Cluster analysis using physical performance and self-report measures to identify shoulder injury in overhead female athletes

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Abstract

Objectives: To evaluate the diagnostic validity of the Kerlan-Jobe orthopedic clinic shoulder and elbow score (KJOC) and the Closed kinetic upper extremity stability test (CKCUEST) to assess functional impairments associated with shoulder injury in overhead female athletic populations.

Design: Cross-sectional design.

Methods: Thirty-four synchronized swimming and team handball female athletes completed the KJOC and the CKCUEST during their respective team selection trials. Unsupervised learning using *k*-means algorithm was used on collected data to perform group clustering and classify athletes as *Injured* or *Not Injured*. Odds ratios, likelihood ratios, sensitivity and specificity were computed based on the self-reported presence of shoulder injury at the time of testing or during the previous year.

Results: Seven of the 34 athletes were injured or had suffered a time-loss injury in the previous year, representing a 20.5% prevalence rate. Clustering method using KJOC data resulted in a sensitivity of 86%, a specificity of 100% and a 229.67 diagnostic odds ratio. Clustering method using CKCUEST data resulted in a sensitivity of 86%, a specificity of 37% and a 3.53 diagnostic odds ratio.

Conclusions: KJOC had good diagnostic validity to assess shoulder function and differentiate between injured and non-injured elite synchronized swimming and team handball female athletes. The CKCUEST seemed to be a poor screening test but may be an interesting test to evaluate functional upper extremity strength and plyometric capacity. Unsupervised learning methods allow to make decisions based on numerous variables which is an advantage when considering the usually substantial overlap in screening test scores between high- and low-risk athletes.

Keywords

Shoulder stability; kinetics; scapula; rotator cuff; k-means,

Introduction

Shoulder injuries are among the most common injuries in aquatic and overhead sports such as synchronized swimming and handball [1,2]. Although extensive research exists on the risk factors associated with shoulder injury in overhead sports, there are yet to be universal guidelines regarding the screening process for shoulder injuries in these athletes.

Pre-participation screening and periodic health examination are recommended to help identify which athletes are injured or at an increased risk of injury [3,4]. While in the medical field the purpose of screening is to detect a disease as early as possible (before the appearance of noticeable signs or symptoms of the disease), screening for injury risk usually relies on detecting performance impairments which may predispose an athlete to an injury based on known risk factors [5]. Traditionally, screening has been done through the use of reliable performance and clinical tests evaluating strength and mobility deficits. Yet, these standardized clinical tests generally show poor predictive validity and Cook et al. [6] suggested that it may be because these tests do not assess an individual's movement quality and thus cannot detect functional deficits. To remedy this problem, a functional evaluation integrating qualitative and quantitative assessments of an athlete's performance on a task or sport-specific manoeuver has been proposed as a better alternative to assess function and the associated injury risks [7–9]. Various methods exist to assess function and usually fall into two general categories: physical performance measures (PPMs) and self-report measures (SRMs) [8,10]. Screening needs to be reliable, sensitive, specific, inexpensive, easy to perform and widely available [3]. To date, there are no single PPM able to predict shoulder injuries on its own [4,7,8].

Hegedus et al. [8] have recently suggested the Kerlan-Jobe orthopedic clinic shoulder and elbow score (KJOC) in combination with the closed kinetic chain upper extremity stability test

(CKCUEST), as SRM and PPM of the shoulder function for athletic population, respectively. The KJOC is a 10-item visual analog scale focusing on the functional/performance parameters, symptoms and interpersonal relationships of overhead athletes, where a score of 100 represents the highest level of function [11]. It has been validated in subgroups of asymptomatic and injured baseball [11,12], softball [13], football [14] and swimming populations [15] and generally shows high sensitivity and specificity as a diagnostic tool for upper extremity sport-related injuries [8]. However, there are no reports of its use in handball or synchronized swimming athletes.

