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Original Research

The shoulder endurance test (SET): A reliability and validity and comparison study on healthy overhead athletes and sedentary adults

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ABSTRACT

Objectives: The primary purpose was to examine the reliability of a new shoulder physical performance test -the Shoulder Endurance Test (SET)- in young healthy overhead athletes and sedentary adults and to provide preliminary reference values. The secondary objective was to determine whether there are differences on SET scores based on groups, sides and days. The third objective was to evaluate the relationship between the SET and shoulder rotational isometric strength in both groups.
Design: Reliability and validity study.
Setting: Laboratory setting.
Participants: A total sample of 92 participants volunteered to participate in this study (30 healthy overhead athletes - 62 sedentary adults).
Main outcome measures: We used a two-session measurement design separated by seven days to evaluate the reliability. We calculated intraclass correlation coefficients to determine relative reliability and used standard error of measurement and minimal detectable change to quantify absolute reliability. Systematic differences in SET scores between groups, days and sides were analysed with a two-way analysis of variance (ANOVA) for repeated measures. To check for systematic differences within groups between day 1 and day 2, a Wilcoxon Signed Rank Test was performed. Relationship between shoulder rotational isometric strength and the SET was determined using the Spearman Rank test (r_s).
Results: Relative reliability was high to very high in both groups (intraclass correlation coefficient [2,1] range = 0.78–0.93) and absolute reliability was clinically acceptable. The standard error of measurement varied from 10.7 s to 16.45 s. The minimal detectable change ranged from 29.6 s to 45.6 s. Weak correlations were found between the SET and isometric shoulder rotational strength (r_s range = 0.309 −0.431).
Results: of the ANOVA for repeated measures showed a significant two-way interaction effect for day x groups (p = 0.020) and a significant main effect for side (p= < 0.001). Results of the Wilcoxon Signed Rank Test showed no systematic differences in group 1 between day 1 and day 2 for both sides (p = 0.79 dominant side; p = 0.66 non-dominant side).
Conclusions: The SET is a reliable clinically applicable shoulder physical performance test in young adult overhead athletes and sedentary adult.

1. Introduction

The incidence of shoulder injury is increasing Caine D, Harmer P, Schiff M. Epidemiology of injury in olympic sports. Wiley-Blackwell; 2010 (Smucny et al., 2016). and injury rates are reported to be between 18% and 61% in overhead throwing or smashing sports (Asker et al., 2018; Caine & Schiff, 2010; Cools et al., 2020). Overhead throwing requires muscular strength and endurance, flexibility, and neuromuscular control of the shoulder in order to maintain functional stability. If any of these factors is deficient, performance diminishes and shoulder injuries are more likely to occur (Lee et al., 2003; Warner et al., 1990).

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Whereas strength, strength balance and flexibility have been well documented in the literature (Warner et al., 1990), muscular endurance of the shoulder girdle in throwing athletes has received limited research attention (Evans et al., 2018; Olds et al., 2019). Muscular endurance is the ability of a muscle to sustain activity over time, performed as an isometric or isotonic contraction, and is crucial to maintain muscle function over many throws and long seasons (Evans et al., 2018). Athletes with a history of shoulder pain demonstrated more shoulder muscle fatigue compared with their healthy counterparts and arm fatigue has been identified as a common risk factor for shoulder pain in baseball pitchers (Moore et al., 2013). Moreover, muscle fatigue alters muscle activation patterns, force couples and kinematics that may lead to injury (Cools et al., 2002; Ebaugh et al., 2006; Joshi et al., 2011; McQuade et al., 1995; Tripp, Yochem, & Uhl, 2007a, 2007b; Tsai et al., 2003). However, it is not commonly evaluated clinically, as no standard test exists (Evans et al., 2018).

