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ORIGINAL ARTICLE

EXERCISE PHYSIOLOGY AND BIOMECHANICS

Reliability of a handball specific strength test battery and the association with sprint and throwing performance in young handball players

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ABSTRACT

BACKGROUND: A greater motivation for coaches to be more involved in assessment could be the development of specific strength tests closer to specific handball tasks. Therefore, the aims were to determine the reliability of a handball specific strength test battery in young handball players using a functional electromechanical dynamometer (FEMD) and to evaluate the association between the strength test battery and performance measurements.

METHODS: Thirty-two young handball players (25% males and 75% females) performed a repeated-measurement design over four weeks. The players conducted one session per week, with each measurement consisting of two isometric tests to obtain isometric peak force, and four incremental tests. Moreover, performance handball tests (sprint and throwing velocity [TV]) were recorded.

RESULTS: The reliability of the whole handball specific strength tests was very high for the peak and mean strength (ICC=0.70-0.85; CV=8.49-13.99; SEM=0.44-0.67 kg). The step forward had a moderate association with 5 to 10 meters' time. The highest correlation between TV_{mean} was found with the peak strength of standing lift and between TV_{peak} with peak strength of unilateral throw. The sprint total time could be explained by Body Mass Index and peak strength of the standing lift in the 40% and the TV_{peak} could be explained by arm span and mean strength of the standing lift in the 68%.

CONCLUSIONS: The high reliability for all exercises and the significant correlation with handball performance (sprint time and TV) allow us to include these tests in handball team evaluation and training.

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KEY WORDS: Adolescent; Muscle strength dynamometer; Physical education and training; Sports; Athletic performance.

Handball is a collaboration-opposition sport with a large number of body contacts; consequently, physical preparation is essential for athlete development.[1] This intermittent sport is characterized by several high-intensity and short-duration actions, along with lower-intensity actions, such as accelerations, jumps, and throws.[2, 3] The force athletes apply to these movements is a determining factor in the execution of explosive actions.[4] In this context, strength has been shown to be one of the most decisive capabilities in handball.[5]

Long-term development of young players, including improvements in physical fitness and movement competency, should be a priority in training.[6] Prioritizing strength training, applied and supervised properly as a fundamental building block of athleticism, is essential to generate greater movement competency.[6, 7] Traditionally, strength training exercises have been performed bilaterally, looking for a stable and symmetrical workout.[8] In young handball players, a relationship is sought between the transfer and applicability of force production during the game.[9, 10] For the biological development of young players, unilateral exercises allow a great richness of movement and a challenge for stabilizers to fit the physical requirements of sports.[11]

In handball and other team sports, strength training in multiplane movements is crucial for meeting the demands of sports.[12] Most evaluation tests are performed with basic training exercises such as squats or bench press, although this is far from the specificity of sporting skills. Throwing velocity (TV), sprint or change of direction have been investigated with field tests to bring the tests closer to the real game.[13] However, strength and power assessments in young handball players have been performed with isometric tests or jump variations with low familiarization requirements.[6] A greater motivation for coaches and young players to be more involved in assessment could be the development of specific strength tests to assess different movements closer to specific handball tasks.

Technology has developed considerably in recent years, allowing devices to replicate sport-specific movements and, therefore, enabling more ideal methods for load control and measurement.[14] The use of flywheels has been extended owing to a greater response to resistance training than to free-weight training.[15] Moreover, isokinetic dynamometers have improved with the ability to replicate sports-specific skills.[16] Within this technology, the most advanced model is functional electromechanical dynamometers (FEMD), which is proposed as an optimal tool for sports training and injury rehabilitation.[17] Moreover, FEMD have been used to measure strength specific exercises in elite handball players.[18]

Considering the variability of the movements and the reduced resistance training experience of young handball players, this study aimed to determine the reliability of four specific strength tests in young handball players using a FEMD: unilateral throw, standing lift, rotational trunk, and step-forward; and to evaluate the association between the strength tests and performance measurements (sprint and TV). We hypothesized that these tests would be a reliable method for the assessment of specific strength in young handball athletes. The second hypothesis of the present study is that the peak force of step-forward is associated with sprint time and the peak force of unilateral throw, standing lift, rotational trunk, and step-forward is associated with TV. These results are expected to provide new information on the strength and conditioning training of young handball athletes.