The CKCUEST is a functional test designed to assess stability of the shoulder that is easy to administer and interpret for professionals in the field [16]. The CKCUEST imposes upper extremity axial loading in a closed-kinetic chain pattern where the athlete needs to alternatively lift one hand and touch the opposite hand as many times as possible over 15 seconds, while maintaining an extended push-up position with the hands 36 inches apart. Many studies have reported high reliability for the test [7,16–18] but its validity and responsiveness are still unsupported [4,8]. Although the CKCUEST is simple to administer and score, kinetic measures recorded by force platforms (e.g. peak ground reaction forces, rate of force development) could provide further information about its validity and may also help identify underlying performance impairments in injured athletes. A biomechanical analysis of the CKCUEST was carried out by Tucci et al. [19] to determine if scapular kinematics and kinetic measures were modified for three different distances between the hands at start. They reported no differences in scapular kinematics and kinetics between the original 36 inches, the inter-acromial length and the 150 % inter-acromial length distances when performing the CKCUEST. Yet, their study had many limitations and associations between kinematic or kinetic measures and CKCUEST performance were not reported. Pontillo et al. [20] are the only ones who evaluated the diagnostic validity of the CKCUEST. In college football athletes, they reported that a cut-off score of 21 touches resulted in a sensitivity of 0.83 and a specificity of 0.79 in determining whether a player would sustain a shoulder injury during the season. Yet, the diagnostic capacity of the CKCUEST in identifying overhead athletes at risk of shoulder injury has not yet been established [8] and requires further research.

The purpose of this study was therefore to evaluate the diagnostic validity of the KJOC and CKCUEST to assess functional impairments associated with shoulder injury in an overhead athletic population composed of synchronized swimming and handball athletes. More specifically, the objective was to determine if the results from those tests could correctly identify injured from non-injured athletes. To that end, unsupervised learning methods (k-mean clustering) and 2x2 contingency tables were used.

Methods

The present study was completed with the Canadian national synchronized swimming and team handball programs as part of their respective team selection trials. Every active athlete attending their respective team selection trials was eligible for participation, irrespective of their shoulder pain status or history. Exclusion criteria was a current injury preventing them from training or completing the CKCUEST at the time of testing. In total, 34 female athletes (age: 21.7 ± 5.2 years; height: 167.5 ± 6.6 cm; mass: 61.7 ± 8.5 kg) agreed to participate in this study: 23 synchronized swimmers and 11 handball players. Most participants were right-handed (31 of 34) and had on average 13.4 ± 3.5 years of experience in their sport. The local University Research Ethics Committee approved all procedures undertaken in this study and all participants read and signed a written informed consent form before testing. When participants (n = 7) were younger than 18 years, parental/legal guardian consent was obtained.

The athletes first completed the KJOC questionnaire which included a demographic intake sheet where data on sports participation and injury history were collected. Athletes also had to report whether they were either: (1) playing with no pain, (2) playing with pain, or (3) not playing due to pain, the latter being an exclusion criterion for the present study. The athletes then completed the CKCUEST over two AccuGait (AMTI, Watertown, MA, USA) force platforms. Although force platforms are not required to evaluate athletes on the CKCUEST, we chose to use them to complement this functional test for two reasons: (1) a better understanding of the biomechanics of the test could allow for an improved validity assessment and (2) it is possible that variables other than the CKCUEST score could be linked to injury risk. The centers of the force platforms were marked by a piece of tape and spaced 36 inches center-to-center. The participants performed three trials of the CKCUEST with 45 seconds rest between trials, as described by Goldbeck et al. [16]. The number of hand touches of the best two trials were kept for analysis. The evaluators were blinded to the injury status of the athletes as the KJOC questionnaire was compiled post hoc.

Force and moment data were acquired during the CKCUEST along the *X*-axis (medio-lateral), *Y*-axis (antero-posterior) and *Z*-axis (vertical) at a sampling rate of 400 Hz using NetForce 2.4 software (AMTI, Watertown, MA, USA). Only the best two trials were kept for analysis. A zero-lag 4th order Butterworth low-pass filter with a cut-off frequency of 20 Hz was applied to the raw force plate signals. Support and swing phases of each arm were then identified from the Z-axis force signals using 10 N as the cut-off value. For each axis, peak ground reaction force (GRF), time to peak GRF (TTP) and rate of force development (RFD) over 100 ms at impact were extracted for each repetition of each arm and were then averaged over the two trials. After normalizing GRF and RFD to bodyweight, mean GRF, TTP and RFD for the dominant and non-dominant arms were used for analysis.

