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Relationship Between Throwing Velocity, Muscle Power, and Bar Velocity During Bench Press in Elite Handball Players

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Purpose: The purpose of this study was to examine the relationship between ball-throwing velocity during a 3-step running throw and dynamic strength, power, and bar velocity during a concentric-only bench-press exercise in team-handball players. ***Methods:*** Fourteen elite senior male team-handball players volunteered to participate. Each volunteer had power and bar velocity measured during a concentric-only bench-press test with 26, 36, and 46 kg, as well as having 1-repetition-maximum (1-RMBP) strength determined. Ball-throwing velocity was evaluated with a standard 3-step running throw using a radar gun. ***Results:*** Ball-throwing velocity was related to the absolute load lifted during the 1-RMBP (r = .637, P = .014), peak power using 36 kg (r = .586, P = .028) and 46 kg (r = .582, P = .029), and peak bar velocity using 26 kg (r = .563, P = .036) and 36 kg (r = .625, P = .017). ***Conclusions:*** The results indicate that throwing velocity of elite team-handball players is related to maximal dynamic strength, peak power, and peak bar velocity. Thus, a training regimen designed to improve ball-throwing velocity in elite male team-handball players should include exercises that are aimed at increasing both strength and power in the upper body.

Key Words: upper extremity, strength, team handball

Team handball is a contact Olympic sport[1,2] that is also played professionally in Europe.[3] It consists of intense, intermittent activities such as running, sprinting, and jumping, as well as regular throwing, hitting, blocking, and pushing between players.[1,2] In addition to technical and tactical skills, it has been argued that one of the key skills necessary for success in team handball is throwing performance.[1-4] Ball velocity and throwing accuracy are the most important factors for scoring in team handball.[5-7] Three factors are essential with regard to efficiency of throwing: mechanics, coordination of consecutive actions of body segments, and upper and lower extremity muscle strength and power.[5,8-10] Although muscle strength and power

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have been reported to be associated with throwing velocity in team handball,[2,5,7] limited data have been published on elite male handball players.[3]

To our knowledge, few studies have examined the relationship between ball-throwing performance in elite team-handball players with indices of dynamic strength,[1-3,5,11] power,[8] and bar velocity[1,8] during muscle contractions of the upper extremity in concentric-only bench-press exercise. Other investigations have used isokinetic and isometric tests as indices of strength,[2,5,7] but single-joint actions and handgrip strength are not specific assessment strategies. In other words, using a strength test with constant speed (ie, isokinetic) or a test in which muscle action is not accompanied by motion (ie, isometric) might be less suitable for athletics than a test that allows for variable speeds throughout the range of motion (ie, isotonic). We chose to use the bench-press exercise because it seems most specific to overhand-throwing technique.[5] Thus, using a multijoint exercise such as the bench-press test should be advantageous when exploring for relationships with a dynamic movement such as throwing. None of the previous studies examined throwing velocity with maximal-strength dynamic performance together with power output and bar velocity during a concentric-only bench-press exercise in male handball players. Therefore, the aim of this study was to determine the relationships between ball-throwing velocity in elite team-handball players and selected measures of strength, power, and bar velocity during a concentric-only bench-press exercise. Examination of these relationships could be of great importance for the optimal development of resistance-training programs to improve handball-throwing performance in professional handball athletes.

Methods

Subjects

A group of 14 senior elite male team-handball players volunteered to participate in the study (average age 22, range 18–28; Table 1), which included 4 Portuguese international players. Participants had been trained by the same coach and for the same club team for the 2 years before testing. The team has been rated as one of the best Portuguese elite team-handball squads. Before commencing the study, players had a physical examination by the team physician, and each was cleared for any medical disorders that might limit full participation in the investigation. Subjects were required to sign an informed-consent form before the study that had been approved by the Institutional Review Committee Board of the local Committee for

Table 1 Descriptive Characteristics of the Subjects

Anthropometric characteristic	Mean ± SD
Age (y)	22.3 ± 3.7
Height (cm)	182.1 ± 6.7
Body mass (kg)	82.5 ± 12.2
Arm span (cm)	184.4 ± 7.8
Training time (y)	9.5 ± 1.9

Medical Research Ethics, conformed with current Portuguese law and regulations, and was carried out according to the Helsinki Declaration. No players were taking exogenous anabolic–androgenic steroids or other drugs or substances expected to affect physical performance or hormonal balance during this study.

