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Research article

THE RELATIONSHIPS BETWEEN MUSCULAR STRENGTH AND POWER WITH THROWING VELOCITY IN HIGH SCHOOL BOYS WATER POLO PLAYERS FOLLOWING A STRENGTH TRAINING BLOCK

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Robert G. Lockie[1], Alexander M. Wakely[1], J. Jay Dawes[2,3], Erika Viramontes[1], Jacob D. Patron[1]

[1]Department of Kinesiology, California State University, Fullerton, Fullerton, CA, USA
[2]School of Kinesiology, Applied Health and Recreation, Oklahoma State University, Stillwater, OK, USA
[3]Tactical Fitness and Nutrition Lab, Oklahoma State University, Stillwater, OK, USA

Abstract. *A high school strength and conditioning program should ideally improve fitness and develop sport-specific motor skills in athletes. This could be a targeted goal if research details relationships between sport-specific motor skills and measures of fitness in high school athletes. The aim of this study was to investigate the relationships between throwing velocity with muscular strength and power in boys high school water polo athletes after a 4-week resistance training block targeting strength. Eighteen athletes from one high school were recruited. Age, height, and body mass were recorded prior to training. Performance testing occurred in one day after the 4-week training block; strength was measured using combined handgrip strength from both hands and isometric lower-body strength via a leg/back dynamometer. Power was measured by a countermovement jump and 2-kg seated medicine ball throw. As a motor skill metric, participants maximally threw a water polo ball to measure throwing velocity. Partial correlations and stepwise regression controlling for age calculated relationships between throwing velocity with handgrip strength, leg/back strength, the countermovement jump, and medicine ball throw ($p<0.05$). Combined handgrip strength ($r=0.712$), leg/back strength ($r=0.656$), and the medicine ball throw ($r=0.684$) all showed significant positive relationships with throwing velocity. Age and combined handgrip strength predicted throwing velocity with 61.3% explained variance ($r^2=0.658$, $p<0.001$). The data indicated that throwing velocity significantly related to handgrip and leg/back strength and upper-body power (measured by the medicine ball throw). As the program targeted these qualities, this could have influenced the relationships with the sport-specific motor skill of throwing.*

Key words: *isometric strength, upper-body power, motor skill, resistance training, teenager*

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Corresponding author: Robert G. Lockie
Department of Kinesiology, California State University, Fullerton, Fullerton, CA, USA
E-mail: rlockie@fullerton.edu

INTRODUCTION

In the USA, more than 4 million boys and 3 million girls participate in structured high school sports (National Federation of State High School Associations, 2019). Depending on the school, athletes may have access to strength and conditioning programs, in addition to their traditional sport training. For both adolescent and adult populations, strength and conditioning programs are generally designed to enhance physical fitness and performance, while also reducing athlete injury risk (Howe, Waldron, & Read, 2017). Resistance training will often feature in high school strength and conditioning programs (Duehring, Feldmann, & Ebben, 2009; Reynolds et al., 2012). Further, high school athletes may experience numerous benefits from a strength and conditioning program that features resistance training (Coutts, Murphy, & Dascombe, 2004; Faigenbaum et al., 2009; Millar et al., 2020; Valovich McLeod, Armstrong, Miller, & Sauers, 2009; Wakely, Dawes, Hernandez, & Lockie, 2022).

To provide some specific examples, appropriate strength and conditioning programs enhanced upper- and lower-body strength, vertical countermovement jump (CMJ), and sprint speed in teenage male rugby league players (Coutts et al., 2004), and dynamic balance in high school female basketball players (Valovich McLeod et al., 2009). Other benefits may include improvements to motor skill performance (Faigenbaum et al., 2009). Millar et al. (2020) found that a 6-week whole-body resistance training program for high school girls soccer athletes improved not only strength (measured by a three-repetition maximum back squat and three-repetition maximum hip thrust), power (CMJ and standing broad jump), and change-of-direction speed (pro-agility shuttle), but kicking velocity as well. Wakely et al. (2022) documented that a 4-week resistance training program targeting strength led to significantly improved isometric handgrip strength and throwing velocity in varsity boys' water polo athletes.