Physical performance tests (PPTs) have been developed to provide a complete picture of functional status of the athlete's upper extremity (Creighton et al., 2010; Negrete et al., 2011; Tucci et al., 2014). PPTs are typically used in the follow-up of athletic patients (Negrete et al., 2011), such as evaluating progress following surgery or injury, predicting the risk of new injuries, guiding rehabilitation, predicting the season's performance and to facilitate decision-making regarding whether athletes are ready to return to sport (Hegedus & Cook, 2015). In this context, PPTs should be representative of the demands of the sport to which the athlete evolves (Cho et al., 2006; Olds et al., 2019). However, most of the current PPTs evaluate one construct (eg, strength, power, agility, mobility, stability)(Chmielewski et al., 2014; Decleve et al., 2020a; Goldbeck & Davies, 2000; Gorman et al., 2012; Harris et al., 2011; Tucci et al., 2014) and do not examine muscle endurance capability. To fill this gap, we have developed a new shoulder performance test, the Shoulder Endurance Test (SET) that may more closely replicate overhead sporting activity. Therefore, the first purpose of our study is to evaluate the test-retest reliability of the SET on young healthy overhead athletes and sedentary adults and to provide preliminary reference values. The second purpose is to determine whether there are differences on SET scores based on groups, sides and days. The third objective is to assess the construct validity of the SET, by examining the correlations between the SET and shoulder isometric rotational strength using the Self-Assessment Corner (Decleve et al., 2020b) is to determine whether there are differences on SET scores based on groups, sides and days.

2. Methods

2.1. Participants

A total sample of 92 participants from the Parnasse-ISEI volunteered to participate in this study between September 2019 and December 2019. A first sample of 30 healthy athletes (Group 1: 16 males - 14 females), involved in overhead sports at competitive level minimum 5 h per week (mean hours = 7 ± 2.4), was recruited (age = 20 ± 1.76; body mass = 70.9 ± 9.2; height = 172.9 ± 8.8). A second sample of 62 sedentary adults (Group 2: 30 males − 32 females) not, or less than 3 h/week, involved in overhead sports (mean hours = 0.6 ± 1.2) was recruited (age = 20.5 ± 2.2; body mass = 67.3 ± 11.2; height = 172.8 ± 9.0). Participants of both groups were included if they were aged between 18 and 30 years and were in good general health. The exclusion criteria for both groups were a history of orthopaedic surgery of the upper quadrant or spine or reports of pain in these regions within a 6-month period prior to the study. All participants provided written informed consent, and the study was approved by the Ethical Committee of the UCL University 2019/03JUL/289- N°B403201940915 and signed by participants.

2.2. Study design

This research was designed (1) to examine the reliability of the SET in healthy overhead athletes and healthy adults using a two-session measurement design separated by seven days, (2) to check for systematic differences between groups, sides and days (3), and, to examine the relationship between shoulder isometric rotational strength and the SET in both study samples. The study hypotheses were that the SET would show high reliability values, would demonstrate groups and side differences and no difference would be found between days. Our last hypothesis was that no correlation would be found between isometric rotational strength and the SET.

2.3. Procedure

The participants attended two assessment sessions conducted by the same investigators (two fourth-year physical therapy students under supervision of a physical therapist with over 15 years of clinical experience). In order to evaluate test-retest reliability, the SET was performed on two sessions (day 1 and day 2) separated by seven days. We tested the shoulder isometric rotational strength prior to the SET on day 1. For both tests, the dominant and non-dominant sides were tested and the side order was randomized. The dominant side was determined by the participant's arm used to throw a ball.