Group clustering was determined using *k*-means for KJOC (individual item and total scores) and CKCUEST (GRF, TTP, RFD, number of touches) data separately in order to assign athletes in one of two clusters (*Injured* and *Not Injured*). *K*-means clustering is an unsupervised iterative process where an algorithm is used to assign *n* observations into *k* sets so as to minimize the within-cluster sum of squares (i.e. variance) [21]. Prior to using *k*-means clustering, KJOC and CKCUEST data were standardized using a Z-score to ensure all variables had the same *units* and *weight* in the *k*-means algorithm. There are two advantages to using *k*-means clustering here: (1) it enables to use multiple variables at the same time to classify the athletes and (2) it doesn't require to set cut-off values for each variable, which usually results in substantial overlap between high and low risk of injury [5]. Then, 2x2 contingency tables were created to compare *Injured* and *Not Injured* clusters with the athletes' self-reported injury status. An athlete was placed in the *Injury* group if she identified herself as "playing with pain" and/or had answered "yes" to the KJOC question asking if she suffered any time-loss injury in the past year. Sensitivity, specificity, positive (LR+) and negative (LR-) likelihood ratios as well as diagnostic odds ratio (DOR) were computed from the contingency tables. When sensitivity or specificity was equal 100%, 0.5 was added to every value in the contingency table, which is a commonly used method to calculate an approximation of the diagnostic odds ratio [22]. Finally, for each variable, centroids (mean of the clusters) were extracted for the *Injured* and *Not Injured* clusters and the difference in the mean was computed as an effect size (ES) to determine which variables explained most of the differences between the clusters. All data processing and statistical analyses were carried out using R 3.4.3 software [23].

Results

At the time of testing, 7 of the 34 athletes were injured or had suffered a time-loss injury in the previous year according to the self-reported answers from the KJOC, equating to a 20.5% prevalence rate. Athletes who reported an injury scored 32.1 ± 2.3 while those competing without an injury scored 27.3 ± 3.5 touches on the CKCUEST.

Contingency tables resulting from *k*-means clustering using KJOC and CKCUEST data are presented in Table 1. Clustering using KJOC data resulted in a sensitivity of 86%, a specificity of 100% (LR+ = 43.88, LR- = 0.19, DOR = 229.67). Clustering using CKCUEST data resulted in a sensitivity of 86%, a specificity of 37% (LR+ = 1.36, LR- = 0.39, DOR = 3.53).

[Insert Table 1 about here]

KJOC item about feeling of instability was the parameter with the biggest difference between the two clusters (ES = -9.31 [95% CI ± 2.51]). In addition, total KJOC score (ES = -5.35 [95% CI ± 1.63]) and effect on the level of competition (ES = -4.19 [95% CI ± 1.4]) also showed large effect sizes between the clusters (Figure 1). For the CKCUEST, dominant and non-dominant peak RFD in the *Y*-axis showed the biggest absolute differences between the two clusters (ES = 2.69 [95% CI ± 1] and 2.12 [95% CI ± 0.91], respectively), followed by the number of touches (ES = 2.11 [95% CI ± 0.91]) and TTP in *Y* and *Z* axes for the dominant hand (ES between -2.06 and -2.26), as shown in Figure 2.

[Insert Figure 1 about here] [Insert Figure 2 about here]

Discussion

The purpose of this study was to evaluate the diagnostic validity of the KJOC and the CKCUEST, to assess functional impairments associated with shoulder injury in synchronized swimming and handball athletes. While athletes classified to the *Injured* cluster based on KJOC results were 229.67 times more likely to have a shoulder injury, athletes in the *Injured* cluster based on CKCUEST results were only 3.53 times more likely to be injured than the athletes in the *Not Injured* cluster.

