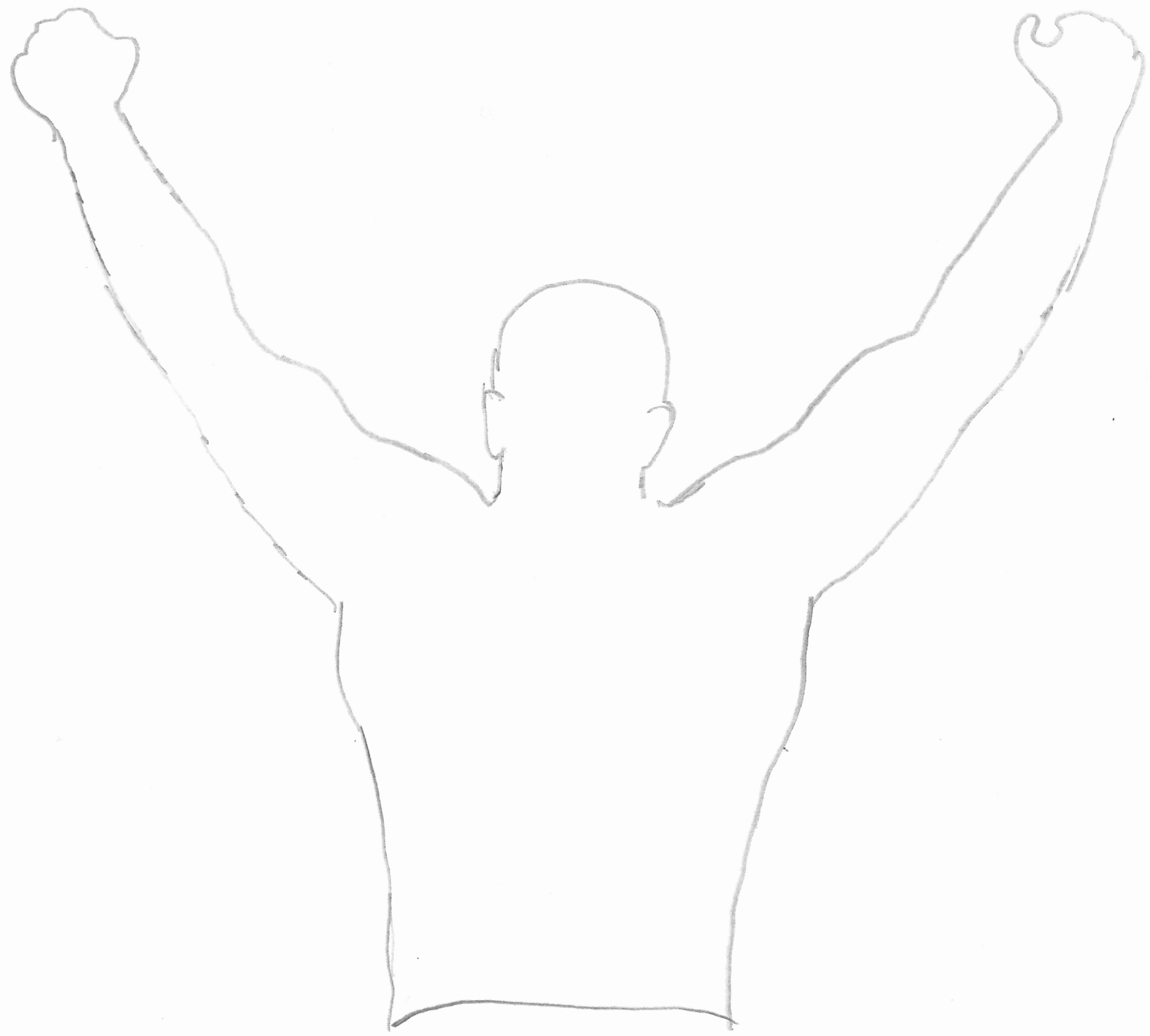

Analytical and Functional Assessment of the Athlete's Shoulder

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Thesis submitted to fulfill the requirements for the degree of Doctor in Health Sciences
Ghent University, 2021

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TABLE OF CONTENTS

LIST OF ABBREVIATIONS

ABER	Abduction External Rotation
CKCUEST	Closed Kinetic Chain Upper Extremity Stability Test
DA	Dominant arm
e.g	Exempli gratia
ER	External rotation
ICC	Intraclass Correlation coeficient
IR	Internal Rotation
MCKCUEST	Modified Closed Kinetic Chain Upper Extremity Stability Test
MDC_{95}	Minimal detectable change with 95% confidence interval
Min	Minute
n	Number of participants
N	Newton
NDA	Non dominant arm
PPTs	Physical Performance tests
PSET	Posterior Shoulder Endurance Test
RC	Rotator Cuff
ROM	Range of motion
s	Seconds
SAC	Self-Assessment Corner
SD	Standard Deviation
SEM_{95}	Standard error of measurement with 95% confidence interval
SET	Shoulder Endurance test
SMBT	Seated Medicine Ball Throw
SPSS	Statistical Package for the Social Sciences
SRT	Seated trunk rotation test
ULRT	Upper Limb Rotation Test
YBT-UQ	Y-Balance Test – Upper quarter

GENERAL INTRODUCTION

GENERAL INTRODUCTION

The general introduction of this dissertation consists of three parts. In a first paragraph, we will discuss the "sporting shoulder", including the role of the kinetic chain, the most common shoulder injuries and the known risk factors related to shoulder pain in the overhead athlete. Secondly, we will give an overview of analytical and functional screening of shoulder function. Finally, we will specify the research questions and aims of this dissertation.

1. The sporting shoulder

Overhead throwing is the fastest athletic movement performed in sports and is characterized by a multitude of repetitive and highly specific patterns of throwing, smashing or serving movements[1, 2]. This complex overhead movement involves activating all the kinetic chain segments to achieve accuracy and velocity[3, 4]. The kinetic chain refers to the mechanical linkages of body segments which allow for the sequential transfer of forces and motions when performing an overhead motion[5, 6]. An alteration in one segment of this kinetic chain, known as the "catch up" phenomenon, creates changes throughout the entire system by increasing the load placed on the distal segments[7-9] which makes the overhead shoulder highly susceptible to injury[10, 11]. For example, the trunk is a crucial structure to deliver the force produced by the lower limbs to the upper limbs and, combined with the hip, contributes approximately 50% of the kinetic energy and force to the entire throwing motion[12]. Previous studies using mathematical modeling demonstrated that a reduction in trunk kinetic energy development increased the demand in the distal segment to maintain the same energy ball release, resulting in increased constrain placed in the shoulder and elbow joint[13-15]. For this reason, the assessment and management of overhead athletes should not be limited to the shoulder joint or function but should also extend to the whole kinetic chain, including the lower extremities, the trunk, and the more distal joints of the arm.

There has been an increase in youth sport participation over the past years, with athletes starting practicing in early childhood with an early sport specialization and an enormous amount of training during adolescence[16-19]. Due to the high loads and forces on the shoulder complex during overhead sports over a long period of time which overlaps with skeletal and muscular development, adolescent athletes are at increased risk of shoulder pain or injury[16-20]. Therefore, early identification and modification of risk factors in youth are thus warranted for primary prevention of the subsequent musculoskeletal disorders in adults[21].

Shoulder injuries are common among adolescent and adult overhead athletes with prevalence rates ranging from 4%-61%[2, 17-30]. Injuries can occur after a traumatic event on the shoulder or as a result of chronic overuse. These overuse injuries are traditionally defined as injuries that occur with gradual onset over time[22]. Recent studies have demonstrated that overuse shoulder problems dominate[23, 24]. Regarding these injuries among adolescent and adult overhead athletes, previous studies have identified modifiable risk factors such as deficits in shoulder internal rotation (IR) and total range of motion (ROM), rotator cuff (RC) weakness, scapular dyskinesis and increased training load, as well as non-modifiable risk factors such as sex or age[2, 18, 20, 29, 33-40]. However, the evidence is conflicting[25-27] and may be explained by the complex multifactorial background of shoulder overuse injuries[28, 29] and the different sport-specific biomechanical demands on the shoulder[30]. Inconsistent findings have been reported concerning the ROM or scapular dyskinesis on adolescent or adult overhead athletes on the one hand, and depending on the sport, on the other hand[31, 32]. With respect to ROM, a recent systematic review with a meta-analysis suggested that professional baseball pitchers whose external rotation ROM in the throwing arm was not at least 5° greater than their non-throwing arm were twice as likely to sustain in-season shoulder injuries[31]. Nevertheless, similar findings were not observed in adolescent or high school baseball pitchers[31]. Moreover, adolescent swimmers with external rotation (ER) ROM lower or higher than 93° and 100° are at a higher risk of shoulder injuries compared with swimmers whose shoulder ER ROM is within 93° and 100°. But the authors also reported that ROM screening might not be effective in identifying handball, softball, volleyball and tennis players at risk of shoulder injury[31]. However, these results should be interpreted cautiously since the majority of the studies focused on baseball population. Concerning scapular dyskinesis, Clarsen et al.[33] and Kawasaki et al.[34] showed that scapular dyskinesis was significantly associated with a shoulder injury on adult handball or rugby players respectively. Asker et al.[35] reported that adolescent male handball players with scapular dyskinesis had an increased rate of shoulder injury, while Moller et al.[21] reported on adolescent handball players that scapular dyskinesis was a significant risk factor in participants who had a 20% increase in training load. Nevertheless, other studies did not confirm a significant association between scapular dyskinesis and the development of shoulder injury[2, 25, 36-38].

RC weakness in overhead athletes has been well documented in the literature[21, 24, 33, 39-42]. Decreased isometric and isokinetic ER or IR strength as well as imbalance in ER:IR strength ratio have been shown to increase the risk of sustaining shoulder pain or injury in both adolescent and adult handball and baseball players[21, 23, 26, 33, 35, 37, 43] as well as adult volleyball players[2, 21, 23, 33, 35, 43-46].

Despite this inconsistency previously reported on risk factors, some cut-off values can be drawn for ROM and strength. For IR ROM deficit, cut-off values range from 18° to 25° depending on the study design and population[47]. Furthermore, the difference in total ROM should not be more than 10°[48].

With respect to rotator cuff strength, overhead athletes often exhibit a relative decrease in the strength of the external rotators and thus muscular imbalance in the rotator cuff[48]. Concerning cut-off values distinguishing a healthy shoulder from a shoulder at risk, an isokinetic ER/IR ratio of 63% to 72% (depending on the testing position)[43, 49, 50] or an isometric ER/IR ratio of 75% to 100% (depending on the testing position)[51] is advised, with a general rotator cuff strength increase by 10% of the dominant versus non-dominant throwing side[30].

Concerning the load, it can be divided into internal and external loads, with external loads representing the quantification of work and internal loads corresponding to the physical loading experienced by an athlete[52-54]. The International Olympic Committee consensus statements on load in sport and risk of injury[55] have stated that injury etiology is multifactorial and that load monitoring needs to include a combination of both external and internal loads. A range of subjective and objective measures exists to monitor both loads (e.g. training volume/exposure/duration/distance, rating of perceived exertion, hear rate, blood screening, questionnaire)[53, 54].

Fatigue is another crucial aspect to monitor. It can be defined as the decreasing baseline psychological and physiological function of the athlete[54] which has a significant negative impact on performance[56] and results in an increased risk of injury for the athletes[56-59]. It highlights the importance of fatigue screening, i.e. mental, physical and emotional, in response to training loads in order to minimize injury[60].

However, muscular endurance of the shoulder girdle in overhead athletes has received limited research attention[61-65]. Muscular endurance is crucial to maintain muscle function over many throws and long seasons[62], and muscle fatigue alters muscle activation patterns, force couples and kinematics, leading to injury[66-71]. Recently, muscle fatigue has been identified as a common risk factor for shoulder pain in baseball pitchers[72-74]. By screening athletes for risk factors at a specific point in time we may not take into account that appearance of risk factors may change over time due to several factors such as training and match demands[28]. Monitoring athletes continuously with screening tests over the seasons may help to obtain a more complete and nuanced picture of the athlete's shoulder and guide us for an appropriate intervention[28, 75].

2. Screening and monitoring overhead athletes

Screening of upper extremity performance may be either analytical or functional. In order to enable this continuous analytical and functional screening, all measurement tools or procedures must be trustworthy. Trustworthiness is evaluated according to reliability and validity. Concerning the analytical screening, reliable and valid measurement tools and procedures have been developed and are already available. These techniques or protocols include isokinetic and isometric assessments or goniometer and inclinometer range of motion measurements[43, 50, 51, 76-82]. Although considered the gold standard, the isokinetic testing may not be suitable for evaluating and monitoring an athlete's shoulder strength longitudinally during a season[83]. Isometric hand-held dynamometer testing is frequently used in clinical settings as it is valid, cost-effective and portable[83, 84]. However, the assessor's strength variability, the lack of stabilization, inconsistency among testing procedures and the need for a skilled assessor may complicate the continuous screening of the athlete[79, 85].
In spite of its relevance, this analytical screening does not meet the high demands of shoulder loading sports. Therefore, functional screening is complementary to analytical screening and should be part of the monitoring to obtain a more complete picture of the athlete's shoulder. Concerning functional assessment, we can either use self-report questionnaires or perform physical performance tests. However, the disadvantage of questionnaires is that memory, candor, pain, or even mood can affect self-report measures and therefore, may not solely and accurately evaluate the function[86-90]. Thus, to complete the assessment of shoulder function, physical performance tests (PPTs) are of interest. Physical performance tests require an athlete to physically perform a task that is believed to represent the sports demands or involve the entire kinetic chain[91]. These PPTs may evaluate a single construct or a combination of constructs such as strength, power, mobility , agility, endurance or specific physical movements[90] and are attractive because first, they are easy to use in a sports-medicine clinic or on the field and, second, they are affordable[92, 93].
Several upper extremity PPTs have been described and studied in the literature[61, 72, 94, 95], but they are not profuse compared to lower extremity PPTs[94, 95]. Amongst them, The Y Balance Test for Upper Quarter (YBT-UQ), the Posterior Shoulder Endurance Test (PSET), the Closed Kinetic Chain Upper Extremity Stability Test (CKCUEST), and the Seated Medicine Ball Throw (SMBT) seem to be the most popular. The CKCUEST and SMBT were used in this doctoral project due to their popularity and the time required for the testing procedure. We will only briefly

describe the YBT-UQ and PSET (not used in this dissertation), and will describe more extensively the CKCUEST and SMBT.

Y Balance Test for Upper Quarter (YBT-UQ)

The YBT-UQ (figure 1) is a closed kinetic chain test used for assessing upper body mobility and stability[95]. Various studies have used the YBT-UQ according to the protocol described by Gorman et al.[90, 95-103] The test requires a fixed stance platform with three pipes attached to it (Y balance Test kit, Move2perform, Evansville, IN, USA), representing the directions (medial, inferolateral and superolateral) reached during the test. To perform the test, participants adopt a push-up position with the feet shoulder width apart and the tested hand on the stance platform with the thumb behind the red line. The red reach indicator is pushed away as far as possible with the other hand in medial, inferolateral and superolateral directions. The YBT-UQ is reliable (ICC values for test-retest and interrater ranging from 0.80 to 1.00) but its validity remains unclear[95].

Figure 1 Y- Balance Test for Upper Quarter

Posterior Shoulder Endurance Test (PSET)

The PSET (figure 2), elaborated by Moore et al.[72], allows to measure the posterior shoulder muscles' endurance in open chain. The PSET is a dynamic test performed in a prone position with the arm perpendicular to the floor. The participant holds a weight equal to 2% of his body weight while lifting the arm to 90° of horizontal abduction at a shoulder abduction angle of 90° at a cadence of 30 beats per minute. Repetitions are performed until the participant is fatigued.

The test has proven to be reliable (ICC value for test-retest = 0.85) but its validity remains unknown.

Figure 2: Posterior Shoulder Endurance Test

Closed Kinetic Chain Upper Extremity Stability Test (CKCUEST)

The CKCUEST (figure 3), as initially described by Goldbeck and Davies[104], is a closed chain PPT, performed in a push-up position with a flat back parallel to the floor and with the hands 91.4 cm apart, determined by two aligned lines on the floor. For 15 seconds, the participant is instructed to move alternatively one hand to touch the opposite hand's dorsum and then return the hand to the starting position. Three trials are performed with 45-second rest in between. The CKCUEST has been studied or used in various studies[90, 105-117]. Some authors have modified the original procedure by implementing a modified kneeling push-up position for females[105, 106], by modifying hand spacing position[90, 110, 113, 115] or by extending the duration of the test to one minute[61, 108].

Figure 3 Closed Kinetic Chain Upper Extremity Stability Test

The reliability of the CKCUEST has been investigated in asymptomatic sedentary, active and athletic adults[104, 105, 111-113, 115] and on symptomatic adults[105, 112] with moderate to excellent interrater and intrarater results (ICC range = 0.77 – 0.96). The literature is scarce concerning the reliability of the CKCUEST on adolescents with a weak reliability score (ICC = 0.68) reported by Oliveira et al.[106] Regarding the validity of the test, the literature is limited, with only two studies[111, 118] establishing the validity of the CKCUEST in relationship to isokinetic shoulder rotational strength (r range = 0.55 – 0.94) and isometric hand grip strength (r range= 0.78 – 0.79). Two studies[119, 120] have investigated the predictive values of the CKCUEST, with conflicting results. Pontillo et al.[119] found that footballers with a lower score than 18.75 were more likely to sustain a shoulder injury but these findings could not be confirmed on swimmers[120].

Seated Medicine Ball Throw (SMBT)

The SMBT (figure 4) is an open chain PPT, performed with the participant sitting on the ground with his lower extremities extended and his back, shoulders, and head against a wall. The participant is instructed to throw a two-kilogram medicine ball straight ahead and as far as he/she can using a basketball chest pass. Four trials are performed with one-minute rest between throws. It should be pointed out that the SMBT has a variety of names in the literature such as bilateral seated shot put[121], seated chest throws[122], the seated medicine ball toss[123], medicine ball put test[124, 125], seated chest pass[126], chest medicine ball throw[127-130], single arm shot put[131, 132], one arm shot put[133] and unilateral seated shot put[134].

From this variety of names result a variety of procedures and hence a lack of testing standardization. The test has been performed to assess upper body strength and power in many populations such as healthy non athletic adults[125, 131, 132], elderly adults[135], athletes[126, 129, 130, 136, 137], students [122, 124, 133, 134], soldiers[128] and children[123, 127, 138]. Concerning validity, two studies[121, 139] reported fair evidence on the criterion validity of the seated shot-put test in relationship to one repetition maximum bench press. Borms et al.[109] observed moderate to strong correlations with isokinetic rotational shoulder and elbow strength (r range = 0.595 to 0.855).

