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Arm/Shoulder Specific Strength Device for Throwers

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Abstract: Research has proposed various ways to develop ballistic/explosive arm rotational movements for throwers but demonstrated inherent limitations for the lack of traditional resistance training respecting sport-specific tasks. A prototype device was conceived for ballistic multi-joint throwing exercises. Forty-three high-level competitive U19 male handball players participated in the study aged 18.42 ± 1.17 years; 82.36 ± 3.07 mass kg; and 184.91 ± 6.06 m height. Subjects underwent tests on the ASSSD, which operates into consecutive accelerative and decelerative actions, for throwing characteristics determination. Concentric (CON) and eccentric (ECC) variables during overhead throws as force, power, velocity, acceleration and angle when occurred peak force (PF), power (PP) and velocity (PV) were defined. The relative reliability was calculated using the intraclass correlation coefficients (ICCs) showing strong agreement between trials. The absolute reliability was analyzed using standard error of measurement SEM (0.03-2.75), and Coefficients of variation CVs (2.84-4.59%) for studied variables, reveals excellent interday reliability. Validity was assessed using linear regressions, r and p values showing good relationship between PF and PP gathered from ASSSD and isokinetic peak torques at different angular velocities of dominant arm (DA). The device sensitivity was verified when assessing CON-ECC PF, CON-ECC PP and CON PV with elite/non-elite players. The ASSSD has demonstrated its reliability, validity and sensitivity intended for testing, training monitoring and sport performance assessment.

Keywords: Ballistic, Concentric, Eccentric, Multi-joints Motion, Throwing Device

1. Introduction

Ballistic exercises soliciting specific sport tasks are important for power improvement and throwing velocity increase [1-4]. Various ways were proposed to develop explosive strength but they demonstrated inherent limitations for the lack of sport-specific tasks achievement. It has been stated, that the identification of the individual optimal load

(IOL) that maximize peak power (PP) output in ballistic multi-joint throwing tasks, promoting training skills transfer to athletic performance, seems to be a suitable training approach [5-9].

Isotonic resistance training has already proven its benefits in dynamic sport disciplines, since it offers good results in strength, power and velocity gains [1, 3, 10, 11]. Actually, variants of bench press and other techniques with free weights or machines were described for ballistic upper-body movements. However, the direction of resistance movement is less relevant to the specific tasks encountered in real sport condition of throwing exercising [3, 6, 10].

The different isokinetic dynamometers are widely used for improving strength gains in used limited and inadequate constant velocity, but they cannot access the high-speeds attainted in throwing tasks [12-14].

Variants of different over- or underweighted medicine ball complicate comparisons of their results and are not adapted to individual capabilities [15-16].

For elastic bands or tubing, although they demonstrated positive outcomes, but not in sport performance, they are not recommended for speedball improvement because when they are taut, their tension increases leading to gradually slowing the movement speed, while, maximum speed is required for faster ball release [17-20].

Although, the cited approaches are necessary for overall strength development [1, 10], they are not as effective for non-matching sport-specific movement where kinetic and/or kinematic characteristics are not respected.

Taking in consideration all the above, we worked on the design of an innovative testing and training device adapted to ballistic throwing movements, which mechanically mimics kinetic and kinematic characteristics involving the active muscular chain in respect to synchronized joints movement.

Thus, the aim of this study was to investigate the reliability and the sensitivity of the Arm/Shoulder Specific Strength Device (ASSSD), and its validity compared to gold standard isokinetic dynamometer for muscular performance measurements while achieving ballistic throws. We hypothesized that the new device will be sensitive, present reliable measurements and will be valid when compared to isokinetic dynamometer at used speeds.

2. Materials and Methods

2.1. Experimental Approach to the Problem

To the best of our knowledge, no device and no data have yet been reported on dynamic multi-joints pattern using specific plyometric exercises that involve ballistic throws with prescribed IOL for throwers seeking specific strength components improvement, shoulder muscles strengthening as well as correcting their imbalance without range of motion (ROM) reduction. The invention of such device seems to be timely and necessary for training progression monitoring, performance enhancement and injury risk reduction for both muscles and joints, as the ASSSD operates into consecutive accelerative and decelerative actions. This manuscript, which aims only at the validity, the reliability and the sensitivity of a new specific device, is the first of a series of studies in order to highlight the importance of the first specific throwing device and its effects.