Materials and methods

Sample

Thirty-two young handball players, eight males (15.14±0.38 years, 61.83±11.04 kg, 1.73±0.06 m and 21.46±2.09 kg/m^2) and twenty-four females (15.91±0.72 years, 59.77±8.57 kg, 1.60±0.05 m and 23.34±2.49 kg/m^2), from two Spanish handball teams, participated in this study. The inclusion criteria were: 1) absence of musculoskeletal injury during the three months preceding data collection; and 2) at least two years of handball experience. The measurements were taken over four weeks in the post-season period. During this period, the players continued with their specific handball training; 3 days of one hour and a half. Players, coaches, and legal tutors were informed of the nature, aims, and risks associated with the experimental procedure before they provided written consent to participate. The study protocol was approved by our Biomedical Committee and was conducted following the Declaration of Helsinki.

Study design

A repeated-measures design was used to evaluate the different protocols over 4 weeks. One familiarization week, consisting of two days of three sets of six repetitions of each exercise, was completed using elastic bands. In the following three weeks, the participants were tested on three different days, separated by one week. On the first testing day, anthropometric measurements and performance handball tests (sprint and TV) were recorded. On the second and third testing days, the subjects completed an isometric test of unilateral throw with the dominant arm, an isometric test of standing lift with the dominant arm closer to the device, and four incremental tests until failure (no further repetition was possible) or not available to maintain the technique (loss of correct technique in each exercise as a guideline supervised for a sports science coach). All evaluations were conducted at the same time of the day (±1 h) for each participant and under similar environmental conditions (~21° C and ~60% humidity). The order of the tests was established randomly using a computer program.

Instrument

Isometric and incremental test were evaluated with a FEMD (Dynasystems, Granada, Spain).[18-21] Sprint time was measured with photocells (DSD Laser System; DSD, León, Spain)[22] and TV was measured with a radar (Stalker Pro II; Stalker Radar, Plano, TX, USA).

Testing procedures

The measurements were performed from 16:00 to 20:00. On the first testing day, subjects attended the university facilities where field tests were recorded. First, a general warm-up consisting of 5 min of jogging and 3 min of specific joint mobility was performed. For the TV test, the subjects conducted a specific warm-up consisting of two sets of six push-ups, ten handball passes, and five submaximal throws. Subsequently, three repetitions of maximal throwing were performed. The specific warm-up for the sprint test consisted of two sets of five bodyweight squats, two sets of five submaximal bilateral countermovement jumps (CMJ), 10 single-leg frontal bounds, a 10-m linear sprint at 80% of maximal self-perceived intensity, and a 10-m sprint at maximal intensity. Subsequently, three repetitions of the 20-m maximal sprint were tested.

On the second and third testing days, subjects attended the university laboratory to perform strength tests with FEDM. The general warm-up was identical to the first testing day. In addition, a specific warm-up consisted of two sets of five repetitions of the testing tasks with elastic bands. After that, participants performed two isometric tests during 6 seconds in the initial testing position (unilateral throw and standing lift) to calculate the 30% of isometric peak force (IPF) and four incremental tests with dominant side (unilateral throw, standing lift, rotational trunk, and step-forward) with 3 min of rest between trials. The unilateral throw and standing lift assessment started with the 30% of IPF and the rotational trunk and step-forward started with the 20% of body weight (BW). In unilateral throw and rotational trunk, the increment of the load was 1 kg per rep, in standing lift 2 kg, and in step forward this increment was modified according to BW (1 kg <60 kg BW, 2 kg 60-80 kg BW, 3 kg 81-100 kg BW, and 4 kg >100 kg BW) (Figure 1).