Applying *k*-means clustering technique on the results from the KJOC questionnaire, we were able to correctly identify all non-injured athletes and all but one injured athletes. KJOC scores ranging from 89.7 to 97.5 have been reported in uninjured collegiate athletes while KJOC score can range from 47.5 to 82 in athletes with upper extremity injuries [8]. In the present study, mean KJOC score was 64.8 ± 6.7 and 94.6 ± 5.3 for the first (*Injured*) and second (*Not Injured*) clusters, respectively, which represented a -5.35 [95% CI ± 1.63] effect size. Because of this very large difference in score between the two clusters, it turns out that a cut-off value between 76.3 (highest value of the *Injured* cluster) and 82.3 (lowest value of the *Not Injured* cluster) would have resulted in the same sensitivity and specificity as our current model. This cut-off criterion would have been similar to the previously reported 81.3 [24] and 86.0 [25] cut-off scores, which provided similar diagnostic accuracy (91-100% sensitivity and 83-90% specificity) as our present model. Therefore, the KJOC appears to have good diagnostic validity and would be a useful SRM tool to assess functional impairments associated with shoulder injury in synchronized swimming and handball athletes.

On the other hand, applying *k*-means clustering on the CKCUEST results showed poorer diagnostic validity in identifying athletes suffering from shoulder injury from the healthy athletes. Although the CKCUEST seemed to have a good capacity to correctly detect injured athletes (sensitivity of 86%), it is important to note that injured athletes had higher CKCUEST score than non-injured athletes (32.1 ± 2.3 and 27.3 ± 3.5 touches, respectively). Taking into account that the purpose of the CKCUEST as a screening test is to identify functional impairments to the upper extremities that may predispose an athlete to injuries, the test does not seem to fulfill its objective. Pontillo et al. [20] had suggested a cut-off criteria of 21 touches in a population of college football players. Had this cut-off criteria been used, the resulting sensitivity of 0% and specificity of 96% would have led to no single injury detected by the CKCUEST. Contrary to Pontillo et al. [20], Sciascia & Uhl [7] reported that the CKCUEST could not distinguish between individuals with and without shoulder symptoms, yet their study only included non-athletic participants. Furthermore, Tarara [25] did not find a significant difference in the number of touches on the CKCUEST between injured and non-injured groups of baseball players. Our results are in accordance with these observations and suggest that the CKCUEST should not be used as a stand-alone screening tool for shoulder injury in overhead athletes, at least in synchronized swimming and female handball athletes.

Despite its poor utility in identifying overhead athletes suffering from a shoulder injury, the CKCUEST may have some utility if the objective is to assess upper extremity closed-kinetic functional strength. Indeed, data obtained from the force platforms showed that higher RFDs and peak GRFs were associated with higher CKCUEST score, as illustrated in Figure 2 and confirmed by a supplementary correlation analysis (see Supplementary Table). Tucci et al. [19] also reported high GFRs during the CKCUEST (up to 68 % of bodyweight) and suggested that for this reason, the test may not be suitable for populations with severe shoulder dysfunction. Furthermore, average contact time per repetition was 0.64 ± 0.11 s, which is even smaller than contact times recorded during common plyometric push-up variations [26]. To that end, CKCUEST could be regarded as an interesting PPM to assess plyometric performance of the upper extremities, as suggested by Westrick et al. [27]. In sports such as American football, where most shoulder injuries are caused by direct trauma to the shoulder [28] and main sport-specific actions are closed-chain (pushing, tackling), higher functional strength in closed-kinetic chain movements, like the CKCUEST, may have a protective effect. On the other hand, the most common cause of shoulder injuries in synchronized swimmers and handball players is overuse [1,2] and those sports involve mostly open-chain sport-specific movements (throwing, sculling). This could explain why Pontillo et al. [20] observed that college football players with low CKCUEST score were 18.75 more likely to get a shoulder injury than high performers while high CKCUEST score was not protective of shoulder injury in the present study. The CKCUEST may thus have some utility as a shoulder injury screening test in contact sports, such as football and rugby, although further research is required. Alternative tests targeting open-chain movements, such as the unilateral seated shot put [4] should be further explored in overhead athletes populations.