2.2. Subjects

Forty-three high-level competitive U19 male junior team handball players (32 right handed, 11 left handed), playing in the national team and first division of the Tunisian handball championship at the time of testing, aged 18.42 ± 1.17 years; 82.36 ± 3.07 mass kg; and 184.91 ± 6.06 m height, participated in the study. The inclusion criteria were regular participation in training and competition, and at least 5 years of competitive background in handball. Parents and participants were informed about the purpose, experimental procedures and possible risks and benefits of the investigation. Written parental consent was obtained for participants younger than 18. The study was in accordance with the current ethical standards and approved by the Ethics Committee of the Tunisian National Centre of Medicine and Science in Sports.

2.3. Testing Procedure

The ASSSD went through tests for validity (compared with Cybex Norm isokinetic device). The reliability was assessed by comparing measurements made in 2 different sessions 4 days apart, by the same experimenter and at the same hour of the day. The sensitivity was determined by comparing the elite/non-elite players).

To avoid learning effects, two preliminary familiarization sessions in separate days were undertaken with participants who had to perform a low volume (3 sets of 5 repetitions). Three minutes are given between trials for rest and arm-shoulder stretching exercises.

A multi-stage procedure was followed to record studied variables. Throws were initiated with light and medium loaded ball 7-10 days prior the pre-testing procedure to set participants IOL. Several practice sets at different loads (bar level and weight) were performed while receiving immediate feedback during each repetition to target PP. The load was individually adjusted until it matched the target individual PP. During the test, the research assistant provided verbal encouragement.

2.4. Device Description

The ASSSD is a power throw machine operating on the pendulum system, schematically presented in Figure 1. The suspended rotating bar is connected from the top to the measurement and braking systems and from the bottom to the ball.

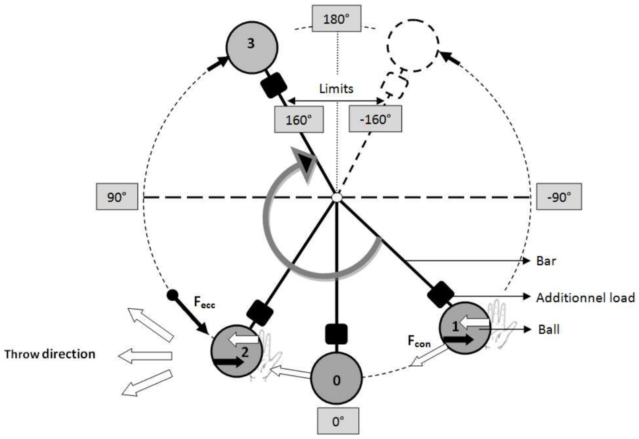

Figure 1. *Throw direction of loaded ball and bar displacement limits of the ASSSD.*

The operator can adjust the player's individual load and height at the target angles allowing the execution of a wide range of throw type's gestures in a single continuous movement, mimicking the full range of motion (ROM) of targeted throw. The mass of both ball and bar does not apply any weight heaviness (absence of gravitational weight force) on the hand (s), allowing a smooth and swift execution of the throwing motion.

The bar range of rotation is fixed at ±160° while the vertical down position was set at 0° which constitutes a reference position separating the concentric (CON) and the eccentric (ECC) throwing phases. The accelerated bar, which moves forward to the maximum limit of rotation, is stopped by an electromagnetic frame absorbing the applied force and assures a free drop of the bar without bouncing. This was intended to avoid the stretch reflex and potential damage to muscles and joints, due to the quick and sudden bar return.

2.5. Test Description

Subjects were placed in a standing position with the dominant arm (DA) abducted to approximately 90° and the elbow flexed to 90° where the inner face of the hand is positioned just in contact to the force transducer placed in the ball. The front foot opposite to the DA and the other foot are placed on either side of a line drawn on the floor just at the neutral position (0°) of the suspended bar. Both feet were kept in contact with the floor at all times for the standing throws. Throwing exercises were conducted on the spot first with two arms and DA, then after 3-step run-up to get the feel of the ASSSD and to develop so-called kinesthetic sense. For the throws with run-up, players received the descending ball after 3 step forward run-ups exerting a braking force followed by propelling the ball explosively. Once the ball was released, the subject took 3 steps back initiating another throwing act.