Figure 4 Seated Medicine Ball Throw

Reference values based on age, gender and sports exist for the CKCUEST, SMBT, and YBT-UQ[140], which may help clinicians and coaches benchmark the athlete's performance. More recently, Olds et al.[61] developed and established the reliability of a shoulder test battery that replicates shoulder demands of athletes engaged in sports, suggesting that the "power" of a test battery to examine functional performance may be higher than using only one test. However, little is known about the capacity of these PPTs to screen for injury, for prognosing performance or determining a return-to-play[141, 142].

3. Aims and outline of the dissertation

In spite of the fact that numerous studies have been published looking at optimal ways to screen the athlete's shoulder for strength and function[75, 76, 94], it seems that still, substantial gaps exist in the current literature.
Firstly, despite the multitude of reliable and valid measurement tools to assess shoulder rotational weakness[50, 76-81, 83, 143], the need for a skilled assessor, the lack of stabilization and/or the assessor's strength variability could be considered as a limitation for a continuous screening of the athlete. Therefore, there is a need for a robust system or tool that allows the athlete to perform a "self-screening" protocol, independently from the presence of a professional assessor, in a standardized manner.
Secondly, current PPTs are not at all times satisfactory because they do not always consider the specific demands found in throwing sports, or do not assess endurance capacity in an overhead position. There is a clear need for new PPTs, specifically focusing more on endurance, and more challenging demanding positions of the shoulder in ABER.
Thirdly, despite reliable and valid results concerning the CKCUEST on adults[104, 105, 111-113, 115, 118], literature on adolescent is scarce[106]. Results on adults should not be generalized to adolescents because of the differences in anthropometric characteristics.
Therefore, there is a need to explore the reliability and validity of existing PPTs in a population of adolescent overhead athletes.

The purpose of this dissertation is to provide new field measurement tools to facilitate the screening and the monitoring of the athlete's shoulder strength and function, not only on adults but also on adolescents. This dissertation addresses the mentioned issues with 3 major parts and related research questions:

PART 1: A self-assessment corner to monitor isometric shoulder strength: Is it reliable and valid? Is there a relationship between existing physical performance tests and the self-assessment corner measurement?

The first objective was to develop and study the reliability and validity of a self-assessment corner for shoulder isometric strength on the one hand, and to study the relationship between the isometric strength using the self-assessment corner and two physical performance tests on the other hand **(chapter 1).**

PART 2: Can we develop new reliable and valid upper extremity physical performance tests?

The second objective was to develop additional PPTs, in view of the existing ones' known limitations, and investigate their correlation to shoulder isometric rotational strength and trunk rotation mobility. **Chapter 2 and chapter 3** include studies regarding the reliability, validity and correlations to shoulder isometric rotational strength and trunk rotation mobility of the 2 new physical performance tests: the "Upper Limb Rotation Test" (**Chapter 2**) and the "Shoulder Endurance Test" (**Chapter 3**).

PART 3: Is the Modified Closed Kinetic Chain Upper Extremity Stability Test reliable and valid when performed by adolescent athletes?

The third objective was to gain more insight into a Modified CKCUEST in adolescent athletes and confirm the relationship to shoulder isometric strength found in an adult population.
In **Chapter 4,** the reliability and validity of the Modified CKCUEST will be explored in this specific population.

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PART 1

A self-assessment corner to monitor isometric shoulder strength: Is it reliable and valid?
Is there a relationship between existing physical performance tests and the self-assessment corner measurement?

Chapter 1

The Self-Assessment Corner for Shoulder Strength: Reliability, Validity, and Correlations With Upper Extremity Physical Performance Tests

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Published in Journal of Athletic Training, 2020
Original article; SCI_{2019} = 2.416; Q2 in Sport Sciences (38/85)

Context*:* Rotator cuff weakness and rotation ratio imbalances are possible risk factors for shoulder injury among overhead athletes. In consensus statements, organizations have highlighted the importance of a screening examination to identify athletes at risk of injury. The screening should be portable and designed to be feasible in many different environments and contexts.

Objective*:* To evaluate the reliability and validity of the Self- Assessment Corner (SAC) for self-assessing shoulder isometric rotational strength and examining whether performance on 2 physical performance tests was correlated with isometric shoulder rotational strength using the SAC in handball players.

Design*:* Cross-sectional study.

Setting*:* Sport setting.

Patients or Other Participants*:* A first sample of 42 participants (18 men, 24 women) was recruited to determine the reliability and validity of the SAC. In a second sample of 34 handball players (18 men, 16 women), we examined correlations between physical performance tests and the SAC.

Intervention(s)*:* The SAC was used to measure isometric rotational strength with the upper extremity at 90° of abduction in the frontal plane and 90° of external rotation and the elbow flexed to 90° with neutral rotation of the forearm.

Main Outcome Measure(s): The SAC findings were compared with those from manual testing. Results from the seated medicine ball throw (SMBT) and closed kinetic chain upper extremity stability test (CKCUEST) were used to establish relationships with the SAC. We calculated intraclass correlation coefficients to determine relative reliability and used standard error of measurement and minimal detectable change to quantify absolute reliability. Relationships among the different strength-testing procedures and with the physical performance tests were determined using the Pearson product moment correlation coefficient (r) or Spearman rank correlation coefficient (r_S).

Results: We observed good to excellent reliability (intra-class correlation coefficient [2,k] range=0.89 to 0.92). The standard error of measurement varied from 3.45 to 3.48 N. The minimal detectable change with 95% confidence intervals ranged from 8.06 to 8.13 N. Strong correlations were present among strength procedures (r= 0.824, r_S range= 0.754–0.816). We observed moderate to strong correlations between the CKCUEST findings and rotational strength (r range= 0.570 – 0.767). Moderate correlations were found between rotational strength and SMBT (r range= 0.573–0.626).

Conclusions: The SAC is a clinically applicable and standardized protocol for self-assessing rotational strength in young healthy adults without pathologic conditions. Performance on the SMBT and CKCUEST may be valuable as a screening tool to further assess shoulder strength.

Key Words: rotator cuff strength, handheld dynamometer, injury prevention.

Key Points

- The Self-Assessment Corner demonstrated good to excellent relative reliability and clinically acceptable absolute reliability for self-assessing rotator isometric strength.
- The seated medicine ball throw and closed kinetic chain upper extremity stability test may be valuable screening tools to further assess functional upper extremity strength during on-field testing of handball players.

According to the current literature, rotator cuff (RC) weakness, particularly external-rotation (ER): internal-rotation (IR) imbalance, is a possible risk factor for shoulder injury and might accentuate the effect of load on the shoulder-injury rate among overhead athletes, such as handball players[1–3]. Many reported shoulder injuries are muscle strains, implying a process over time, with chronic overload leading to injury[4]. Chronic shoulder pain in overhead athletes can be attributed to sport-specific adaptations or alterations in upper extremity strength, flexibility, and functional performance[4]. Consensus statements[5,6] released by health care and sports organizations have highlighted the importance of a screening examination as part of the periodic health evaluation to identify athletes at risk for injury.

Clinical examination, such as RC strength and physical performance tests (PPTs), are part of this screening and must be reliable, sensitive, specific, inexpensive, easy to perform, and widely available[5,7]. Although valid and reliable measurement techniques exist to assess shoulder rotational strength[8–10], some limitations may interfere with season-long evaluation (eg, tester strength variability, lack of stabilization, inconsistency among testing procedures, the need for a skilled assessor, and high costs)[9–11]. For example, whereas isokinetic testing is considered the criterion standard for strength evaluation, its implementation in facilities, such as courts, fitness centers, or gymnasiums, may be compromised because of the extensive equipment required. Therefore, we developed a self-assessment technique, the Self-Assessment Corner (SAC), to simplify evaluation of shoulder ER and IR isometric strength and eliminate the examiner's influence on the procedure and test results. As far as we know, no research has been conducted on the reliability and validity of a self-assessment technique for evaluating RC isometric strength. Therefore, the primary purpose of our study was to evaluate the reliability and validity of the SAC.

Physical performance tests, such as the seated medicine ball throw (SMBT) and the closed kinetic chain upper extremity stability test (CKCUEST), have been developed to assess upper body function and are routinely used on the field for injury prediction, performance assessment, or outcome measures in return-to-play decisions[12–31]. Although the reliability of these tests has been established[23,28,32–35], comparisons of clinical examinations and PPTs are uncommon. To the best of our knowledge, no investigators have examined the relationship between these PPTs and shoulder ER and IR isometric strength using a self-assessment technique. Therefore, the secondary purpose of our study was to examine whether performance on the SMBT and CKCUEST was correlated with the isometric shoulder ER and IR strength of handball players.

METHODS

Study Design

Our research was designed to evaluate the reliability and validity of the SAC using a 2-session measurement design separated by 7 days (sample 1) and determine the relationship between 2 upper extremity field tests (SMBT and CKCUEST) and the isometric strength of the shoulder external and internal rotators using the SAC (sample 2).

Self-Assessment Corner Reliability and Validity. On day 1, we assessed 2 strength measures on the dominant side using the SAC procedure. The *dominant side* was defined as the upper limb participants used to throw a ball. On day 2, the same measurements were performed to evaluate reliability. To investigate the validity of the SAC, 2 manual strength procedures were also conducted for comparison with the SAC. To avoid fatigue due to the length of the protocol, we randomized measures by instructing participants to choose cards to determine which position would be tested first.

Physical Performance Tests and Relationship With the SAC. The testing procedure (SAC or PPTs) was randomized. For practical reasons, the order of the PPTs was always the same: SMBT and then CKCUEST.

Participants

Two samples of healthy adults were recruited. The first sample (sample 1) of 42 healthy adults (24 women: age= 21.10 ± 1.87 years, height=1.66 ± 0.04 m, mass= 61.5 ± 9.3 kg; 18 men: age= 21.6 ± 1.9 years, height=1.76 ± 0.04 m, mass= 73.5 ± 7.8 kg) was recruited from Parnasse-ISEI, Brussels, Belgium, and participated in the study to establish the reliability and validity of the SAC. Volunteers were included if they were between 18 and 30 years old, were in good general health, and participated in overhead sports for less than 3 h/wk.

The second sample (sample 2) of 34 healthy handball players (16 women: age 21.10 ± 2.62 years, height =1.66 ± 0.05 m, mass= 68.40 ± 9.89 kg; 18 men: age=22.30 ± 3.29 years, height= 1.87 ± 0.07 m, mass= 81.70 ± 9.05 kg) was recruited from handball clubs (Don Bosco Gent, Handball Club Evergem, Belgium) to examine the relationship between PPTs and isometric shoulder ER and IR strength in an overhead athlete population. Athletes were included if they played at a competitive level in a club and practiced for a minimum of 3 h/wk.
Separate samples were chosen for each part of the study to avoid any influence of fatigue or familiarization from one testing protocol to the other. The exclusion criteria for both groups were a history of orthopedic surgery of the upper quadrant or spine or pain in these regions within 6 months of the study. All participants provided written informed consent, and the study was approved by the Ethical Committee of the Ghent University and the Université Catholique de Louvain.

Instrumentation

The SAC is composed of 2 main parts. The first part involves an aluminum tube attached with suction cups to a wall, a door, or a window at both ends to ensure the stability of the second part. This second part consists of a custom-made steel receptacle to ensure the stability of the handheld dynamometer (HHD; Figure 1). It can be adjusted to the participant's height by gliding the receptacle up and down. Measurements were performed independently by the participant in a standardized manner without any external fixation or assistance.

Figure 1. The Self-Assessment Corner, A, without and, B, with the handheld dynamometer placed in the receptacle

We used the MicroFET2 handheld dynamometer (HHD; Hoggan Health Industries Inc, West Jordan, UT) to assess isometric strength.

Self-Assessment Corner Procedure

The SAC procedure started with oral instructions from the assessor (P.D.). Participants were barefoot and instructed to stand up straight, with the nondominant hand on the back (L4–L5) and the opposite foot of the tested upper extremity placed forward (Figure 2). The forearm was positioned against the HHD 2 cm proximal to the ulnar styloid process on the dorsal (ER) or ventral (IR) forearm for the strength assessment[36]. We gave specific information about the ER and IR strength tests to be performed: ''After bringing your arm in the correct starting position, we want you to gradually push against the device until you reach maximum strength. Then, you keep your maximal strength for 5 seconds without moving the rest of your body [sic].'' At the end of the instructions, the assessor warned about compensatory movements, such as side bending, tilting, or rotating the trunk. Participants performed 3 submaximal familiarization trials to ensure they understood the procedure, followed by 3 test trials.

Figure 2. The Self-Assessment Corner procedure.

Both ER and IR were assessed with the upper extremity in 90° of abduction in the frontal plane and 90° of ER and the elbow flexed to 90° with neutral rotation of the forearm (90°– 90° position). Three 5-second repetitions of maximal voluntary effort were performed using a make test with 10 seconds of rest between trials. Participants built their force gradually to a maximal voluntary isometric contraction over a 2-second period and maintained the contraction for 5 seconds[36]. The nondominant side was always tested first. The absolute isometric strength data were expressed in newtons.

Manual Strength-Testing Procedures

Participants were assessed in standing (STAND) and sitting (SIT) positions (Figure 3). The ER and IR were tested in the same SAC upper extremity strength position (90°–90°) and following the SAC procedure, but the assessor (P.D.) held the HHD. In the STAND position, the assessor stood behind the participant and used his forearm to gently hold the participant's elbow and arm by placing them underneath his arm. In the SIT position, participants sat on a chair with the trunk straight, the nondominant upper extremity relaxed on the thigh, and the feet placed on the floor; the assessor was positioned as for the STAND test. For all procedures, participants and the assessor were blinded to the results. Study assistants (E.D.B., J.V.D., J.V.) recorded all data.

Figure 3. Manual procedures. A, Standing position. B, Sitting position

Seated Medicine Ball Throw

We placed a 10-m tape on the floor with the end fixed to the wall. A 2-kg medicine ball was covered in magnesium carbonate (gymnastics chalk) to leave a clear print on the floor after each throw so that the throwing distance could be easily determined[34,37,38]. Participants sat on the ground with their lower extremities extended and their back, shoulders, and head against a wall (Figure 4)[23,37]. They held the medicine ball in both hands[25,37] with the upper extremities in 90° of abduction and the elbows flexed. They were instructed to throw the medicine ball straight ahead as far as possible using a basketball chest pass and without losing wall contact with the head, shoulders, and back[23,25,29,35,37]. After 3 practice trials followed by a 2- minute rest, participants performed 4 maximal-effort throws with a 1-minute rest between throws. Correct throwing technique was monitored by the study assistants (E.D.B., J.V.D., J.V.). To allow for different upper extremity lengths, participants were instructed to adopt the test position with their elbows fully extended instead of flexed and to drop the ball straight down onto the tape measure[29]. To calculate the normalized throwing distance, we subtracted the distance between the wall and the most proximal tangent of the medicine ball from the total throwing distance. For further analysis, the mean distance of the 4 test trials was calculated.

Figure 4. Seated medicine ball throw

Closed Kinetic Chain Upper Extremity Stability Test

The CKCUEST was performed following the guidelines described by Tucci et al.[33] Male participants adopted a push-up position, and female participants assumed a modified (kneeling) push-up position. All adopted this position with their backs flat and parallel to the floor.

On the floor, we marked 2 parallel aligned lines 91 cm apart[4] to determine the position of the hands. For 15 seconds, participants moved 1 hand to touch the dorsum of the opposite hand and then returned the hand to the starting position. Subsequently, they performed the same movement with the other hand. Participants were instructed to perform as many alternating touches as possible. We recorded the floor, we marked 2 parallel aligned lines 91 cm apart[4] to determine the position of the hands. For 15 seconds, participants moved 1 hand to touch the dorsum of the opposite hand and then returned the hand to the starting position. Subsequently, they performed the same movement with the other hand. Participants were instructed to perform as many alternating touches as possible. We recorded the number of touches. After receiving instructions and a demonstration, participants performed a 5-repetition familiarization trial. Oral cues were given when necessary. Finally, 3 test trials were performed. Each trial lasted 15 seconds, with a 45-second rest between trials. The CKCUEST provides 3 scores: the number of touches the participant performed in 15 seconds; the normalized score is obtained by dividing the number of touches by body length; and the power score is calculated by multiplying the average number of touches by 68% of the participant's body weight in kilograms, which corresponds to the weight of the upper extremity, head, and trunk divided by 15.

Statistical Analysis

Means and standard deviations (SDs) were calculated across participants for all dependent variables. The SAC ER and IR strength (in newtons), ER:IR ratio, SMBT (in centimeters), and CKCUEST (mean number of touches, normalized score, and power score) were analyzed. We used the Shapiro-Wilk test to evaluate the normality of the distribution within all measurements.

Reliability Analysis (Sample 1). To assess the intra-examiner reliability of the SAC between trials on days 1 and 2 and evaluate the test-retest reliability between days 1 and 2, we calculated intraclass correlation coefficients (ICCs [2,k]). To examine the absolute reliability of the SAC, we calculated the standard error of measurement (SEM) and the minimal detectable change (MDC). The SEM was calculated as

SD x $\sqrt{1 - \mathrm{ICC}}$, where SD was the SD of all scores from participants[17,23]. The SEM was used to calculate the MDC with 95% confidence intervals ($MDC_{95\%}$): SEM x 1.96 x $\sqrt{2}$. Given that the assumptions of the parametric test were not met for strength measurements, we ran a related-samples Wilcoxon signed rank test to determine any systematic strength differences between the SAC measurements on days 1 and 2.

Validity Analysis (Sample 1). We used the Pearson product moment correlation (*r*) or the Spearman rank test (r_S), depending on the distribution of the data (normal or not), to assess the relationships among all strength procedures (SAC, STAND, SIT). The *r* and r_S values were categorized as *weak* (<0.499), *moderate* (0.5–0.707), or *strong* (>0.707)[28].

Systematic differences were also of interest and tested between strength procedures. Given that the assumptions of the parametric test were not met for all strength procedures, a Kruskal-Wallis Test was performed.

Correlation Analysis (Sample 2). To analyze a possible correlation among the strength variables and performance on the SMBT and CKCUEST, we used the Pearson product moment correlation. Based on the correlation coefficients, the coefficient of determination was calculated as R^2. The α level was set at .05. All statistical analyses were performed using SPSS (version 23; IBM Corp, Armonk, NY).

RESULTS

Results are summarized in Tables 1 through 5.

Self-Assessment Corner Reliability and Validity Analysis

The ICC (2,k) reflected excellent intraexaminer reliability between trials on day 1 (range=0.93 [ER] to 0.96 [IR]) and day 2 (0.96 for both ER and IR). The test-retest reliability between days 1 and 2 showed excellent reliability for IR (ICC [2,k]=0.92) and good reliability for ER (ICC [2,k]= 0.89). The SEM varied from 3.45 N (IR) to 3.48 N (ER). The $MDC_{95\%}$ ranged from 8.06 N (IR) to 8.13 N (ER). A related-samples Wilcoxon signed rank test showed no differences between days for all measurements ($P > .05$).

Strong correlations were present among all procedures, ranging from r_S=0.754 (SAC versus STAND for IR) to *r*= 0.824 (SAC versus SIT for ER). The Kruskal-Wallis test results showed no differences among SAC, STAND, and SIT for ER (P = .94) or IR (P = .89).