Participants were allowed to use a self-selected length for each exercise. Upper limb strength was measured with a unilateral throw, core and hip muscles strength with standing lift and rotational trunk, and plantar extension with step-forward. In the unilateral throw test, initially, one hand holds the handle overhead (elbow flexion selected by the user), and the contralateral foot is forward. The task was to apply a similar handball throwing technique. In the standing lift, the initial position was with both hands holding the handle in front of the body from a standing position with feet shoulder-width apart and toes slightly pointed outward. The rope angle depends on the players' height (1.5; 1.9 m). The subjects rotated the torso forcefully until they reached the opposite shoulder, after which they were required to slowly return to the initial position. The rotational trunk test started with the contralateral foot forward with a vest on the trunk. The task was to forcefully rotate the torso to the opposite side and then slowly return to the starting position. And the step-forward test started with the contralateral foot forward with a belt on the waist. The participants advanced with the foot as fast as possible, and then they were instructed to control the return to the starting position.

Figure 1.—The initial and final position of the exercises performed with the FEMD: A) unilateral throw; B) standing lift; C) rotational trunk; and D) step-forward.
FEMD: functional electromechanical dynamometer.

Sprint

The participants performed a 20-m maximal sprint. Timing gates were positioned at 0 m, 5 m, 10 m and 20 m. The data of the 5, 10 and 20 meters, 5 to 10 meters and 10 to 20 meters were recorded. Three trials were completed recording the best score for statistical analysis.

Throwing velocity

The participants were placed at the 7 meters line and the assessor stood behind the goal with the radar at a height of 1.3 meters and the participants were instructed to throw as fast as possible. If the throw was outside the goal, it was not recorded. The mean and peak TV (TV_{mean} and TV_{peak}) were registered. The ball size was specific to the category of each participant (size I of the International Handball Federation with 50 to 52 cm of circumference and 290 to 330 grams and size II of the International Handball Federation with 54 to 56 cm and 325 to 375 grams).

Anthropometric measurements

Body mass (kg) was measured using a digital bioimpedance scale (model 331; Tanita, Tokyo, Japan), height (m) with a SECA stadiometer (model 214; SECA, Hamburg, Germany) and arm span as previously reported.[23]

Statistical analysis

Descriptive data are presented as mean±standard deviation (SD). Reliability was assessed using *t*-tests of paired samples with the effect size (ES), coefficient of variation (CV), standard error of measurement (SEM), and intraclass correlation coefficient (ICC). The scale used for interpreting the magnitude of the ES was: negligible (<0.2), small (0.2-0.5), moderate (0.5-0.8), and large (≥0.8).[24] Hopkins *et al.* classify through a qualitative scale the magnitude of the values of the ICC, the values close to 0.1 low reliability, 0.3 moderate, 0.5 high, 0.7 very high, and those close to 0.9 extremely high.[25] Reliability analysis was performed using a customized spreadsheet.[25]

A Pearson's bivariate correlation was calculated to quantify the association between the specific handball strength tests with sprint and throwing performance. The strength of the *r* coefficients was interpreted as follows: trivial (0.00-0.09), small (0.10-0.29), moderate (0.30-0.49), large (0.50-0.69), very large (0.70-0.89), nearly perfect (0.90-0.99) and perfect (1.00).[25] Finally, in order to develop a more precise equation for the sample, a multiple backward linear regression model was performed to assess which variable best predicted the total sprint and TV_{peak} performance. Statistical significance for all tests was accepted at the 5% level. All statistical analyses were conducted with the statistical software package SPSS v23.0 (SPSS Inc., Chicago, IL, USA).

Results

Finally, two players were not able to perform the throwing velocity test due to a shoulder injury, so the data of reliability are presented with 32 handball players (15.72±0.71 years, 61.48±8.89 kg, 1.64±0.09 m and 22.84±2.49 kg/m^2) and the association between throwing velocity and specific handball strength test with 30 handball players.

The reliability of the whole handball specific strength tests was very high for the peak and mean strength (ICC=0.70-0.85, CV=8.49-13.99, SEM=0.44-0.67 kg) with negligible and small ES (ES<0.33) (Table I).

