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Original Research

Intrarater reliability and agreement of a modified Closed Kinetic Chain Upper Extremity Stability Test

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A B S T R A C T

Objectives: To assess the reliability of a modified procedure for Closed Kinetic Chain Upper Extremity Stability Test (CKCUEST).
Design: Intra- and intersession reliability and agreement;
Setting: Clinical.
Participants: Twenty-seven asymptomatic athletes.
Main outcome measures: The modifications (m-CKCUEST) in CKCUEST procedure consisted in hand spacing at one half arm-span, and to complete the three regular-series of 15 s exertion by performing a fourth 1-min series during which the number of touches was counted every 15 s. The intra- and intersession reliability and agreement were assessed for the numbers of touches in order to produce two outcome measures: m-CKCUEST score and muscular endurance index.
Results: The most reliable m-CKCUEST score was obtained when averaging the numbers of touches of the second and third sets (Intraclass Coefficient of Correlation(3,k); ICC = 0.92). Good reliability was found for muscular endurance index computed when dividing the one-half number of touches counted during the last 30 s of 1-min set, by the m-CKCUEST score calculated above (ICC = 0.86).
Conclusions: The m-CKCUEST allowed the production of two reliable outcome measures, which assessed the upper limb stability and the muscular endurance. Such outcomes may be used in a follow-up to assess performance or rehabilitation level.

1. Introduction

Drawn from the exercises proposed for rehabilitation (Ellenbecker, Manske, & Davies, 2000), the Closed Kinetic Chain Upper Extremity Stability Test (CKCUEST) has been developed by Goldbeck and Davies (Goldbeck & Davies, 2000) to assess objectively and simultaneously both the muscle capacity and neuromuscular control of the upper extremities (Pontillo, Spinelli, & Sennett, 2014). However, a large variety of testing procedures is used in the literature, making the inter-study comparisons difficult.

Originally, Goldbeck and Davies (Goldbeck & Davies, 2000) proposed a CKCUEST procedure as following. The participant adopts a push up position, with hands placed 36-in (91.4 cm) apart on two lines. After a training set, the participant touches alternatively and as quick as possible, the floor with a hand crossing over the supporting hand during three sets of 15 s with a 45-s recovery. The CKCUEST score is computed by averaging the number of touches performed during three maximal sets. As all participants adopt similar body position, in particular a hand spacing of 36 in, a normalisation of this score by participant's height is recommended for interindividual comparisons. This standardized body position allows time to be saved when the CKCUEST is implemented in clinical setting (Goldbeck & Davies, 2000). The validity of the CKCUEST among participants presenting various body dimensions may be however questioned (Tucci et al., 2017). As hand spacing

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affects the shoulder muscle activity (Cogley et al., 2005) and scapular positioning (Tucci et al., 2017), it may be assumed that shoulder functions targeted when performing CKCUSET are individual-dependent. For instance, with a fixed hand spacing, a tall individual has narrow base hand placement, while a small individual has a wide base hand placement, resulting in differences in the rate of exertion during CKCUEST between individuals. This could explain the inconsistency in body position in previous studies. Some authors adapt this body position with kneeling push up position (de Oliveira et al., 2017; Tucci, Martins, de Carvalho Sposito, Ferreira Camarini, & de Oliveira, 2014) or hands spacing at shoulder width (Tarara, Hegedus, & Taylor, 2014). It then appeared that normalizing the hand spacing by body dimensions may be an alternative to improve the consistency in CKCUEST testing procedure.