Correlation Analysis

We observed a strong correlation between the CKCUEST power score and IR strength for the nondominant side (r = 0.767), and the coefficient of determination was 0.588.

Moderate correlations were found between IR strength and SMBT for the dominant (r = 0.618) and nondominant (r = 0.573) sides, ER strength and SMBT for the dominant (r = 0.599) and nondominant (r = 0.626) sides, IR strength and CKCUEST mean touches for the dominant (r = 0.570) and nondominant (r = 0.647) sides, ER strength and CKCUEST mean touches for the nondominant side (r = 0.590), IR strength and CKCUEST power score for the dominant side (r = 0.700), and ER strength and CKCUEST power score for the dominant (r = 0.608) and nondominant (r = 0.664) sides. The ER:IR ratio showed only a low correlation with the SMBT or CKCUEST (r range = −0.093 to 0.193), and none of the CKCUEST normalized scores demonstrated moderate to strong correlations (r range = 0.3 to 0.39) with shoulder-strength variables.

Table 1 Results for Trial-to-Trial Reliability and Test-Retest Repeatability (Sample 1, n=42)

	Trial-to-Trial Reliabilility, ICC (2,k) (95% CI)		Test-Retest Repeatability					
Rotation	Day 1	Day 2	Day1, N (Mean ± SD)	Day 2, N (Mean ± SD)	ICC (2,k) (95% CI)	Standard Error of Measurement, N	Minimal Detectable Change With 95% CIs, N	Wilcoxon Signed Rank Test *P* Value
External	0.93 (0.89, 0.98)	0.96 (0.93, 0.98)	39.20 ± 10.08	38.89 ± 11.04	0.89 (0.79, 0.94)	3.48	8.13	.32
Internal	0.96 (0.93, 0.98)	0.96 (0.93, 0.98)	40.36 ± 12.53	40.54 ± 11.42	0.92 (0.84, 0.95)	3.45	8.06	.86

[a] The 95% CI for intertrial values using the Self-Assessment Corner

[b] The 95% CI, standard error of measurement, and minimal detectable change with 95% CIs for mean values using the Self-Assessment Corner between days 1 and 2

Table 2 Descriptive Analysis (Mean ±SD) for the Self-Assessment Corner, Seated Medicine Ball Throw, and Closed Kinetic Chain Upper Extremity Stability Test (Sample 2, n=34)

	Men		Women	
Variable	Dominant Extremity	Nondominant Extremity	Dominant Extremity	Nondominant Extremity
Strength				
External-rotation absolute value, N	74.4 ± 17.5	68.2 ± 13.5	53.9 ± 14.3	45.8 ± 16.6
Internal-rotation absolute value, N	90.8 ± 17.8	79.4 ± 15.5	64.1 ± 14.7	55.3 ± 17.3
ER : IR	0.8 ± 0.1	0.9 ± 0.1	0.8 ± 0.1	0.8 ± 0.2
Seated medicine ball throw, cm	303.6 ± 42.5		233.8 ± 28.7	
Closed kinetic chain upper extremity stability test				
Normalized score	14.9 ± 1.30		15.2 ± 2.9	
Power score	103.1 ± 15.0		79.3 ± 23.1	
Mean touches	27.8 ± 2.4		25.2 ± 4.5	

Table 3 Correlation Coefficients and Comparative Analysis of Similar Measurements After Different Procedures (Sample 1, N=42)

Self-Assessment Corner	Pairwise Correlation	Kruskal-Wallis Test Result	*P* Value
External rotation	Self-Assessment Corner X standing procedure	0.776[a]	.94
	Self-Assessment Corner X sitting procedure	0.824[b]	
	Standing procedure X sitting procedure	0.798[a]	
Internal rotation	Self-Assessment Corner X standing procedure	0.754[a]	.89
	Self-Assessment Corner X sitting procedure	0.798[a]	
	Standing procedure X sitting procedure	0.816[a]	

[a] Spearman rank test (r_s).
[b] Pearson product moment correlation coefficient (r)

DISCUSSION

The primary purpose of our study was to demonstrate the reliability and validity of a novel technique, the SAC, to self-assess ER and IR isometric strength. This technique was developed to eliminate the influence of examiner strength considering the limitations of the HHD and to simplify the strength assessments with a standardized, easy to-use procedure to facilitate implementation in a sporting area. The second objective of our study was to examine relationships between the SAC and 2 functional shoulder tests (SMBT and CKCUEST). We established good to excellent reliability for evaluating isometric strength using the SAC and its validity to assess RC isometric strength. Moderate to strong correlations were also observed between the SAC and the functional tests.

Self-Assessment Corner Strength Assessment

To the best of our knowledge, no other authors have focused on an isometric strength self-assessment in a 90°- 90° shoulder position in the STAND position. Therefore, direct comparisons with related reports in the literature are difficult. In contrast, the reliability of manual isometric strength testing in various populations and shoulder positions with or without an external-stabilization device has been reported in the literature[39], demonstrating similar relative ICC values to those in our study, ranging from 0.86 (ER 90°– 90°) to 0.92 (IR 90°– 90°) in a seated position. Cools et al[36] described relative ICCs between 0.93 and 0.99 while seated, supine, or prone and with the shoulder in various positions. In these studies, no external mechanical support was used. Kolber et al[9] used an external stabilization device held by an examiner and reported excellent relative reliability for ER and IR (ICC = 0.97).

The SEM and MDC provide the extent of measurement error and are clinically useful for determining if the strength changes are real or within measurement error. Depending on the particular shoulder isometric strength assessment, SEM varied from 3.45 N (IR) to 3.48 N (ER), and the $MDC_{95\%}$ ranged from 8.06 N (IR) to 8.13 N (ER), indicating that a change from 8.06 to 8.13 N was required to be 95% certain that this change was not due to intratester variability of measurement error. In comparison, Cools et al[36] showed $MDC_{90\%}$ values ranging from 7.87 to 26.6 N, depending on shoulder or patient positions; these values were slightly larger than ours. We may conclude that our absolute reliability results were similar to the results of other recommended clinical isometric strength assessments.

We compared the SAC results with manual muscle-testing procedures (STAND, SIT) to validate our protocol. No differences were present among the SAC, STAND, and SIT for ER (P=.94) and IR (P=.89) testing. These results highlight the fact that strength assessment in a functional position with the SAC does not differ from manual testing with an examiner. The principle of external fixation of an HHD is not new and has been implemented by others[9]. Indeed, Kolber et al[9] used a stabilization device, but they maintained the trunk in fixed position with a stabilization belt and placed the upper extremity at 30° with the help of an arm apparatus. These additional procedures and the presence of a skilled assessor may complicate implementation in sporting areas compared with the functional position used for the SAC. Therefore, the SAC might be an alternative and easier way for coaches or players to evaluate isometric strength during the season in the sporting area.

Table 4 Correlation Coefficients and Coefficient of Determination Between the Seated Medicine Ball Throw and the Dominant and Nondominant Shoulder Isometric External and Internal Rotation Strength (Sample 2, n=34)

Variable	Pearson Product Moment Correlation Coefficient (*r*)		Coefficient of Determination (R^2)		*P* Value	
	Dominant Extremity	Nondominant Extremity	Dominant Extremity	Nondominant Extremity	Dominant Extremity	Nondominant Extremity
External-rotation absolute strength	0.599	0.626	0.359	0.392	<.001[a]	<.001[a]
Internal-rotation absolute strength	0.618	0.573	0.382	0.328	<.001[a]	<.001[a]
External rotation : internal rotation	0.039	0.193	0.001	0.04	.83	.28

[a] indicates correlation ($P < .05$).

Table 5 Pearson Product Moment Correlation Coefficients and Coefficient of Determination Between the Closed Kinetic Chain Upper Extremity Stability Test (Mean Touches and Power Scores) and Dominant and Nondominant Shoulder Isometric External and Internal Rotation Strength

	Correlation Coefficient (*r*)				Coefficient of Determination (R^2)				*P* Value			
	Mean Touches		Power Score		Mean Touches		Power Score		Mean Touches		Power Score	
Variable	Dominant Extremity	Nondominant Extremity	Dominant Extremity	Nondominant Extremity	Dominant Extremity	Nondominant Extremity	Dominant Extremity	Nondominant Extremity	Dominant Extremity	Nondominant Extremity	Dominant Extremity	Nondominant Extremity
External-rotation strength	0.499	0.590	0.608	0.664	0.348	0.297	0.370	0.441	<.001[a]	<.001[a]	<.001[a]	<.001[a]
Internal-rotation strength	0.570	0.647	0.700	0.767	0.325	0.418	0.490	0.588	<.001[a]	<.001[a]	<.001[a]	<.001[a]
ER : IR	-0.092	0.045	-0.093	-0.043	0.008	0.002	0.008	0.002	.61	.80	.60	.81

[a] indicate correlation (P < .05).

Correlation Analysis

For the SMBT, we observed a moderate correlation with shoulder isometric ER and IR strength, which indicated that a greater throwing distance on the SMBT was correlated with stronger shoulder muscles. Our results are in line with those of Borms et al[37], who examined the relationship between functional shoulder performance tests and isokinetic strength measurements in overhead athletes. In their study, the SMBT results were moderately to strongly correlated with isokinetic ER and IR shoulder strength (r range = 0.595 – 0.803).

For the CKCUEST, a strong correlation between the CKCUEST power score and IR strength for the nondominant side was demonstrated. Moderate correlations were found between the CKCUEST mean touches and IR and ER strength and between the CKCUEST power score and ER and IR strength. To the best of our knowledge, only Sciascia and Uhl[18] have examined the reliability of strength and performance testing measures and their relationships. However, they tested strength by elevation only in the scapular plane. To our knowledge, no other researchers have investigated the relationship between the CKCUEST results and shoulder isometric ER and IR strength in 90° of abduction and ER.

Lee and Kim[32] examined the relationship between the CKCUEST and shoulder isokinetic ER and IR strength. They noted a high correlation between the CKCUEST results and isokinetic ER and IR strength (r range = 0.87 – 0.94).

Clinical Implications

The SAC method was developed to simplify strength assessments with an easy-to-use procedure applicable in most settings. Strength can be reliably measured without bias in such areas as tester strength, lack of stabilization, and inconsistency between testing procedures, and no external fixation or skilled assessors are needed. This method is advantageous whenever the amount of time spent and the testing of many athletes are important concerns. Therefore, the SAC could be suitable for evaluating and monitoring player RC strength longitudinally during a season. We also demonstrated that performances on the SMBT and CKCUEST were moderately to strongly correlated with isometric tests for strength of shoulder ER and IR in a population of handball players. These results may aid athletic trainers and physical therapists in evaluating upper extremity performance in a field setting.

Limitations

Despite the SAC's being an easy-to-use, field-setting method, our study had limitations. All of the measurement techniques and procedures were performed using field-measurement tools. Although we tried to standardize the procedure and avoid compensation, we did not use additional external fixation for reasons of clinical relevance. External fixation makes the procedure more time consuming and the device less attractive for the clinician. However, the clinician's ability to consistently and accurately place participants in a 90°–90° position was a limitation. The STAND position is functional and easy to use. However, this position might have influenced our results due to compensation from the lower extremities. Testing asymptomatic participants was also a limitation. Interpretation of our results is restricted to reporting reliability and validity of the SAC in a sample of healthy participants. Our protocol was based on previous studies[9,36,39,40], but fatigue may have strongly influenced our results. Future researchers should focus on continuing data collection to enhance the depth of the findings in view of our rather small sample and exploring the use of the SAC in different sports and patient populations.

CONCLUSIONS

The first purpose of this study was to establish the relative and absolute reliability, as well as the validity, of a novel way to self-assess rotator isometric strength. Relative reliability was good to excellent and absolute reliability was clinically acceptable. The second objective was to examine correlations between the SAC and 2 functional shoulder tests. The results suggested that the CKCUEST and SMBT may be valuable as screening tools to further assess functional upper extremity strength during on-field testing of handball players.

ACKNOWLEDGMENTS

This study was presented in part at the International Olympic Committee World Conference on Prevention of Injury & Illness in Sport, March 16–18, 2017, Grimaldi Forum, Monaco.

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PART 2

Can we develop new reliable and valid upper extremity physical performance tests?

Chapter 2

The "upper limb rotation test": Reliability and validity study of a new upper extremity physical performance test.

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Published in Physical Therapy in Sport, 2020
Original article; SCI_{2019}= 1.926; Q2 in Rehabilitation (22/68)

ABSTRACT

Objectives: The primary purpose was to evaluate the reliability of the Upper Limb Rotation Test (ULRT). The secondary objective was to evaluate the relationship between the ULRT and to PPTs (SMBT and CKCUEST), trunk rotation range and motion (SRT) and shoulder rotational isometric strength.

Design: Reliability study and correlation study

Setting: Laboratory

Participants: 91 healthy adults participated to establish the reliability and validity of the ULRT.

Main outcome measures: We used a two-session measurement design to evaluate the reliability of the ULRT. The SMBT, CKCUEST, SAC and the SRT were performed to determine relationships with the ULRT.

Results: Results showed good reliability. The SEM_{95} and the MDC_{95} showed clinically acceptable absolute reliability values for the ULRT. A moderate correlation was found between the ULRT and CKCUEST scores. A moderate correlation was found between ULRT and SMBT scores.

Conclusions: Results demonstrated good relative reliability and clinically acceptable absolute reliability values for the ULRT. Performances on the ULRT were moderately correlated with the PPTs

INTRODUCTION

Several risk factors for throwing-related shoulder injuries such as Glenohumeral Internal Rotation Deficit (GIRD), loss of total range of motion, scapular dyskinesia or external/internal rotation strength ratio imbalances are described in the literature[1-7]. Techniques and protocols to evaluate these deficits are already available[8-10]. However, the rate of shoulder injuries in overhead throwing athletes still remains particularly high[2,11] in spite of the use of these screening procedures suggesting that improvement strategies to screen athletes at risk are required. From this perspective, physical performance tests (PPTs) have been developed to provide a more complete picture of the functional status of the athlete's upper extremity. These PPTs are routinely used for injury prediction[12], performance enhancement or post-rehabilitation outcome measures.[1, 13-15] Furthermore, PPTs are, most of the time, easily performed in many different environments and contexts with minimal material[16] and are thus,

very attractive. However, in comparison to PPTs for the lower extremity, upper extremity PPTs are not profuse[17]. Some PPTs have been developed to evaluate upper extremity function in a closed kinetic chain (CKC) such as the Closed Kinetic Chain Upper Extremity Stability Test (CKCUEST). The functionality of this test lays in the involvement of the entire kinetic chain in test performance. For open kinetic chain (OKC) evaluation, the seated medicine ball throw (SMBT) is often used to assess bilateral upper body strength or power in overhead athletes[18, 19]. However, this test is performed with the arms at shoulder height. One common limitation of many upper extremity PPTs currently available is that they do not fully take into account the specific requirements of overhead throwing, including a combination of OKC, CKC and a trunk rotation as well as 90°/90° shoulder position[5]. In order to comply with this need, we have elaborated a new test, the Upper Limb Rotation Test (ULRT), which promotes weight bearing, requires shoulder motor control and stability, involves the entire kinetic chain and places the shoulder in a more complex position of 90° abduction and 90° external rotation.
Therefore, the primary purpose of our study was to determine the relative and absolute reliability of the ULRT in a population of healthy adults, and report preliminary reference data for that population. The secondary objective was to examine the correlations of this test with two widely used PPTs, the CKCUEST and SMBT, and two clinical measurements, shoulder isometric rotational strength using the Self-Assessment Corner (SAC)[20] and trunk rotational range of motion (SRT).

METHODS

Participants

A sample of 91 healthy adults (45 females; age = 21.5 ± 2.27 years old, height = 1.67 ± 0.06 meters, weight = 60.1 ± 9.41 kilograms and 46 males; age = 21.07 ± 2.29 years old, height = 1.78 ± 0.06 meters, weight = 72.4 ± 12.61 kilograms) participated in the study to establish the reliability and validity of the Upper Limb Rotation Test. Volunteers were included if they were aged between 18 to 30 years old, were in good general health, and participated in overhead sports for less than 3 hours per week. The exclusion criteria were a history of orthopaedic surgery of the upper quadrant or spine or reports of pain in these regions within a 6-month period before the study and overhead sports participation more than 3 hours per week. All participants provided written informed consent, and the study was approved by the Ethical Committee of the Université Catholique de Louvain 2018/12SEP/341- B403201837497.

Study design

This research was designed (1) to evaluate the reliability of the ULRT using a two-session measurement design separated by seven days and (2) to determine the relationship between the ULRT and two previously published upper extremity PPTs: the Seated Medicine Ball Throw and the Closed Kinetic Chain Upper Extremity Stability Test, and commonly used clinical measurements: shoulder external and internal rotators isometric strength using the Self-Assessment Corner, and the trunk rotation range of motion -Seated Trunk Rotation Test.

Procedure

The participants attended two assessment sessions conducted by the same investigators (two fourth-year physical therapy students were the primary investigators under the direct supervision of a physical therapist with over 10 years of clinical experience). In order to evaluate test-retest reliability, the ULRT was performed on two sessions (day 1 and day 2), separated by seven days. In addition to the ULRT, we performed the SRT and CKCUEST on day 1 and the SMBT and the shoulder isometric rotational strength using the SAC on day 2. We decided to space out the tests between day 1 and day 2 to avoid fatigue as a result of the length of the protocol. For all procedures, participants were blinded to the results.

ULRT procedure

Participants started in a modified (on elbows) push-up position, back flat parallel to the floor, elbows flexed at 90° and feet apart at shoulder width and arms positioned perpendicular to the floor (Fig.1). Forearms and fists rested on the floor. Participants were positioned next to a wall in order to allow the shoulder, the elbow epicondyle, the greater trochanter and the lateral malleolus of the ankle to touch the wall. Participants were asked to perform a trunk rotation, coupled with an external rotation of the shoulder in a 90°-90° position (90° abduction, 90° external rotation) touching the tape placed vertically on the wall as quickly as possible for 15 seconds. They had to touch the marker fixed on the wall with the elbow before returning to the starting position. We placed the tape to ensure that participants would touch the wall in a 90°-90° shoulder position when rotating with the non-weight-bearing arm. After getting the instructions and a demonstration, participants performed a familiarization trial consisting in 3 repetitions for each side. Verbal cues were given when necessary. Finally, three 15-second test trials were performed, with 45 seconds rest between each trial. We opted for a 1:3 work-rest ratio because it is optimal recovery time following a short-duration and high-intensity test[21].

For practical reasons, participants started with their right shoulder against the wall. The number of repetitions was recorded. We consider the tested arm is the one that maintains the CKC position. The test was considered fully completed if the subject kept his or her back flat, the arm in a 90°-90° position, knees did not touch the floor and his or her feet remained in the initial position. The Borg Scale was used to assess participant exertion. In order to minimize the effect of fatigue on the results, we decided to use a Borg rating of perceived exertion scale to assess participant's subjective experiences of fatigue after 45 seconds[22]. This scale is a valid measure of local upper extremity exertion[23].