The choice of using *k*-means clustering instead of using a cut-off value to classify athletes based on their KJOC or CKCUEST score was motivated by the substantial overlap previously reported in screening test scores between athletes with high and low risk of injury [5]. In addition, cut-off criteria can vary from one population to another. For instance, optimal cut-off criteria for the CKCUEST in the present study (maximizing the product of sensitivity and specificity [29]) would have been 30 touches compared to the 21 touches suggested by Pontillo et al. [20], yet it would have resulted in poor sensitivity and specificity of 29% and 26%, respectively. *K*-means clustering aims to find similarities among data points through an iterative process and can take in multiple variables at once. Considering the fact that no single PPM has sufficient test properties to predict upper extremity injuries on its own [4,8], *k*-means clustering may provide an advantage for analyzing numerous parameters at the same time. This method proved to be highly accurate at identifying injured athletes using KJOC data. Cluster analysis using CKCUEST data was not as successful, although the obtained diagnostic accuracy was superior to using a cut-off criterion.

The present study has some limitations. Although our results show that the KJOC could identify injured athletes with high accuracy, there is no assurance that it would be as accurate in predicting future injuries. In fact, the self-responsive nature of the KJOC [8] and its high responsiveness to shoulder function suggest it could be a better tool for diagnostic than prediction. Only female athletes were included as part of this study which limits the generalizability of our results to male athletic populations. Although our sample size was small and only included 7 injuries, the prevalence rate was similar to those reported in the literature for the populations of interest [1,2]. Future research involving different cohorts and bigger sample size should be carried to validate our findings.

Conclusions

The current study showed that the KJOC questionnaire could be a valid and useful SRM to assess shoulder function and differentiate between injured and non-injured athletes, in synchronized swimming and team handball. On the other hand, the CKCUEST seemed to be a poor screening test but appeared to be an interesting tool for evaluating upper extremity functional strength and plyometric capacity. Therefore, contrary to the suggestion of Hegedus et al. [8], we doubt that the CKCUEST can be considered an interesting PPM to be used in combination with the KJOC when screening for shoulder injuries in overhead athletes. It may, however, have some utility as a screening tool in contact sports such as football or rugby where shoulder injuries are often caused by direct trauma rather than overuse. Finally, *k*-means clustering appears to be an interesting method to group athletes with similarities over an ensemble of parameters which could improve the accuracy of screening protocols in identifying athletes at high or low risk of shoulder injury.

Practical implications

- The KJOC questionnaire is a valid and useful screening tool to identify athletes competing with a shoulder injury.
- The CKCUEST should not be used as a stand-alone screening tool in identifying injured athletes but appears to be an interesting test for evaluating upper extremity functional strength and plyometric capacity.
- Unsupervised learning such as *k*-means provides an advantage over the use of cut-off criteria as it can take into account multiple parameters to identify injured athletes which in turn improves sensitivity and specificity.

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Tables

Table 1: 2×2 contingency tables indicating in which cluster (*Injured* or *Not Injured*) an athlete was classified and if they had suffered a shoulder injury or were healthy, using k-means clustering on KJOC data (left) and CKCUEST data (right).

KJOC	Injury	Healthy
Injured	6	0
Not Injured	1	26

CKCUEST	Injury	Healthy
Injured	6	17
Not Injured	1	10

Note: one athlete omitted to answer the KJOC questions and was only included in the CKCUEST analysis which explains the differing sample sizes.

Captions to Figures

Figure 1: Effect size (point) and 95% CI (line range) between *Injured* and *Non-Injured* clusters' centroids sorted in descending order for the KJOC data. A negative effect size indicates a higher Z-score for the *Non-Injured* cluster.

Figure 2: Effect size (point) and 95% CI (line range) between *Injured* and *Non-Injured* clusters' centroids sorted in descending order for the CKCUEST data. A positive effect size indicates a higher Z-score for the *Injured* cluster and vice-versa. GRF, peak ground reaction force; TTP, time to peak ground reaction force; RFD, rate of force development; D, dominant arm; N-D, non-dominant arm.