Experimental Design and Methodology

All testing was carried out at the completion of the second period of in-season training in 1 session. Subjects were familiar with all the testing procedures and exercises, because they had been performing them as part of their regular training routine. The concentric-only bench-press exercise was used to simultaneously assess dynamic strength, power, and bar velocity and was performed after the evaluation of throwing velocity.

Ball-throwing velocity was evaluated on an indoor team-handball court by an overarm throw using a 3-step running throw, which is commonly performed during team handball. The standing (ie, stationary) throw is also used in team handball and has been used frequently in previous studies,[6,7] but during competition it is only used during penalty shots and is far less commonly performed than the 3-step throw.

After a 10-minute standardized warm-up the subjects were instructed to throw a standard handball (mass 480 g, circumference 58 cm) with maximal velocity at a standard goal, using their preferred throwing hand and throwing technique. Players were allowed only a 3-step preparatory run and were required to release the ball behind the 9-m line. Each subject executed 5 throws, with 2 minutes rest between trials. An average of the 4 throws with the greatest velocity was used for analysis. The coaches supervised the entire throwing test to ensure that the subjects were using an overarm-throwing technique regularly used in handball.[6] As motivation, athletes were immediately informed of their performance. The ball-throwing velocity was determined using a Doppler-radar gun (Sports Radar 3300, Sports Electronics Inc) with ±0.1-km/h accuracy within a field of 10° from the gun. The Doppler-radar gun was located behind a wooden target (perimeter: 60 cm) that had a hole in the middle to permit optical contact with the ball and the player. The intraclass correlation coefficient (ICC) for ball-throwing velocity was .95 (95% confidence interval: 0.87–0.97), and the coefficient of variation (CV) was 3.4%.

Dynamic strength was assessed with a 1-repetition concentric-only maximal bench-press action (1-RMBP) using a free-weight barbell machine. To begin the test and with the help of 2 coaches, the bar was positioned on the athlete's chest and was required to remain there for about 1 second before he initiated movement in an effort to minimize any countermovement effect on any of the performance indices. Next, the athlete was instructed to perform a concentric-only action from this starting position, as quickly as possible, until full extension of the elbows occurred. A trial was discounted if there appeared to be an initial countermovement of the bar, if the athlete's lower back or buttocks were elevated off the bench, or if the athlete failed to achieve full elbow extension. The 1-RMBP showed an ICC of .91 (95% interval 0.62–0.98) and a CV of 9.7%.

All participants used an initial weight of 26 kg, which was subsequently increased by increments of 10 or 5 kg for each trial until an individual could not execute a successful lift. Subjects performed a single repetition at each absolute load, with at least 3 minutes of rest between trials to reduce the likelihood of fatigue. The last bearable load was determined as the 1-RM. Bar displacement, average velocity (m/s), and average power (W) were recorded by attaching a rotary encoder to the end of the bar. The rotary encoder recorded the position and direction of the bar to within an accuracy of 0.0002 m. Customized software (JLML I+D, Madrid, Spain) was used to calculate average power for each repetition of the bench press performed throughout the whole range of motion as a most representative mechanical parameter associated with a contraction cycle of arm-extensor muscles participating in the bench press (ie, elbow and shoulder joints).[1,2,8] Strong verbal encouragement was given to each subject to motivate maximal and rapid performance of each test action. The reproducibility of the measurements has been reported elsewhere.[1,2,8] For testing, absolute (ie, 26, 36, and 46 kg) rather than relative 1-RM loads were used, as reported previously.[12,13] Baker et al[12,13] used absolute loads in bench throwing, varying from 40 to 80 kg, rather than individually predetermined selected percentages of 1-RM, following the precedent of Hakkinen and Komi.[14,15] The absolute loads used in the current study represented approximately 38%, 52%, and 67% of the group mean 1-RM. Only the first 3 trials were taken for analysis because power declined significantly ($P = .037$) after the third trial (46 kg).