2.4. Shoulder endurance test (SET)

Participants were instructed to stand up straight with their back against a wall, barefoot, with the non-tested hand on the back (L4-L5) and the opposite foot of the tested arm placed forwards. The tested arm was placed in a 90°forward flexion holding a 1-m long thera-band® fixed at shoulder height on a graduated stick. Participants were asked to pull the thera-band® from the starting position (Fig. 1-A) −90°forward flexion-to a 90° external rotation and 90° abduction (90°90°position) (ending position) (Fig. 1-B) at an alternated cadence given by a metronome. Repetitions were performed until the participant was fatigued indicated by one of the following conditions: The inability to keep the pace or reach the ending position after 2 verbal cues or verbal report of the inability to continue. A tape was fixed on the wall to ensure participants would touch the 90°90° ending position. We choose the thera-band® resistance according to the participant's sex. Males were asked to pull a green thera-band® (2.1 kg) and females a red thera-band® (1.7 kg). The choice of the color was determined from a previous study (Evans et al., 2018). They reported the use of an external load to fatigue the cuff ranging from 1.4 to 1.6 kg for females and ranging from 2.05 to 2.5 kg for males. Therefore, we used the Thera-band chart to evaluate the tension needed to obtain approximately the same load for each gender as reported by Evans et al. (Evans et al., 2018). Based on the chart, a 100% elongation of the red or green thera-bands provide a load of 1.7 kg and 2.1 kg respectively. The graduated stick was placed at 2 m from the ending position allowing a 100% stretch of the length of thera-band® between the starting and the ending positions. The cadence increased every 20 s starting from 60 beats per minute (bpm) to 150 bpm (60 bpm − 90 bpm − 120 bpm − 150 bpm)(video 1).

Supplementary video related to this article can be found at https://doi.org/10.1016/j.ptsp.2020.12.005

. At 150 bpm, the cadence remained the same until the end of the test. We used the application Pro Metronome © (EUMlab, Xanin

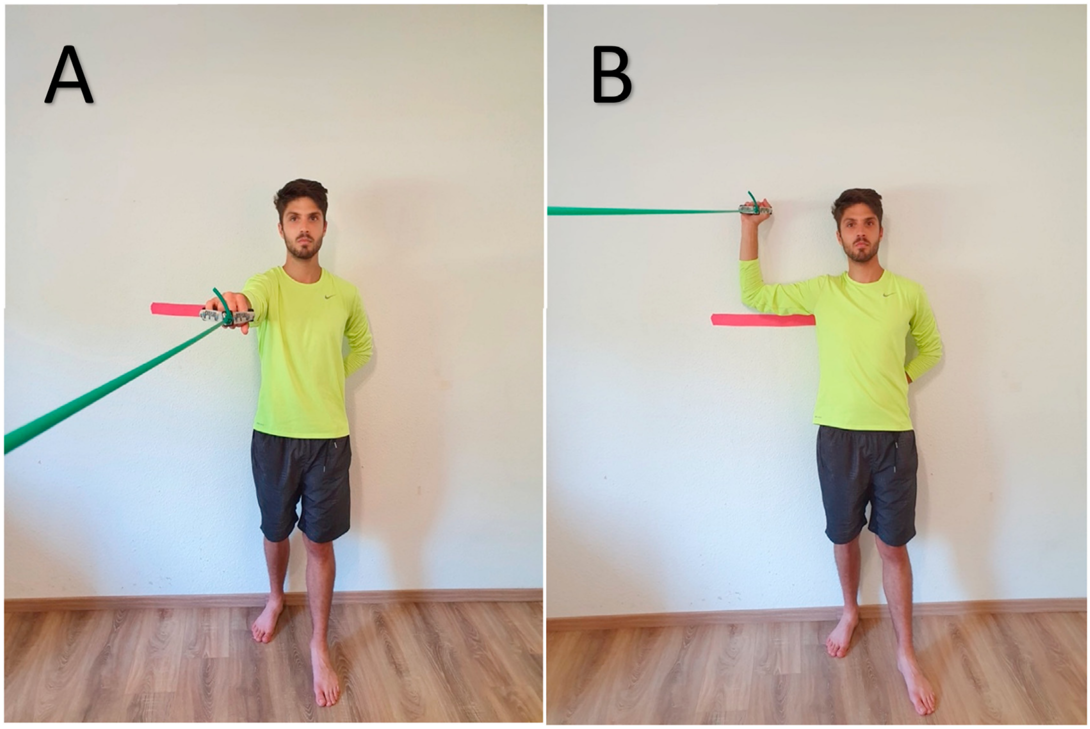

Fig. 1. SET starting (A) and ending position (B).

Tech, GmbH) to pre-set all settings before the SET.