The throwing exercise consists of five sequences of ball propulsion and reception against loaded ball inertia involving active muscle chain. Both CON and ECC actions are shackled in fast and explosive throws respecting correct throwing pattern. During explosive throws, developed power output elicits substantial acceleration and higher end velocity at ball release benefiting from the elastic energy stored in the active muscle chain, tendons and ligaments during ECC contraction triggering the potentiated CON movement [1, 4]. When initiating ECC movement, the subject exerts a countermovement with large braking force to overcome the inertia of the loaded ball until the end of the arm-cocking phase followed by a short transition for prompt propulsive action as hard as possible, where maximal acceleration is required for all repetitions.

2.6. Optimal Load Determination

This device has the specific and so far unique characteristic of allowing for the simultaneous assessment of specific variables of the throwing exercise. For the accurate IOL definition giving PP achievement for DA, each participant was asked to attend 3x5 repetitions performed as quickly as explosively as possible, at progressive augmented weight (3-5 kg) and at different ten height levels of 10 cm each plotted on a graduated bar. The load was gradually increased in ascending order, by sliding the weight from the top at marked 10 centimeters and progressively downward to the maximal bar limit at 100 centimeters, until the power peaked at a given level, which was determined thanks to the data obtained by the computer. The highest load and the level at which the participant elicited his PP was recorded and used during a training program according to a predefined protocol. At each height level, time, power, force, velocity, acceleration and angle (bar displacement) were instantaneously calculated from trials and displayed in order to assess CON-ECC PF, CON-ECC PP and CON PV (Figure 2).

ms	°/	Nm	m/s	Watt	$m\ s^{-2}$			
Time	Angle	Force	Velocity	Power	Acceleration	Name	Sequence	Test
254,00	-5,00	87,00	2,46	214,00	11,41818182	K	2,00	3,00
255,00	-1,00	87,00	2,53	221,00	6,850909091	K	2,00	3,00
256,00	2,00	87,00	2,81	246,00	28,16484848	K	2,00	3,00
257,00	4,00	88,00	3,18	280,00	37,29939394	K	2,00	3,00
258,00	7,00	87,00	3,63	318,00	44,91151515	K	2,00	3,00
259,00	12,00	87,00	4,12	358,00	48,71757576	K	2,00	3,00
260,00	17,00	102,00	4,66	479,00	54,04606061	K	2,00	3,00
261,00	23,00	104,00	5,19	542,00	53,28484848	K	2,00	3,00
262,00	28,00	104,00	5,66	591,00	46,43393939	K	2,00	3,00
263,00	36,00	103,00	6,04	623,00	38,06060606	K	2,00	3,00
264,00	41,00	102,00	6,41	660,00	37,29939394	K	2,00	3,00
265,00	50,00	104,00	6,93	722,00	52,52363636	K	2,00	3,00
266,00	58,00	104,00	7,14	743,00	20,55272727	K	2,00	3,00
267,00	66,00	104,00	6,53	680,00	-60,8969697	K	2,00	3,00
268,00	73,00	104,00	6,00	626,00	-53,2848485	K	2,00	3,00
269,00	79,00	104,00	5,86	612,00	-13,7018182	K	2,00	3,00
270,00	86,00	104,00	5,64	589,00	-22,0751515	K	2,00	3,00
271,00	92,00	104,00	5,55	579,00	-9,13454545	K	2,00	3,00
272,00	98,00	122,00	5,56	682,00	1,522424242	K	2,00	3,00
273,00	104,00	122,00	5,47	670,00	-9,89575758	K	2,00	3,00
274,00	111,00	123,00	5,31	653,00	-15,9854545	K	2,00	3,00
275,00	116,00	124,00	5,15	642,00	-15,2242424	K	2,00	3,00
276,00	123,00	122,00	4,96	609,00	-19,030303	K	2,00	3,00
277,00	128,00	124,00	4,77	594,00	-19,030303	K	2,00	3,00
278,00	133,00	66,00	4,68	309,00	-9,13454545	K	2,00	3,00
279,00	138,00	57,00	3,84	219,00	-83,7333333	K	2,00	3,00

Figure 2. *Instant display of time, angle, force, velocity, power and acceleration during one sequence of throwing exercise.*

Coupling variables were also assessed by overlaying the force-, power, and velocity-time curves (Figure 3) for different times of peaks determination [21].

