press	3 x 8 @ 50, 60, 70%	B2. Side Plank with Hip Abduction	3 x 10
C1. Front squat	3 x 5 @ 70% 1RM	B2. Trap Bar Deadlift	3 x 5 LWP+5	B3. Reverse Plank Marches	3 x 10
C2. Landmine Anti-rotation	3 x 8	C1. Bench Press	3 x 8 @ 50, 60, 70% 1RM	C1. Partner Nordic Hamstring Curl	3 x 5 @ 3 seconds
D1. Wide-grip Pull-ups	3 x 1 @ 30 seconds	C2. Trap Bar Deadlift	3 x 5 LWP+5	C2. Pull-up	3 x 8

D2. In-outs	3 x 10 @ 25 lbs	D1. Bird Dog Row	10, 8, 6, LWP+2.5, 5, 10	C3. Zottman Curls	3 x 10
D3. Dumbbell Bicep Curls	3 x 15 LWP+5	D2. Scap Push-up	3 x 6		
		E1. Incline Triceps Extension	3 x 12 LWP+2.5		
		E2. Side Plank Rotation	3 x 8 @ 2.5. lbs		
Week 3					
Session 1 (Monday)		Session 2 (Tuesday)		Session 3 (Thursday)	
A. Front Squat	8, 8, 6 @ 50, 60, 65% 1RM	A1. Wide-grip Pull-ups	4 x 5 @ 3 secondsA2.	A1. Hang Snatch Warm-up	1 x 1
B. Front Squat	3 x 6 @ 70, 75, 75% 1RM	A2. Dumbbell Bicep Curls	15, 12, 10, 8 LWP+5	A2. Hang Clean Warm-up	1 x 1
C1. Wide-grip Pull-ups	3 x 8 @ 30 seconds	A3. Toe Touches	4 x 15 @ 25 lbs	B1. Bench Press	3 x 8 @ 50, 60, 70% 1RM
C2. Hollow Body Holds	3 x 45 seconds @ 25 lbs			B2. Side Plank with Shoulder Eccentrics	3 x 6
C3. Dumbbell Bicep Curls	3 x 12 LWP+5			C. Bench Press	3 x 8 @ 75% 1RM
				D1. Inverted Row	3 x 8
				D2. Dumbbell Triceps Extension	3 x 10
				E1. Barbell Bicep Curl	3 x 8
				E2. Leg Raises	3 x 15
Week 4					
		Session 1 (Tuesday)		Session 2 (Thursday)	
		A. Hang Clean Warm-up	1 x 1 @ 45 lbs	A1. Romanian Deadlift	3 x 8 @ 50, 60, 65% 1RM
		B. Hang Clean	4 x 5	A2. Bird Dog Row	3 x 8
		C1. Front Rack Split-Squat	3 x 8 @ 20, 30, 35% 1RM	B1. Romanian Deadlift	3 x 6
		C2. Landmine Anti-rotation	3 x 8 @ 25, _, _ lbs	B2. Bird Dog Row	3 x 6
		D1. Front Rack Split-Squat	3 x 6 @ 40, 45, 45% 1RM	C1. Incline Bench Press	8, 6, 6 @ 35, 35, 45% 1RM
		D2. Landmine Half-kneeling Shoulder Press	3 x 8	C2. Side Plank with Shoulder Eccentrics	3 x 8
		E1. Strict Bodyweight Pull-up	3 x 6	D1. Bench Press	3 x 5 @ 50% 1RM

	E2. Single-arm Overhead Farmer's Walk	3 x 20 yards	D2. Russian Twist	3 x 10
	F1. Banded Triceps Pushdown	3 x 15	E1. Reverse Grip Barbell Bicep Curl	3 x 10
	F2. Dumbbell Half-kneeling Low-to-High Chop	3 x 8 @ 30 lbs	E2. Leg Raises	3 x 15
			E3. Cable Rope Bicep Curl	3 x 12