After getting the instructions and a demonstration, participants performed a familiarization trial in order to control the participant's understanding of the procedure. The familiarization trial consisted to perform first the movement without any resistance and any cadence. Then, participants had to execute the movement three times for each cadence (60bpm-90bpm-120bpm-150bpm) using a lighter thera-band® (yellow). A 5-min rest was allowed between the familiarization trial and testing trial to minimalize to potential effect of fatigue. The testing trial was performed once and the score was expressed in seconds. To assess participant's subjective experiences of fatigue, we used a Borg rating of perceived exertion scale immediately after the test (Borg's's, 1998). This scale is a valid measure of local upper extremity exertion (Kang et al., 1998). We considered the participants to be fatigued when they reported an exertion level exceeding 14 of 20[29]. A rating of 15 on the rating of perceived exertion scale corresponds with "hard/heavy work or strain and fatigue on muscles" (Borg's's, 1998).

2.5. Shoulder isometric rotational strength

The procedure was performed following the guidelines as described by Decleve et al. (Decleve et al., 2020b) using the Self-Assessment Corner. After verbal instructions from the investigators, participants were instructed to stand up straight, barefoot, with the non-tested hand on the back (L4-L5) and the opposite foot of the tested arm placed forwards. The forearm was placed against the Hand-Held Dynamometer (HHD) (MicroFET2 HHD, Hoggan Health industries Inc, West Jordan, UT, USA) 2 cm proximal of the ulna styloid process on the dorsal for external rotation (ER) or ventral forearm for internal rotation (IR) for strength assessment. Both ER and IR were assessed in a 90°90° position. Three repetitions of 5 s of maximal voluntary effort were performed using a « make » test with 10 s of rest between trials. The absolute isometric strength data were expressed in Newton (N).

2.6. Statistical analysis

Means and standard deviations were calculated across participants of group 1 and group 2 for dependent variable. The SET (in seconds) was the primary dependent variable. The Shapiro-Wilk test was first used to evaluate the normality of the distribution within all measurements and non-parametric tests were applied when necessary.

2.7. Reliability analysis

To assess relative reliability, intraclass correlation coefficients (ICC)(2,1) were calculated with the corresponding 95% confidence intervals (CI) (de Vet et al., 2006). The ICC values ranges from 0 to 1:1, perfect reliability: 0.90 to 0.99, very high reliability: 0.70 to 0.89, high reliability: 0.50 to 0.69, moderate reliability: 0.26 to 0.49, low reliability and 0.00 to 0.25 little, if any, reliability (Portney & Watkins, 2000). In order to examine the absolute reliability of the SET, the standard error of measurement (SEM) and the minimal detectable change (MDC) and MDC% were calculated. The SEM was calculated as SD x $\sqrt{1\text{-ICC}}$, where SD is the SD of all scores of participants (Weir, 2005). The SEM was used for calculating the MDC_{95}, which was calculated as SEM x 1.96 x $\sqrt{2}$[32]. The MDC% was obtained by dividing the MDC by the average values of the test and retest and by multiplying the result by one hundred (Thorborg et al., 2010).

Groups, sides and days comparisons Analysis.

The SET data displayed a non-normal distribution and were transformed logarithmically for analysis. Differences in SET scores were analysed with a two-way analysis of variance (ANOVA) for repeated measures in which the within-subject factors was side (two levels) and days (2 levels) and the between-subject factor was groups (two levels). In the ANOVA, three-way interactions (side x day x group) were of interest. In case of absence of significant three-way interactions, two-way interactions among the variables of interest were examined. In the absence of any interaction effects, main effects (for side, day or groups) were analysed. To check for systematic differences within groups for dominant and non-dominant sides between day 1 and day 2, a Wilcoxon Signed Rank Test was performed.

2.8. Correlation analysis

The Spearman Rank test (r_s) was used to assess the possible relationship between the SET and shoulder isometric internal external and external rotational strength. The r_s values were categorized as weak (<0.499), moderate (0.50 −0.707), or strong (>0.707) (Stockbrugger and Haennel, 2003). The Alpha was set at 0.05. All statistical analyses were performed using SPSS (version 23; IBM Corp, Armonk, NY, USA).