A B

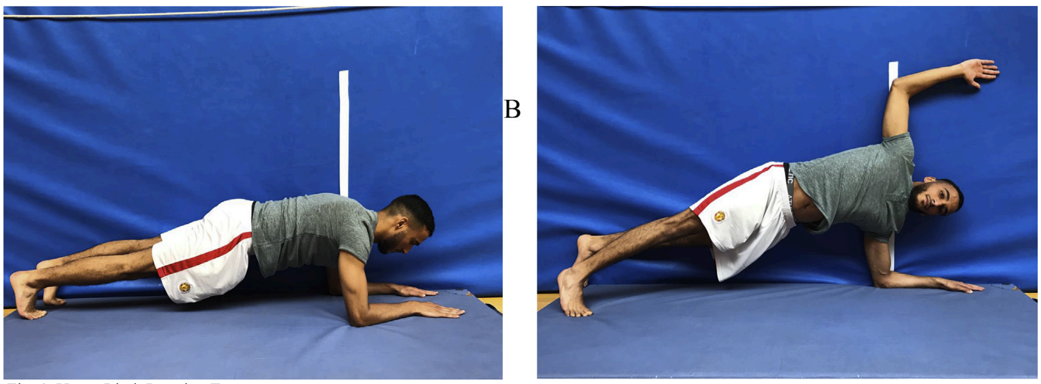

Fig. 1. Upper Limb Rotation Test.
A. Starting position.
B. Final position.

We considered the participants to be fatigued when they reported an exertion level exceeding 14 of 20[24]. A rating of 15 on the rating of perceived exertion scale corresponds with ''hard/heavy work or strain and fatigue on muscles''[22]. An extra 45- second rest was allowed if the score was 14 or higher.

SAC procedure

The procedure was performed following the guidelines as described by Declève et al[20]. We started with verbal instructions from the investigators. Participants were instructed to stand up straight, barefoot, with the non-tested hand on the back (L4L5) 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 (ER) or ventral forearm (IR) for strength assessment. We gave specific information about the external and internal rotation strength tests to perform: "After bringing your arm in the correct starting position we want you to gradually push against the device until you reach maximum strength. Then, you keep your maximal strength for 5 seconds without moving the rest of your body". To end the instructions, the assessor warned the participants against compensatory movements such as side bending, tilt or rotation of the trunk. After the instructions, three familiarization trials were performed submaximally in order to control the participant's understanding of the procedure, followed by three testing trials. Both ER and IR were assessed in a 90°90° position (90° of abduction in the frontal plane, 90° of ER and 90° of elbow flexion with neutral rotation of the forearm). Three repetitions of 5 seconds of maximal voluntary effort were performed using a «make» test with 10 seconds of rest between trials. Participants had to build their force gradually to a maximum voluntary contraction over a 2-second period and had to keep the maximal voluntary contraction for 5 seconds[10]. The non-dominant side was always tested first. The absolute isometric strength data were expressed in Newton (N). The SAC procedure was found to be reliable and valid compared to manual HHD testing procedure[20].

Seated Medicine Ball Throw (SMBT)

The participants were sitting on the ground with their lower limbs extended and their backs, shoulders, and heads against the wall[18, 19]. A 2-kilogram medicine ball was held in both hands[19] with the upper limbs at 90° of abduction and elbows flexed.

In this position, they were instructed to throw the medicine ball straight ahead as far as possible using a basketball chest pass and without losing contact with the wall with their heads, shoulders and backs[18, 19]. After 3 practice trials followed by a 2-minute rest, the participants performed 4 maximal effort throws with a 1-minute rest between throws. Correct throwing technique was monitored by the researcher. A 10-meter tape was placed on the floor with the end fixed to the wall. The medicine ball was covered in magnesium carbonate (gymnastics chalk) to leave a clear print on the floor after each throw so that the throwing distance could be easily determined[19]. To allow for different upper limb lengths, participants were instructed to adopt the test position with their elbows fully extended (instead of flexed) and to drop the ball straight down onto the tape measure. To calculate the normalized throwing distance, the distance between the wall and the most proximal tangent of the medicine ball was subtracted from the total throwing distance. For further analysis the mean distance of the four test trials was calculated.

Closed Kinetic Chain Upper Extremity Stability Test (CKCUEST)

The test was performed following the guidelines as described by Tucci et al.[14] Participants adopted a push-up position with a flat back parallel to the floor. However, in order to avoid the influence of the anthropometric characteristics of individuals[25], we used the inter acromial distance of each participant instead of the standardized between hands distance of 91.4 cm. Two parallel and aligned lines with the inter acromial distance of individuals in between were marked on the floor to determine the position of the hands. For 15 seconds, participants were instructed to move one hand to touch the dorsum of the opposite hand and then return the hand to the starting position. Subsequently, the same movement was performed by the other hand. Participants were instructed to perform as many alternating touches as possible. The number of touches was recorded. After instructions and demonstration, a familiarization trial was performed, consisting of 5 repetitions. Verbal cues were given during familiarization when necessary. Finally, three test trials were performed. Every trial lasted 15 seconds with 45 seconds rest in between. The CKCUEST provided three scores. The number of touches represents the number of touches that the participant was able to perform in 15 seconds. The normalized score is obtained by dividing the number of touches by the body length. Finally, the power score is calculated by multiplying the average number of touches by 68% of the participant's body weight in kilograms, which corresponds to the weight of the arms, head and trunk, divided by 15.

The Seated Trunk Rotation Test (SRT)

Participants sat upright on a chair with knees and feet together and arms across the chest[26]. Participants held a stick horizontally at the sternum just below the clavicles. We used the EasyAngle©(Gymna; reference: Meloq AB, Sweden), a digital goniometer with a display attached in the middle of a hard plastic ruler and provided with a position sensor, always aware of its position in space. The EasyAngle© was attached to the stick and provided data expressed in degrees (°). The procedure started with 3 trunk rotations to the right followed by 3 trunk rotations to the left. Participants had to rotate as far as possible to the end of their range of motion and to keep the position until the examiner recorded the measurement, before returning to the starting position. Trunk rotation was accepted if knees and feet remained together, ischium did not take off from the chair and the head followed the movement. For further analysis, the mean results of the 3 test trials were calculated.

Statistical Analysis

Means and standard deviations were calculated across participants for all dependent variables. The ULRT (mean number of touches), SAC ER and IR strength (N), ratio ER/IR, SMBT (cm), and CKCUEST (mean number of touches, normalized score and power score), SRT (mean degrees) were analyzed. The Kolmogorov-Smirnov test was first used to evaluate the normality of the distribution within all measurements.

Reliability analysis

To assess the intra-session reliability of the ULRT between trials on day 1 and day 2 and to evaluate the test-retest reliability between day 1 and day 2, intraclass correlation coefficients (ICC_{2k}) were calculated. The ICC values ranges from 0 to 1: 1= perfect reliability: 0.90-0.99 = very high reliability: 0.70-0.89 = high reliability: 0.50-0.69 = moderate reliability: 0.26-0.49 = low reliability and 0.00-0.25 little, if any, reliability[27]. In order to examine the absolute reliability of the ULRT, the standard error of measurement (SEM) and the minimal detectable change (MDC) were calculated. The SEM was calculated as SD x $\sqrt{1-ICC}$, where SD is the SD of all scores of participants[28]. The SEM was used for calculating the MDC_{95}, which was calculated as SEM x 1.96 x $\sqrt{2}$[28]. To check for systematic differences between day 1 and day 2, a paired-t-test was performed.

Correlation analysis between PPTs, SAC and SRT.

The Pearson correlation coefficient (*r*) parametric test was used to assess the possible relationship between ULRT and performances on PPTs (CKCUEST, SMBT), strength (SAC) and range of motion (SRT) procedures. The *r* values were categorized as weak (<0.499), moderate (0.5-0.707), or strong (>0.707)[29]. Based on the correlation coefficients, the determination coefficient was calculated as R^2. The alpha level was set at .05. All statistical analyses were performed using IBM SPSS 23 software (IBM Corp, Armonk, NY, USA).

RESULTS

Descriptive analysis for ULRT, SMBT, CKCUEST, SAC and SRT results are summarized in table 1. Reliability and correlation analysis are summarized in tables 2-3.

ULRT reliability

The ICC (2,k) reflected very high reliability for intra-session reliability between trials with values within day 1 and day 2, ranging for day 1 from 0.93 on the dominant arm (DA) to 0.96 on the non-dominant arm (NDA). For day 2, the ICCs (2k) were 0.97. The Test Retest reliability between day 1 and day 2 showed high reliability ranging from 0.76 (DA) to 0.78 (NDA). The SEM_{95} varied from 1.14 touches (DA) to 1.18 touches (NDA). The MDC_{95} ranged from 3.15 touches (NDA) to 3.27 touches (DA) (Table 1).

Correlation analysis between ULRT and CKCUEST, SMBT, SAC and SRT

A moderate correlation was found between the ULRT and CKCUEST mean touches ($r = 0.553$ for DA; $r = 0.615$ for NDA) and the determination coefficient was 0.306 and 0.378 respectively. Moderate correlations were found between ULRT and CKCUEST normalized score ($r = 0.505$ for DA; $r = 0.566$ for NDA) and CKCUEST power score ($r = 0.512$ for DA; $r = 0.589$ for NDA). A moderate correlation was found between ULRT (NDA) and SMBT mean score ($r = 0.556$) and SMBT normalized score ($r = 0.544$). The ULRT showed only low correlation with SAC (*r* range =0.303 – 0.455) and SRT (*r* range =- 0.017-0.178) (Table 2).

Table 1 Descriptive analysis (mean and SD) for SAC results, SMBT, CKCUEST and SRT scores for global, male and female participants (n=91)

	Global (n=91)		Male (n=46)		Female (n=45)	
	DA	NDA	DA	NDA	DA	NDA
	Mean ± SD		Mean ± SD		Mean ± SD	
Strength IR (N)	35.36 ± 11.51	34.89 ± 11.96	41.26 ± 11.50	40.13 ± 13.10	29.33 ± 7.87	29.54 ± 7.73
Strength ER (N)	34.43 ± 11.49	33.04 ± 12.16	39.82 ± 12.55	38.93 ± 13.16	28.91 ± 6.91	27.01 ± 7.19
SMBT (cm) (normalized)	232.77 ± 48.58		269.82 ± 36.92		198.89 ± 23.02	
CKCUEST normalized score	17.60 ± 3.78		18.46 ± 4.47		16.72 ± 2.71	
CKCUEST power score	1379.02 ± 428.75		1602.02 ± 404.40		1151.10 ± 321.90	
CKCUEST mean touches	30.44 ± 6.86		32.8 ± 7.72		27.9 ± 4.78	
SRT (°) (left)	59.81 ± 8.85		59.32 ± 7.95		60.31 ± 9.75	
SRT (°) (right)	62.08 ± 9.78		61 ± 9.56		63.20 ± 9.98	

DA, Dominant arm; NDA, non dominant arm; IR, internal rotation; Er, external rotation; N, Newton; cm, centimeter; SD, standard deviation; °, degree.

Table 2 Results for Trial to Trial Reliability And Test Retest Repeatability (ICC2k) with their 95% CI, SEM, MDC95% for mean values (number of touches) using the ULRT between day 1 and day 2 (n= 91)

	Trial to Trial Reliability within Day 1 and Day 2		Test Retest Repeatability Between Day 1 and Day 2					
	Day 1	Day 2	Mean D1 ± SD	Mean D2 ± SD	ICC (CI)	SEM	MDC	Paired T-Test
ULRT DA	0.93 (0.86-0.96)	0.97 (0.95-0.98)	10.1 ± 2.12	11.9 ± 2.38	0.76 (-.066-0.91)	1.18	3.27	<0.001
ULRT NDA	0.96 (0.94-0.98)	0.97 (0.96-0.98)	10.4 ± 2.24	12.1 ± 2.40	0.78 (0.54-0.92)	1.14	3.15	<0.001

ICC, Intraclass Correlation Coefficient; CI, Confidence Interval; SD, Standard Deviation; SEM, Standard Error Measurement; MDC, Minimal Detectable Change; ULTR, Upper Limb Rotation Test; DA, Dominant Arm; NDA, Nondominant Arm.

Table 3 Correlation Coefficients between the ULRT, the CKCUEST, the SMBT normalized score, the SAC (internal and external rotations) and SRT (N=91)

	Correlation Coefficient (*r*)									
	CKCUEST mean touches	CKCUEST normalized	CKCUEST power score	SMBT normalized score	SAC-IR		SAC-ER		SRT	
					DA	NDA	DA	NDA	Left	Right
ULRT DA	.553°	.505°	.512°	.456°	.424°	.346°	.303°	.312°	.099	.178
ULRT NDA	.615°	.566°	.589°	.544°	.455°	.408°	.391°	.393°	-.017	.040

DA, dominant arm; NDA, non dominant arm; IR: internal rotation; ER: external rotation. ° indicates correlation (P < .05); ° indicates correlations at the 0.01 level.

DISCUSSION

The primary purpose of this study was to demonstrate the reliability of a new physical performance test, the ULRT. This test was developed to propose to clinicians a new closed chain upper extremity functional test. The second objective of this study was to examine correlations between the ULRT and two widely used closed and open-chain upper extremity PPTs, the CKCUEST and SMBT, and two clinical measurements, the shoulder rotational isometric strength using the SAC and the SRT. This study established very high reliability for intra-session reliability between trials within day 1 and day 2 and high reliability for test-retest reliability. Moderate correlations were found between the ULRT and the CKCUEST and the SMBT (NDA).

Relative and absolute reliability.

Our study provided appropriate levels of intra-session and test-retest reliability with intra-session ICC values varying from 0.93 to 0.97 and test-retest ICC values ranging from 0.76 to 0.78. Our results regarding intra-session and test-retest reliabilities are in accordance with reliability studies[14, 30] on another widely used closed-chain PPT, the CKCUEST.

In comparison, studies which have evaluated the intra-session and test-retest reliability of the CKCUEST have shown values varying from moderate to very high reliability[14, 21, 30], Intra-session ICC values ranged between 0.86 to 0.97 depending on the population[14] whilst test-retest ICC values varied between 0.68 to 0.96[14, 21, 30].The SEM indicates the limit for the smallest change that explains a real modification or change in the number of touches in groups of subjects, while the MDC should be used for single subjects[31]. Our results showed SEM varying from 1.14 (NDA) to 1.18 (DA) and MDC_{95} ranging from 3.15 (NDA) to 3.27 (DA) indicating that a change from 3.15 to 3.27 is required to be 95% certain this change is not due to intra tester variability of measurement error. In comparison to other studies on the CKCUEST, Tucci et al[14] showed SEM values ranging from 1.45 to 2.76 touches and MDC varying from 2.05 to 3.91 in subjects with and without shoulder impingement syndrome. De Oliveira et al[30] found SEM and MDC values of 2.17 and 6.01 respectively in an adolescent population. The question of the acceptable level of reliability using SEM or MDC is unanswered in the literature. However, the reliability of the ULRT is similar to the reliability of other upper extremity PPTs, which are recommended for the examination and the follow-up of overhead throwing patients[32].

Correlations between ULRT and CKCUEST, SMBT, SAC and SRT.

The second purpose of our study was to determine relationships between the ULRT and two widely used closed and open-chain upper extremity PPTs, the CKCUEST and SMBT, and with two clinical measurements, the shoulder rotational isometric strength using the SAC and the SRT. We observed a moderate correlation between the ULRT and CKCUEST scores (*r* range= 0.505- 0.589) and SMBT scores (*r* range= 0.544 - 0.556 on NDA) and coefficients of determination showed that CKCUEST can account for 30.6% to 37.8% of the variance in the ULRT performance. We found low correlation with SAC (*r* range = 0.303 – 0.455) and SRT (*r* range =- 0.017-0.178).

The results of the correlation analysis between PPTs can be discussed in relation to the characteristics of test performance and more specifically, the kinetic chain involvement and shoulder position at which the test is performed. The CKCUEST is performed in a closed chain and the SMBT is executed in an open chain. Like the CKCUEST, the ULRT is performed in a closed chain. But the ULRT starts with shoulders placed in a 90° shoulder forward flexion and ends in a 90°90° shoulder abduction while the CKCUEST is performed with both shoulders perpendicular to the hands apart from the inter acromial distance. The differences in task characteristics may explain the moderate correlation between the ULRT and the CKCUEST and SMBT. Since the ULRT is not strongly related to the CKCUEST and SMBT, we suggest implementing all three tests when screening for shoulder function.

Clinical measurements such as shoulder isometric rotational strength and trunk rotational range of motion are widely used on the field and provide important data for shoulder rehabilitation and prevention. We found low correlation between the ULRT and both shoulder isometric rotational strength and SRT. These observations could be explained by the test characteristics because the ULRT is performed in a closed kinetic chain and isometric strength assessment is performed in the open kinetic chain. Regarding the trunk mobility, it could also be explained by not challenging enough the trunk range of motion. In a previous study[20], we found moderate to strong correlation (*r* range= 0.570-0.767) between the isometric rotational strength and CKCUEST. The results of this present study highlight the fact that performance on the ULRT does not depend solely on isometric rotational strength and trunk rotational range of motion.

LIMITATIONS AND FUTURE DIRECTION

Some limitations of our study need to be considered. All measurement techniques and procedures performed in this study used field measurement tools for reasons of clinical relevance. The clinician's ability to consistently and accurately place the subject in a 90/90 position needs to be acknowledged as a limitation. In addition, participation of a narrow age range asymptomatic individuals also needs to be acknowledged as a limitation. The increase in the ULRT mean score between days might be attributed to the learning effect. The Interpretation of our results is limited to reporting the reliability and relationships of the ULRT in a sample of healthy subjects. Like in many other studies, our study is limited to one test and does not evaluate all the different characteristics of a performance task. Future research should evaluate the effect of test duration on the ULRT results. Moreover, considering the poor correlation to shoulder isometric strength, a weight relative to the participant's body mass might be added to the wall reach arm to increase muscle demand during the test. The future lies in the development of a shoulder test battery. A first attempt was proposed by Olds et al.[32], but they only reported the reliability of the tests that were part of the test battery and not the relationships between the tests or the shoulder strength.

CONCLUSIONS

The first purpose of this study was to establish the relative and absolute reliability of a new physical performance test, the ULRT. Results demonstrate very high reliability for intra-session reliability and high reliability for test-retest reliability as well as clinically acceptable absolute reliability values.

The second objective was to examine correlations between the ULRT and two widely used PPTs, the CKCUEST and SMBT and two clinical measurements, shoulder isometric rotational strength and trunk rotational range of motion. Results suggest that the ULRT is moderately correlated with the CKCUEST and SMBT and poorly correlated with shoulder isometric rotational strength and SRT. 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 ULRT in different sports and patient populations.