Statistical Analyses

Standard statistical methods were used for the calculation of means and SDs. The Pearson product–moment correlation coefficient was used to examine the association between strength, power, and velocity from the concentric-only bench-press exercise at each absolute load with ball-throwing velocity. Differences on each dependent variable between the 3 absolute loads were determined using a 1-way ANOVA with a Tukey post hoc analysis when appropriate. Statistical significance was accepted at $P \leq .05$ for all analyses.

Results

The mean values of maximal 1-RMBP and ball-throwing velocity were 68.88 ± 10.06 kg (mean ± SD) and 23.98 ± 1.7 m/s, respectively. Power and bar velocity during the concentric-only bench press with 26, 36, and 46 kg are presented in Figure 1. Velocity decreased ($P < .0001$) over the range of absolute loads. For peak power a significant decrease was found between 26 and 46 kg ($P = .02$), and for average power a significant difference was found between 36 and 46 kg ($P = .0001$).

Pearson product–moment correlation coefficients are presented in Table 2. Maximal strength (1-RMBP) had a positive relationship with throwing velocity ($r = .637$, $P = .014$; Table 2). In addition, significant correlations were observed between throwing velocity and peak bar velocity at 26 kg and 36 kg ($r = .563$ and $r = .625$, respectively; $P < .04$) and peak power at 36 kg and 46 kg ($r = .58$, $P < .03$; Table 2). Also shown in Table 2 are the correlations between 1-RM with power, as well as bar velocity with the different loads. In addition, significant correlations were found between peak power output and peak bar velocity at each load ($r \geq .89$, $P \leq .0001$) and between average power output and average bar velocity at each load ($r \geq .91$, $P \leq .0001$).

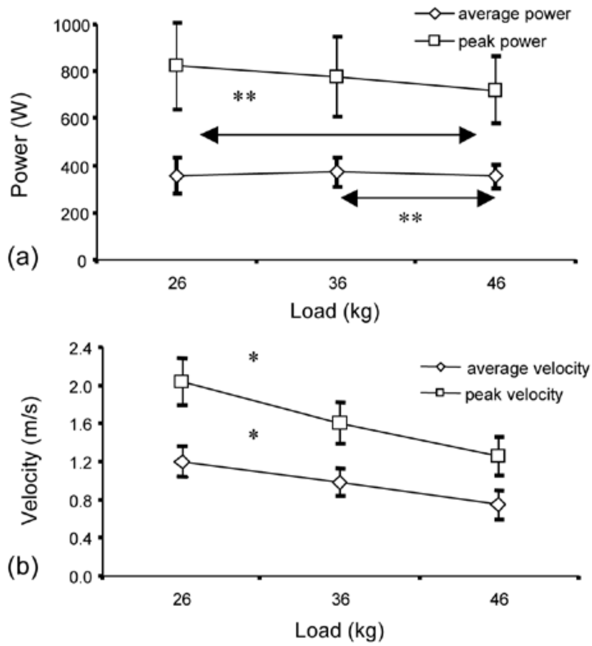

Figure 1 — (a) Average and peak power and (b) average and peak velocity at 26, 36, and 46 kg (38%, 52%, and 67% of maximal dynamic strength). *Significant difference on a .05 level between all loads. **Significant difference on a .05 level between these 2 loads.

Table 2 Correlations Between Throwing Velocity, 1-RMBP, and Measures of Strength, Power, and Bar Velocity During Concentric-Only Bench Press

Correlation	*r* with throwing velocity	*r* with 1-RM_{BP}
$1RM_{BP}$	.637[a]	—
$V_{av}26$	.383	.637[a]
$V_{av}36$	.521	.675[a]
$V_{av}46$	.376	.620[a]
$V_{peak}26$	.563[a]	.707[a]
$V_{peak}36$	.625[a]	.711[a]
$V_{peak}46$	.503	.597[a]
$P_{av}26$	.360	.639[a]
$P_{av}36$	.500	.672[a]
$P_{av}46$	.246	.563[a]
$P_{max}26$	.379	.628[a]
$P_{max}36$	.586[a]	.830[a]
$P_{max}46$	.582[a]	.748[a]

Abbreviation: 1-RM_{BP}, maximal dynamic strength; V_{av}, average bar velocity; V_{peak}, peak bar velocity; P_{av}, average power; P_{max}, peak power.