A large correlation was found between TV_{mean} and peak strength of the unilateral throw (*r*=0.627, P<0.001), peak strength of the standing lift (*r*=0.646, P<0.001) and peak strength of the rotational trunk (*r*=0.503, P=0.005) and a moderate correlation with peak strength of the step-forward (*r*=0.446, P=0.014). A large correlation was found between TV_{peak} and peak strength of the rotational trunk (*r*=0.544, P=0.002), peak strength of the unilateral throw (*r*=0.599, P<0.001), peak strength of the standing lift (*r*=0.596, P<0.001) and a moderate correlation with peak strength of the step-forward (*r*=0.444, P=0.014). For all sprint times taken, no correlation was found between the first 5 meters with standing lift and step forward. A large correlation was found between the time from 5 to 10 meters, the time from 10 to 20 meters and total sprint time

TABLE I.—*Reliability of the incremental testing protocol on Dynasystem dynamometer.*

Exercises		Test (kg)	Retest (kg)	ES (d)	ICC (95% CI)	CV (95% CI)	SEM (kg)
Unilateral throw	Peak strength	9.7±2.3	10.3±2.4	0.26	0.85 (0.71-0.92)	9.35 (7.47-12.50)	0.44
	Mean strength	5.4±1.1	5.7±1.1	0.33	0.48 (0.15-0.71)	13.87 (11.04-18.64)	1.07
Standing lift	Peak strength	19.6±4.3	20.3±5.5	0.14	0.83 (0.68-0.91)	10.47 (8.39-13.92)	0.47
	Mean strength	10.8±2.2	11.2±2.8	0.18	0.59 (0.31-0.78)	14.80 (11.86-19.67)	0.86
Rotational trunk	Peak strength	21.8±4.3	22.7±5.8	0.18	0.64 (0.39-0.81)	13.96 (11.19-18.56)	0.76
	Mean strength	11±3.2	11.8±2.5	0.25	0.70 (0.47-0.84)	13.99 (11.22-18.60)	0.67
Step forward	Peak strength	37.6±13.7	39.6±17.7	0.13	0.43 (0.09-0.67)	31.34 (25.13-41.67)	1.19
	Mean strength	15.3±3.5	16.1±2.8	0.23	0.83 (0.68-0.91)	8.49 (6.80-11.28)	0.46

Data are presented as mean±SD.
ES: effect size; SD: standard deviation; ICC: intraclass correlation coefficient; CV: coefficient of variation; SEM: standard error of measurement (kg); 95% CI: 95% confidence interval.

with the peak and mean strength of standing lift (*r*>-0.539, all P<0.05), except for the mean strength of the standing lift with total sprint that a moderate correlation was found (*r*=-0.471, P=0.007). A moderate correlation was found between the time from 5 to 10 meters, the time from 10 to 20 and the total time in 20 meters with the peak strength of step-forward (*r*=-0.414, P=0.02; *r*=-0.357, P=0.05; *r*=-0.360, P=0.043; respectively) (Table II).

Table II.—*Pearson's bivariate correlation between throwing velocity and sprint performance with exercises performed with the FEMD.*