However, the provision of strength and conditioning for the high school athlete can be inconsistent in its delivery. Some schools employ strength and conditioning coaches with specific credentials (e.g., Certified Strength and Conditioning Specialists), while others may not (Duehring et al., 2009). This is important, as certified coaches are expected to follow established guidelines in their practice as it relates to designing training programs (National Strength and Conditioning Association, 2017). Some schools may not employ a strength and conditioning coach, but rather use physical education teachers or sport coaches (Reynolds et al., 2012). For those schools that have a strength and conditioning coach, some sport coaches may not require their athletes to participate in their programs (Reynolds et al., 2012).

It would be beneficial to document whether certain qualities that can be targeted by a strength and conditioning program (e.g., strength and power) relate to motor skill performance in high school athletes following a training block. Even though a training program for high school athletes may improve strength and power (Coutts et al., 2004; Millar et al., 2020; Wakely et al., 2022), it would be of interest for coaches to see whether these qualities relate to sport-specific motor skills post-training. This would help support the need for strength and conditioning interventions to potentially improve both fitness and motor skill performance among high school athletes.

Therefore, this study investigated the relationships (controlling for age) between muscular strength and power on throwing velocity in male high school water polo athletes after a 4-week strength training block. Throwing velocity was used as a measure of motor skill performance as throwing is an essential skill in water polo (Botonis, Toubekis, &

Platanou, 2019; McCluskey et al., 2010; Smith, 1998; Vila et al., 2009). The 4-week training block was that documented by Wakely et al. (2022), and all participants in this sample completed that program. It was hypothesized that strength and power, as they had been targeted within the 4-week training block (Wakely et al., 2022), would relate to and predict throwing velocity in water polo athletes.

METHODS

Participants

The convenience sample comprised 18 water polo players from one high school in southern California. The age, height, and body mass of participants is shown in Table 1. All participants completed a 4-week strength training block and testing after this block as part of their pre-season during early 2022. The sample size in the study by Wakely et al. (2022) (N = 14) was different from the current study (N = 18), as not all participants from this study completed pre-testing prior to the training block. All participants received an explanation of the research, including the risks and benefits of participation. Following this, consent and assent forms were given to participants to take home to their parents/guardians. Parents/guardians were provided contact details for the researchers if they had any questions. A parent/guardian completed the consent form, while the participant completed the assent form. G*Power software (v3.1.9.2, Universität Kiel, Germany) was used to confirm post hoc that the sample size of 18 was sufficient for a correlation, point biserial model such that data could be interpreted with a moderate effect level of 0.58 (Hopkins, 2004), and a power level of 0.81 when significance was set at 0.05 (Faul, Erdfelder, Lang, & Buchner, 2007). The 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 (World Medical Association, 1997).

Procedures

As stated, all participants in this study completed the 4-week training program described by Wakely et al. (2022). Further, the testing procedures for this study have been described by Wakely et al. (2022). The procedures will be detailed here for convenience to the reader. Prior to the 4-week training block, participants 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. Age, height, and body mass were also recorded prior to the training block. 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).

In the week after the training block, participants completed post-testing in one 60-minute session. The session was conducted at approximately 4 p.m. in the weight room at the high school. The head coach took the participants through their standard warm-up prior to testing. The dynamic warm-up included movements such as quadriceps, hamstring, and calf stretches, lunges, leg kicks and swings, hip openers, and jumps. As described by Wakely et al. (2022), participants were split in two groups, and completed either handgrip strength and leg/back dynamometer tests, or CMJ and seated medicine ball throw (MBT) tests. Following completion of the test pair, participants switched to the other pair.

Participants rotated through in the same order for both test pairs, which ensured sufficient recovery. After completing the strength and power tests, the participants completed the maximum throwing velocity test outside the weight room. For all tests, three trials were completed and organized such that recovery periods of approximately one minute were provided (Lockie et al., 2020a; Lockie et al., 2018a; Lockie et al., 2020d), which limited fatigue effects (Fernandes, Brito, Vieira, & Marins, 2014). The averages from the three trials for each test were used for analysis.