[a]Significant correlations ($P < .05$).

Discussion

The purpose of this study was to examine the relationships between 3-step ball-throwing velocity and selected measures of dynamic strength, power, and bar velocity during a concentric-only bench-press test in elite team-handball players. The major findings of this study were the significant correlations between maximal strength, peak bar velocity, and peak power measures during concentric bench press and ball-throwing velocity. These data suggest that aspects of both muscle strength and power of the upper extremities and torso play a role in the ability to throw a ball at high velocity.

Previous published reports examining the relationship between throwing performance and indices of upper body strength have provided equivocal findings, with some studies reporting a relationship[4,11] and others failing to observe a positive association.[7,8] For example, van den Tillaar and Ettema[7] reported a weak correlation between isometric handgrip strength and ball-throwing velocity for female team-handball players ($r = .49$, $P = .027$), as well as for male team-handball players ($r = .43$, $P = .056$). On the other hand, Fleck et al[5] observed stronger correlations with peak torque during shoulder flexion ($r = .63$, 300°/s) and elbow extension ($r = .63$, 240°/s; $r = .65$, 300°/s) in a group of team-handball players. Hoff and Almasbakk[4] observed a greater association between ball-throwing velocity and 1-RMBP ($r = .883$) in female team-handball players, suggesting that dynamic, multijoint tests might prove more useful than isometric or single-joint assessments. The findings of the current study did not reveal as strong a relationship between throwing velocity and 1-RMBP ($r = .64$) as that observed in the study by Hoff and Almasbakk[4] ($r = .88$) and might represent gender differences or the use of different bench-press protocols. Gorostiaga et al[2] and, more recently, Marques and González-Badillo[3] observed no association between the 3-step running throwing velocity and maximal dynamic-strength increments (1-RM) after a resistance-training regimen in a group of male professional handball players.

It is difficult to compare the results of studies that have investigated the relationships between throwing velocities and maximal strength in elite team-handball players because they differ markedly in a number of factors, including the method of measurement of maximal strength. Several studies used isokinetic[5,11] and isometric techniques,[7] whereas others employed isoinertial methods.[1-3,8] A problem with the use of isometric tests is that they only represent the strength at the specific angle measured.[8] Furthermore, in team handball not many of the movements are isometric during the throwing action, and therefore it is not natural to test isometric strength in relationship with a high-velocity movement such as throwing.[8] Isokinetic tests involve movements performed at a constant speed and typically assess a single joint motion, such as shoulder[16] or elbow flexion,[5] that is not specific to throwing.[8] The bench press is very frequently used in resistance-training programs in team handball[1-4] to increase strength but also to enhance throwing performance.[1-4] Another factor that could possibly contribute to the different outcomes between previous investigations with respect to the relationships between throwing velocity is the training and playing experience of participants.

Ball-throwing velocity was observed to have significant correlations with $P_{max}36$ and $P_{max}46$ but not with $P_{max}26$ (Table 2). This was surprising considering that peak power was greatest during the trial using 26 kg (Figure 1). One explanation for this finding could be the deceleration of the bar before maximizing peak movement velocity. Mayhew et al[17-19] investigated the relationships between bench-press power when using 20 kg and the seated shot put in female college athletes and reported only a small correlation (r = .38).[17] In a training study Mayhew et al[19] observed that the changes in seated shot-put performance were not correlated to changes in bench-press power. In contrast, Mayhew et al[18] found that seated shot put was significantly correlated to bench-press absolute power (r = .51) in 40 college football players. These findings suggest that the relationship between muscle power and seated shot-put performance could be influenced by the mass of the bench-press load, the mass of the shot put, or gender differences.