Statistical Analysis

Statistical analyses were processed using the Statistics Package for Social Sciences (Version 27; IBM Corporation, New York, USA). Descriptive statistics (mean ± standard deviation [SD]) were calculated for the pre- and post-test data. Normality of the data was evaluated by visual analysis of Q-Q plots (Callaghan et al., 2020; Jeffriess et al., 2015; Orjalo, Callaghan, & Lockie, 2020; Orjalo, Lockie, Balfany, & Callaghan, 2020) and the Kolmogorov-Smirnov test (Ghasemi & Zahediasl, 2012; Lockie, Orr, & Dawes, 2022). Following the training period, data was analyzed via a two-way repeated measures ANOVA ($p < 0.05$), including groups as a between-subjects factor measured at two levels (junior varsity and varsity) (Bloomfield, Polman, O'Donoghue, & McNaughton, 2007; Lockie et al., 2014a; Lockie, Schultz, Callaghan, & Jeffriess, 2014b; Spinks, Murphy, Spinks, & Lockie, 2007). The within-subject factor (time) represented the pre- and post-training measures. As only two repeated measures were employed, the assumption of Mauchly's test of sphericity was not applicable (Lockie et al., 2014a; Lockie et al., 2014b; Spinks et al., 2007). All other repeated measures ANOVA assumptions were considered, with the Levene statistic used to determine homogeneity of variance. If a significant F ratio was detected, post hoc tests were performed using the Bonferroni adjustment procedure. Effect sizes (*d*) were also derived for the pre- to post-test comparisons within each group, where the difference between the means was divided by the pooled SD (Cohen, 1988). A *d* less than 0.2 was considered a trivial effect; 0.2 to 0.6 a small effect; 0.6 to 1.2 a moderate effect; 1.2 to 2.0 a large effect; 2.0 to 4.0 a very large effect; and 4.0 and above an extremely large effect (Hopkins, 2004).

In order to further investigate between-group comparisons, change scores were calculated for each variable for the junior varsity and varsity groups (Cocke, Dawes, & Orr, 2016). Change scores were calculated as the difference between the post-test and pre-test data (Cocke et al., 2016). Independent samples t-tests compared the change scores between the groups ($p < 0.05$). Levene's test for equality of variances were checked to determine whether equal variances were to be assumed for each variable or not. Effect sizes were also calculated for the change score comparisons.

RESULTS

The Kolmogorov-Smirnov data for the junior varsity group indicated all pre- and post-test variables were normally distributed ($p = 0.200$). With regards to the varsity group, all pre- and post-test variables were normally distributed ($p = 0.103$-0.200) except for leg/back strength ($p = 0.029$-0.037). However, visual analysis of the Q-Q plots indicated no outliers, so it was deemed appropriate to use parametric statistics. There was a significant main effect for time ($F(1, 12) = 31.539$, $p < 0.001$), but not time*group ($F(1, 12) = 2.295$, $p = 0.156$) for combined grip strength. Post hoc analyses indicated that both groups significantly improved this metric following the training intervention (moderate effects for both groups), although the varsity group was stronger at both time points. For leg/back strength, there was a significant main effect for time ($F(1, 12) = 6.781$, $p = 0.023$), but not time*group ($F(1, 12) = 3.311$, $p = 0.094$). Post hoc data revealed that the junior varsity group significantly improved their leg/back strength (moderate effect), but the varsity group did not (trivial effect). The varsity group was superior in leg/back strength in the pre-test ($p = 0.040$), but not the post-test ($p = 0.185$). With regards to the VJ, was a significant main effect for time ($F(1, 12) = 17.638$, $p = 0.001$), but not time*group ($F(1, 12) = 2.585$, $p = 0.134$). Post hoc analyses revealed that the junior varsity group significantly improved their VJ (moderate effect); the varsity group did not (small effect). The varsity group had a higher VJ in the pre-test ($p = 0.009$), but not the post-test ($p = 0.095$). There were no significant interactions for time ($F(1, 12) = 2.746$, $p = 0.123$) or time*group ($F(1, 12) = 3.768$, $p = 0.076$) for the MBT. As there was no significant interaction for time, post hoc analyses for the effects of training were not considered for the MBT. There was, however, a small effect for the increase in MBT distance for the junior varsity group. The varsity group had a trivial decline in MBT distance from pre- to post-test. The varsity group had a greater MBT distance for the pre-test ($p = 0.016$) but not the post-test ($p = 0.104$). Lastly, for throwing velocity there was a significant main effect for time ($F(1, 12) = 5.996$, $p = 0.031$), but not time*group ($F(1, 12) = 4.013$, $p = 0.068$). Post hoc calculations indicated that the varsity group significantly improved their throwing