3. Results

Reliability and descriptive analysis are summarized in Tables 1 and 2. Rate of perceived exertion analysis is reported in Table 3.

3.1. SET reliability

The Test Retest reliability between day 1 and day 2 showed very high reliability with ICC values of 0.93 for the dominant side on overhead athletes. High reliability values were found for the non-dominant side on overhead athletes and on both sides for sedentary adults. The SEM ranged between 10.7 s (dominant side overhead athletes) to 16.4 s (dominant side sedentary adults). The MDC_{95} ranged between 29.6 s (dominant side overhead athletes) to 45.6 s (dominant side sedentary adults).

3.2. Groups, sides and days comparisons analysis

Results of the ANOVA for repeated measures showed a significant two-way interaction effect for day x groups ($p = 0.020$) and a significant main effect for side ($p = < 0.001$). Regarding the sides, results demonstrate statistically significant differences on SET scores between the dominant and non-dominant sides with higher SET scores on the dominant side on both groups.

Results of the Wilcoxon Signed Rank Test showed no systematic differences in group 1 between day 1 and day 2 for both sides with 124 s compared to 123.1 s on dominant side ($p = 0.79$) and 104.2 s compared to 103.4 s on non-dominant side ($p = 0.66$). But, systematic differences were found on group 2 for both sides with 112 s compared to 119.4 s on dominant side ($p = 0.014$) and 98.7 s compared to 107.3 s on non-dominant side ($p = 0.002$).

3.3. Correlation analysis between the SET and shoulder isometric rotational strength

Weak significant correlations were found between the SET and shoulder isometric internal and external rotations (r_s range = 0.309–0.431).

3.4. Rate of perceived exertion

The rates of perceived exertion for both groups are described in table XX. When comparing both days, participant's reported Borg RPE was not statistically significantly different between day 1 and day 2 on the dominant side for the overhead athletes ($p = 0.256$) but a statistically significant difference was found on the non-dominant side for overhead athletes ($p = 0.001$). Regarding the sedentary adults, statistically significant differences were found on the dominant and non-dominant sides ($p = 002$ and $p = 0.001$ respectively). However, in both groups, differences reported between days are too small to be clinically relevant. Participants reported being not able to continue the test because of the fatigue which prevented them to maintain the cadence or to keep the arm above the line.

4. Discussion

4.1. Relative and absolute reliability

The first purpose of our study was to determine test retest reliability of the SET on overhead athletes and sedentary adults. To the best of our knowledge, only one study (Moore et al., 2013) has assessed the reliability of non-instrumented test for shoulder endurance test in open chain on 10 baseball players in a prone position. In this study, Moore et al. (Evans et al., 2018) elaborated the Posterior Shoulder Endurance Test (PSET) in order to measure endurance of the posterior shoulder muscles in the clinical setting with minimal equipment requirements (Evans et al., 2018). The PSET is a dynamic test performed in a prone position while lifting the arm to 90° of horizontal abduction at a shoulder abduction angle of 90° at 30 beats per minute. Test-retest reliability of the PSET (ICC 0.85) is comparable to the reliability of the SET. Nevertheless, during the PSET, the position of the participant or the beat used may not be representative of the demands of overhead sports. Therefore, the SET could be more appropriate for the examination of throwing functionality on overhead athletes.

The evidence suggests that the SEM and MDC are directly related to the reliability and, therefore, it is important to calculate them to make valid clinical decisions (Johansson et al., 2015). The SEM indicates the limit for the smallest change that explains a real modification or change in the number of seconds in groups of subjects (Sole et al., 2007; Tighe et al., 2010) while the MDC is defined as the minimal change that falls outside the measurement error in the score of the test used (Johansson et al., 2015; Kovacs et al., 2008). In our study, considering values of SEM and MDC for group 1 we could consider as a true change when a change of 29.6 s on the dominant side or 38.2 s on the non-dominant side occurs. For group 2, we could consider as a true change when a change of 45.6 s on dominant side or 40.2 s on non-dominant side occurs. In light of these results, it appears that the absolute reliability of the SET is higher on group 1. Considering that the MDC can also be presented as a MDC %, an indirect comparison with other shoulder PPTs described in the literature is possible. In our study, the MDC%

Table 1
Test retest reliability ICC (CI) and their SEM, MDC95 and %MDC95 on overhead athletes (group 1) and sedentary adults (group 2) on dominant and non dominant sides.