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Chapter 3

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

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Published in Physical Therapy in Sport, 2021.
Original article; SCI_{2019} = 1.926 ; Q2 in Rehabilitation (22/68)

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.

Settings: 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 seconds to 16.45 seconds. The minimal detectable change ranged from 29.6 seconds to 45.6 seconds. 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.

KEYWORDS

Physical performance test, assessment, rehabilitation, shoulder, endurance, return-to-play

INTRODUCTION

The incidence of shoulder injury is increasing[1-4] and injury rates are reported to be between 18% and 61% in overhead throwing or smashing sports[2-4]. 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[5, 6].

Whereas strength, strength balance and flexibility have been well documented in the literature[6], muscular endurance of the shoulder girdle in throwing athletes has received limited research attention[7, 8]. 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[8]. 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[9]. Moreover, muscle fatigue alters muscle activation patterns, force couples and kinematics that may lead to injury[10-15]. However, it is not commonly evaluated clinically, as no standard test exists[8]. Physical performance tests (PPTs) have been developed to provide a complete picture of functional status of the athlete's upper extremity[16, 17 18]. PPTs are typically used in the follow-up of athletic patients[16], 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[19]. In this context, PPTs should be representative of the demands of the sport to which the athlete evolves[7, 20]. However, most of the current PPTs evaluate one construct (eg, strength, power, agility, mobility, stability)[17, 21-25] 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[26] is to determine whether there are differences on SET scores based on groups, sides and days.

METHODS

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 hours 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 hours/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 to 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.

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.

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.

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® (1.7kg). The choice of the color was determined from a previous study[8]. 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[8]. 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 meters 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 seconds starting from 60 beats per minute (bpm) to 150 bpm (60 bpm – 90 bpm – 120 bpm – 150 bpm). At 150 bpm, the cadence remained the same until the end of the test. We used the application Pro Metronome © (EUMlab, Xanin Tech, GmbH) to pre-set all settings before the SET.

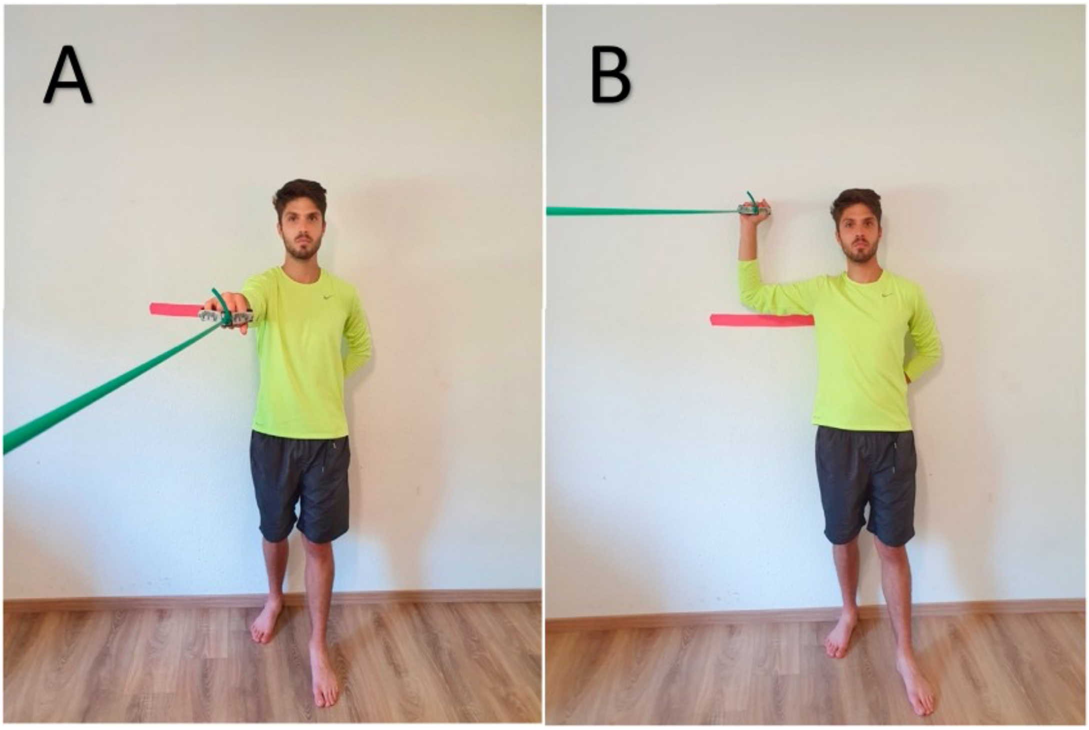

Fig. 1. SET starting (A) and ending position (B).

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[27]. This scale is a valid measure of local upper extremity exertion[28]. 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''[27].

Shoulder isometric rotational strength

The procedure was performed following the guidelines as described by Declève et al[26] 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 seconds of maximal voluntary effort were performed using a « make » test with 10 seconds of rest between trials. The absolute isometric strength data were expressed in Newton (N).

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.

Reliability Analysis

To assess relative reliability, intraclass correlation coefficients (ICC)(2,1) were calculated with the corresponding 95% confidence intervals (CI)[30]. 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[31]. 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 $\sqrt{1-ICC}$, where SD is the SD of all scores of participants[32]. 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[33].

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.

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 -.707), or strong (>0.707)[34]. The Alpha was set at 0.05. All statistical analyses were performed using SPSS (version 23; IBM Corp, Armonk, NY, USA).

RESULTS

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

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 Nondominant sides

	Overhead Athletes (n=30)		Sedentary Adults (n=62)	
	Dominant	Nondominant	Dominant	Nondominant
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	Nondominant		Wilcoxon Signed Rank Test	Dominant		Wilcoxon Signed Rank Test	Nondominant		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.

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 seconds (dominant side overhead athletes) to 16.45 seconds (dominant side sedentary adults). The MDC_{95} ranged between 29.6 seconds (dominant side overhead athletes) to 45.6 seconds (dominant side sedentary adults).

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 seconds compared to 123.1 seconds on dominant side ($p = 0.79$) and 104.2 seconds compared to 103.4 seconds on non-dominant side ($p = 0.66$). But systematic differences were found on group 2 for both sides with 112 seconds compared to 119.4 seconds on dominant side ($p = 0.014$) and 98.7 seconds compared to 107.3 seconds on non-dominant side ($p = 0.002$).

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).

Rate of perceived exertion

The rates of perceived exertion for both groups are described in table 3 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.

DISCUSSION

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[9] 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[8] 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[8]. 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[35]. 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[36, 37] while the MDC is defined as the minimal change that falls outside the measurement error in the score of the test used[35, 38]. 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 seconds on the dominant side or 38.2 seconds on the non-dominant side occurs. For group 2, we could consider as a true change when a change of 45.6 seconds on dominant side or 40.2 seconds 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% amounted from 24% (dominant side on overhead athletes) to 39% (non-dominant side on sedentary adults) versus 19% to 30% for MDC% on recommended PPTs such as the closed kinetic chain upper extremity stability test (CKCUEST) and upper limb rotation test (ULRT)[17, 22, 39, 40]. 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[2, 17, 22, 39, 40]. 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.

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[7], 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.

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[41].
Selection of appropriate PPT requires careful consideration of relevance, specificity and practicality[42]. Single PPT which determine return to sport have limited clinical utility as they measure only one construct[7]. 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[7, 42].

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.

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.

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PART 3

Is the Modified Closed Kinetic Chain Upper Extremity Stability Test reliable and valid when performed by adolescent athletes?

Chapter 4

Reliability of the Modified CKCUEST and Correlation with Shoulder Strength in Adolescent Basketball and Volleyball Players.

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Published in Brazilian Journal of Physical Therapy, 2021.
Original article; SCI_{2019} =2.100; Q2 in Rehabilitation (18/68)

ABSTRACT

Background: Physical performance tests provide a more complete picture of the functional status of the athlete's upper extremity.

Objectives: The primary purpose was to evaluate the reliability of the Modified Closed Kinetic Chain Upper Extremity Stability Test (MCKCUEST) in adolescent volleyball and basketball players. The secondary objective was to evaluate the relationship between the MCKCUEST and shoulder rotation isometric strength in this population.

Methods: Seventy-three healthy basketball (n=39) and volleyball (n=34) players participated to establish the reliability and correlations of the MCKCUEST. We used a two-session measurement design to evaluate the reliability of the MCKCUEST. Shoulder rotation isometric strength was performed to determine relationships with the MCKCUEST.

Results: The intraclass correlation coefficients ($ICC_{2,1}$) for intra-session reliability of the MCKCUEST ranged from 0.86 to 0.89, and the between days test-retest reliability ($ICC_{3,1}$) was 0.93. The standard error of measurement (1 touch) and the minimal detectable change (3 touches) showed clinically acceptable absolute reliability values. A weak correlation was found between the MCKCUEST power score and shoulder rotation isometric strength (r values between 0.3 and 0.4).

Conclusions: Results demonstrated good to excellent relative reliability and clinically acceptable absolute reliability values for the MCKCUEST on adolescent basketball and volleyball athletes. Performances on the MCKCUEST were weakly associated with shoulder rotation strength.

KEYWORDS

Physical performance test; rehabilitation; return to play; young athletes.

INTRODUCTION

The increase in adolescent sport participation over the past years and the specialization in a single sport with intensive repetitive activity at younger ages increase the risk of sustaining an overuse injury[1-3]. This risk is nearly twice higher compared to adolescents with low specialization[1-3]. In total, 30% of sports-related injuries among throwing young athletes occur in the shoulder[3]. Consensus statements released by healthcare and sports organisations recognize the importance of upper limb screening examination as part of the periodic young athlete's health evaluation[4-6].

Physical performance tests are a part of this screening examination, provide a more complete picture of the functional status of the athlete's upper extremity, and are routinely used for performance enhancement or post-rehabilitation outcome measures[7-10]. Furthermore, physical performance tests are, most of the time, easily performed in many different environments and contexts with minimal material[5, 11], and are thus, very popular. The Closed Kinetic Chain Upper Extremity Stability Test (CKCUEST) is one of the most popular physical performance tests to assess upper body function[11]. Despite reliable and valid results within the adult population[9, 12-16], data about the CKCUEST on adolescents is scarce[17]. Moreover, results on adults should not be generalized to young athletes because of the differences in anthropometric characteristics. In previous studies, the CKCUEST was performed in accordance with the guideline described by Tucci et al.[9] and Goldbeck and Davies[14] with participants adopting a push-up position with a fixed 91.4 cm distance between hands. However, this standardized distance may not be appropriate for adolescents by being too wide for some young individuals or too narrow for others[12, 17, 18]. Other studies performed the test with participants adopting a push-up position with their hands located directly under their shoulders[12, 19] or with hands placed at a width 50% of the participant's height[12].

Overuse injuries have been associated with strength impairments affecting the balance between shoulder internal and external rotator muscles[20-22]. To the best of our knowledge, only a few studies have examined the relationship between the CKCUEST and shoulder rotation strength[23, 24]. Lee and Kim[23] reported a high correlation between the CKCUEST mean touches and isokinetic shoulder rotation strength while Declève et al.[24] showed moderate correlations between the CKCUEST mean touches and power score and shoulder rotation strength. However, normalizing the hand spacing at shoulder width may influence the relationship found in these previous studies.

The primary purpose of our study was to determine the relative and absolute reliability of the Modified CKCUEST (MCKCUEST)[12] in a population of healthy adolescent volleyball and basketball players. We hypothesized that normalizing the hand spacing at shoulder width may be an alternative to improve the consistency in the CKCUEST on adolescent athletes. The secondary purpose of our study was to examine if performance on the MCKCUEST was correlated with the isometric shoulder rotation strength of adolescent volleyball and basketball players.

METHODS

Study design and participants

This cross-sectional study was performed following the STROBE recommendations[25]. The study was conducted from September to December 2019. Participants were recruited from local basketball and volleyball settings in Brussels and Charleroi (Belgium). Participants were included if they were aged between 12 to 17 years, were in good general health, and played at competitive level minimum 3 hours per week. 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 before the study. All participants provided written informed consent signed by the legal guardians. The study was approved by the Ethical Committee of the Cliniques universitaires Saint-Luc, Brussels, Belgium 2018/04JUL/275-N°B403201837036.

Sample size

Based on a pilot study on 12 adolescents, sample size was calculated based on our primary purpose using the G*power 3.1.7 program and considering: $\alpha = 0.05$; $\beta = 0.10$ (90%); power correlation ratio to null hypothesis (ρH0) = 0.35; correlation ratio for alternative hypotheses (ρH1) = 0.80, and a potential loss of 20%[26, 27]. At least 34 participants were needed for the study..

Procedure

The participants attended two assessment sessions conducted by the same investigators properly trained for the test (four fourth-year physical therapy students under supervision of a physical therapist with over 14 years of clinical experience). Two investigators were responsible for counting the touches and the timing and two others were responsible for the test performance.
To evaluate test-retest reliability and to avoid possible memory recall, the MCKCUEST was performed on two sessions (day 1 and day 2), separated by seven days. Participants were not informed about the scores obtained during the first assessment to minimize the motivational effects. In addition, on day 1, we performed strength assessment using the Self-Assessment Corner[24]. The testing order was randomized on day 1 by instructing participants to choose cards to determine which test would be done first.

Modified Closed Kinetic Chain Upper Extremity Stability Test (MCKCUEST)

Participants adopted a push-up position with a flat back parallel to the floor (Figure 1)[9, 14]. Previous studies have suggested that females should assume a modified push-up position, with knees on the ground, when performing the CKCUEST[9, 17] . However, we decided to test the female participants with the same push up position that was used to test the male participants to standardize the procedure for both sexes. To avoid the influence of the anthropometric characteristics of individuals[18], we used the inter-acromial distance, measured with a tape measure from the tip of the right acromion to the tip of the left acromion of each participant, instead of the standardized between hands distance of 91.4 cm[9, 12, 14] .Two parallel and aligned lines with the inter-acromial distance of the individual were marked on the floor to determine the position of the hands. For 15 seconds, participants were instructed to move one hand to touch the dorsum of the opposite hand and then return the hand to the starting position. Subsequently, the same movement was performed with the other hand. Participants were instructed to perform as many alternating touches as possible. The number of touches was recorded. After instructions and demonstration, a familiarization trial was performed, consisting of 5 repetitions. Verbal cues were given during familiarization when necessary. Finally, three test trials were performed. Every trial lasted 15 seconds with 45 seconds rest in between[14]. The MCKCUEST provides 3 scores: 1) the number of touches the participant performed in 15 seconds; 2) the normalized score that is obtained by dividing the number of touches by height, and 3) the power score is calculated by multiplying the average number of touches by 68% of the participant's body mass in kilograms, (which corresponds to the mass of the upper extremity, head, and trunk), and then divide that score by 15[14].

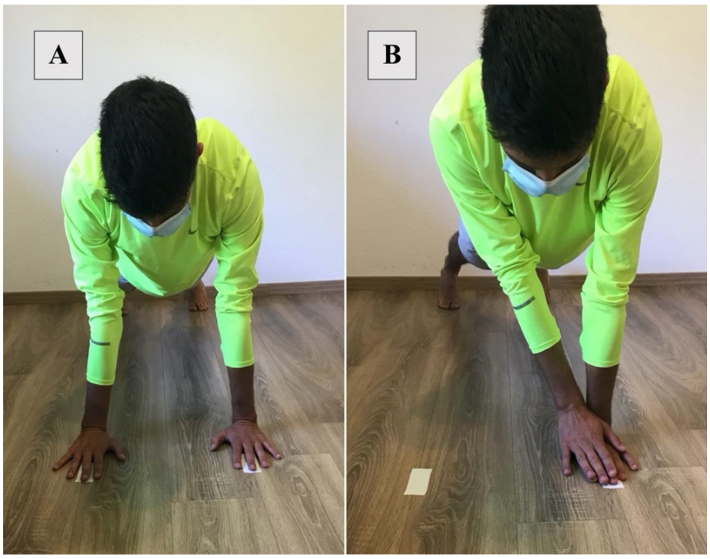

Figure 1 Modified Closed Kinetic Chain Upper Extremity Stability Test. (A) Starting position. (B) Ending position.

Self-Assessment Corner procedure

The procedure was performed following the guidelines as described by Declève et al.[24, 28] We started with verbal instructions from the investigators. Participants were instructed to stand up straight, barefoot, with the non-tested hand on the back at the level of the 4th and 5th lumbar vertebrae and the opposite foot of the tested arm placed forward (Figure 2). The forearm was placed against the hand-held dynamometer (MicroFET2 HHD, Hoggan Health industries Inc, West Jordan, UT, USA) 2 cm proximal of the ulnar styloid process on the dorsal or ventral forearm for strength assessment for external and internal rotation, respectively. Both external rotation and internal rotation were assessed in 90° of shoulder abduction in the frontal plane, 90° of shoulder external rotation, and 90° of elbow flexion with neutral rotation of the forearm. This shoulder position allows to test in a more overhead functional position. Three repetitions of 5 seconds of maximal voluntary effort were performed with

Figure 2 Self-Assessment Corner.

10 seconds of rest between trials. Participants had to build their force gradually to a maximum voluntary contraction over a 2-second period and had to keep the maximal voluntary contraction for 5 seconds[29].
The Self-Assessment Corner test has good to excellent reliability[24]. The absolute isometric strength data were expressed in Newton (N).

Statistical Analysis

Means and standard deviations were calculated across participants for all dependent variables. The MCKCUEST (mean number of touches, normalized score, and power score) and shoulder external and internal rotation strength were analyzed. The Shapiro-Wilk test was first used to evaluate the normality of the distribution within all measurements. All data were normally distributed.

To assess relative reliability, intraclass correlation coefficients (ICC) were calculated with the corresponding 95% confidence intervals (CI)[30]. To assess intra-session reliability between trials within day 1 and day 2, we calculated $ICC_{2,1}$. To assess test retest reliability between day 1 and day 2 we calculated $ICC_{3,1}$. Interpretation was based on the guidelines by Shrout and Fleiss,[31] with values > 0.90 reflecting excellent reliability; values between 0.80 and 0.89, good reliability; between 0.70 and 0.79, moderate reliability; and values < 0.70, low reliability. To examine the absolute reliability of the MCKCUEST, the standard error of measurement (SEM) and the minimal detectable change (MDC) were calculated using between days measurements. The SEM was calculated as SD x $\sqrt{1-ICC}$, where SD is the SD of all scores of the participants[32]. The SEM was used for calculating the MDC_{95}, which was calculated as SEM x 1.96 x $\sqrt{2}$.

To analyze a possible correlation among the performance on the MCKCUEST (mean number of touches, normalized score, and power score) and the strength variables, we used the Pearson product moment correlation (r). The r value was categorized as weak (<0.499), moderate (0.5-0.707), or strong (>0.707)[33]. The Alpha was set at 0.05. All statistical analyses were performed using SPSS (version 23; IBM Corp, Armonk, NY, USA).