Another discrepancy in CKCUEST assessment is about the total number of sets, which impacts the computation of the outcome measure. In most studies, the outcome measure is based on three maximal sets with 45 s recovery (Borms & Cools, 2018; de Oliveira et al., 2017; Ismail & El Shorbagy, 2014; Lee & Kim, 2015; Roush, Kitamura, & Waits, 2007; Tucci et al., 2014), as originally proposed by Goldbeck and Davies (Goldbeck & Davies, 2000). However, in other studies, the outcome measure is based one set (Tarara et al., 2014; Taylor, Wright, Smoliga, DePew, & Hegedus, 2016), or two sets with 45 s or 1 min recovery (Pontillo et al., 2014; Sciascia & Uhl, 2015). It then appeared that the reliability of the outcome measure computed from different numbers of sets need to be assessed, particularly when the hand spacing is modified.

The endurance capacity for a muscle group is a key-factor for sport performance when repeated specific sport motion is required in a given time. Some authors argue that CKCUEST also evaluate the upper extremity muscle endurance (Pontillo et al., 2014). However, the recovery of 45 s between sets was originally designed to limit fatigue occurrence during CKCUEST (Goldbeck & Davies, 2000), while the endurance capacity for a muscle group is commonly assessed by fatigue task. Various fatigue protocols have been used in the literature. In clinical practice, the number of contractions performed as many times as possible is measured (McQuade, Dawson, & Smidt, 1998; Pontillo et al., 2014). Another approach consists of performing a fixed number of repetitions and expressing the outcome measure of the last repetitions relative to the measure obtained during the first repetitions (Pincivero, Lephart, & Karunakara, 1997). Consequently, CKCUEST, in its current form, cannot reflect the muscular endurance capacity, but performing additional sets when reducing recovery may be a promising way to produce an upper extremity muscular endurance index, for which the reliability demands to be assessed.

Any change in a testing procedure or a new testing procedure demands an assessment of the reliability of the outcome measure. The aim of this study was to therefore assess the intra- and intersession reliability and agreement of a modified procedure of CKCUSET, i.e. hand spacing normalized by body dimension and additional sets, in adult athletes. It was hypothesized that the modified version of the CKCUEST meets reliability criteria for two outcome scores assessing muscle capacity and endurance of the upper extremities.

2. Methods

2.1. Participants

Twenty-seven male athletes (age: 22.5 ± 3.2 years; height: 177.7 ± 7.7 cm; mass: 79.9 ± 9.1 kg; hand dominance: 22 right and 5 left; sport: rugby (n = 11), judo (n = 5), soccer (n = 3), fitness (n = 2), basketball (n = 2), climbing (n = 1), volleyball (n = 1), yoga (n = 1); running (n = 1); sport experience: 9.4 ± 5.4 years; weekly training: 8.6 ± 5.8 h) volunteered to participate in this study, which was approved by the Ethical Committee (n°2018-A03013-52). Inclusion criteria were being 18–30 years old and having asymptomatic upper limbs at the time of the study. Exclusion criteria were being injured at the upper limb during the six months preceding the study or having undergone surgery at the upper limbs. The arm span of each participant was computed based on the sum of distances, measured using a tape, from the C7 spinous process to the most distal tip of each middle finger, when upper limbs abduct at 90° in the frontal plane (181.3 ± 8.6 cm; range: 164.4; 206.3).

2.2. Procedure

Each participant performed two sessions of a modified CKCUEST one week apart. The same standardized warm up was performed for both the session, namely exercises with a 2-kg medicine ball: 10 elbow flexion-extension, 10 humeral flexion-extension, 10 push-pull, 10 waist-revolutions, 10 head-revolutions; 5 pushes-up against wall with wide base hand placement and 5 with narrow base hand placement; 15-s right-lateral-core, 30-s frontal-core and 15- left-lateral-core training. Thereafter, the participant adopted a push up position on the floor when hands were placed on two pieces of standard athletic tape spaced at one half of participant's arm span (90.7 ± 4.3 cm, min: 82.2 cm; max: 103.2 cm). Then, the participant had to support his body weight on one extended arm while the hand of the other side moved to touch the floor outside the supporting hand. Then the participant came back to the baseline position and alternated the moving hand. The participant was instructed to attempt as many touches as possible under vocal encouragements in the allotted time, while only correct touches were considering by the examiner. After a training set, each participant performed the original procedure of the CKCUEST (Goldbeck & Davies, 2000), such as three maximal sets (sets 1 to 3), with a 45-s recovery (Fig. 1). This procedure was completed with a fourth 1-min set, performed after 15-s recovery following the third set, while the examiner counted the number of touches during each 15 s of the minute (sets 4 to 7; Fig. 1).