FIGURE 1:

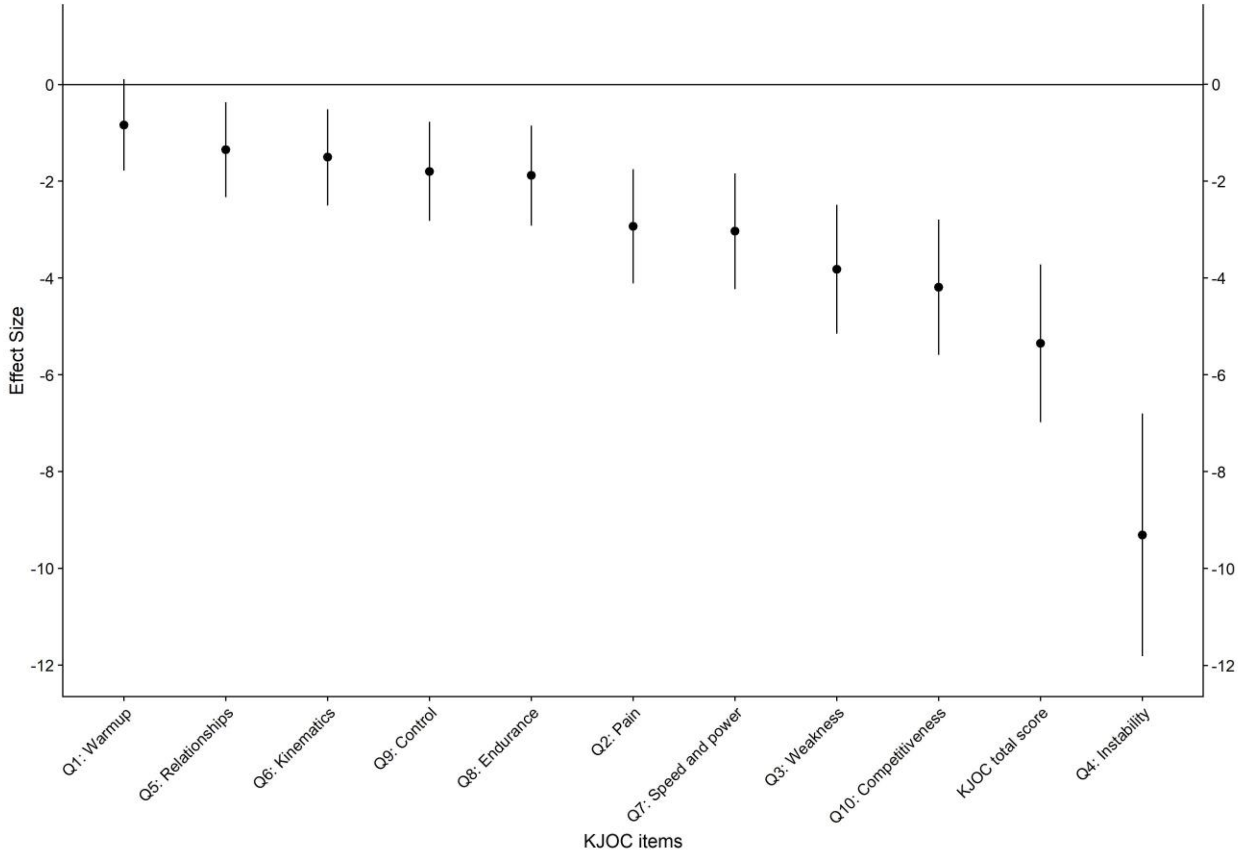
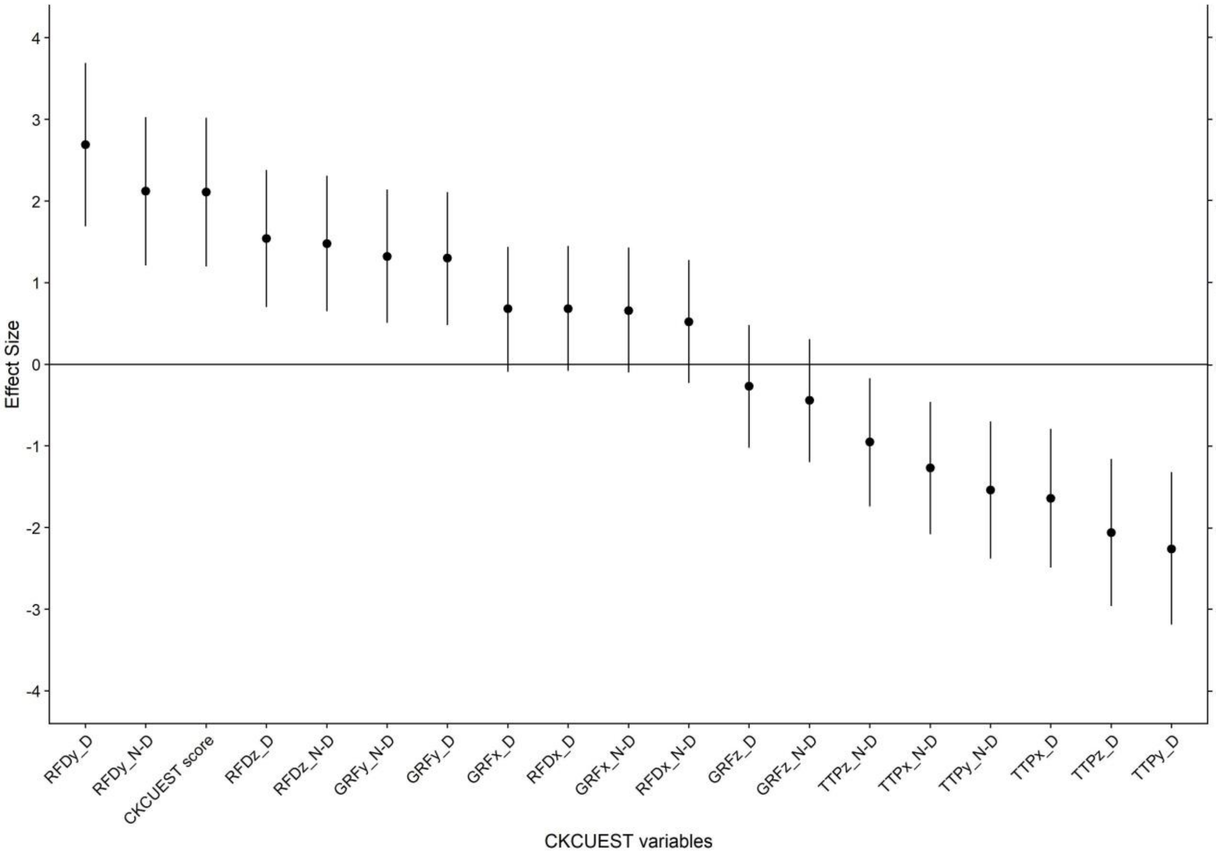