Handgrip Strength

Handgrip strength provided a metric for upper-body strength (Ruprai, Tajpuriya, & Mishra, 2016). A handgrip dynamometer (Takei Scientific Instruments, Niigata City, Japan) was used and followed established procedures (Lockie et al., 2021; Lockie et al., 2020c; Wakely et al., 2022). Participants kept their testing arm by their side and squeezed the handle as hard as possible for approximately 2 seconds (s), with the left hand tested first. The average for both hands were summed together to provide the handgrip strength measurement in kilograms (kg).

Leg/Back Strength

Leg/back isometric strength were measured by a leg/back dynamometer (Fabrication Enterprises, Inc., New York, USA). As shown in Fig. 1, participants stood on the dynamometer before being positioned so that their arms were extended and both hands were on the handle placed at the midthigh (knee angle of approximately 110°) (Dawes et al., 2019; Dawes et al., 2017; Lockie et al., 2020b; Lockie et al., 2020c; Wakely et al., 2022). Participants then pulled the handle upward as hard as possible for approximately 5 s (Haff et al., 2015; McGuigan & Winchester, 2008; McGuigan, Winchester, & Erickson, 2006), by attempting to extend the hips and knees, while maintaining proper spinal alignment and their feet flat on the base. Data was recorded in kg.

Fig. 1 Frontal (A) and sagittal (B) view of the set-up for the leg/back dynamometer test.

Vertical Countermovement Jump (CMJ)

The CMJ indirectly measured lower-body power via a jump mat (Just Jump, Probotics Inc., Huntsville, USA) (Lockie et al., 2018b; McFarland, Dawes, Elder, & Lockie, 2016; Wakely et al., 2022). Participants stood on the jump mat, completed a countermovement with arm swing and jumped as high as possible. No restrictions were placed on the countermovement range of movement and participants were to maintain extended legs during flight, before landing on both feet. Within the jump mat software, CMJ height was calculated in inches before being converted to cm for this research.

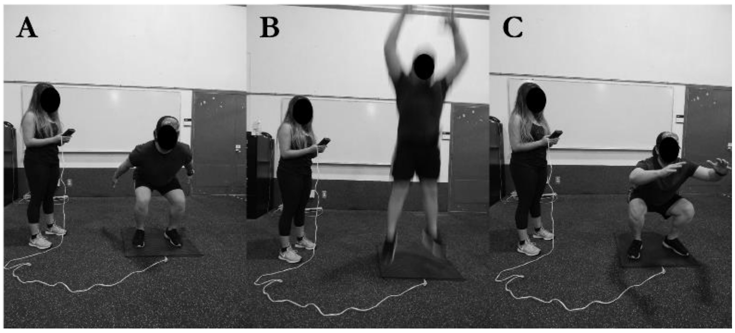

Fig. 2 Start position (A), flight, (B), and landing positions (C) for the CMJ with a jump mat.

Seated Medicine Ball Throw (MBT)

The seated MBT indirectly measured upper-body power and this test used standard procedures (Lockie et al., 2021; Lockie et al., 2018a; Wakely et al., 2022). 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. The perpendicular distance from the wall to the where the ball first contacted the ground was taken using a tape measure (Apex Tool Group, Sparks, USA).

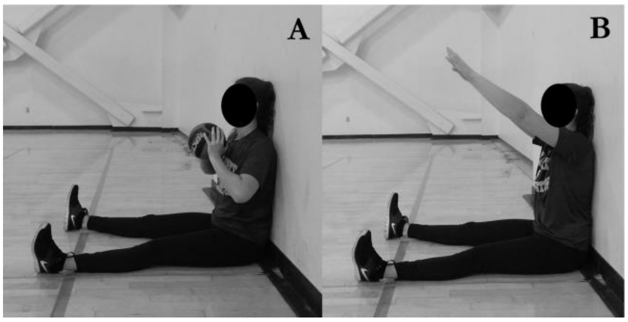

Fig. 3 Starting (A) and finish (B) positions for the MBT.