The m-CKCUEST score was determined when considering the number of touches during sets 1, 2 and 3. The muscular endurance index (MEI) was based on a number of touches from sets 4, 5, 6 and 7 expressed in reference to the m-CKCUEST score.

2.3. Statistical analysis

Descriptive data are presented by mean ± standard deviation. For the m-CKCUEST score, the intrasession reliability was examined between sets 1 and 2, sets 2 and 3, and between the three sets in both the sessions. The intersession reliability was examined for each set and for the mean between sets 1 and 2, sets 2 and 3, and between the three sets. The choice of the sets kept for building the m-CKCUEST score was then the combination presenting the best reliability and agreement between sessions. For MEI, the intersession reliability was examined for each set and for moving averages between two and four sets (mean between sets 4 and 5, between sets 4, 5 and 6, between sets 4, 5, 6, 7, between 5 and 6, etc.). The most reliable combination was then divided by the m-CKCUEST score to compute the MEI. The intersession reliability and agreement of MEI was also assessed.

In line with GRRAS recommendations (Kottner et al., 2011), the reliability assessment was based on the coefficient of intra-class correlation (3,k) (ICC), with its confident interval at 95%. Values higher than 0.70 were interpreted as having 'good' reliability, values between 0.40 and 0.69 'fair' reliability, and values less than 0.60 'poor' reliability. The agreement was based on the standard

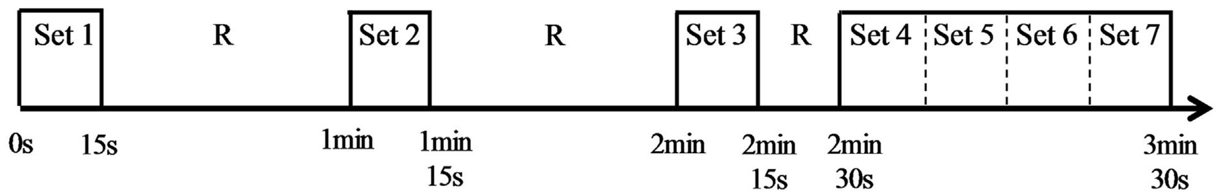

Fig. 1. Testing flaw diagram. R stands for recovery period.

error of measurement (SEM), the minimal detectable change at 95% ($MDC_{95\%}$) and Band-Altman plots. The coefficient of variation (CV) was calculated to represent the consistency between repeated measurements, with acceptable variability when CV value was lower than 12%, and unacceptable variability when CV value was higher than 20% (Albertus-Kajee, Tucker, Derman, & Lambert, 2010). The software SPSS 11.0 was used for the statistical tests.

3. Results

3.1. m-CKCUEST score

The numbers of touches for each set and for the mean between sets 1 and 2, sets 2 and 3, and between the three sets are presented in Table 1.

The intrasession reliability (Table 2) was good between the first and second sets, between the second and third sets and between the three first sets, and variability between sets was acceptable. The highest value for ICC was found between the second and third sets, i.e. line (2,3) in Table 2.

The intersession reliability (Table 3) was moderate for the first set, and good for the second and third sets as well as for mean numbers of successive sets, and variability between sessions was acceptable for all sets and in mean combinations. The highest ICC value was obtained for the mean number of touches between the second and third sets; this outcome was therefore kept for the subsequent analysis as the m-CKCUEST score. The bias was −0.77 touch, indicating a slightly higher performance during the second session. The Bland and Altman plot shows that 26 (96.3%) individuals were into the limits of agreement [-2.65; 1.09] (Fig. 2).