Effect Size
0
-2
-4
-6
-8
-10
-12
Q1: Warmup
Q5: Relationships
Q6: Kinematics
Q9: Control
Q8: Endurance
Q2: Pain
Q7: Speed and power
Q3: Weakness
Q10: Competitiveness
KJOC total score
Q4: Instability
KJOC items

FIGURE 2:


Effect Size
4
3
2
1
0
-1
-2
-3
-4
RFDy_D
RFDy_N-D
CKCUEST score
RFDz_D
RFDz_N-D
GRFy_N-D
GRFy_D
GRFx_D
RFDx_D
GRFx_N-D
RFDx_N-D
GRFz_D
GRFz_N-D
TTPz_N-D
TTPx_N-D
TTPy_N-D
TTPx_D
TTPz_D
TTPy_D
CKCUEST variables

Supplementary Table

Supplementary Table 1: Pearson *r* coefficients between CKCUEST score and the kinetic parameters obtained with the forceplate, sorted by descending order.

Forceplate parameter	Pearson *r* coefficient
RFDy_D	0.72
RFDz_D	0.67
RFDz_N-D	0.62
RFDy_N-D	0.62
GRFx_N-D	0.49
GRFx_D	0.48
GRFy_D	0.42
GRFy_N-D	0.41
RFDx_N-D	0.26
RFDx_D	0.26
GRFz_D	0.12
GRFz_N-D	-0.11
TTPx_D	-0.43
TTPz_N-D	-0.43
TTPx_N-D	-0.50
TTPy_N-D	-0.52
TTPz_D	-0.54
TTPy_D	-0.71