Table 2 Descriptive (mean ± SD) data for the junior varsity and varsity groups pre- and post-training for combined grip strength (GS), leg/back strength (LBS), vertical jump (VJ), medicine ball throw (MBT), and throwing velocity (TV).

	Junior Varsity (*n* = 6)				Varsity (*n* = 8)			
	Pre	Post	*p*	*d*	Pre	Post	*p*	*d*
GS (kg)	63.56 ± 4.80	74.00 ± 15.45*	0.019	0.91	83.75 ± 18.15§	101.92 ± 14.81ϕ*	<0.001	1.10
LBS (kg)	105.84 ± 25.26	119.70 ± 26.97*	0.013	0.53	137.59 ± 25.67§	140.05 ± 26.63	0.560	0.09
VJ (cm)	41.62 ± 10.15	49.16 ± 10.14*	0.002	0.74	54.91 ± 5.76§	58.28 ± 8.68	0.071	0.46
MBT (m)	5.16 ± 0.87	5.63 ± 0.78	na	0.57	6.48 ± 0.88§	6.44 ± 0.90	na	0.04
TV (km/hr)	59.28 ± 6.92	59.55 ± 7.48	0.773	0.04	65.45 ± 5.98	68.13 ± 7.23*	0.005	0.40

§ Significantly ($p < 0.05$) different from the junior varsity pre-test data.
ϕ Significantly ($p < 0.05$) different from the junior varsity post-test data.
* Significant ($p < 0.05$) change from pre- to post-test.
na Post hoc analyses were not considered for this variable.

velocity post-testing (small effect), while the junior varsity group did not (trivial effect). There were no significant differences between the groups for the pre- ($p = 0.099$) or post-test ($p = 0.051$) throwing velocity.

Change score data were also used to analyze between-group differences following the training protocols, and these are shown in Table 3. Equal variances were assumed for all variables except VJ. There were no significant differences between the junior varsity and varsity groups in any of the change scores. There was a moderate effect for the greater change in grip strength experienced by the varsity group compared to the junior varsity group. All other effects were trivial-to-small.

Table 3 Change score data (mean ± SD) for the junior varsity and varsity groups for combined grip strength, leg/back strength, vertical jump, medicine ball throw, and throwing velocity.

	Junior Varsity ($n = 6$)	Varsity ($n = 8$)	p	d
Combined Grip Strength (kg)	10.33 ± 8.91	18.33 ± 9.64	0.134	0.868
Leg/Back Strength (kg)	9.07 ± 13.92	6.05 ± 12.31	0.674	0.233
Vertical Jump (cm)	4.57 ± 7.30	5.60 ± 3.11	0.756	0.195
Medicine Ball Throw (m)	0.33 ± 0.48	0.07 ± 0.58	0.379	0.494
Throwing Velocity (km/hr)	1.16 ± 2.97	2.01 ± 2.18	0.548	0.334

Discussion

This study provided a preliminary investigation of the effects of a 4-week structured strength and conditioning program on the strength, power, and throwing velocity of junior varsity and varsity male high school water polo players. It was hypothesized that the training program would improve strength, power, and throwing velocity, with performance changes being greater in the junior varsity group. The study results provided some credence to this concept, and supported previous research in high school-aged athletes that showed 4 weeks of specific training can improve movement capabilities and neuromuscular coordination (Boucher et al., 2021; Dobbs et al., 2021; Hammett & Hey, 2003). In the current study, this occurred even though there was a two-week break in the middle of the program due to extenuating circumstances (Spring break and absence of the strength and conditioning coach due to jury duty). The junior varsity group significantly improved their grip strength, leg/back strength, and VJ. The varsity group significantly grip strength and throwing velocity. These data suggested some adaptations specific to the junior varsity and varsity groups. However, there were no significant time*group interactions or differences in change scores, which suggested that within this sample there were no differences in the rate of change for any of the variables tested. As will be discussed, the results provide support for structured strength and conditioning programs for high school athletes.