Throwing Velocity

Throwing velocity was included because it has been used as a metric for measuring motor skill performance (Stodden, Langendorfer, & Roberton, 2009) and is an essential for water polo (Botonis et al., 2019; McCluskey et al., 2010; Smith, 1998; Vila et al., 2009). Trials were performed outdoors (limited to no wind during the tests), with velocity measured by a radar gun (Stalker Sport 2, Stalker/Applied Concepts, Texas, USA). As stated by Wakely et al. (2022), 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. A researcher was positioned approximately 40 feet (12.19 m) in front of the participant. Similar to previous research (Callaghan et al., 2021; Callaghan et al., 2019; Wakely et al., 2022), the researcher aimed the radar gun at the ball release point during the throw to measure throwing velocity. The initial metric was in kilometers per hour before being converted to meters per second (m/s). Although previous water polo research has measured in-water throws (De Siati et al., 2016; Ferragut et al., 2011), in the context of this study the throw was conducted out-of-water to provide a general measure of motor skill ability (Barnett et al., 2008; Stodden et al., 2009).

Statistical Analysis

Statistical analyses were conducted using the Statistics Package for Social Sciences (Version 27; IBM Corporation, New York, USA). Descriptive statistics (mean ± standard deviation [SD]) were calculated for all variables. Normality of the data was evaluated by visual analysis of Q-Q plots and the Kolmogorov-Smirnov test. Skewness and kurtosis values that were between 0±2 were considered acceptable (George & Mallery, 2018). Partial correlations controlling for age ($p < 0.05$) calculated relationships between combined handgrip strength, leg/back strength, the CMJ, and the MBT with throwing velocity recorded after the 4-week training block. The strength of the correlations (r) was defined as: an r between 0 to ±0.3, small; ±0.31 to ±0.49, moderate; ±0.5 to ±0.69, large; ±0.7 to ±0.89, very large; and ±0.9 to ±1 near perfect for relationship prediction (Hopkins, 2013). Stepwise linear regression ($p < 0.05$), with age as a control variable, determined whether any strength or power variable predicted throwing velocity. Age was controlled for in the correlation and regression analyses as previous research has shown age can influence muscular strength and power in high school-aged populations (McKay et al., 2017; Tomkinson et al., 2018).

RESULTS

Participant details and the performance test data recorded after the 4-week training block is presented in Table 1. All data were normally distributed. The partial correlation data is shown in Table 2. Combined handgrip strength had a very large significant positive relationship with throwing velocity after the 4-week training block. Leg/back strength and the MBT displayed significant positive large relationships with throwing velocity. The CMJ did not significantly relate to throwing velocity after the training block. Stepwise regression data is displayed in Table 3. Age by itself explained 26.4% of the variance with throwing velocity. When combined handgrip strength was added to the regression equation, explained variance rose to 61.3%. No other variable significantly predicted throwing velocity in boys high school water polo athletes after the 4-week training block.

Table 1 Descriptive data (mean ± SD) for age, height, body mass, combined handgrip strength, leg/back strength, countermovement jump, medicine ball throw, and throwing velocity in high school water polo athletes (N = 18).

Variables	Mean ± SD
Age (years)	15.50 ± 0.86
Height (cm)	177.05 ± 6.78
Body Mass (kg)	74.28 ± 15.70
Combined Handgrip Strength (kg)	88.26 ± 19.29
Leg Back Strength (kg)	131.71 ± 25.47
Countermovement Jump (cm)	55.80 ± 9.41
Medicine Ball Throw (m)	5.97 ± 0.88
Throwing Velocity (m/s)	17.77 ± 2.21

Table 2 Partial correlations controlling for age for combined handgrip strength, leg/back strength, countermovement jump, and medicine ball throw with throwing velocity in high school water polo athletes (N = 18).

Variable	Throwing Velocity	
	r	*p*
Combined Handgrip Strength	0.711*	0.001
Leg/Back Strength	0.656*	0.004
Countermovement Jump	0.131	0.615
Medicine Ball Throw	0.684*	0.002

* Significant ($p < 0.05$) relationship with throwing velocity.

Table 3 Stepwise linear regression analysis for throwing velocity.

Variables	*r*	r^2	Adjusted r^2	β	*p*
Age	0.554	0.307	0.264	0.554	0.017
Age Handgrip Strength	0.811	0.658	0.613	0.266 0.658	0.133 0.001

DISCUSSION

This study investigated the relationships between throwing velocity with isometric handgrip and leg/back strength, the CMJ, and the MBT in boys high school water polo athletes after they had completed a 4-week strength training program. The training program completed by the participants, and the resulting changes in fitness and performance, was documented by Wakely et al. (2022). It was hypothesized that the strength and power tests would relate to the motor skill test of throwing, and the current results indicated that was generally the case. Combined handgrip strength, leg/back strength, and the MBT all had large-to-very large relationships with out-of-water throwing velocity. Handgrip strength also predicted throwing velocity following the training block. Interestingly, the CMJ did not relate to or predict throwing velocity. Nonetheless, the results from this study help support the value of strength and conditioning programs in high school athletes and how they could impact sport-specific motor skill performance.