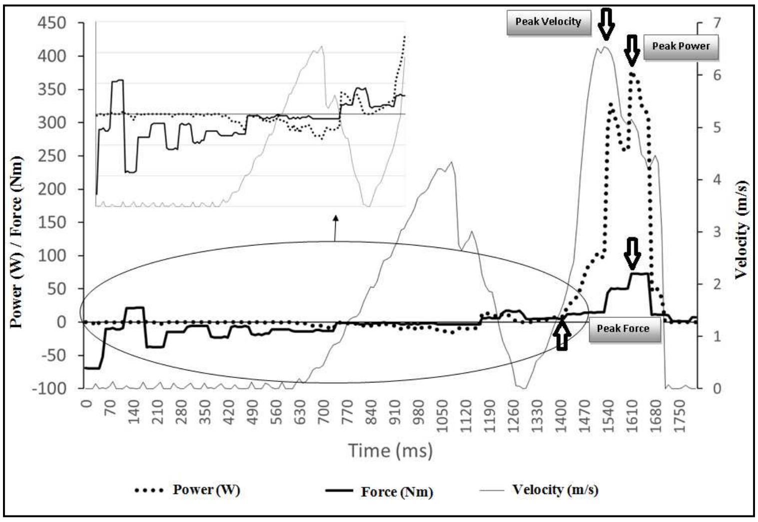

Figure 3. *The shape of the force-, power-, and velocity-time curves change during optimal loaded ball throwing on the ASSSD.*

2.7. Throwing Device Measuring Components

The device was used to yield isoinertial measurements obtained from applying force on the ball, from:

An industrial force-transducer (Model DBBP Series- S-Beam with a Smart Powered Strain Bridge/Load 1600B). The force-transducer was connected to an interface for analog-signals-analysis, converting and transferring measurement data to a personal computer where a customized software calculates, displays and stores all values presented in an Excel spreadsheet (Figure 2).

A certified tachometer (DOGA DO162.4102.2B00/3025 12V DC Motor 2000RPM 0.20NM) fitted to the bar displayed velocity and acceleration.

A Multi-Turn wire wound potentiometer (WXD3-13-2W 2.2 K ohms) investigates the range of bar displacement and specify the angle at which PF, PP and PV are achieved.

An electromagnetic brake (COMBISTOP N 20 Nm 30.13X) actuated a dual-surface spring-applied DC-brake and a bridge-rectifier (INTORQ 6-pole bridge rectifier BEG-16) for full-wave rectification.

A connector block, cable-connected to a PC via USB cable, includes filtering and conditioning unit (FCU) with control unit and digital processing (CUDP). The CUDP ensures the data reading collected by the sensors, and controls the electromagnetic brake through the interface unit (IU) respecting the bar rotation limits.

2.8. Statistical Analyses

Means and SD were calculated. The relative reliability was calculated using the intraclass correlation coefficients (ICCs). The 95% confidence intervals (CI) were determined and complemented by paired t-test and Bland-Altman graphical plots [22] for limits of agreement (LoA). Standard error of the mean (SEM), effect size (ES) and coefficient of variation (CV) was used as criteria for reliability [23, 24]. For validity analysis, linear regression analyses and Pearson correlation coefficients (r) were used. Statistical significance was set at $p \leq .05$. Statistical analyses were processed using the Package (SPSS 20.0; IBM Corporation, New York, USA).

3. Results

3.1. Reliability Analysis

Establishing the mechanical reliability of this prototype device was the first step of the study. During each session, players completed 3x5 repetitions of throwing exercise with run-up for PP assessment. Descriptive statistics for the test-retest sessions are presented in Table 1.

The reliability of selected variables showed no significant differences between the sessions ($p>.05$). The relative reliability of the measurement device was assessed using intraclass correlation coefficients (ICCs) which were set between 0.932 and 0.992, denoting an excellent agreement of the measuring tool and good relative reliability of the testing procedure. The values of absolute consistency of these variables CVs were less than 5% [25].

Table 1. *Test-retest reliability of studied variables measured with the ASSSD in handball players (n=43).*

Variables	Trial 1	Trial 2	ES	ICC [95% CI]	SEM	CV (%)
Peak CON Power (W)	513.43±109	524.32±100.2	0.10	0.99 [0.98-0.99]	2.75	2.84
Peak ECC Power (W)	-40.60±7.92	-40.35±8.23	0.03	0.97 [0.95-0.99]	0.40	4.59
Peak CON Force (N)	80.48±12.84	83.95±14.95	0.27	0.98 [0.97-0.99]	0.53	4.18
Peak ECC Force (N)	-68.5±10.57	-68.88±10.79	0.03	0.97 [0.95-0.99]	0.54	3.59
Peak Velocity (m/s)	6.21±0.42	6.52±0.41	0.72	0.93 [0.88-0.96]	0.03	4.07

SEM: Standard Error of the Mean; CV: Coefficients of variation (%); Cohen d: effect size ES; ICC: Intraclass Correlation Coefficient; CI: 95% Confidence Interval.