The varsity group significantly outperformed the junior varsity group in all pre-tests except throwing velocity, although the varsity group still had a 10% faster throw. This was expected, with the physiological changes that occur with increased age and maturation during adolescence (e.g., increased strength, muscle mass, neuromuscular development, coordination) (Radnor et al., 2018; Tumkur Anil Kumar et al., 2021). Interestingly, for the post-test data the varsity group was only significantly better in grip strength. This provides some indication that the junior varsity group was able to improve such that their strength, power, and throwing velocity to progress closer to that of their varsity counterparts. Nonetheless, and as previously stated, there was no significant time*group interactions of differences between the change scores. Although commentary on specific aspects of maturation (e.g., skeletal age) are outside the scope of this study, the results do provide some evidence for the value of strength and conditioning in high school athletes. This is reflected in some of the specific results from the current research.

Grip strength has direct application to water polo players (Ferragut et al., 2011), as players need to wrestle with their opponents and throw the ball with high velocities (Botonis et al., 2019). Developing grip strength has been recommended for wrestling (Zemke & Wright, 2011) and grip has been related to throwing velocity in elite water polo players (Ferragut et al., 2011). Both groups were able to significantly improve combined grip strength following the 4-week training intervention. Grip strength is required in almost all resistance training exercises where a bar or dumbbell needs to be gripped. As grip strength relates to manual lifting and carrying tasks (Leyk et al., 2007), it is not unexpected that both groups were able to experience improvements in this strength metric. Nevertheless, the results from this study demonstrate that an appropriately designed 4-week strength and conditioning program can significantly improve grip strength on both junior varsity and varsity water polo players.

Isometric leg/back strength has been related to different aspects of physical performance, including dynamic strength (i.e., repetition maximum strength tests) (McGuigan, Newton, Winchester, & Nelson, 2010), jumping (Dawes et al., 2019; McGuigan et al., 2010; Merrigan, Stone, Hornsby, & Hagen, 2021), linear speed (West et al., 2011), and change-of-direction speed (Lockie, Post, & Dawes, 2019; Post, Dawes, & Lockie, 2022; Spiteri et al., 2015). Although high school water polo players may not need to run in their sport, lower-body strength is essential within this sport (Botonis et al., 2019). Previous research in adult law enforcement recruits has shown that a strength and conditioning program that features exercises such as front squats and cleans can improve leg/back isometric strength by approximately 10% (Lockie et al., 2020b). However, the program analyzed by Lockie et al. (2020b) was conducted over a total of 27 weeks. The junior varsity group in this study was able to significantly improve leg/back strength by 13% after 4 weeks. However, the 4-week period was not sufficient for the varsity group to significantly improve isometric leg/back strength. This may relate to the lower leg/back strength and the start of the training intervention for the junior varsity group, and these athletes may have had a larger adaptive reserve for improvement (Muehlbauer, Gollhofer, & Granacher, 2012). Nonetheless, the data from this study demonstrated that even a short-term strength and conditioning program can lead to improved lower-body strength in junior varsity athletes. Future research should investigate the effects of longer-term strength and conditioning programs on high school athletes.