Parameters	Pearson	P value
TV_{peak}		
Peak strength of unilateral throw	0.599	<0.001
Mean strength of unilateral throw	0.417	0.022
Peak strength of standing lift	0.596	<0.001
Mean strength of standing lift	0.577	<0.001
Peak strength of rotational trunk	0.544	0.002
Mean strength of rotational trunk	0.042	0.824
Peak strength of step-forward	0.444	0.014
Mean strength of step-forward	0.156	0.412
TV_{mean}		
Peak strength of unilateral throw	0.627	<0.001
Mean strength of unilateral throw	0.432	0.017
Peak strength of standing lift	0.646	<0.001
Mean strength of standing lift	0.622	<0.001
Peak strength of rotational trunk	0.503	0.005
Mean strength of rotational trunk	0.060	0.753
Peak strength of step-forward	0.446	0.014
Mean strength of step-forward	0.199	0.293
Sprint 5 meters		
Peak strength of standing lift	-0.127	0.489
Mean strength of standing lift	-0.093	0.614
Peak strength of step-forward	-0.138	0.452
Mean strength of step-forward	0.208	0.254
Sprint 5 to 10 meters		
Peak strength of standing lift	-0.663	<0.001
Mean strength of standing lift	-0.543	0.001
Peak strength of step-forward	-0.414	0.018
Mean strength of step-forward	-0.161	0.380
Sprint 10 to 20 meters		
Peak strength of standing lift	-0.580	<0.001
Mean strength of standing lift	-0.556	<0.0001
Peak strength of step-forward	-0.357	0.045
Mean strength of step-forward	-0.046	0.804
Sprint 10 meters		
Peak strength of standing lift	-0.457	0.009
Mean strength of standing lift	-0.367	0.039
Peak strength of step-forward	-0.324	0.070
Mean strength of step-forward	0.047	0.797
Total sprint		
Peak strength of standing lift	-0.539	0.001
Mean strength of standing lift	-0.471	0.007
Peak strength of step-forward	-0.360	0.043
Mean strength of step-forward	0.011	0.951

FEMD: functional electromechanical dynamometer.

Multiple backward linear regression analyses, with all TV_{peak} values as independent variables and arm span and mean strength of the standing lift, revealed that TV_{peak} could only be significantly predicted by the arm span and the mean strength of the standing lift (P<0.01). The resulting regression equation could be written as: TV_{peak}=-76.70 + 1.40 arm span + 1.92 mean strength of standing lift (Adjusted R^2=0.68).

Multiple backward linear regression analyses, with all sprint total time values as independent variables and BMI and peak strength of the standing lift, revealed that sprint total time could only be significantly predicted by the BMI and the peak strength of the standing lift (P<0.01). The resulting regression equation could be written as: sprint total time = 3.137 + 0.34 BMI + -0.021 peak strength of standing lift (Adjusted R^2=0.40).

Discussion

The present study was designed to determine the reliability of four specific strength tests (unilateral throw, standing lift, rotational trunk, and step-forward) in young handball players using FEMD and to evaluate the association between the tests and performance measurements (sprint and TV). The results provided very high reliability for the peak strength of unilateral throw and peak strength of standing lift (ICC>0.83; CV<10.47), and mean strength of the rotational trunk and mean strength of step-forward (ICC>0.70; CV<13.99). The step forward had a moderate association with 5 to 10 meters' time. The highest correlation between TV_{mean} was found with the peak strength of standing lift and between TV_{peak} with peak strength of unilateral throw. The sprint total time could be explained by BMI and peak strength of the standing lift in the 40% and the TV_{peak} could be explained by arm span and the mean strength of the standing lift in the 68%. These results demonstrated that the unilateral throw, step-forward and standing lift test using FEMD, may be used to evaluate young handball players with low familiarization process. In addition, the exercise measured with FEMD that better explains the physical performance in young handball players was the standing lift.

On the one hand, few studies have evaluated handball performance measurements with a FEMD.[18, 20, 26] Martinez-Garcia *et al.* studied the acute effect of preactivation on the overhead throwing velocity without finding any differences in female handball players.[26] The development of strength tests with movements closer to specific handball tasks has been recently studied with elite handball players, reporting a high reliability with peak velocity when two-steps test was performed with FEMD.[20] Morenas-Aguilar *et al.* demonstrated in previous studies that the reliability of three handball-specific exercises assessed with the FEMD in elite players is highly reliable when familiarization with the measuring device is performed.[27] Moreover, Aguilar-Sánchez *et al.* ound significant correlations between throwing velocity with unilateral pullover and step-forward strength.[18] However, the sample of the present study were younger handball players, and they have less experience (training and competition) than the elite handball players involved in the previous studies. Despite this, the reliability of the tests is comparable in some exercises with elite players.