The Bland–Altman plots reveal good limits of agreement between sessions since almost all data points fell within the 95% limits (Figure 4).

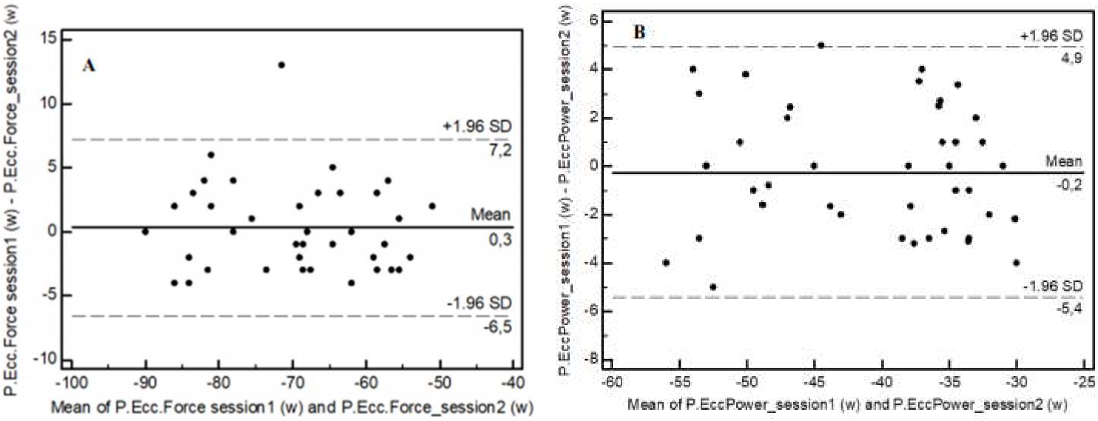

Figure 4. *Bland-Altman limits of agreement between the two sessions assessment on the ASSSD for peak eccentric force (A) and peak eccentric power (B) measurements. Middle solid line: the mean bias between sessions; dashed lines: the 95% limits of agreements (±1.96 standard deviation SD).*

3.2. Validity Analysis

To examine the concurrent validity, linear regression analyses and Pearson product-moment correlations were used to define the relationships between PF and PP obtained from the ASSSD, and gold standard isokinetic device peak torques at different velocities in concentric internal (IR) and external (ER) rotations. The correlation coefficients are shown (Figure 5). The graphs show linear regressions fit of both systems, with the corresponding regression equation, correlation coefficients and p values (n=43). The correlation coefficients showed good relationships between PF and PP obtained from the ASSSD and peak torques gathered from isokinetic device in IR and ER at 60°/s, 180°/s and 300°/s speeds (p<.001).