Lower-body power is essential quality for water polo players (De Siati et al., 2016; McCluskey et al., 2010; Smith, 1998), in addition to many athletes in general, so it would be very beneficial for a short-term strength and conditioning program to improve this quality in high school athletes. The junior varsity group significantly improved VJ by 18% following the 4-week training intervention. Lower-body strength relates to VJ performance (Dawes et al., 2019; McGuigan et al., 2010; Merrigan et al., 2021), so the improved leg/back strength for the junior varsity group likely contributed to the enhanced jump performance. The larger adaptive reserve for the junior varsity athletes would also be a factor (Muehlbauer et al., 2012), especially considering the VJ results for the varsity group. The 6% VJ increase experienced by the varsity group was not a significant change, and this may mean the 4-week period was not sufficient to improve the jump in these participants. However, technique and coordination is also an important part of being able to translate force production into an effective jump (Hudson, 1986; Vanezis & Lees, 2005), and this can be developed through appropriate periodization (Haff, 2016). Indeed, the primary goal of this 4-week program was strength as opposed to power, so this could also form part of the reason why there was not a significant VJ increase for the varsity group. Future studies should investigate long-term strength and conditioning programs for high school athletes, with periodization plans to develop strength and power. This could especially be impactful for older high school athletes.

The MBT provides a measure of upper-body power (Lockie et al., 2021; Lockie et al., 2018a; Lockie et al., 2020d). There was no significant interaction for time in this study, so post hoc analyses were not considered for either the junior varsity or varsity groups. The upper-body push actions for the MBT are somewhat dissimilar to upper-body actions required in water polo, such as for the swimming stroke and overhead throwing (Botonis et al., 2019; Smith, 1998). This could have affected the results seen in this study. Further to this, power was not the primary focus of the strength and conditioning program completed by the athletes in this study. Nevertheless, it should be noted that there was a 9% increase in MBT distance for the junior varsity group which also had a small effect, which could be somewhat reflective of the results seen for grip strength, leg/back strength, and the VJ. The larger adaptive reserve for the junior varsity group provided more scope for improvement in upper-body power following a short-term strength and conditioning program (Muehlbauer et al., 2012). Further research is needed on whether a long-term strength and conditioning program can influence upper-body power in high school athletes, whether measured by the MBT or some other upper-body test (e.g., bench throw velocity).

Throwing velocity has been used to assess motor skill competence (Stodden et al., 2009), and is an essential skill for water polo (Botonis et al., 2019; McCluskey et al., 2010; Smith, 1998; Vila et al., 2009), so has direct application for the participants in this study. The junior varsity group did not significantly improve their throwing velocity following the 4-week training intervention. In contrast, the varsity group had a significant 4% increase in throwing velocity after training. This supports previous research by Millar et al. (2020), who found 6 weeks of resistance training could improve kicking distance in female high school soccer players. The neuromuscular development of the varsity group may have left them better equipped to facilitate and adaptations from the strength and conditioning program (e.g., greater grip strength) into the more complex skill of throwing. Age can be a factor in being able to translate resistance training adaptations into throwing performance (Martínez-García et al., 2021). Additionally, motor skill development for high school athletes is very important. Individuals that display better motor competence during childhood or adolescence tend to be more physically active during adulthood, which can greatly impact health outcomes (Robinson et al., 2015; Stodden et al., 2009). The increase in throwing velocity by the varsity athletes is an important result, as these data indicate that a structured strength and conditioning program can improve a sport-specific motor skill in high school athletes. Notwithstanding the potential fitness benefits that can result from a training program (Faigenbaum et al., 2009), the current results also provide a counterpoint for coaches who feel more training time should be dedicated to sport-specific skill development (Duehring et al., 2009; Reynolds et al., 2012). Motor skill performance could be positively influenced by an effective strength and conditioning program. Prospective studies should investigate a longer-term strength and conditioning program on motor skill performance in high school athletes, as more time may be required for younger athletes (i.e., junior varsity) to experience positive adaptations.

There are study limitations that need to be acknowledged. The sample size was small (*N* = 14), and only male athletes from one sport were used in this study. Future research into high school strength and conditioning programs should use larger samples, males and females, and athletes from a range of sports. Nonetheless, this study provided an important step in the analysis of structured strength and conditioning for high school athletes, and the results should be generalizable across other junior varsity and varsity athletes. The training program investigated was only over a short time period of 4 weeks, so future studies are needed to investigate longer-term strength and conditioning programs for high school athletes (e.g., over the course of a semester). As previously noted, there was a two-week break in the middle of the program due to outside factors. Nonetheless, this study provided an analysis of a real-world example of a strength and conditioning within the high school environment. In addition to this, the participants in this study were still able to experience improvements in strength and power even within a less-than-optimal program design. The testing battery adopted in this study was relatively limited, which was due to time constraints and the restrictions placed by the high school strength and conditioning and sports coaching staff. Forthcoming research on high school strength and conditioning would benefit from analyzing other fitness tests (e.g., anaerobic and aerobic capacity, linear and change-of-direction speed) and motor skill assessments (e.g., jumping, landing, kicking).