	Overhead Athletes (N = 30)		Sedentary Adults (N = 62)	
	Dominant	Non dominant	Dominant	Non dominant
ICC (IC)	.932 (.862–.967)	.781 (.588–.890)	.884 (.806–.931)	.853 (.728–.917)
SEM	10.7	13.8	16.4	14.5
MDC95	29.6	38.2	45.6	40.2
%MDC95	24%	37%	39%	39%

ICC,Intraclass correlation coefficient; CI,confidence interval; SD, Standard Deviation; SEM,standard error measurement; MDC, minimal detectable change.

Table 2
Descriptive analysis (mean and SD) for SET results expressed in seconds on overhead athletes (group 1) and sedentary adults (group 2) on day 1 and day 2.

Overhead Athletes (N = 30)						Sedentary Adults (N = 62)					
Dominant		Wilcoxon Signed Rank Test	non dominant		Wilcoxon Signed Rank Test	Dominant		Wilcoxon Signed Rank Test	non dominant		Wilcoxon Signed Rank Test
SET D1	SET D2	p value	SET D1	SET D2	p value	SET D1	SET D2	p value	SET D1	SET D2	p value
124 ± 40.9	123.1 ± 41.8	.79	104.2 ± 32.3	103.4 ± 26.9	.66	112 ± 47	119.4 ± 49.6	.014	98.7 ± 36	107.3 ± 39.2	.002

SD, Standard Deviation; SET, Shoulder Endurance Test; D1, day 1; D2, day 2.

Table 3
Rates of borg rating perceived exertion scale for the SET (mean and SD).

	Overhead Athletes (n = 30)	Sedentary Adults (n = 62)
Dominant D1	16.4 ± 1.9	15.1. ± 1.9
Dominant D2	16.8 ± 1.4	15.7 ± 1.9
Non dominant D1	16.2 ± 1.7	14.7 ± 2.3
Non dominant D2	17.2 ± 1.3	15.6 ± 1.9

SD, standard deviation; D1; Day 1; D2, Day 2.

amounted from 24% (dominant side on overhead athletes) to 39% (non-dominant side on sedentary adults) versus 19%–30% for MDC % on recommended PPTs such as the closed kinetic chain upper extremity stability test (CKCUEST) and upper limb rotation test (ULRT) (Callaway et al., 2020; Decleve et al., 2020a; Sciascia & Uhl, 2015; Tucci et al., 2014). Even if the question of the acceptable level of reliability using the MDC is unanswered in the literature, we can consider that the reliability on the dominant side on group 1 is similar to recommended PPTs (Callaway et al., 2020; Cools et al., 2020; Decleve et al., 2020a; Sciascia & Uhl, 2015; Tucci et al., 2014). Our study shows high to very high relative reliability on both groups, but, the lowest SEM and MDC are on the dominant side for group 1 and, therefore it suggests that it is the most sensitive to change.

Consequently, it is our recommendation that clinicians, coaches, athletic trainers use the SET to assess shoulder endurance on the dominant side.

4.2. Groups, sides and days analysis

Although not the primary research question but relevant for clinicians, the second objective was to determine whether there are differences on SET scores between groups, sides and days.

Concerning the groups, our study shows no significant difference on SET scores between groups highlighting the fact that the SET is applicable to both groups to assess overhead functionality. However, the Wilcoxon Signed Rank Test used to compare the possible presence of a significant difference between day 1 and day 2 for each group's dominant and non-dominant side demonstrates no systematic difference between days on group 1 compared to group 2. From a clinical perspective, this finding highlights the absence of a learning effect across days on group 1. As supported by Odds et al. (Olds et al., 2019), the absence of a learning effect allows the clinician to use the SET to benchmark athletes without prior practice.