3.2. Muscular endurance index

The mean number of touches for the sets 4 to 7, and moving averages between two and four sets are presented in Table 4.

The intersession reliability (Table 5) was fair for the number of touches for the fourth and fifth sets, and good for the sixth and seventh sets. The highest ICC value was obtained for the mean between sets 6 and 7, i.e. line mean(6,7) in Table 5.

MEI was then obtained by mean(6,7)/mean(2,3), with mean(2,3) corresponding to the m-CKCUEST score. The mean values for MEI were 0.72 ± 0.14 [range: 0.40; 0.93] for the session 1, and 0.74 ± 0.14 [range: 0.32; 0.96] for the session 2, indicating the fatiguing condition conducted to a decrease of about 25% in touch number when referring to the maximal performance assessed by m-CKCUEST score. The reliability and agreement of MEI was good (ICC = 0.86 [$CI_{95\%}$: 0.71; 0.93]; SEM = 0.06 [$CI_{95\%}$: 0.04; 0.08]; $MDC_{95\%}$ = 0.15; CV = 10.03%). The bias was −0.02, indicating a slightly higher performance during the second session. The Bland and Altman plot shows that all individuals were into the limits of agreement [-0.17; 0.14] (Fig. 3).

Table 1
Mean (±standard deviation, range in brackets) numbers of touches for the first three sets, the mean numbers of touches for successive combinations of these three sets in each session.

Set	Session 1	Session 2
1	21.2 ± 2.3 [16; 25]	22.9 ± 2.2 [19; 27]
2	22.6 ± 2.3 [18; 27]	23.4 ± 2.1 [19; 28]
3	22.9 ± 2.3 [18; 26]	23.7 ± 2.5 [20; 30]
Mean(1,2)	21.8 ± 2.2 [18; 26]	23.1 ± 2.0 [19.5; 27]
Mean(2,3)	22.7 ± 2.2 [18; 26.5]	23.5 ± 2.2 [19.5; 28.5]
Mean(1,2,3)	22.2 ± 2.2 [18; 26]	23.3 ± 2.2 [19.7; 27.7]

4. Discussion

The aim of this study was to assess the intra- and intersession reliability and agreement of a modified version of the CKCUEST for score (i.e., number of touches) and the innovative muscular endurance index. The main findings of this study were that the m-CKCUEST score and the muscular endurance index displayed good reliability and agreement when (i) averaging the numbers of touches for the second and third sets of 15 s sets for the m-CKCUEST score, (ii) and dividing half the number of touches counted for the last 30 s of the 1-min set, by the m-CKCUEST score for the muscular endurance index.

The CKCUEST is originally performed when the participant adopts a push up position with hands 36-in apart (Goldbeck & Davies, 2000). Such a fixed hand positioning may conduct to interindividual differences in upper extremity constraints, according to the muscle length-strength relationship. For example, with Goldbeck & Davies' definition of the CKCUEST, our participant with an arm span of 1.64 m would present a wider relative base hand placement than our participant with an arm span of 2.06 m. In order to normalize the body position, we chose to place the participant's hands at one half arm span, which corresponds to the mean of distances from the C7 spinous process to the most distal tip of each middle finger, when upper limbs abduct at 90°. Measuring these distances might be time-consuming in a busy clinical setting (Goldbeck & Davies, 2000). But, as the CKCUEST needs to be implemented in a test battery to characterize the upper extremity functions (Goldbeck & Davies, 2000) and as other tests for shoulder function assessment used these distances (Borms & Cools, 2018), we thought that individualizing hand spacing allowed similar muscular conditions, e.g. relative length and moment arm, to perform the CKCUEST with a clinically acceptable increase in testing time.

