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

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1 **Abstract**

2 *Objectives*: To evaluate the diagnostic validity of the Kerlan-Jobe orthopedic clinic

3 shoulder and elbow score (KJOC) and the Closed kinetic upper extremity stability test

4 (CKCUEST) to assess functional impairments associated with shoulder injury in overhead

5 female athletic populations.

6 *Design*: Cross-sectional design.

7 *Methods*: Thirty-four synchronized swimming and team handball female athletes

8 completed the KJOC and the CKCUEST during their respective team selection trials.

9 Unsupervised learning using *k*-means algorithm was used on collected data to perform group

10 clustering and classify athletes as *Injured* or *Not Injured*. Odds ratios, likelihood ratios, sensitivity

11 and specificity were computed based on the self-reported presence of shoulder injury at the time

12 of testing or during the previous year.

13 *Results*: Seven of the 34 athletes were injured or had suffered a time-loss injury in the

14 previous year, representing a 20.5% prevalence rate. Clustering method using KJOC data

15 resulted in a sensitivity of 86%, a specificity of 100% and a 229.67 diagnostic odds ratio.

16 Clustering method using CKCUEST data resulted in a sensitivity of 86%, a specificity of 37%

17 and a 3.53 diagnostic odds ratio.

18 *Conclusions*: KJOC had good diagnostic validity to assess shoulder function and

19 differentiate between injured and non-injured elite synchronized swimming and team handball

20 female athletes. The CKCUEST seemed to be a poor screening test but may be an interesting

21 test to evaluate functional upper extremity strength and plyometric capacity. Unsupervised

22 learning methods allow to make decisions based on numerous variables which is an advantage

23   when considering the usually substantial overlap in screening test scores between high- and

24   low-risk athletes.

25   **Keywords**

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

27

Introduction

29   Shoulder injuries are among the most common injuries in aquatic and overhead sports

30 such as synchronized swimming and handball [1,2]. Although extensive research exists on the risk

31 factors associated with shoulder injury in overhead sports, there are yet to be universal

32 guidelines regarding the screening process for shoulder injuries in these athletes.

33   Pre-participation screening and periodic health examination are recommended to help

34 identify which athletes are injured or at an increased risk of injury [3,4]. While in the medical field

35 the purpose of screening is to detect a disease as early as possible (before the appearance of

36 noticeable signs or symptoms of the disease), screening for injury risk usually relies on detecting

37 performance impairments which may predispose an athlete to an injury based on known risk

38 factors [5]. Traditionally, screening has been done through the use of reliable performance and

39 clinical tests evaluating strength and mobility deficits. Yet, these standardized clinical tests

40 generally show poor predictive validity and Cook et al. [6] suggested that it may be because these

41 tests do not assess an individual's movement quality and thus cannot detect functional deficits.

42 To remedy this problem, a functional evaluation integrating qualitative and quantitative

43 assessments of an athlete's performance on a task or sport-specific manoeuver has been

44 proposed as a better alternative to assess function and the associated injury risks [7–9]. Various

45 methods exist to assess function and usually fall into two general categories: physical

46 performance measures (PPMs) and self-report measures (SRMs) [8,10]. Screening needs to be

47 reliable, sensitive, specific, inexpensive, easy to perform and widely available [3]. To date, there

48 are no single PPM able to predict shoulder injuries on its own [4,7,8].

49   Hegedus et al. [8] have recently suggested the Kerlan-Jobe orthopedic clinic shoulder and

50 elbow score (KJOC) in combination with the closed kinetic chain upper extremity stability test

4

51 (CKCUEST), as SRM and PPM of the shoulder function for athletic population, respectively. The

52 KJOC is a 10-item visual analog scale focusing on the functional/performance parameters,

53 symptoms and interpersonal relationships of overhead athletes, where a score of 100 represents

54 the highest level of function [11]. It has been validated in subgroups of asymptomatic and injured

55 baseball [11,12], softball [13], football [14] and swimming populations [15] and generally shows high

56 sensitivity and specificity as a diagnostic tool for upper extremity sport-related injuries [8].