On the other hand, previous reliability research has assessed similar exercises to those conducted in this study.[28, 29] In a study performed by Decleve *et al.*, they found high levels of reliability in throwing shoulder, that is an exercise comparable to unilateral throw.[28] Specifically, the position described is identical to the one used for the isometric test in unilateral throw and the initial position for the incremental test.[28] In addition, the better reliability found by Decleve *et al.* could be due to the differences in exercise type, however, the isometric test of Reichert *et al.* is comparable to the reliability of the present study.[28, 29] In addition, other authors have reported good and high reliability with agility-specific handball tests including offence and defensive actions in young and adult handball players.[30, 31] In fact, measurements taken during specific handball movements in young players were found to be more reliable indicators compared to general physical tests.[32] Accordingly, with the results of the present study, it seems that tests close to sport-specific tasks in young handball players are accurate for testing and training prescription.

The association between strength and handball performance variables seems to be important for training preparation.[33, 34] Most of the studies of lower-body strength have evaluated vertical plane exercises as squat or jump variations. However, the present study focuses on horizontal plane exercises finding an association between sprint time with standing lift and step-forward strength from 5 meters and up. This may be due to the need for greater application of strength and stability once the body is accelerated. Elite players have demonstrated better performance in 5 and 15-m sprints.[35] On the contrary, some authors have shown a null or worse correlation of sprint with exercise in vertical vectors such as a half squat or countermovement jump.[34, 36] Apart from that, in the present study, TV reveals a significant correlation with peak strength of unilateral throw. In line with that, moderate correlations have been found with isometric shoulder strength and medicine ball throw with handball players.[28] Moreover, the role of trunk strength has been associated with rotational medicine ball throwing in college students[37] and baseball players.[38] Specifically, isometric shoulder strength and muscle preactivation measured with FEMD have been correlated with handball TV.[18, 26] Most of these studies have focused on adult or elite players, in contrast to the lack of experience of the sample of this study. However, Ramos *et al.* indicated an important physical contribution to game performance parameters in young basketball players.[39] In fact, the correlation for TV in the present study is higher than the correlation with isometric shoulder strength in elite players.[18] In addition, a high relationship was also found between the strength of the standing lift, rotational trunk and step-forward with the TV. These results highlight the importance of the kinetic chain in TV,[29] showing the need for multicomponent strength training to improve handball performance.

Upper-body movements, such as overhead throwing, frequently need a strong whole-body movement through the lower-body and transfer through the core.[40] Despite this, most of the studies used isometric strength tests (*i.e.*, hand grip) or power tests (*i.e.*, bench press throw) for measuring upper-body strength without including these types of movements.[29] Multiple backward linear regression analyses lead us to believe that trunk muscles measured with standing lift are crucial for sprint total time and TV_{peak} in young handball players. In accordance, Massuca *et al.* highlighted the need for the inclusion of trunk training exercises in handball players due to the huge importance of being a successful handball player.[23] Moreover, trunk strength is important for sports performance including throwing velocity, however, trunk training and testing should have similar conditions to those during competition to improve the outcomes.[40]

Limitations of the study

This study is not without limitation, only the dominant side was analyzed so the possible differences between sides could not be assessed. Although the dominant side is the most used, both sides are important for performance in team sports. However, the low familiarization requirement provides a time reduction in team evaluation allowing trainers to have relevant data in a short time. In addition, these results highlight the fact that strength assessment in tasks closer to sports gestures with FEMD does not differ from traditional and more analytic measurements with young handball players.

Conclusions

The high reliability for all exercises and the significant correlation with handball performance (sprint time and TV) allow us to include these tests in handball team evaluation and training due to the importance of these factors in the determinant actions of the match. The predictor model identifies the influence of morphological aspects (BMI and arm spam) and trunk strength on sprint time and TV to adjust and reduced the battery of tests for assessment and training.

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Conflicts of interest
The authors certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

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Authors' contributions
María Dolores Morenas-Aguilar and Diego Soto-García have given substantial contributions to study design and data collection, Angela Rodríguez-Perea and Daniel Jerez Mayorga to data collection and analysis, and manuscript writing, Aldo Borja Avalos Solitario to data collection and manuscript revision, Luis Javier Chirosa Ríos to manuscript critical revision, Helena Vila to manuscript writing. All authors read and approved the final version of the manuscript.

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