Regarding the side, the results demonstrate statistically significant differences on SET scores between the dominant and non-dominant sides with higher SET scores on the dominant side on both groups. This confirms that the SET discriminates side differences whether participants practice overhead activities or are sedentary. From a clinical perspective, the SET can test both sedentary and overhead athletes. This test makes it possible to differentiate both sides as well in overhead athletes as sedentary. However, the learning effect analysis and the reliability analysis clearly show that the test could be more suitable for monitoring athletes.

4.3. Correlation between the SET and shoulder isometric rotational strength

The third purpose of our study was to determine the relationship between the SET and shoulder isometric rotational strength on overhead athletes and sedentary adults. We observed weak correlations between the SET and the isometric internal and external rotations in both groups. These results highlight the fact that performance on the SET does not depend solely on isometric rotational strength. The weak correlations suggest that both measures should not be used interchangeably and should be evaluated separately. A possible explanation may be that muscle contractions elicited by endurance tests are equal to 40–52% of the maximal voluntary contractile force and induce specific muscle activation strategies (Holmström et al., 1992).

Selection of appropriate PPT requires careful consideration of relevance, specificity and practicality (Manske & Reiman, 2013). Single PPT which determine return to sport have limited clinical utility as they measure only one construct (Olds et al., 2019). Thus, to accurately measure an athlete's readiness to return to sport, we should a battery of tests which evaluates different constructs such as strength, endurance, power, range of motion and neuromuscular control to improve our ability to determine a safe return to sport (Manske & Reiman, 2013; Olds et al., 2019).

4.4. Limitations and future perspective

Some limitations of our study need to be considered. All of the measurement techniques and procedures were performed using field-measurement tools for reasons of clinical relevance.

In addition, participation of a narrow age range asymptomatic overhead and sedentary individuals also needs to be acknowledged as a limitation and extrapolation on other age categories should be done with caution. The small overhead heterogeneity of the group needs to be acknowledged as limitation. The interpretation of our results is limited to reporting the reliability and relationships of the SET in a sample of healthy subjects. The SET focus mainly on the rotational movements of the glenohumeral joint in a standing position and does not include the entire kinetic chain. The elastic properties of the resistance might diminish across time and, therefore might have influenced the results. Another limitation of the SET is that it might not be suitable for initial or mild-level stages of shoulder rehabilitation due to its challenging requirements. The SET allows to test the endurance of the shoulder in a 90°90° position but, might be not representative of the demands of some sports. Therefore, we urge clinicians to choose multiple tests accordingly to the demands of the sports. The future lies in the development of a shoulder test battery which evaluates different constructs such as strength, endurance, power, range of motion and neuromuscular control to improve our ability to determine a safe return to sport.

5. Conclusions

The first purpose of this study was to establish the relative and absolute reliability of the SET on overhead athletes and sedentary adults. Relative reliability was high to very high in both groups and absolute reliability was clinically acceptable. The second purpose was to determine whether there are differences on SET scores based on groups, sides and days. The SET is applicable to both groups to assess overhead functionality and discriminate side differences.

The third objective was to examine the relationship between the SET and isometric shoulder rotational strength. Weak correlations were found between the SET and isometric shoulder rotational strength. Future research should focus on continued data collection to enhance the depth of the findings and assess the validity and clinical importance of the test of the SET in different sports and patient populations.

Ethical approval

Approval opinion of the Research Ethics Committee of the University of Louvain-La-Neuve – Saint-Luc. Protocol UCL University 2019/03JUL/289- N°B403201940915.

Ethical statement

The study was approved by Research Ethics Committee of the University of Louvain-La-Neuve-Saint-Luc protocol UCL University 2019/03JUL/289- N°B403201940915 and all participants signed a free and informed consent form.

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None.

Declaration of competing interest

The authors declare no conflict of interest.

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