CONCLUSIONS

This study showed that a 4-week strength and conditioning program could improve the strength, power, and throwing velocity for male high school water polo players. Although there were no significant time*group interactions or differences between change scores, there were some specific adaptations for junior varsity and varsity athletes. The junior varsity group significantly improved their grip strength, leg/back strength, and VJ. The varsity group significantly improved their grip strength and throwing velocity. A greater adaptive reserve may have been present in the junior varsity athletes such that they could experience significant changes in upper-body and lower-body isometric strength, in addition to lower-body power. However, junior varsity athletes may require more time to translate these adaptations into a specific motor skill such as throwing. A longer strength and conditioning program may be required for varsity athletes to experience more pronounced changes in strength and power. Nevertheless, they could translate any changes in these qualities into the specific motor skill measured in this study. Future research should investigate longer-term strength and conditioning programs and how they influence fitness outcomes and motor skill performance in high school athletes.

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EFEKTI ČETVORONEDELJNOG PROGRAMA TRENINGA SNAGE I KONDICIONOG TRENINGA NA SNAGU, SILU I BRZINU BACANJA MEĐU PRVORANGIRANIM I DRUGORANGIRANIM TIMOVIMA VATERPOLISTA SREDNJOŠKOLSKOG UZRASTA

*U ovom istraživanju analizirani su efekti četvoronedeljnog progama treninga snage i kondicionog treninga na snagu, silu, i brzinu bacanja među vaterpolistima srednjoškolskog uzrasta, pripadnika prvorangiranog i drugorangiranog tima. Šest pripadnika drugorangiranog i osam pripadnika prvorangiranog vaterpolo tima regrutovani su za potrebe ovog istraživanja. Pretest i post-test uključivali su izometrijski test hvata i snage nogu/leđa; skok u vis (VJ); bacanje medicinke od 2-kg; i maksmialna brzina bacanja vaterpolo lopte. Svi ispitanici učestvovali su u četvoronedeljnom programu treninga snage i kondicionom treningu kako bi uvećali osnovne vrednosti snage. Podaci su analizirani dvosmernom ANOVA testom sa ponovljenim merama ($p<0.05$), gde je pripadnost grupi bila faktor merenja između ispitanika na dva nivoa (prvorangirani i drugorangirani tim). Vrednosti merenja pre i posle treniranja predstavljale su faktor promene između ispitanika (vreme). Promene u vrednostima izračunate su za svaku varijablu; t-test za nezavisne uzorke ($p<0.05$) poredio je promene u vrednostima između grupa. Značajne interakcije sa vremenom uočene su za snagu hvata, snagu nogu/leđa, i VJ ($p\leq0.019$). Prvorangirana grupa poboljšala je snagu hvata i brzinu bacanja ($p\leq0.005$). Nisu uočene značajne interakcije vreme*grupa ($p=0.068$-0.156), ili značajne razlike između grupa u promeni vrednosti ($p=0.134$-0.756). Samim tim, stopa poboljšanja nije se razlikovala između grupa. Ipak, veća adaptivna rezerva možda je postojala među pripadniciam drugorangiranog tima tako da su među njima uočena poboljšanja za snagu hvata, snagu nogu/leđa i VJ nakon kraćeg programa treninga. Duži program treninga je potreban kako bi prvorangirani tim mogao značajnije da napreduje u pogledu snage i sile. Ipak, ove adaptacije bi mogle da dovedu do veće brzine bacanja.*

Ključne reči: *adolescenti, izometrijska snaga, snaga donjih ekstremiteta, motoričke veštine, skok u vis*

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