The change in body position to perform CKCUEST made difficult the comparison in number of touches assessed in our study with previous ones. However, in athletes of similar ages and sex, our mean values (22–23 touches) remained lower than those previously reported (27–28 touches) (Borms & Cools, 2018; Goldbeck & Davies, 2000), with a lower dispersion (~2 vs ~4 touches, respectively). Regarding the reliability of the m-CKCUEST score, our results were in line with those reported in the literature. To the best of our knowledge, the intra-session reliability for the three first sets was only assessed by Tucci et al. (Tucci et al., 2014), who reported an ICC value of 0.89 for the three first sets of 15 s. With 0.90 for the

Table 2
Intrasession reliability and agreement for numbers of touches in the first three sets.

Sets	Session	ICC	SEM (touches)	$MDC_{95\%}$ (touches)	CV (%)
(1,2)	1	0.86 [0.72; 0.93]	0.88 [0.70; 1.21]	2.44	5.43
	2	0.84 [0.67; 0.92]	0.89 [0.70; 1.21]	2.45	5.11
(2,3)	1	0.95 [0.89; 0.98]	0.55 [0.43; 0.75]	1.52	3.33
	2	0.92 [0.83; 0.96]	0.67 [0.53; 0.92]	1.87	3.31
(1,2,3)	1	0.90 [0.82; 0.95]	0.74 [0.61; 0.95]	2.04	4.38
	2	0.88 [0.79; 0.94]	0.79 [0.65; 1.01]	2.18	4.21

Abbreviations: ICC for intraclass coefficient of correlation, SEM for standard error of measurements, $MDC_{95\%}$ for minimal detectable change at a confidence level of 95%, and CV for the coefficient of variation. Values in brackets correspond to the confidence interval at 95%.

Table 3
Intersession reliability and agreement for the numbers of touches for sets 1 to 3 and mean numbers for successive sets.

Sets	ICC	SEM (touches)	$MDC_{95\%}$ (touches)	CV (%)
1	0.68 [0.41; 0.84]	1.29 [1.01; 1.76]	3.57	7.70
2	0.89 [0.76; 0.95]	0.78 [0.61; 1.05]	2.13	4.62
3	0.87 [0.74; 0.94]	0.88 [0.70; 1.21]	2.45	4.83
mean(1,2)	0.83 [0.67; 0.92]	0.90 [0.70; 1.23]	2.48	5.46
mean(2,3)	0.92 [0.82; 0.96]	0.68 [0.53; 0.93]	1.87	4,07
mean(1,2,3)	0.89 [0.77; 0.95]	0.74 [0.59; 1.02]	2.06	4.44

Abbreviations: ICC for intraclass coefficient of correlation, SEM for standard error of measurements, $MDC_{95\%}$ for minimal detectable change at a confidence level of 95%, and CV for the coefficient of variation. Values in brackets correspond to the confidence interval at 95%.

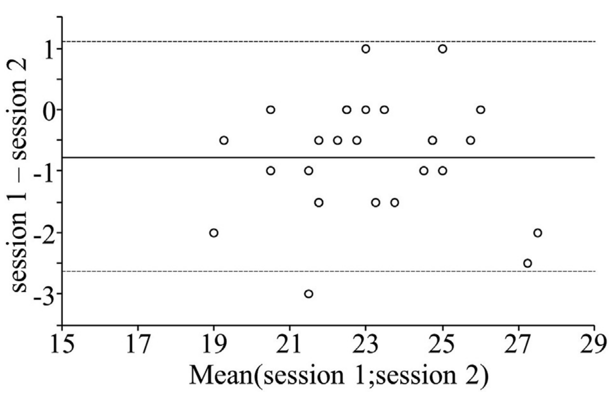

Fig. 2. Bland-Altman plot between the first and second sessions for m-CKCUEST score.

Table 4
Mean (±standard deviation, range in brackets) number of touches for the last four sets, mean sum of touches for combination of these sets in each session.