The out-of-water throwing velocity of the participants in this study (17.77 ± 2.21 m/s) was below that of similar-aged adolescents throwing a tennis ball (23.7 ± 4.7 m/s) (Lorson, Stodden, Langendorfer, & Goodway, 2013). This is not surprising, given the differences in size and weight of a tennis ball versus that of a water polo ball. Interestingly, the out-of-water throwing velocity of the current participants was greater than that of in-water throws during competition for elite male water polo players (16.94 ± 3.38 m/s) (García-Cervantes, Ruiz-Lara, Argudo Iturriaga, & Borges-Hernández, 2017). While these studies provide some context for the throwing velocity recorded in the current study, it is still more important to consider how strength and power could potentially influence the throwing skill in high school boys water polo players following a resistance training block.

As stated, combined handgrip strength, leg/back strength, and the MBT all significantly correlated with out-of-water throwing velocity in the high school water polo players, with large-to-very large relationships. The 4-week training block included exercises targeting these qualities (e.g., squats, presses, pull-ups, hang cleans), and this likely impacted the relationships between strength, power, and throwing velocity seen in this study. Indeed, Wakely et al. (2022) found that their 4-week resistance training program led to significant 13-18% improvements in handgrip strength, leg/back strength, and the CMJ in junior varsity boys' water polo athletes. Although the change was not significant, Wakely et al. (2022) also detailed a 9% increase in MBT following the intervention for the junior varsity boys. Relative to varsity boys, Wakely et al. (2022) documented a 22% significant increase in handgrip strength, and 4% significant increase in throwing velocity post-intervention. In the current study, the sample was not split into junior varsity or varsity athletes, but rather controlled for age in the analysis. This was done as age can influence the strength and power of adolescents (McKay et al., 2017; Tomkinson et al., 2018), and to increase the study power for the correlation and regression analysis (Faul et al., 2007). This could have impacted the results found in the current research. Nevertheless, upper- and lower-body strength and upper-body power, which were a focus in the strength training intervention (Wakely et al., 2022), correlated with out-of-water throwing velocity in boys' water polo athletes. These data suggest that the development of these physical qualities could impact the sport-specific motor skill of throwing in high school athletes.

In addition to age, handgrip strength predicted throwing velocity in the athletes from this sample. As stated, Wakely et al. (2022) recorded significant improvements in grip strength for both junior varsity and varsity boys' water polo players following their intervention. In elite teenage water polo players, right- (r = 0.936) and left-hand (r = 0.975) grip strength correlated with throwing velocity in a scenario where the throw was completed in the pool with an opponent (López-Plaza, Borges, Alacid, & Argudo, 2021). Moreover, grip strength is needed in almost all resistance training exercises where a load, whether it is a barbell, dumbbell, kettlebell, or some other type of equipment, needs to be gripped. The current data suggests that handgrip strength following a strength training intervention relates to and predicts throwing velocity in high school water polo players. Accordingly, positive changes to handgrip strength could also positively influence the motor skill of throwing in high-school aged athletes.

CMJ performance did not significantly relate to throwing velocity in this sample after the 4-week training block. Previous research in adult female water polo players found that although lower-body power was a predictor of throwing velocity, CMJ height as a measure was not (McCluskey et al., 2010). The movement patterns between the CMJ and throwing are different, which could be a contributing factor (Freeston et al., 2016). Perhaps most notably, Wakely et al. (2022) did not find a significant change in the CMJ for varsity water polo players following their training program. If the sample in this study was split into junior varsity and varsity groups, this may have changed the correlation data (and this is a potential venue for future research), but this was not done in an attempt to boost the study power (Faul et al., 2007). Nonetheless, the current results suggest that following a 4-week strength training intervention, CMJ did not significantly relate to throwing velocity in high school boys' water polo players.