57 However, there are no reports of its use in handball or synchronized swimming athletes.

58 The CKCUEST is a functional test designed to assess stability of the shoulder that is

59 easy to administer and interpret for professionals in the field [16]. The CKCUEST imposes upper

60 extremity axial loading in a closed-kinetic chain pattern where the athlete needs to alternatively

61 lift one hand and touch the opposite hand as many times as possible over 15 seconds, while

62 maintaining an extended push-up position with the hands 36 inches apart. Many studies have

63 reported high reliability for the test [7,16–18] but its validity and responsiveness are still

64 unsupported [4,8]. Although the CKCUEST is simple to administer and score, kinetic measures

65 recorded by force platforms (e.g. peak ground reaction forces, rate of force development) could

66 provide further information about its validity and may also help identify underlying performance

67 impairments in injured athletes. A biomechanical analysis of the CKCUEST was carried out by

68 Tucci et al. [19] to determine if scapular kinematics and kinetic measures were modified for three

69 different distances between the hands at start. They reported no differences in scapular

70 kinematics and kinetics between the original 36 inches, the inter-acromial length and the 150 %

71 inter-acromial length distances when performing the CKCUEST. Yet, their study had many

72 limitations and associations between kinematic or kinetic measures and CKCUEST performance

73 were not reported. Pontillo et al. [20] are the only ones who evaluated the diagnostic validity of the

74 CKCUEST. In college football athletes, they reported that a cut-off score of 21 touches resulted

75 in a sensitivity of 0.83 and a specificity of 0.79 in determining whether a player would sustain a

76   shoulder injury during the season. Yet, the diagnostic capacity of the CKCUEST in identifying

77   overhead athletes at risk of shoulder injury has not yet been established [8] and requires further

78   research.

79   The purpose of this study was therefore to evaluate the diagnostic validity of the KJOC

80   and CKCUEST to assess functional impairments associated with shoulder injury in an overhead

81   athletic population composed of synchronized swimming and handball athletes. More

82   specifically, the objective was to determine if the results from those tests could correctly identify

83   injured from non-injured athletes. To that end, unsupervised learning methods (k-mean

84   clustering) and 2x2 contingency tables were used.

85   **Methods**

86   The present study was completed with the Canadian national synchronized swimming

87   and team handball programs as part of their respective team selection trials. Every active athlete

88   attending their respective team selection trials was eligible for participation, irrespective of their

89   shoulder pain status or history. Exclusion criteria was a current injury preventing them from

90   training or completing the CKCUEST at the time of testing. In total, 34 female athletes (age:

91   21.7 ± 5.2 years; height: 167.5 ± 6.6 cm; mass: 61.7 ± 8.5 kg) agreed to participate in this study:

92   23 synchronized swimmers and 11 handball players. Most participants were right-handed (31 of

93   34) and had on average 13.4 ± 3.5 years of experience in their sport. The local University

94   Research Ethics Committee approved all procedures undertaken in this study and all

95   participants read and signed a written informed consent form before testing. When participants

96   (n = 7) were younger than 18 years, parental/legal guardian consent was obtained.

97   The athletes first completed the KJOC questionnaire which included a demographic

98   intake sheet where data on sports participation and injury history were collected. Athletes also

99   had to report whether they were either: (1) playing with no pain, (2) playing with pain, or (3) not

100 playing due to pain, the latter being an exclusion criterion for the present study. The athletes

101 then completed the CKCUEST over two AccuGait (AMTI, Watertown, MA, USA) force platforms.