Set	Session 1	Session 2
4	22.0 ± 2.6 [18; 28]	22.4 ± 2.0 [19; 27]
5	18.9 ± 3.0 [9; 24]	19.2 ± 2.6 [13; 23]
6	16.7 ± 3.7 [7; 21]	17.7 ± 3.2 [9; 23]
7	16.2 ± 3.2 [10; 22]	17.2 ± 3.9 [5; 23]
mean(4,5)	20.4 ± 2.6 [14; 26]	20.8 ± 2.1 [17; 24.5]
mean(4,5,6)	19.2 ± 2.7 [12.7; 24.3]	19.8 ± 2.3 [14.3; 24]
mean(4,5,6,7)	18.5 ± 2.7 [12.3; 23.8]	19.1 ± 2.6 [12; 23.8]
mean(5,6)	17.8 ± 3.2 [9.5; 22.5]	18.4 ± 2.9 [11; 22.5]
mean(5,6,7)	17.3 ± 3.0 [10; 22.3]	18.0 ± 3.1 [9; 22.8]
mean(6,7)	16.5 ± 3.3 [8.5; 21.5]	17.4 ± 3.5 [7; 23]

first session and 0.88 for the second one, our ICC confirmed the good intrasession reliability. However, these values were increased when only the second and third sets were considered; 0.92 and 0.95, respectively. When we compared the numbers of touches between both the sessions, these numbers increased between the

Table 5
Inter-session reliability and agreement for the numbers of touches for sets 4 to 7, and mean of touches for combinations of these sets.

Sets	ICC	SEM (touches)	$MDC_{95\%}$ (touches)	CV (%)
4	0.65 [0.36; 0.82]	1.42 [1.12; 1.95]	3.93	8.77
5	0.48 [0.14; 0.73]	2.03 [1.96; 2.78]	5.61	13.42
6	0.80 [0.61; 0.90]	1.60 [1.26; 2.20]	4.45	12.67
7	0.76 [0.54; 0.88]	1.80 [1.42; 2.46]	4.98	12.26
mean(4,5)	0.59 [0.28; 0.79]	1.51 [1.19; 2.06]	4.18	9.80
mean(4,5,6)	0.70 [0.44; 0.85]	1.42 [1.12; 1.95]	3.95	9.86
mean(4,5,6,7)	0.80 [0.61; 0.90]	1.22 [0.96; 1.67]	3.32	8.59
mean(5,6)	0.71 [0.46; 0.86]	1.66 [1.31; 2.28]	4.61	12.20
mean(5,6,7)	0.81 [0.63; 0.91]	1.37 [1.08; 2.84]	3.81	10.11
mean(6,7)	0.87 [0.73; 0.94]	1.28 [1.01; 1.75]	3.56	9.87

Abbreviations: ICC for intraclass coefficient of correlation, SEM for standard error of measurements, $MDC_{95\%}$ for minimal detectable change at a confidence level of 95%, and CV for the coefficient of variation. Values in brackets correspond to the confidence interval at 95%.

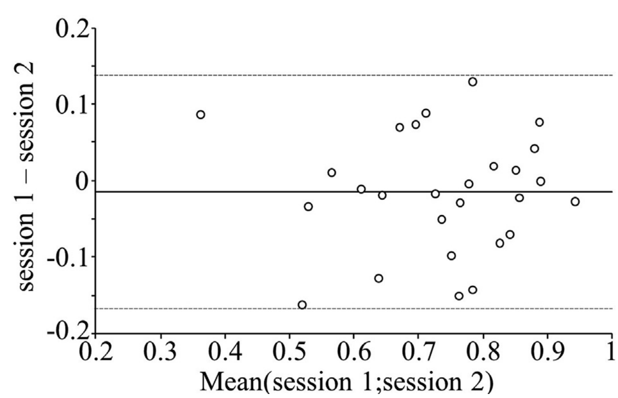

Fig. 3. Bland-Altman plot between the first and second sessions for Muscular Endurance Index.