There are limitations to this study that should be recognized. The sample size was small (N = 18), and only a boys team from the one sport and one club of water polo were investigated. Future research should analyze boys and girls with larger water polo samples and from more sports. This study analyzed the relationships between muscular strength and power with throwing velocity at one point in time (i.e., after a 4-week training intervention). Future research could identify how the relationships between muscular strength and power with motor skills such as throwing change over the course of a training program (Nimphius, McGuigan, & Newton, 2010). The number of fitness tests used in this study was limited, and future research in high school athletes would benefit from analyzing more fitness tests of different physical capacities (e.g., flexibility, anaerobic capacity, cardiovascular endurance, linear speed, change-of-direction speed and agility) and motor skill assessments (e.g., kicking, jumping/landing). Nonetheless, this study provided an important step in the analysis of strength, power, and motor skill performance in high school athletes, and the potential benefits of strength and conditioning programs for these athletes. Furthermore, the data should have application across other high school athlete populations.

CONCLUSIONS

In conclusion, the results from this study indicated that following a 4-week resistance training intervention that primarily targeted strength in high school boys' water polo athletes, muscular strength and power did significantly relate to the motor skill metric of throwing velocity. Specifically, combined handgrip strength, leg/back strength, and MBT distance (which provided a measure of upper-body power) had large-to-very large relationships with out-of-water throwing velocity. Additionally, age and combined handgrip strength predicted throwing velocity with 61.3% explained variance. It is possible that the training adaptations experienced by the athletes in this study contributed to the observed significant relationships between muscular strength and power and throwing velocity. Regardless, the current data suggests improving upper- and lower-body strength and upper-body power could facilitate enhancements to the motor skill of throwing in high school water polo athletes.

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ODNOSI IZMEĐU MIŠIĆNE SNAGE I MOĆI, I BRZINE BACANJA KOD VATERPOLISTA SREDNJOŠKOLACA NAKON BLOKA TRENINGA SNAGE

Program snage i kondicije namenjen srednjoškolcima bi idealno trebalo da poboljša kondiciju i razvije motoričke veštine specifične za sport kod sportista. Za ovaj problem bi se moglo naći rešenje ukoliko bi istraživanja detaljno opisala odnose između motoričkih veština specifičnih za sport i kondiciju sportista sredноškolaca. Cilj ovog istraživanja bio je da se ispita odnos između brzine bacanja sa mišićnom snagom i silom kod vaterpolista srednjoškolaca nakon 4-nedeljnog treninga otpora koji je ciljao snagu. Regrutovano je osamnaest sportista iz jedne srednje škole. Starost, visina i telesna masa zabeleženi su pre treninga. Testiranje učinka obavljeno je u jednom danu nakon blok treninga u trajanju od 4 nedelje; snaga je merena korišćenjem kombinovanom snagom stiska obe šake i izometrijske snage donjeg dela tela upotrebom dinamometra nogu/leđa. Sila je merena skokom iz počučnja i bacanjem medicinske lopte od 2 kg sedeći. Radi merenja motoričke veštine, učesnici su maksimalno bacali vaterpolo loptu da bi se izmerila brzina bacanja. Delimične korelacije i kontrola stepena regresije za odnose izračunate su prema uzrastu između brzine bacanja sa snagom stiska, snagom nogu/leđa, skoka iz počučnja i bacanja medicinske lopte ($p<0,05$). Kombinovana snaga stiska ($r=0,712$), sila nogu/leđa ($r=0,656$) i bacanje medicinske lopte ($r=0,684$) pokazali su značajnu pozitivnu vezu sa brzinom bacanja. Starost i kombinovana snaga stiska predviđaju brzinu bacanja sa 61,3% objašnjene varijanse ($r2=0,658$, $p<0,001$). Rezultati su pokazali da je brzina bacanja značajno povezana sa snagom stiska i nogu/leđa i snagom gornjeg dela tela (mereno bacanjem medicinske lopte). Pošto je program ciljao ove kvalitete, mogao bi uticati na odnose sa motoričkom veštinom bacanja koja je specifična za sport.

Ključne reči: *izometrijska snaga, snaga gornjeg dela tela, motoričke veštine, trening otpora, tinejdžeri*