102 Although force platforms are not required to evaluate athletes on the CKCUEST, we chose to

103 use them to complement this functional test for two reasons: (1) a better understanding of the

104 biomechanics of the test could allow for an improved validity assessment and (2) it is possible

105 that variables other than the CKCUEST score could be linked to injury risk. The centers of the

106 force platforms were marked by a piece of tape and spaced 36 inches center-to-center. The

107 participants performed three trials of the CKCUEST with 45 seconds rest between trials, as

108 described by Goldbeck et al. [16]. The number of hand touches of the best two trials were kept for

109 analysis. The evaluators were blinded to the injury status of the athletes as the KJOC

110 questionnaire was compiled post hoc.

111   Force and moment data were acquired during the CKCUEST along the X-axis (medio-

112 lateral), Y-axis (antero-posterior) and Z-axis (vertical) at a sampling rate of 400 Hz using

113 NetForce 2.4 software (AMTI, Watertown, MA, USA). Only the best two trials were kept for

114 analysis. A zero-lag 4th order Butterworth low-pass filter with a cut-off frequency of 20 Hz was

115 applied to the raw force plate signals. Support and swing phases of each arm were then

116 identified from the Z-axis force signals using 10 N as the cut-off value. For each axis, peak

117 ground reaction force (GRF), time to peak GRF (TTP) and rate of force development (RFD) over

118 100 ms at impact were extracted for each repetition of each arm and were then averaged over

119 the two trials. After normalizing GRF and RFD to bodyweight, mean GRF, TTP and RFD for the

120 dominant and non-dominant arms were used for analysis.

121   Group clustering was determined using k-means for KJOC (individual item and total

122 scores) and CKCUEST (GRF, TTP, RFD, number of touches) data separately in order to assign

123   athletes in one of two clusters (*Injured* and *Not Injured*). *K*-means clustering is an unsupervised

124   iterative process where an algorithm is used to assign *n* observations into *k* sets so as to

125   minimize the within-cluster sum of squares (i.e. variance) [21]. Prior to using *k*-means clustering,

126   KJOC and CKCUEST data were standardized using a Z-score to ensure all variables had the

127   same *units* and *weight* in the *k*-means algorithm. There are two advantages to using *k*-means

128   clustering here: (1) it enables to use multiple variables at the same time to classify the athletes

129   and (2) it doesn't require to set cut-off values for each variable, which usually results in

130   substantial overlap between high and low risk of injury [5]. Then, 2x2 contingency tables were

131   created to compare *Injured* and *Not Injured* clusters with the athletes' self-reported injury status.

132   An athlete was placed in the *Injury* group if she identified herself as "playing with pain" and/or

133   had answered "yes" to the KJOC question asking if she suffered any time-loss injury in the past

134   year. Sensitivity, specificity, positive (LR+) and negative (LR-) likelihood ratios as well as

135   diagnostic odds ratio (DOR) were computed from the contingency tables. When sensitivity or

136   specificity was equal 100%, 0.5 was added to every value in the contingency table, which is a

137   commonly used method to calculate an approximation of the diagnostic odds ratio [22]. Finally, for

138   each variable, centroids (mean of the clusters) were extracted for the *Injured* and *Not Injured*

139   clusters and the difference in the mean was computed as an effect size (ES) to determine which

140   variables explained most of the differences between the clusters. All data processing and

141   statistical analyses were carried out using R 3.4.3 software [23].

142   **Results**

143   At the time of testing, 7 of the 34 athletes were injured or had suffered a time-loss injury

144   in the previous year according to the self-reported answers from the KJOC, equating to a 20.5%

145   prevalence rate. Athletes who reported an injury scored 32.1 ± 2.3 while those competing

146   without an injury scored 27.3 ± 3.5 touches on the CKCUEST.

147   Contingency tables resulting from *k*-means clustering using KJOC and CKCUEST data

148   are presented in Table 1. Clustering using KJOC data resulted in a sensitivity of 86%, a

149   specificity of 100% (LR+ = 43.88, LR- = 0.19, DOR = 229.67). Clustering using CKCUEST data

150   resulted in a sensitivity of 86%, a specificity of 37% (LR+ = 1.36, LR- = 0.39, DOR = 3.53).