By implementing both speed- and strength-oriented training strategies or a specific power-training method, power and other performance variables might be enhanced.[12] Baker[13] observed that the average power produced at 55% of 1-RM bench-press throwing in highly trained rugby players was maximal compared with averaged power at other 1-RM load percentages. The bench press is an exercise deemed to indicate upper body power capabilities. It also should be noted that the average power output with loads of 46% and 62% of 1-RM bench throw were not significantly different from each other. In the current study we found that the highest average power output occurred at 52% of 1-RM, which was in accordance with the findings of Baker et al.[12,13] Baker and Nance[20] stated that the highest power output occurred in the range of 46% to 62% of 1-RM and not at loads of 30% to 45% because the subjects in their studies were specifically power-trained athletes. In the current study the athletes were also power trained.

Gorostiaga et al[2] observed a positive relationship between bar velocity during a bench-press test using 30% of 1-RMBP and standing ball-throwing velocity for elite (r = .67) and amateur team-handball players (r = .71). The 3-step throwing velocity was associated with the bar velocity at 30% , 60%, and 70% of 1-RMBP (r = .57–.72), but only in the elite players, suggesting a difference for open- and closed-kinetic-chain movements between elite and amateur players. The current investigation is in agreement with that of Gorostiaga et al[2] in that we observed significant correlations between peak bar velocity during the concentric-only bench-press trials using 26 kg (r = .563) and 36 kg (r = .625). Although peak bar velocity at 46 kg was not statistically correlated (r = .501, P = .68) with throwing velocity, the relative load and correlation fall within the range reported by Gorostiaga et al.[2] Taken together these data suggest that 3-step throwing velocity is related to the capacity to move low loads with upper limbs at maximal velocities.[8] The significant relationship observed between upper extremities and 3-step throwing velocity in the current study has been previously reported during concentric isokinetic elbow extensions in top team-handball players.[5] This suggests that 3-step throwing velocity is related to the capacity to move low external loads with upper limbs at maximal velocities.[5] These correlations were not very high, however, because the kinematics of overarm throwing differ very much from the kinematics of the bench press. For example, in overarm throwing it was observed that the timing of pelvis movement is very important for good throwing performance.[10] Recently, van den Tillaar and Ettema[10] investigated the contribution of upper extremity, trunk, and lower extremity movements in overarm throwing in team handball. The analysis consists of maximal angles, angles at ball release, and maximal angular velocities of the joint movements and their timing during the throw. Only the elbow angle

(r = .64; extension movement range) and the level of internal-rotation velocity of the shoulder at ball release showed a significant relationship with throwing performance (r = .67). In addition, a strong correlation was found for the timing of the maximal pelvis angle with ball velocity (r = –.84), indicating that better throwers started to rotate their pelvis forward earlier during the throw. No other relationships with throwing velocity were found, indicating that these specific characteristics are of primary importance for throwing performance in team-handball players. Thus, muscles involved in pelvis rotation were not tested by the bench-press exercise, which could explain the low significant correlation between throwing velocity and peak bar velocity.

There are several limitations to this study that should be noted. First, we used a small sample size, which might influence correlations if outliers are present. Normality was assessed for each of the performance outcomes, and it does not appear that the results of this investigation were affected by outliers. Second, we only assessed upper body strength and power, whereas van den Tillaar and Ettema[10] have indicated that other kinetic and kinematic variables play an important role in throwing velocity for team-handball players. Given the fact that throwing is a highly complex motor skill, a single test that could account for nearly all the variability in throwing velocity is unlikely.

Conclusions and Applications

Within the confines of our study limitations, these findings highlight the important relationship between throwing velocity and maximal upper body strength, as assessed by the 1-RM (r = .63), peak power at 52% and 67% of 1-RM (r = .58), and bar velocity at 38% (r = .56) and 52% of 1-RM (r = .62). It would seem that throwing-velocity performance would benefit from training regimens aimed at improving these performance qualities. These findings should be interpreted with caution because correlations provide only associations and do not represent causation; additional research is required to elucidate whether improvements in upper body strength, velocity, or power as a result of resistance or plyometric training will indeed improve maximal throwing velocity in elite team-handball athletes.