RESULTS

Seventy-three adolescent healthy basketball and volleyball players completed the study. Demographic characteristics of all participants are presented in table 1. Results of the MCKCUEST and isometric shoulder rotation strength stratified by sex and sports for day 1 and day 2 are summarized in table 2.

Intra-session reliability between trials within day 1 and day 2 showed good reliability with $ICC_{2,1}$ values ranging from 0.86 (95% CI = 0.80, 0.90) on day 2 to 0.89 (95% CI = 0.81, 0.93) on day 1. The test-retest reliability between day 1 and day 2 showed excellent reliability with $ICC_{3,1}$ value of 0.93 (95% CI = 0.63, 0.97). The SEM was 1.1 touches and the MDC_{95} was 3.04 touches.

Results of the correlation analysis are summarized in table 3. Weak non-significant correlations were found for all variables except for the MCKCUEST power score that showed significant weak correlation with shoulder strength variables (r ranging from 0.3 to 0.4).

Table 1 Demographic characteristics of the total sample and stratified by sports

	Total sample (*n* =73)	Basketball (*n* =39)	Volleyball (*n* =34)
Age (years)	14.7 ± 1.4	14.9 ± 1.4	14.4 ± 1.4
Body mass (kg)	60.2 ± 12	61.6 ± 11.5	58.6 ± 12.5
Height (m)	1.7 ± 0.1	1.7 ± 0.1	1.7 ± 0.1
Sex (Male/female)	41 / 32	25 / 14	16 / 18
Hours a week	7.4 ± 3.9	8.8 ± 4.5	5.8 ± 1.9

Date are presented as mean ± standard deviation.

Table 2 Descriptive analysis for the MCKCUEST and isometric internal and external rotation strength stratified by total, sex and sports between day 1 and day 2

	MCKCUEST number of touches		MCKCUEST normalized scores		MCKCUEST power scores		Dominant IR strength	Dominant ER Strength	Nondominant IR strength	Nondominant ER strength
	Day 1	Day 2	Day 1	Day 2	Day 1	Day 2				
Total (*n* =73)	30.8 ± 4.0	32.2 ± 4.0	18.0 ± 2.7	18.9 ± 2.7	83.7 ± 18.9	87.7 ± 19.8	32.3 ± 11.1	27.2 ± 9.7	27.8 ± 11.3	24.1 ± 8.4
Females (*n* =32)	31.3 ± 3.7	32.7 ± 3.8	19.0 ± 2.6	19.9 ± 2.6	76.4 ± 12.0	80.1 ± 12.6	27.6 ± 8.4	23.9 ± 6.4	21.9 ± 5.7	20.6 ± 5.7
Males (*n* =41)	30.4 ± 4.3	31.8 ± 4.1	17.3 ± 2.5	18.1 ± 2.5	89.1 ± 21.4	93.4 ± 22.2	35.8 ± 11.6	29.7 ± 11.0	32.2 ± 12.4	26.7 ± 9.2
Volleyball global (*n* =34)	30.9 ± 3.7	32.7 ± 3.7	18.2 ± 2.4	19.3 ± 2.4	81.9 ± 19.5	86.7 ± 20.5	28.7 ± 10.2	22.9 ± 6.3	22.5 ± 7.3	20.2 ± 6.6
Volleyball females (*n* =18)	30.4 ± 3.9	32.1 ± 4.0	18.4 ± 2.6	19.4 ± 2.7	73.6 ± 12.4	77.8 ± 13.8	26.4 ± 9.4	21.9 ± 4.7	19.8 ± 5.0	18.3 ± 5.2
Volleyball males (*n* =16)	31.5 ± 3.7	33.5 ± 3.3	17.9 ± 2.1	19.1 ± 2.2	91.2 ± 22.1	96.8 ± 22.6	31.3 ± 10.6	24.0 ± 7.7	25.5 ± 8.4	22.2 ± 7.5
Basketball global (*n* =39)	30.7 ±4.3	31.8 ± 4.2	17.8 ± 2.9	18.5 ± 2.8	85.3 ± 18.6	88.6 ± 19.3	35.4 ± 11.1	31.0 ± 10.7	32.5 ± 12.1	27.5 ± 8.3
Basketball females (*n* =14)	32.4 ± 3.4	33.6 ± 3.4	19.8 ± 2.3	20.5 ± 2.3	80.3 ± 10.5	83.2 ± 10.6	38.5 ± 11.6	33.2 ± 11.4	36.4 ± 12.7	29.4 ± 9.1
Basketball males (*n* =25)	29.8 ± 4.5	30.9 ± 4.3	16.9 ± 2.7	17.5 ± 2.5	87.7 ± 21.3	91.2 ± 22.1	29.2 ± 6.8	26.5 ± 7.6	24.8 ± 5.5	23.7 ± 5.0

Data are presented as mean ± standard deviation; MCKCUEST data are expressed as number of touches; strength data are expressed in Newton, MCKCUEST, Modified Closed Kinetic Chain Upper Extremity Stability Test

Table 3 Results for correlations analysis between the Modified closed Kinetic Chain Upper Extremity Stability Test (mean touches and normalized and power scores) and the Dominant and Nondominant shoulder isometric external and internal rotation strength (n=73)

	MCKCUEST mean touches		MCKCUEST normalized score		MCKCUEST power score	
	Pearson product moment correlation coefficient *(r)*					
	Dominant	Nondominant	Dominant	Nondominant	Dominant	Nondominant
External rotation isometric strength	0.09	0.05	-0.11	-0.12	0.31*	0.33*
Internal rotation isometric strength	0.05	0.10	-0.15	-0.10	0.43*	0.40*

* Significant correlation ($p < .05$)

DISCUSSION

The primary purpose of our study was to evaluate the intra-session and test-retest reliability of the MCKCUEST on adolescent athletes. This test was modified from the original testing procedure proposed by Goldbeck and Davies[14] by spacing hands at shoulder width using the inter-acromial distance to adapt the starting position to the anthropometric characteristics of the individuals[12, 18].

The MCKCUEST displayed good to excellent intra-sessions and test-retest reliability on the adolescent athletes which is in contrast to the study of Oliveira et al.[17] that found weak ICC value (ICC = 0.68) on adolescents using the initial push-up position with hands placed 91.4 cm apart. The initial standardized hands distance may be a factor that contributes negatively to their results[17, 18]. Spacing hands at shoulder width using the inter-acromial distance placed adolescent athletes at an advantage when performing the MCKCUEST compared to the original CKCUEST. Anthropometric characteristics of individuals such as narrower shoulder width and/or shorter arm length may interfere with the results by increasing effort needed to stabilize the upper body when the initial standardized hands distance is applied[34]. In our study, both sexes used a push-up position while Oliveira et al.[17] adopted a knee push-up position for adolescent females. If we compare our results to other reliability studies performed on adults (ICC range 0.77 - 0.96; SEM range: 0.9 - 2.8; MDC_{95} range: 2.6 -7.8)[9, 12-16, 23, 35], we show similar results. However, a variety of testing procedures used in the literature, makes comparisons between these studies difficult regarding the average number of touches, SEM, and MDC[7, 9, 12-17, 19, 23, 35]. The CKCUEST as originally described by Goldbeck and Davies[14] was performed by athletic male students in a push-up position with their hands touching parallel pieces of tape placed 91.4 cm apart. They reported an ICC of 0.92 and number of touches of 27.8[14] while Lee and Kim[23] reported on adults an ICC of 0.97 and an average number of touches of 13. In the study of Sciascia and Uhl[13] on symptomatic and asymptomatic participants they reported an ICC ranging from 0.85 to 0.86, an average of touches of 22, a SEM of 2, and MDC of 4.

Some other studies adopted a modified knee push-up position for female participants[9, 17]. Tucci et al.[9] evaluated the test-retest reliability of the CKCUEST in sedentary and active individuals with or without shoulder injury. They demonstrated an ICC ranging from 0.82 to 0.96, an average number of touches ranging from 11

to 30, a SEM of 1.4 to 2.8, and an MDC of 2 to 4[9]. De Oliveira et al.[17] studied the reliability of the CKCUEST on male and female adolescents using a knee push-up position for female participants. They reported an ICC of 0.68, an average number of touches of 26.8, a SEM of 2.2, and MDC of 6.
Other studies adapted the starting positions of the hands[12, 19, 34, 36]. Tarara et al.[36] instructed the participants to assume a push-up position with hands located directly under the shoulders to begin the test. The parallel pieces of tapes remained 91.4 cm apart. They reported on active college students an ICC ranging from 0.73 to 0.78 and SEM from 7 to 8. Hollstadt et al.[19] reported on college basketball players an average of touches ranging from 25 to 32 and Taylor et al.[34] reported a range from 23 to 25 on collegiate athletes. Callaway et al.[12] evaluated the reliability of 4 variations of hand starting position on adult males. The first variation was the standard test described by Golbeck and Davies[14] . The second adaptation spaced hands at shoulder width using the inter-acromial distance similar to our testing procedure. The third variation started with hands at shoulder width and reached the 91.4 cm distance, and the last variation placed the hands at 50% of the participant's height. They determined an ICC from 0.84 to 0.93, a SEM ranging from 1.5 to 2.8, and MDC ranging from 4.1 to 7.8 touches. The second variation from Callaway et al.[12] is of interest because it is similar to our testing position and comparisons can be drawn. Even though our study shows similar good ICC values compared to our mean scores, the SEM and MDC_{95} are slightly lower. Our mean score is 30.8 touches on day 1 and 32.2 touches on day 2 while they found 34.2 touches on adult male population. We obtained a SEM of 1 and MDC_{95} of 3 compared to 2.8 and 7.8, respectively. These SEM and MDC_{95} values enhance sensitivity to change. Our MDC_{95} value suggests that a change of 3.04 touches (approximately 10% of the mean score) is indicative of a true change while their study[12] shows a $\%MDC_{95}$ of 23%.
From a clinical perspective, the CKCUEST as originally described[14] may not be appropriate for assessing all athletes interchangeably. Our study demonstrates that the MCKCUEST is a reliable alternative to CKCUEST that enables to standardize the test to any adolescent population regardless of individual anthropometric difference or sex.
Our results showed only weak correlation between the MCKCUEST power score and shoulder strength variables. Previous studies[23, 24] have examined the relationship between the CKCUEST and isokinetic or isometric shoulder rotation strength. Lee and Kim[23] found a high correlation with the isokinetic shoulder external and internal rotation strength at angular speed of 60°/sec and 180°/sec (r range = 0.87 - 0.94) while Declève et al.[24] showed moderate correlation with isometric shoulder external and internal rotation strength (r range = 0.49 – 0.65). In their studies[23, 24] participants

performed the initial CKCUEST with the standardized between hands distance of 91.4 cm in a push-up position[23] or a knee push-up position for female[24]. The body position when performing the initial CKCUEST requires a substantial amount of coordination between scapular, glenohumeral, elbow, and forearm muscles and also trunk strength and stability[16]. In our study, the modification of hands spaced at shoulder width using the inter-acromial distance might influence the results with adolescents relying more on other upper limb or trunk muscles to perform the MCKCUEST.

Limitations and future perspective

The interpretation of our results is limited to reporting the reliability and relationships of the MCKCUEST in a sample of healthy adolescent basketball and volleyball players. Extrapolation of these results to other overhead athletes should be done with caution. The increase in the MCKCUEST mean score between days might be attributed to a learning effect. One limitation of the CKCUEST or MCKCUEST is that it might not be suitable for initial or mild-level stages of shoulder rehabilitation due to its challenging requirements. The development of new shoulder functional tests that are less demanding should be investigated.

CONCLUSIONS

Relative reliability of the test was good to excellent and absolute reliability was clinically acceptable in adolescent basketball and volleyball players. Finally, a weak correlation was found between the MCKCUEST power score and isometric shoulder internal and external rotation strength.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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GENERAL DISCUSSION

GENERAL DISCUSSION

The general purpose of this dissertation was to contribute to the field of knowledge of screening and monitoring the overhead athlete's shoulder by developing new field measurement tools. This dissertation was subdivided into 3 parts. In part 1, we developed and studied the reliability and validity of the self-assessment corner (SAC) to measure isometric rotational strength. Additionally, we investigated the relationship between two PPTs and the self-assessment corner to assess validity (chapter 1). In part 2, the purpose was to evaluate the reliability and validity of two new PPTs (chapters 2 and 3). In part 3, we focused on an adolescent population and we assessed the reliability and validity of a Modified Kinetic Chain Upper Extremity Stability Test (CKCUEST) (chapter 4). The general discussion will focus on 4 questions:

1. Do we have reliable new field measurement tools?
2. What construct do we measure?
3. What is the additional value of our field measurement tools compared to the current literature?
4. What is the impact of our results in an injury prevention, a rehabilitation process or return to play procedure?
5. How do the new functional performance tests fit into the sport specific kinetic chain?

Do we have reliable new field measurement tools?

The first purpose of our dissertation was to provide new field measurement tools to facilitate the screening and the monitoring of the athlete's shoulder strength and function. However, before being clinically useful, these measurement tools must be reliable[1, 2], valid and demonstrate the ability to detect change beyond the measurement error otherwise known as responsiveness[3].
We demonstrated good (0.89) to excellent (0.92) relative reliability for the SAC in ER and IR respectively[4]. Regarding the Upper Limb Rotation Test (ULRT), the relative reliability analysis demonstrated excellent reliability for intra-session between trials within days (0.93 to 0.97) and good reliability between days (0.76 to 0.78)[5], while our results for the Shoulder Endurance Test (SET) showed good to excellent reliability

(0.78 to 0.93) between days[6]. The relative reliability values we found are similar to manual isometric strength testing reported in the literature in various shoulder positions or in accordance with other intra-session and test-retest reliability studies on PPTs[1, 7-15]. However, in order to make the SAC, ULRT and the SET clinically relevant and useful for clinicians, physical therapists and athletic trainers, we need insights concerning their absolute reliabilities. The MDC_{95} helps us to determine if the score changes are real or within measurement error[16, 17]. Thus, a change exceeding this MDC_{95} value seems to be a true response and an examiner can be 95% confident that a true change has occurred beyond measurement error. The absolute reliability of the SAC showed an MDC_{95} varying from 8.06 N to 8.13 N for IR and ER respectively[4]. We established MDC_{95} values being 3 touches for the ULRT regardless of the side measured, and for the SET, they ranged from 30 seconds on dominant side for overhead athletes to 45 seconds on dominant side for sedentary adults[5, 6]. For example, when evaluating the endurance capacity of the athlete's dominant arm during his rehabilitation or his return-to-play process, a minimal change of 30 seconds is requested to mark a true change over time.

When applying these PPTs to a population of adolescent athletes, relative and absolute reliabilities reported on adults should not be generalized to young athletes because of differences such as anthropometric characteristics[18]. Concerning the CKCUEST, in previous studies[11, 15], the test was performed in accordance with the guideline described by Tucci et al.[8] and Goldbeck and Davies[1] with participants adopting a push-up position with a fixed 91.4 cm distance between hands. However, this standardized distance may not be appropriate for adolescents because it may be too wide for some young individuals or too narrow for others, probably accounting for the weak reliability results on adolescents found by Oliveira et al.[9, 18] For this reason, we modified the starting position of the CKCUEST from a distance of 91.4 cm in adults to a shoulder-width position in adolescents. Our results demonstrated good to excellent relative reliability for intra-session and between days reliabilities ranged from 0.86 to 0.93. Regarding the absolute reliability, we reported a MDC_{95} of 3 touches[19].

Thus, we provide clinicians, physical therapists and athletic trainers with new reliable field measurement tools that are not only easy to use in a sports-medicine clinic or on the field but that are also affordable. A summary of our relative and absolute reliability values as well as normal values is given in Table 1.

Table 1: Overview on ICC (CI) , SEM, MDC and normal values for the SAC, ULRT, SET and MCKCUEST.

	ICC (CI) intra session	ICC (CI) inter session	SEM	MDC	Normal values
SAC	0.93 - 0.96 (0.89 - 0.98)	0.89 - 0.92 (0.79 - 0.95)	3.45 - 3.48 N	8.06 - 8.13 N	39 (ER) - 41 (IR)
ULRT	0.93 - 0.97 (0.86 - 0.98)	0.76 - 0.78 (0.54 - 0.92)	1 touch	3 touches	12 (D/ND)
SET		0.78 - 0.93 (0.58 - 0.96)	10.7 - 16.4 seconds	29.6 - 45.6 seconds	123 (OD) - 103 (OND) 119 (SD) - 107 (SND)
MCKCUEST	0.86 - 0.89 (0.80 - 0.93)	0.93 (0.63 - 0.97)	1 touch	3 touches	32

SAC, Self-Assessment Corner; ULRT,Upper Limb Rotation Test; SET, Shoulder Endurance Test, MCKCUEST, Modified Closed Kinetic Chain Upper Extremity Stability Test; ICC, Intraclass Correlation Coefficient; CI, Confidence Interval; SEM, Standard Error of Measurement; MDC, Minimal Detectable Change; N,Newton; ER, External Rotation; IR,Internal Rotation; D,Dominant Side, ND, Nondominant Side; OD, Overhead Dominant Side, OND,Overhead Nondominant side; SD,Sedentary dominant Side, SND, Sedentary Nondominant Side.

Clinical implications

Although relative and absolute reliabilities of the SAC and the PPTs have been established, we should be cautious regarding the interpretation of the individual results of an athlete in view of its clinical applicability, mainly regarding the MDC%. Our MDC% varies from 10% regarding the MCKCUEST, to 20% for the SAC, 24% for the SET on the dominant side for overhead athletes, approximately 28% for the ULRT and almost 40% for the SET on non-overhead athletes or on the non-dominant side for overhead athletes[4-6]. One way to put our results into perspective of current practice is to compare our MDC% to the existing and recommended isometric hand-held strength measurements and PPTs. The MDC% ranges from 20% to 32%[7, 20] and from 12% to 30%[1, 8, 11, 21, 22] for isometric strength measurements and PTTs respectively. From that perspective, our results are in line with previous recommended isometric strength measurements or PPTs.

However, a question emerges from this observation. The purposes of the SAC as well as of PPTs are, amongst others, to monitor strength and functional performances throughout the season and to intervene quickly, should a decrease in strength or functional performance appear. However, with the current MDC% based on our studies, it is not very likely for a subtle change in strength or performance on the PPTs to be detected. As an example, the MDC% for the SAC is approximately 20%, meaning that a 20% difference in strength is necessary to be 95% sure that a true change occurs. From that perspective, the difference by 20% (SAC) or more (ULRT and SET) expected for a true change in the result is probably too high to help us to detect changes in these variables during a season in a healthy population, and to address specific interventions efficiently and quickly. From a clinical perspective, virgule we can assume that the SAC as well as the PPTs may not be relevant to allow a follow-up throughout the season.

Actually, these MDC% values might be more efficient to follow up an athlete after injury, since substantial decreases in strength and performance on PPTs are expected after an injury, with equally substantial increases during the rehabilitation process. We must however acknowledge that none of our tests were performed on a population with acute or chronic throwing related shoulder injury, so such an assumption may be too blunt to apply in the clinical practice. Creating reference values for the screening tests might possibly assist the clinician more than the MDC in order to assess the specific position of the individual athlete with respect to his or her peers.