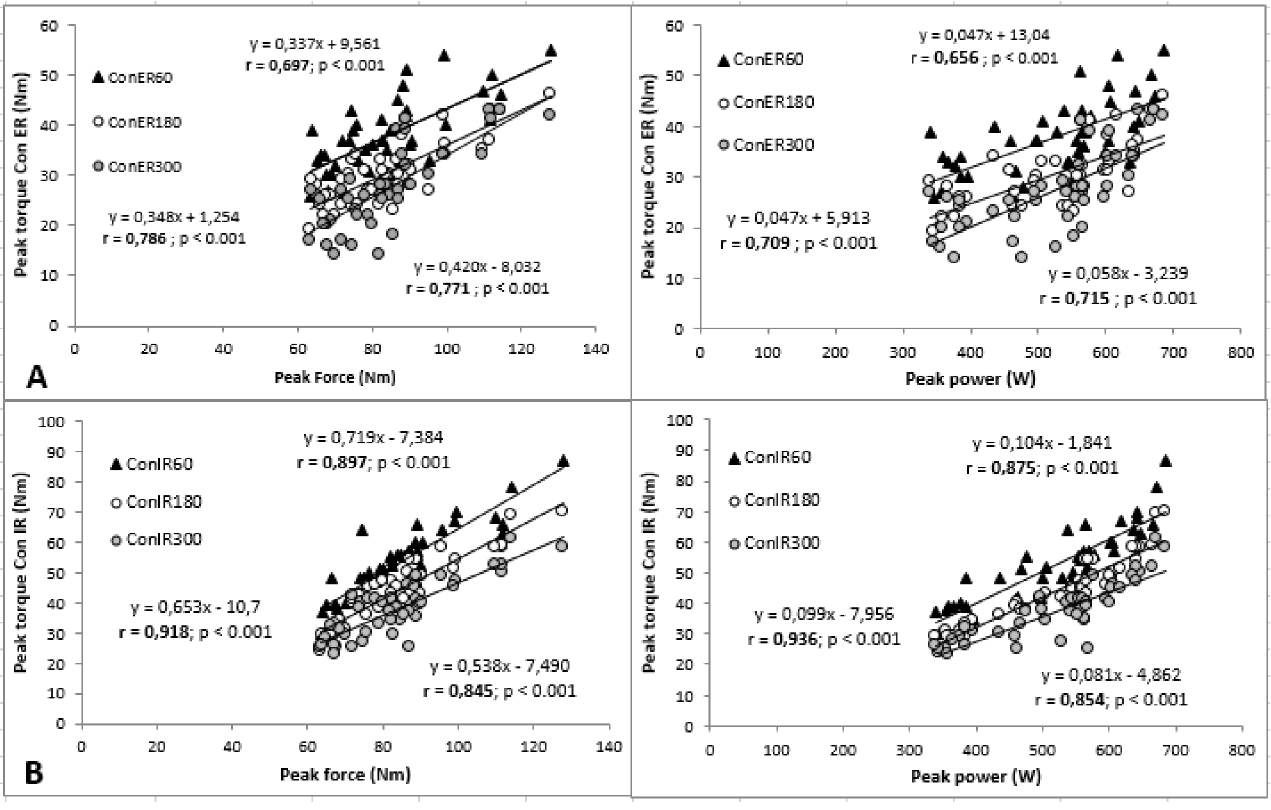

Figure 5. *Relationship between concentric peak force and peak power of DA obtained from the ASSSD and the isokinetic peak torques at angular velocities 60°s^{-1}, 180°s^{-1} and 300°s^{-1} in (A) concentric external ER and (B) concentric internal rotations IR.*

3.3. Sensitivity Analysis

The sensitivity was determined for elite (Tunisian national handball team) and non-elite handball players (from one of the top-ranking teams of first league). No significant differences between the two groups for age (p = 0.11), height (p = 0.20) and body mass (p = 0.24) characteristics with Cohen's small effect size.

The prototype device detected minor differences between the 2 groups in selected variables conducted in the second testing session, which indicates its high sensitivity. The results of the T-test showed significant differences, meaningful to athletic performance, between the elite and non-elite groups in favor of elite players.

4. Discussion

The ASSSD can be used as a testing and training tool in laboratory or field conditions for handball and possibly in other throwing disciplines (Badminton, Baseball, Javelin, Shot put, Tennis, Volleyball, Water polo…). In addition, the ASSSD conception took into consideration the use of plyometric exercises which involve ballistic throws with prescribed IOL [5, 7, 8, 12], where forces are exerted at high velocities throughout the movement [25-27]. These exercises using sequential combination of eccentric muscle contractions rapidly followed by potentiated concentric ones [28, 29], assures more sport-specific stimulus as well as transfer of training skills to athletic performance [7, 12, 30].

Originally, the study aimed at investigating the reliability and the sensitivity of the ASSSD, and its validity compared to a gold standard isokinetic dynamometer in CON and ECC actions. However, since isokinetic dynamometry allows only measurement at a constant velocity, while the ASSSD allows for progressive and higher velocity, which makes comparison between the two devices invalid, we investigated only ASSSD's reliability and sensitivity.

Our results suggest that overhead throwing exercise in handball players, using the ASSSD prototype is reliable, for measuring ECC-CON PP, ECC-CON PF and CON PV of loaded ball.

To define the relative reliability, ASSSD variables showed high ICCs values, with corresponding 95% CI, since they are above a priori defined minimum acceptable level of 0.8 [22, 23]. According to Table 1, the ICCs showed a strong to almost perfect agreement between the two trials based on reliability coefficients which ranging from 0.88 to 0.99. Thus, the relative reliability observed in this study seems to be good to excellent and confirms the formulated hypothesis.