first and second sessions, as reported by Oliveira et al. (de Oliveira et al., 2017) When considering the intersession reliability, performing only one set conducted to moderate reliability (ICC = 0.68) of the m-CKCUEST score, as already reported by Taylor et al. (Taylor et al., 2016) Computing this score based on the two first sets improved intersession reliability because ICC increased to 0.83 in our study and was similar to 0.85 reported by Sciascia et al. (Sciascia & Uhl, 2015) In this case, the lower limit of the ICC confidence interval remained below the threshold for a good reliability, i.e. 0.67. When the three first sets were considered, the ICC value increased to 0.89, which was like that reported by Tucci et al. (Tucci et al., 2014) and slightly lower than 0.92 found by Goldbeck & Davies (Goldbeck & Davies, 2000). However, the ICC value may be increased further when the second and third sets were considered to compute the m-CKCUEST score (ICC = 0.92). In this case, we found that all individuals, except one, were between the limits of agreement. Consequently, the m-CKCUEST score presented good reliability and agreement when averaging the numbers of touches for the second and third sets of 15 s sets with 45 s recovery.

Muscular endurance may be assessed through an index of performance decrement (Pincivero et al., 1997). In accordance with the tests reporting between 20 and 50 repetitions to fatigue an isolated muscle group (Pontillo et al., 2014; Stock, Beck, DeFreitas, & Ye, 2013; Maffiuletti, Bizzini, Desbrosses, Babault, & Munzinger, 2007), we instructed our participants to perform a fourth 1-min set after 15 s recovery following the third set, while the examiner counted the number of touches during each 15 s of the minute (sets 4 to 7). During this 1-min set, the number of touches decreased about 25% from the first 15 s to the last 15 s (Table 4), confirming that such an exertion may generate fatigue. However, the intersession reliability for set 4 was moderate, leading us to use the m-CKCUEST score as the performance baseline. Regarding the number of touches by quarter of the 1-min set, the highest intersession ICC value was obtained for the mean number of touches performed during the last two 15-s sets of the minute. The ratio between this mean and the m-CKCUEST score presented good reliability and agreement between sessions. The reliability observed for our endurance index was similar to the one measured for the shoulder internal/external rotator strength after a fatiguing protocol performed on an isokinetic dynamometer (Roy, Ma, Macdermid, & Woodhouse, 2011). Practically, it may be easier for the examiner to count the number of touches during the last 30 s of the minute and divide this number by two to be in the same temporal standards that the m-CKCUSET score.

This study presents some limitations that warrant discussion. The adaptation in push up position to the individual's body dimensions as well as the prolonged-exertion of the m-CKCUEST may be time-consuming when the m-CKCUEST is performed in clinical settings. Such a procedure however may provide two reliable outcome measures, which seem us to bring additional information on the upper limb functions. In addition, the modified testing procedure was made by male athletes in our study, demanding that the feasibility of this new procedure must be verified in population of different sexes, ages or sports or in population with shoulder problems. However, both the indexes presented in this study may be useful for strength and conditioning coaches and physiotherapists to assess overall shoulder/upper limb function and endurance. In addition, our results were obtained in an athletic population, and may serve as a benchmark for future score comparisons. Further studies also need to assess the validity of the m-CKCUEST score and muscular endurance index in different populations.

In conclusion, the findings of this study showed that normalizing hand spacing by participant's body dimension to perform the CKCUEST allowed a reliable m-CKCUEST score to be provided, when averaging the numbers of touches performed during the second and third sets. Moreover, the prolonged-exertion through a fourth set allowed a reliable index of muscular endurance to be provided. Both the outcome measures may be then used by strength and conditioning coaches and physiotherapists in order to diagnose upper extremity impairments, assess the effects of rehabilitation on upper extremity functions, or follow-up upper extremity abilities.

Conflict of interest

No conflict of interest.

Ethical statement

This study was approved by the Ethical Committee (n°2018-A03013-52).

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ptsp.2019.04.017.

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