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References

1. Gorostiaga EM, Granados C, Ibanez J, Gonzalez-Badillo JJ, Izquierdo M. Effects of an entire season on physical fitness changes in elite male handball players. *Med Sci Sports Exerc*. 2006;38:357-366.
2. Gorostiaga EM, Izquierdo M, Iturralde P, Ruesta M, Ibanez J. Effects of heavy resistance training on maximal and explosive force production, endurance and serum hormones in adolescent handball players. *Eur J Appl Physiol Occup Physiol*. 1999;80:485-493.
3. Marques MC, Gonzalez-Badillo JJ. In-season resistance training and detraining in professional team handball players. *J Strength Cond Res*. 2006;20:563-571.

4. Hoff J, Almasbakk B. The effects of maximum strength training on throwing velocity and muscle strength in female team-handball players. *J Strength Cond Res*. 1995;9:255-258.
5. Fleck SJ, Smith SL, Craib MW, Denahan T, Snow RE, Mitchell MR. Upper extremity isokinetic torque and throwing velocity in team handball. *J Appl Sport Sci Res*. 1992;6:120-124.
6. van den Tillaar R, Ettema G. Instructions emphasizing velocity, accuracy, or both in performance and kinematics of overarm throwing by experienced team handball players. *Percept Mot Skills*. 2003;97:731-742.
7. van den Tillaar R, Ettema G. Effect of body size and gender in overarm throwing performance. *Eur J Appl Physiol*. 2004;91:413-418.
8. Gorostiaga EM, Granados C, Ibanez J, Izquierdo M. Differences in physical fitness and throwing velocity among elite and amateur male handball players. *Int J Sports Med*. 2005;26:225-232.
9. Mikkelsen F, Olesen MN. *Handball 82-84 [Traening af skudstyrken]* [**thesis/dissertation**]. Stockholm, Sweden: Stockholm University; 1976.
10. van den Tillaar R, Ettema GA. Three-dimensional analysis of overarm throwing in experienced handball players. *J Appl Biomech*. 2007;23:12-19.
11. Bayios IA, Anastasopoulou EM, Sioudris DS, Boudolos KD. Relationship between isokinetic strength of the internal and external shoulder rotators and ball velocity in team handball. *J Sports Med Phys Fitness*. 2001;41:229-235.
12. Baker D, Nance S, Moore M. The load that maximizes the average mechanical power output during explosive bench press throws in highly trained athletes. *J Strength Cond Res*. 2001;15:20-24.
13. Baker D. The effects of an in-season of concurrent training on the maintenance of maximal strength and power in professional and college-aged rugby league football players. *J Strength Cond Res*. 2001;15:172-177.
14. Hakkinen K, Komi PV. Changes in electrical and mechanical behaviour of leg extensor muscles during heavy resistance strength training. *Scand J Sport Sci*. 1985;7:55-64.
15. Hakkinen K, Komi PV. Effect of explosive type strength training on electromyographic and force production characteristics of leg extensor muscles during concentric and various stretch-shortening exercises. *Scand J Sport Sci*. 1985;7:65-75.
16. Edwards Van Muijen A, Joris H, Kemper HCG, van Ingen Schenau GJ. Throwing practice with different ball weights: effects on throwing velocity and muscle strength in female handball players. *Sports Med Train Rehabil*. 1991;2:103-113.
17. Mayhew JL, Bemben MG, Piper FC. Assessing bench press power in college football players: the seated shot put. *J Strength Cond Res*. 1993;7:95-100.
18. Mayhew JL, Bemben MG, Rohrs D. Specificity among anaerobic power tests in college female athletes. *J Strength Cond Res*. 1994;8:43-47.
19. Mayhew JL, Ware JS, Johns RA, Bemben MG. Changes in upper body power following heavy-resistance strength training in college men. *Int J Sports Med*. 1997;18:516-520.
20. Baker D, Nance S. The relationship between running speed and measures of strength and power in professional rugby league players. *J Strength Cond Res*. 1999;13:230-235.