What construct do we measure?

Although the reliability of these new field measurement tools has been demonstrated, we also need to provide insights into the construct they measure. Concerning the validity of the SAC, strong correlations were demonstrated with manual isometric strength testing (from 0.75 to 0.82)[4].

Concerning the PPTs, the CKCUEST appears to be a measure of upper-extremity stability and power performed in closed chain while the Seated Medicine Ball Throw (SMBT) is considered to be a test evaluating bilateral upper limb strength and power in an open chain[1, 23, 24]. Lee and Kim[25] and Popchak et al.[26] reported a moderate to high correlation between the CKCUEST and the isokinetic ER and IR strength (r range = 0.55 - 0.94) and hand grip strength (r range = 0.78 – 0.79)[25]. Borms et al.[27] reported moderate to strong correlation between the SMBT and isokinetic rotational shoulder and elbow strength (r range = 0.595 to 0.855). We studied the relationship between the CKCUEST and the SMBT and isometric rotational strength measurements[4]. Our correlation analysis demonstrated moderate correlations between these 2 PPTs and isometric rotational strength (r range= 0.5 – 0.65) suggesting that test performance is moderately related to isometric rotational strength[4]. Moreover, we studied the relationships between the ULRT with analytical measurements – the trunk rotation range of motion and isometric rotational strength measurements - on the one hand, and the relationships between the ULRT and 2 PPTs- the CKCUEST and the SMBT- on the other hand[5]. Concerning the SET, we analyzed its relationship with isometric rotational strength[6]. For these 2 new PPTs, only weak correlations were found with isometric rotational strength (r range = 0.303 to 0.455), highlighting that performances on the ULRT and the SET do not depend solely on isometric strength[5, 6]. When looking at the relationship between the ULRT and 2 other PPTs, we reported a moderate correlation between the ULRT and CKCUEST (r range = 0.553 to 0.615) or SMBT (non-dominant side r = 0.544)[5]. Borms et al.[27] found a moderate correlation between the CKCUEST and SMBT (r = 0.616).

But, we should be cautious regarding correlations reported on adults and we should not generalize to young athletes. Many variations exist concerning the starting position of the CKCUEST on adults. Some authors[10, 28-30] did not use the original 91.4 cm distance between hands as suggested by Godbeck et Davies[1]. Tarara et al.[30], Taylor et al.[29], and Hollstadt et al.[28] instructed the participants to start with a push-up position with hands spaced at shoulder width but the parallel pieces of tapes remained 91.4 cm apart. Callaway et al.[10] studied 2 other variations compared to the abovementioned ones. The first variation is with hands placed at 50% of participant's height and the second with hands placed at shoulder width. Therefore, we should not extrapolate our correlation results to all variations. In addition, by changing the original distance of 91.4 cm in adults to a shoulder-width position in adolescents, we may have changed the stress demands, originally placed on the shoulder[19]. This may explain why we were unable to confirm the correlation of the Modified CKCUEST with isometric strength that we reported on adult population.

Clinical implications

The interest of PPTs is, among other things, to evaluate a single or a combination of constructs of functional performance such as strength, power, endurance, stability, and mobility or specific physical movements on several levels of the kinetic chain, such as the upper limb, the core, or lower extremity[29]. Although moderate correlations have been established between the SAC and ULRT with the CKCUEST and/or SMBT, we were unable to clearly determine which constructs are measured during our new PPTs, therefore limiting the clinical interest of these tests at that particular moment. Knowledge regarding our PPTs is still in its infancy. Consequently, further investigations are needed to provide insights regarding the validity of our PTTs compared to "gold standard" measurements. The only construct that was evaluated during our investigations was isolated isometric shoulder strength. Although it was the specific purpose of this project to use field tests (such as HHD, SAC) and not isokinetic devices, we have to acknowledge that not applying the gold standard for shoulder strength by using the isokinetic dynamometer is a limitation of the assessment of construct validity of the SAC or the PPTs. Moreover, we did not investigate possible constructs regarding core stability, shoulder stability or endurance. We assumed, based on biomechanical components, personal experience, and literature, that these tests may measure different components of core stability such as strength and neuromuscular control (ULRT) or shoulder endurance (SET) and stability (SET – ULRT). The limitation of this project is that these assumptions were not investigated, and therefore not confirmed. To confirm the assumptions, these PPTs should be compared to isokinetic core strength and shoulder endurance measurements. In addition to knowing which construct is assessed, it is also relevant to provide clinicians with a better understanding of the biomechanical forces and moments as well as electromyographical information on core and shoulder muscle activations during these PPTs.

This current lack of knowledge regarding constructs leads to another question: What should we do as clinicians if an athlete scores lower than expected on the ULRT or SET? Regarding the ULRT, based on our previous assumptions, core stability may influence test performance. Therefore, to optimize our intervention, we should firstly

evaluate components of the core stability independently such as core strength and neuromuscular control using analytical and functional tests. For that purpose, we may suggest the use of the Side Bridge test[31] as well as the isometric or isokinetic strength assessment of trunk flexor and extensor to assess core strength[32]. Regarding core neuromuscular control, we recommend the use of the lateral step-down test to evaluate trunk and lumbopelvic neuromuscular control[33].
Secondly, based on this core stability assessment and results obtained, we may advise specific strength and/or neuromuscular control exercises such as plank, side bridge, supine bridge, single-leg stance or single-leg stance on instable surfaces to improve core strength and/or neuromuscular capacities[31].

Concerning the SET, as previously mentioned, we explained that the test was designed to assess shoulder endurance and stability. Again, with a view to optimizing our intervention, we should first assess these components analytically and functionally. However, the assessment of endurance capacity with on-field analytical or functional tests is currently lacking. Little is known regarding the PSET[34] and therefore, its clinical use is limited. Concerning the shoulder stability assessment, even if the CKCUEST is considered as a measure of upper limb stability, this consideration is based on assumption. However, based on EMG studies (ref Escamilla) assessing the 90°90°shoulder position, we recommend strengthening the endurance capacity of the posterior cuff and the scapular muscles at an intensity of 50-60% of one-repetition maximum[35]. Moreover, to improve stability, we recommend the progressive use of stabilization exercises in open chain from low to high load.

What is the additional value of our new field measurement tools compared to the current literature?

As previously mentioned, risk factors such as RC strength weakness fluctuate over time[20, 36-44]. Even if valid and reliable field techniques and protocols to assess the RC weakness exist[7, 42, 45-52], they may not be suitable for assessing and monitoring an athlete's shoulder strength longitudinally during a season. For example, the use of isokinetic device may be compromised because of the extensive equipment required and, regarding the isometric testing, the assessor's strength variability, the lack of stabilization, inconsistency among testing procedures and the need for a skilled assessor may complicate the continuous screening[49, 53, 54]. The SAC might be an alternative to manual isometric strength testing to monitor athletes continuously. This way, we might obtain a more complete picture of the athlete's analytical strength by shifting from a "snapshot" picture of the athlete's strength at some point of the year to a "road movie" of the athlete's strength. However, the SAC may solely help clinicians and coaches by providing field data regarding the analytical isometric strength status of the athlete. The use of the SMBT and CKCUEST may be of interest to complete this strength "road movie" by providing a functional status of the athlete's strength. Indeed, we found that performances on the SMBT and CKCUEST are moderately to strongly correlated with isometric rotational strength[4].

The interest of our PPTs does not lie in replacing the existing ones but in providing clinicians with more choices in the functional assessment of the athlete. If we compare the CKCUEST with ULRT, they share a common goal, namely to assess shoulder stability. To be more precise, the ULRT offers the opportunity to assess both shoulders separately. This enables clinicians to compare the affected limb with the unaffected limb while the CKCUEST assesses bilaterally. Moreover, the ULRT is performed from a sagittal plane to a frontal plane (90°shoulder external rotation and 90° shoulder abduction) and may challenge the shoulder stability to a higher level while the CKCUEST is performed mostly in a sagittal plane. This might be of interest if clinicians want to challenge the shoulder stability during the rehabilitation process.

The SET was developed to overcome the lack of shoulder endurance PPTs[6, 22]. If we compare the SET with the PSET described by Moore et al.[34], we notice that both tests are dynamic but differ by the fact that one is performed in a standing position while the other is performed in a prone position. In addition, the cadence is also different. For the SET, the cadence increases progressively to obtain a final cadence of 150 beats per minute while for the PSET, this cadence remains at 30 beats per minute. Again, depending on the sport performed, it will probably be more interesting to test the athlete in prone or standing position. However, it must be admitted that even if the aim of the SET is to mimic an overhead movement as much as possible, it does not allow an exact replication of the speed at which athletes throw or hit a ball. Moreover, depending on the sport, it does not allow a performance in the correct position. In sports such as volleyball, hitting the ball may be performed in positions higher than the test requires. In addition, depending on the sport practised or even on the field position, the choice of our PPTs may vary.

Currently, we believe that 2 choices are available when using these PPTs (Figure 1).

Based on figure 1, we have two possibilities. We might either be looking for performing a task that is believed to represent the sport's demands or involve the entire kinetic chain or both regardless the construct, or we might be looking for evaluating a construct such as strength based on correlation studies[4, 5, 15, 27]. For example, if our goal is to assess the athlete's functional capacity to perform a sports task in an open chain regardless the construct, we can choose the SET or the

SMBT. If the capacity to perform a sport specific throwing movement such as a ball pass is of interest, the SMBT should be chosen. But, for example, if a functional strength assessment is sought, the CKCUEST and the SMBT will be of interest because of their moderate to strong correlations with isometric and isokinetic strength[4, 15, 27].

In that case, depending on sport demand, the strength can be evaluated in open chain (SMBT) or closed chain (CKCUEST). On the other hand, if stability is sought, the ULRT and the CKCUEST may be more interesting than the SMBT. Generally, the choice of one PPT over the other will depend on the sport practised by the athlete. In that case, we can assess the stability unilaterally (ULRT) or bilaterally (CKCUEST) or from a sagittal to a frontal plane (ULRT) or in a sagittal plane (CKCUEST).

Figure 1: Summary concerning physical performance tests and pathways for decision making based either on the specific functional purpose of the test or based on the existing correlation analysis studies with strength variables and/or amongst the functional tests.

Physical Performance Tests

Based on specific functional purpose

Open Chain		Closed Chain	
unilateral	bilateral	unilateral	bilateral
SET	SMBT	ULRT	CKCUEST / MCKCUEST

Based on correlation analysis studies

Isometric rotational strength (Decleve et al.)

Open Chain		Closed Chain	
unilateral	bilateral	unilateral	bilateral
	SMBT *		CKCUEST *

Isokinetic rotational shoulder strength (Borms et al.Lee et al.)

Open Chain		Closed Chain	
unilateral	bilateral	unilateral	bilateral
	SMBT(ER)* SMBT(IR)**		CKCUEST **

Isokinetic elbow strength (Borms et al.)

Open Chain		Closed Chain	
unilateral	bilateral	unilateral	bilateral
	SMBT **		

Grip strength (Lee et al.)

Open Chain		Closed Chain	
unilateral	bilateral	unilateral	bilateral
			CKCUEST **

ULRT (Decleve et al.)

Open Chain		Closed Chain	
unilateral	bilateral	unilateral	bilateral
	SMBT *		CKCUEST *

CKCUEST (Borms et al. Decleve et al.)

Open Chain		Closed Chain	
unilateral	bilateral	unilateral	bilateral
	SMBT *	ULRT *	

SMBT, Seated Medicine Ball Throw; CKCUEST, Closed Kinetic Chain Stability Test; ULRT, Upper Limb Rotation Test; SET, Shoulder Endurance Test; ER, External Rotation; IR, Internal Rotation. *, Moderately correlated; ** Highly correlated

What is the impact of our results in an injury prevention, a rehabilitation process or return to play procedure?

In his critical review on "W*hy screening tests to predict injury do not work, and probably never will*", Bahr argues that predicting future injury risk through screening tests is unrealistic[55]. Indeed, sports injuries do not arise in isolation, and occur following complex risk factor interactions and are unpredictable, pointing out that analytical screening tests may appear useless[36, 55, 56]. Moreover, we found conflicting evidence concerning the use of PPTs to predict upper extremity injury[57, 58]. While Pontillo et al.[57] reported that college football athletes with a CKCUEST score of 21 touches or less are 18.75 times more likely to sustain a shoulder injury during the season, Gaudet et al.[58] reported a low diagnostic validity of the CKCUEST on female handball players and synchronized swimmers.

However, others support the relevance of screening on individual athletes[36, 59] for injury prevention. Van Mechelen et al.[60] proposed a "sequence of prevention" of sports injuries. His theoretical framework is composed of 4 steps. Step 1 consists to establish the extent of the problem. Step 2 aims at establishing the etiology and mechanism of injury. Step 3 consists to introduce preventive measures and in step 4 we assess their effectiveness by repeating step 1. Finch et al.[61] have proposed a new sequence of sports injury prevention framework named " Translating Research into Injury Prevention Practice" (TRIPP). This framework adds two more steps and takes into consideration implementation issues such as the athlete behavior context (step 5) and the evaluation of the effectiveness within the implementation context (step 6).

Individual athletes' analytical screening for risk factors is part of step 2 of the TRIPP framework and may be useful as baseline testing to look for traits that increase their likelihood of sustaining an injury. This screening may facilitate appropriate decision-making and potential individual intervention known as primary prevention. Moreover, the use of PPTs prior to any injury provides us with individual benchmarks and functional status[36, 62]. These individual "pre-injury" benchmarks may guide us for primary prevention or in our return to play decision by providing a "minimal required goal" to reach[63]. In case these "pre-injury" benchmarks are missing, normative data could be of interest to compare performances with their peers. However, we did not provide clinicians with cut-off values or normative data for different sports, or age categories that may help to benchmark players and more detailed information is needed regarding the predictive value of these physical performance tests on shoulder injury. Therefore, the implementation of our new PPTs in injury prevention is at this time difficult. These PPTs may be used to monitor progression in a rehabilitation process.

Moreover, another value of PPTs is that they have been recommended as part of a comprehensive return-to-play algorithm[2, 64-67]. The Strategic Assessment of Risk and Risk Tolerance model (StARRT) is a biopsychosocial framework that describes three steps in assessing risk in return to play decision-making: (1) assessment of health risk (tissue health), (2) assessment of activity risk (tissue stresses) and (3) assessment of risk tolerance[66]. Physical performance tests take place in the second step of the risk assessment and may help as a small piece of "the return to play decision" puzzle. But, it is important to realize that one PPT does not fit all. The use of a single PPT has a limited utility as it measures one construct[22] or may not represent the sports demand we are aiming at. Olds et al.[22] have recently established the reliability of the Shoulder Arm Return To Sport battery of tests (SARTS) including 4 open chain and 4 closed chain tests. This study is a first step in the development of a shoulder test battery but cannot be applied to all sports or populations. Future test batteries should include PPTs depending on the sport demands and/or the demands required by the field position. Popchak et al.[26] have recently demonstrated the reliability and validity of a new test battery composed of isokinetic, isometric and functional assessments. Future test batteries should include PPTs depending on the sports demands and/or the demands required by the field position.

We would like to provide some clinical advice on the use of our field measurement tools if the purpose is to monitor the athlete's shoulder longitudinally during a season. These recommendations are based on what we believe to be clinically of interest but also by taking into account what it implies for the management and the adherence of a team. We believe that the SAC could be used weekly. From our experience, this strength assessment did not lead to fatigue among participants and therefore, we believe it can be performed prior to a training session. Once the player is familiar with the procedure and setting of the SAC, the presence of clinicians, physical therapists or athletic trainers is not obligatory. It only requires the presence of a second player to check for shoulder position. The procedure is not time consuming. It takes 5 minutes to undergo the procedure.

Concerning the SET, based on recent literature suggesting that fatigue is a risk factor for shoulder injuries[68, 69], we suggest performing the test several times during the season. This assessment may help us to observe if a change occurs in endurance capacity. however, as this test leads to muscular fatigue when it is carried out, we advise to plan a rest period of 30 minutes before the beginning of a training session.

Regarding the ULRT, we think that its performance would also be interesting to evaluate the stabilizing component of the athlete's shoulder. We suggest performing this PPT several times during the season. This test should be done before a training session to avoid the effect of training on the results. Nevertheless, we would like to draw attention to the period in which these tests are carried out. We do not recommend any assessment the day after a game or after a heavy training session to consider the possible influence of fatigue on the results.

How do the new functional performance tests fit into the sport specific kinetic chain?

PPTs are attractive to assess constructs of the kinetic chain by requiring an athlete to physically perform a task that is believed to represent the sports demands or involve the entire kinetic chain[70].

The overhead throwing motion is characterized by a multitude of repetitive and highly specific patterns performed at high speed over a long period of time and involves sequential activation from the lower extremities to upper extremities[37, 71].

More specifically, the hip and trunk areas contribute by as much as 50% of the kinetic energy and force to the entire throwing motion. A decrease in the force and power generation in this area increases stress in distal segments such as the shoulder[71] making the functional assessment of this area a key component to be evaluated for overhead sports such as tennis, volleyball and handball.

Moreover, scapular stability and posterior cuff muscles are also essential to proper kinetic chain function[72]. Furthermore, it is widely accepted that strength and endurance in scapular and posterior shoulder musculature are very important during the arm cocking phase as well as during the deceleration phase to slow down the arm[73]. But, it is believed that most shoulder injuries occur during these phases[73].

Therefore, the arm cocking phase is crucial for overhead athletes and should be evaluated. Our PPTs are meant to partially mimic components of this crucial phase which involves the pelvis and trunk to rotate with subsequent lumbar spine hyperextension and rotation of the upper torso[74] with the throwing shoulder progressing toward maximal external rotational as the shoulder reaches 90° of abduction.

The ULRT, even if performed in a closed chain plank position that is not functional for overhead throwing (standing and open chain position), partially mimics this phase and its clinical relevance may lie in the shoulder and/or core muscle activation during the test as well as the forces applying on the shoulder.

Based on an EMG study[75], prone as well as side plank positions are interesting for recruiting core musculature. The ULRT combined both positions starting from a plank position to a side plank position eventually making the test relevant for assessing core strength. Moreover, Olds et al.[76] have recently investigated forces and muscle activations of the Side Hold Rotation test. The latter is quite similar to the ULRT. The authors reported that the serratus anterior was highly activated (ranging from 73 to 98% MVIC) during different phases of the test[76]. They also demonstrated a moderate subscapularis (37%MVIC) and supraspinatus (41%MVIC) activity as well as a moderate to high activity of the infraspinatus (ranging from 45 to 52% MVIC)[76]. Concerning the forces, anterior force corresponding to 18% of the body weight was found at the maximal horizontal abduction moment of the test, corresponding to the cocking position for overhead athletes. As stated by Olds et al., even if the anterior forces are below the threshold to provoke dislocation, this maximal horizontal abduction is provocative and may guide clinicians to assess if athletes have developed muscular stability and coordination to control these forces[76]. However, we should acknowledge that the testing position of the ULRT also included a prone position, with both shoulders in the sagittal plane. This position is probably more challenging for athletes with posterior instability, which accounts for only 10% of the instability patients[77]. Exploring the applicability of the PPTs, not only of the tests presented in this thesis, but of PPTs for the upper quadrant in general, is a challenge for the future, in order to optimize the applicability in a variety of sports and a variety of sport specific pathologies.