The absolute reliability was analyzed using SEM (0.03-2.75), ES (0.03-0.72) and CVs (2.84-4.59%) values revealing an excellent interday reliability ($p>.05$). The high ICCs in conjunction with low SEM values might support the use of the device in adolescent handball players. To evaluate the magnitude of the difference between the two sessions the ES revealed, large effects for PV, and small ones for peak ECC-CON PP and ECC-CON PF [24]. In addition, the Bland-Altman plotting difference for each individual's mean between sessions for ECC-PF and ECC-PP variables [22, 24], reveals that scores were within the 95% confidence interval (Figure 4). For ECC-PP, the ICC was equal to 0.972 (LoA= 4.9355, -5.4281; $p<.001$) while for ECC-PF, the ICC reached 0.974 (LoA= 7.2306, -6.532; $p<.001$).

Concurrent validity was tested by inter-machine comparison of obtained variables from the ASSSD and a gold standard isokinetic dynamometer. Results revealed statistically significant ($p<.001$) relationships between measurements obtained from both systems with high r values (0.70-0.94) for CON PF and PP of DA obtained from the ASSSD and isokinetic peak torques at different angular velocities in concentric IR and ER (Figure 5). This supports that results obtained from both methods are closely related indicating sufficient validity of the ASSSD.

Moreover, the ASSSD has been shown to be sensitive since it was able to detect small changes in performances between elite and non-elite handball players. The results of the T-test showed significant differences when assessing CON-ECC PF (p=.003), CON-ECC PP (p=.003) and CON PV (p=.04) in favor of elite handball players.

Once the device has demonstrated its reliability and validity and even its sensitivity, and since the ASSSD allows synchronized joints movement that mimic athletic throwing tasks close to real-conditions movements, we can consider that the ASSSD would emphasize the PP and sport performance improvements. Throwing motion, when performed by the ASSSD, promotes kinetic energy transfer from the legs through the torso to the arm, thus improving throwing movement patterns [4, 19, 31, 32]. The ability to assess and improve explosive strength components is therefore important for designing individual training programs, not only for researchers, but also for practitioners in sports. Therefore, strength and conditioning coaches could develop force components during throwing exercising using IOL, for PP enhancement, or different loads (lower or higher) by sliding the weight up or down, for velocity or force improvements respectively [33].

The velocity of the optimal loaded-ball in current study reached around ($7\ m\cdot s^{-1}$) while the ball throwing velocity in handball exceeds ($26\ m\cdot s^{-1}$). In an attempt to take into consideration the specific velocity principle, we lightened the load, by the handling of the sliding weight, to reach similar velocity encountered in training and competition environment [6, 11].

Furthermore, according to Kaczmarek et al. [18] the deceleration phase that occurs just after ball release, is performed at a high angular deceleration reaching ($500.000°/s^2$) in real condition, may lead to the rotator cuff muscles injury [4, 34-36]. It has already been proven that the application of designed accentuated eccentric loading forms has both therapeutic and preventive positive effects related to shoulder injuries [27, 37-39]. The ASSSD was designed to operate into consecutive accelerative optimal loaded and decelerative overloaded actions [7, 28, 38], allowing an accentuated eccentric braking phase promoting shoulder posterior muscles strengthening, and therefore, imbalance correcting, injury prevention as well as post-injury rehabilitation. Further studies are needed to verify these claims; but we can report the cases of two players in the experimental group, in the pretest, were not able to complete the ECC isokinetic test at fast speeds (180°s-1 - 300°s-1). Following two months of training on the ASSSD, these players, at the retest, finished the ECC isokinetic test successfully.

Finally, the device could also be useful as a tool for learning techniques of throwing movements, since movement automation has been shown to result from practice and maximizing repetitions at coveted throwing type [40].

Due to direct practical applications, the ASSSD could be integrated into the training programs tailored to individual abilities of subjects in order to solicit a positive transfer to the coveted throwing gesture. We suggest the use of predefined IOL for PP improvement, or the work on the privileged zones, above or below IOL threshold to improve the force components or movement speed respectively.

5. Conclusion

The study has demonstrated that throwing variables in U19 handball players showed robust assessments of the ASSSD in term of reliability, validity and sensitivity. Possible limitations of this study may reside in the limited variation in age and gender. It would also be interesting to experiment the ASSSD in other throwing disciplines to check its effectiveness in improving specific force components and sports performance.

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Competing Interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Ethics

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Contributorship

All authors contributed to all items in the ICMJE contributorship guidelines.

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