Regarding the SET, the test does not consider the rotational trunk movement generally found in the arm cocking phase in overhead sports. In addition, the speed at which the SET is performed is not at all comparable to the actual rotational speed of up to 7000°/ second[78] found in throwing sports. Moreover, the test requires a standardized 90° ABD 90° ER movement, which may not correspond to the specific patterns of hitting or throwing movements found in tennis, volleyball and handball. However, despite these limitations inherent to the standardization of the procedure, we believe that the position used to perform the SET targets the posterior RC and scapular muscles and therefore, may be relevant to evaluate the posterior RC and scapular muscles endurance capacities.

Based on EMG studies, authors[79-82] found high activation of the infra and supraspinatus as well as the subscapularis (ranging from 50 to 57% MVIC) when performing a standing 90° ER in abduction. Moreover, they also reported high activation of the lower trapezius and serratus anterior (ranging from 66 to 88% MVIC). Comparing these results with EMG studies during overhead throwing phases[73], we have found similar results regarding the arm cocking phase with high RC activity in volleyball serve and spike (54–71% MVIC), tennis serve and volley hitting (40–113% MVIC) and high scapular muscle activity during the tennis serve and volleyball (75% MVIC).

In spite of the assumptions that the PPTs might measure several characteristics of the kinetic chain, which is quite important in overhead sports, two major limitations need to be highlighted from this thesis. To start with, as mentioned earlier, none of these constructs were actually measured during our investigations, putting our assumptions into an uncertain perspective. For future research, we should not only compare positions, movements and forces from our tests with previously published papers investigating maybe a similar, but not the same PPT, but measure these constructs ourselves in the PPTs presented in this thesis. The second limitation, which is not only a limitation of our thesis, but more generally a limitation of the majority of PPTs, is that it is not established for which sports our PPTs are appropriate (in view of sport specific constructs and demands), and for which they are not. The ultimate purpose of every researcher developing PPTs and screening tools is to develop the optimal screening protocol (probably consisting of specific tests, analytical such as strength as well as functional such as the PPTs) for each athlete in his or her specific sport. A tennis player should undergo another screening process than a swimmer or a rugby player. At present, the choice for specific tests is performed by the clinician working with the athlete and is mainly based on personal experience, the available reliable PPTs, and a few laboratory studies investigating the underlying biomechanical processes during these tests. As an example, a clinician working with a tennis player will choose the SET over the CKCUEST, whereas for gymnasts, often working in a closed chain, the CKCUEST or ULRT may be chosen for functional testing.

In the future, in order to select and apply the appropriate PPTs to a specific athlete for physical performance screening or testing before the return to sport, we should consider many variables specific to the sport itself, like degrees of freedom during movement, speed, load, external load such as in collision sports, as well as the amount of acceleration and deceleration.

LIMITATIONS AND FUTURE RESEARCH

With regard to our study limitations, future research recommendations could be suggested.
First, we investigated the reliability and validity of our measurement tools in a physically active adult population. Therefore, it is important to be cautious about extrapolating our reliability results to an adolescent or injured population. Second, it would be of interest to establish normative data categorized by sports, age, gender, level and field position. These normative data could guide us in particular during primary prevention, rehabilitation or return to sport process. Indeed, during the rehabilitation of athletes, we may not be in possession of their individual PPTs results. These normative data could allow us to compare players of the same level, gender or age.
Third, we focused mainly on the correlation between shoulder isometric rotational strength and our PPTs. But in the future, we should study the possible correlations between ULRT and shoulder proprioception and stability, or other parts of the kinetic chain such as core stability tests. Concerning the SET it would be of interest to evaluate its correlation with an isokinetic endurance test.
Last, it may be relevant to develop a battery of physical performance tests that assess not only different constructs but could also be "stage-based" according to the stage of rehabilitation following a traumatic dislocation.

GENERAL CONCLUSION

The first part of this dissertation focused on the development of a self-assessment corner to assess isometric rotational strength. We established its reliability and determined the relationship between the SAC and the CKCUEST and SMBT. Secondly, we developed 2 reliable PPTs but we were unable to determine their correlations to analytical measurements such as isometric strength and/or to trunk rotation. Nevertheless, we established moderate correlations between the ULRT on the one hand, and CKCUEST or SMBT on the other hand.
Last, we established the reliability of the Modified CKCUEST on adolescent athletes but we were unable to confirm the relationship with isometric strength found previously.

Although many future studies need to focus on the usefulness of these new field measurement tools, we hope we have contributed to the field of sports medicine by bringing new insights on the continuous monitoring of the shoulder's athletes.

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ENGLISH SUMMARY
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ENGLISH SUMMARY

Overhead throwing is the fastest athletic movement performed in sports and is characterized by a multitude of repetitive and highly specific patterns of throwing, smashing or serving movements. Shoulder injuries are common among adolescent and adult overhead athletes. Regarding these injuries, previous studies have identified modifiable risk factors. Monitoring athletes continuously with screening tests over the seasons may help to obtain a more complete picture of the athlete's shoulder. Therefore, the main purpose of this dissertation was to contribute to the field of knowledge of screening and monitoring the overhead athletes' shoulder by developing new field measurement tools. This general goal has been tackled in 4 studies divided in three parts.

Part 1 comprises one chapter regarding the reliability and validity of a self-assessment corner (SAC) for shoulder isometric strength on the one hand, and the study of the relationship between the isometric strength using the self-assessment corner and two physical performance tests on the other hand. We were able to establish the reliability and validity of the SAC. Moreover, we demonstrated that performance on the Seated Medicine Ball throw (SMBT) and the Closed Kinetic Chain Upper Extremity Stability Test (CKCUEST) might be valuable as a screening tool to assess shoulder rotational strength.

Part 2 comprises two chapters regarding the reliability and validity of two new physical performance tests (PPTs), Upper Limb Rotation Test (ULRT) and Shoulder Endurance Test (SET). We were able to establish the ULRT and the SET as reliable PPTs. Concerning their validity, moderate correlations were found between the ULRT on one hand, and the CKCUEST and the SMBT on the other hand. These new PPTs may be helpful for the functional assessment of the athlete. Future research should provide reference data for both new PPTs based on age, gender and sports. These reference data might be useful in clinical practice during the rehabilitation or the return to sport process.

Part 3 comprises one chapter focusing on the reliability and validity of a Modified CKCUEST on an adolescent population. We were able to demonstrate that the Modified CKCUEST was reliable on adolescents. But, we could not confirm our previous finding concerning the correlation between isometric rotational strength and the Modified CKCUEST. Therefore, the Modified CKCUEST on adolescents should not be used to assess functional strength performance.

NEDERLANDSTALIGE SAMENVATTING

De bovenhandse werpbeweging is de snelste atletische beweging die kan uitgevoerd worden tijdens het sporten. Ze wordt gekenmerkt door repetitieve en bijzonder specifieke bewegingspatronen, niet enkel tijdens het werpen, maar ook bij voorbeeld tijdens het smashen of serveren. In het licht van deze hoge belasting is de schouder heel kwetsbaar voor kwetsuren, zowel bij adolescenten als bij volwassen bovenhandse sporters.

Diverse studies hebben een aantal intrinsieke risicofactoren geïdentificeerd voor deze schouderklachten, en diverse preventieve programma's focussen op het remediëren van deze risicofactoren. Het is echter belangrijk om tijdens en overheen meerdere seizoenen de atleten continu te screenen op hun performance en deze risicofactoren. Het belangrijkste doel van dit proefschrift is een bijdrage te leveren binnen het domein van de screening en evaluatie van de schouder in de bovenhandse sporter door een aantal nieuwe tools te ontwikkelen. Dit algemeen doel werd uitgewerkt in 3 delen, die samen 4 studies bevatten.

Deel 1 focust op de **continue screening van analytische schouderkracht**, en bestaat uit één studie waarin de betrouwbaarheid en validiteit van een zelf-evaluatie tool (Self Assessment Corner – SAC) voor de kracht van de schouderrotatoren werd onderzocht. Daarnaast evalueerden we de relatie tussen deze analytische krachtresultaten enerzijds, en de resultaten op 2 functionele schoudertesten anderzijds. We toonden aan dat de betrouwbaarheid en validiteit voldoende hoog zijn voor gebruik van dit tool in de praktijk. Dankzij een hoge correlatie met de functionele schoudertesten Seated Medicine Ball Throw (SMBT) en Closed Kinetic Chain Upper Extremity Stability Test (CKCUEST) kunnen deze laatste in de praktijk gebruikt worden als een alternatief om een schatting te maken de schouder rotationele kracht met deze veldtesten.

Deel 2 bestaat uit 2 hoofdstukken, waarin de betrouwbaarheid en validiteit beschreven wordt van **2 nieuwe functionele testen** of "physical performance tests" (PPTs), nl de Upper Limb Rotation Test (ULRT) and Shoulder Endurance Test (SET). Voor beiden werd een goede tot excellente betrouwbaarheid vastgesteld. Met betrekking tot de validiteit werden matige correlaties gevonden tussen de ULRT enerzijds, en de CKCUEST en SMBT anderzijds. Deze nieuwe ontwikkelde PPTs kunnen aangewend worden in de functionele evaluatie van de bovenhandse sporter.

Toekomstig onderzoek moet zich toespitsen op het beschrijven van referentiedata voor deze PPTs, gebaseerd op leeftijd, geslacht en type sport. Deze referentiedata kunnen gebruikt worden in de klinische praktijk in de return-to-sports fase van de revalidatie.

Deel 3 bestaat uit één publicatie, dat focust op de betrouwbaarheid van de CKCUEST, zij het in een aangepaste versie, in een populatie van **adolescente** bovenhandse sporters. We hebben aangetoond dat de Modified CKCUEST betrouwbaar is bij de toepassing op een adolescente populatie. Het was echter niet mogelijk om onze eerdere bevindingen bij volwassenen met betrekking tot de correlatie tussen de Modified CKCUEST en de analytische isometrische kracht van de schouderrotatoren te bevestigen bij adolescenten.

We hopen met dit doctoraal proefschrift een bijdrage geleverd te hebben aan het domein van de sportrevalidatie, in het bijzonder bij de bovenhandse sporter.

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ACKNOWLEDGEMENT

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EDUCATION

2017-Today: PhD in Health Sciences

Department of Rehabilitation Sciences, Faculty of Medicine and Health Sciences, Ghent University (Belgium).

2001-2005: Licenciate's degree (4-year programme) at Parnasse-ISEI (with honours).

PROFESSIONAL EXPERIENCE

CLINICAL EXPERIENCE

- Physiotherapist at a private practice in Brussels (Wolu Sport Clinic): Sports physiotherapy.

September 2007 - Today

- Physiotherapist at a private practice in Corbais (Louvain-la-Neuve): Sports physiotherapy.

September 2006 - March 2007

- Physiotherapist at a private practice in Paris (Montreuil).

October 2005-July 2007

- Physiotherapist within George Pompidou European Hospital (Paris) in the Orthopaedics-Rheumatology and Hand Surgery department.

PRACTICAL TRAINING IN PHYSIOTHERAPY

January 2020: The running clinic: Level 1.0 (Brussels, Belgium)

October 2019: Load Management – Train Smarter and Harder: Tim Gabbet (Ghent, Belgium)

September 2017: Shoulder class: Jeremy Lewis (Leuven, Belgium)

September 2016: Shoulder rehabilitation: Ann Cools Part 3 (Stockholm, Sweden)

January 2016: Dry needling: David G Simons Academy (Louvain-La-Neuve, Belgium)

October 2014: Shoulder Rehabilitation: Ann Cools Part 2 (Stockholm, Sweden)

March 2014: Shoulder Rehabilitation: Ann Cools Part 1 (Oslo, Norway)

October 2013: Scapula Masterclass: Ben Kibler, Tim Uhl (Manchester, UK)

2011-2012: CGE: Thierry Marc (Paris – Toulouse, France)

2009-2010: Certificate in Manual Therapy - ATMS (Namur, Belgium)

2007: Training in dia-cutaneous fibrolysis manipulation (Brussels, Belgium)

2007-2008: Training in sports physiotherapy (KINESPORT) (Paris, France)

2006: Training in the making of postoperative splints after hand surgery (HEGP) (Paris, France)

TEACHING AND EDUCATION

September 2014 – Today

- Trainer in continuous training in sports physiotherapy (Continuous Training Unit, Institut Parnasse-ISEI): « Update in athlete rehabilitation: optional module in sports physiotherapy ».
- Technical advisor with a university certificate in manual therapy: « upper limb motor control module » (Louvain-la-Neuve University).
- Complementary Master's degree in motricity sciences with a musculoskeletal physiotherapy orientation: « upper limb motor control » (Louvain-la-Neuve University).

September 2011 - Today

- Assistant Professor at Parnasse-ISEI, Brussels, Belgium.
  - Clinical Assessment of the Upper Limb (second bachelor).
  - Physiotherapeutic Rehabilitation of the Upper Limb (second bachelor).
  - Physiotherapeutic Rehabilitation of the Upper Limb -advanced- (third bachelor).
  - Clinical Reasoning (first master).
  - Supervision Master thesis students (first master).

PUBLICATIONS

First author

Declève P, Van Cant J, De Buck E, Van Doren J, Verkouille J, Cools AM. The Self-Assessment Corner for Shoulder Strength: Reliability, Validity, and Correlations With Upper Extremity Physical Performance Tests. *J Athl Train*. 2020;55(4):350-358.

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Co-author

Cools AM, Maenhout AG, Vanderstukken F, **Declève P**, Johansson FR, Borms D. The challenge of the sporting shoulder: From injury prevention through sport-specific rehabilitation toward return to play [published online ahead of print, 2020 Apr 29]. *Ann Phys Rehabil Med*. 2020; S1877-0657(20)30082-8.

Gérard R, Gojon L, **Declève P**, Van Cant J. The Effects of Eccentric Training on Biceps Femoris Architecture and Strength: A Systematic Review With Meta-Analysis. *J Athl Train*. 2020;55(5):501-514.

Van Cant J, **Declève P**, Garnier A, Roy J-S. Influence of symptom frequency and severity on hip abductor strength and endurance in individuals with patellofemoral pain. *Phys Ther Sport*.2021. In press.

NATIONAL AND INTERNATIONAL PRESENTATIONS

2017

IOC World Conference on Prevention of Injury and Illness in Sport, Monaco.

Poster presentation: "The Self-Assessment Corner (SAC method): A novel way to self-assess shoulder rotator cuff strength: a reliability and validity study".

Journées Francophones de Kinésithérapie JFK, Paris, France.

Poster presentation: "The Self-Assessment Corner (SAC method): A novel way to self-assess shoulder rotator cuff strength: a reliability and validity study".

2019

Société Francophone de la Médecine et des Sciences du Sport.

Oral presentation: "Return to Play After Shoulder Dislocation."

Sports Medicine Congress, Copenhagen, Denmark.

Poster presentation: "The Self-Assessment Corner for shoulder strength: Reliability, validity and correlations with upper extremity physical performance tests in overhead athletes."

IFSPT World Congress of Sports Physical Therapy, Vancouver, Canada.

Poster presentation: "Upper Limb Rotation Test: Reliability and Correlations of a Novel Upper Limb Physical Performance Test."

ASSOCIATIONS

2016 – Today

Member of the Upper Limb Research Team, Department of Rehabilitation Sciences, Ghent University.

2015-2017

Member of the European Society for Shoulder and Elbow Rehabilitation (EUSSER).

LANGUAGES

French: Native

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First and foremost, I am extremely grateful to my promotor, Prof. Dr. Ann Cools.

Ann, it was such an honor to complete this thesis under your supervision. Your invaluable clinical and scientific experience as well as your enthusiasm and kindness have guided me throughout this adventure. Thank you for all those discussions about the shoulder, whether it was in Ghent, somewhere around the world or, at the Starbuck's in Zaventem. Thank you for giving me so much knowledge and for taking the time to understand my "Frenglish", despite your busy schedule.

I would also like to thank my supervisory committee Prof. dr. Philip Roosen, Prof. dr. Lennert Goossens and Prof.dr Alexander Van Tongel for all their help and advice during this thesis.

I would like to express my sincere gratitude to the members of the examination board, for your time and effort to critically review this doctoral dissertation. Your valuable suggestions and constructive feedback definitely improved the quality of my dissertation. I warmly thank dr. Margie Olds, dr. Dorien Borms, Prof. dr. Roel De Ridder, Prof. dr. Olivier Verborgt and dr. Kristof De Mey. I would also like to thank Prof. dr. Dirk Cambier for his willingness to take on the role of examination chairman and thus steer this doctoral defense in the right direction.

J'aimerais remercier mon ami et collègue Prof. Dr Joachim Van Cant. Nos nombreuses discussions et ses précieux conseils m'ont permis de me lancer dans cette incroyable aventure. Tu as toujours été présent pour m'encourager. Merci!

Je souhaite aussi remercier Didier Lanneau. Merci de m'avoir accordé ta confiance lors de mes débuts. Merci pour ton aide et précieux conseils pour le développement du SAC. Merci!

Je tiens également à remercier Cécile Fayt, le COOK ainsi que Sophie Breedstraet, Directrice du secteur de la santé à la Haute Ecole Leonard de Vinci, de m'avoir tous soutenu dès mes premiers pas dans cette aventure.

Cette thèse n'aurait pu voir le jour sans l'aide précieuse de mes « mémorants ». Merci à Trystan, Amine, Zakaria, Gregory, Julie, Olivia, Matteo, Emma, Tasnim, Simon, Corentin et Valentine. Vous avez grandement contribué à ce travail.

Papa, Maman, vous avez toujours été à mes côtés depuis ma plus tendre enfance, pour m'écouter, me soutenir et me guider que ce soit dans ma vie privée ou professionnelle. Vous êtes une source d'inspiration au quotidien. Merci!

Emilie, ma princesse, je ne pourrai jamais te remercier suffisamment pour avoir été présente à mes côtés et m'avoir soutenu à chaque moment de cette thèse. Ton écoute, tes précieux conseils, tes encouragements, ta patience, ton altruisme ainsi que ton amour m'ont porté tout au long de ce périple, qui sans toi, n'aurait pas pu se réaliser. Merci pour ton positivisme débordant et ton amour de la vie qui rendent le quotidien à tes côtés si léger et merveilleux.

Je terminerai par dire à mes deux adorables filles, Emma et Zoé, que je vous aime plus que tout. Je suis tellement émerveillé de vous voir grandir et tellement fier de qui vous êtes. J'apprends tellement à vos côtés ! N'oubliez jamais une chose: Faites-vous confiance !