151   [Insert Table 1 about here]

152   KJOC item about feeling of instability was the parameter with the biggest difference

153   between the two clusters (ES = -9.31 [95% CI ± 2.51]). In addition, total KJOC score (ES = -

154   5.35 [95% CI ± 1.63]) and effect on the level of competition (ES = -4.19 [95% CI ± 1.4]) also

155   showed large effect sizes between the clusters (Figure 1). For the CKCUEST, dominant and

156   non-dominant peak RFD in the *Y*-axis showed the biggest absolute differences between the two

157   clusters (ES = 2.69 [95% CI ± 1] and 2.12 [95% CI ± 0.91], respectively), followed by the number

158   of touches (ES = 2.11 [95% CI ± 0.91]) and TTP in *Y* and *Z* axes for the dominant hand (ES

159   between -2.06 and -2.26), as shown in Figure 2.

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

161   **Discussion**

162   The purpose of this study was to evaluate the diagnostic validity of the KJOC and the

163   CKCUEST, to assess functional impairments associated with shoulder injury in synchronized

164   swimming and handball athletes. While athletes classified to the *Injured* cluster based on KJOC

165   results were 229.67 times more likely to have a shoulder injury, athletes in the *Injured* cluster

166   based on CKCUEST results were only 3.53 times more likely to be injured than the athletes in

167   the *Not Injured* cluster.

168   Applying *k*-means clustering technique on the results from the KJOC questionnaire, we

169   were able to correctly identify all non-injured athletes and all but one injured athletes. KJOC

170   scores ranging from 89.7 to 97.5 have been reported in uninjured collegiate athletes while KJOC

171   score can range from 47.5 to 82 in athletes with upper extremity injuries [8]. In the present study,

172   mean KJOC score was 64.8 ± 6.7 and 94.6 ± 5.3 for the first (*Injured*) and second (*Not Injured*)

173   clusters, respectively, which represented a -5.35 [95% CI ± 1.63] effect size. Because of this

174   very large difference in score between the two clusters, it turns out that a cut-off value between

175   76.3 (highest value of the *Injured* cluster) and 82.3 (lowest value of the *Not Injured* cluster)

176   would have resulted in the same sensitivity and specificity as our current model. This cut-off

177   criterion would have been similar to the previously reported 81.3 [24] and 86.0 [25] cut-off scores,

178   which provided similar diagnostic accuracy (91-100% sensitivity and 83-90% specificity) as our

179   present model. Therefore, the KJOC appears to have good diagnostic validity and would be a

180   useful SRM tool to assess functional impairments associated with shoulder injury in

181   synchronized swimming and handball athletes.

182   On the other hand, applying *k*-means clustering on the CKCUEST results showed poorer

183   diagnostic validity in identifying athletes suffering from shoulder injury from the healthy athletes.

184   Although the CKCUEST seemed to have a good capacity to correctly detect injured athletes

185   (sensitivity of 86%), it is important to note that injured athletes had higher CKCUEST score than

186   non-injured athletes (32.1 ± 2.3 and 27.3 ± 3.5 touches, respectively). Taking into account that

187   the purpose of the CKCUEST as a screening test is to identify functional impairments to the

188   upper extremities that may predispose an athlete to injuries, the test does not seem to fulfill its

189   objective. Pontillo et al. [20] had suggested a cut-off criteria of 21 touches in a population of

190   college football players. Had this cut-off criteria been used, the resulting sensitivity of 0% and

191   specificity of 96% would have led to no single injury detected by the CKCUEST. Contrary to

192   Pontillo et al. [20], Sciascia & Uhl [7] reported that the CKCUEST could not distinguish between

193   individuals with and without shoulder symptoms, yet their study only included non-athletic

194   participants. Furthermore, Tarara [25] did not find a significant difference in the number of touches

195   on the CKCUEST between injured and non-injured groups of baseball players. Our results are in

196   accordance with these observations and suggest that the CKCUEST should not be used as a

197   stand-alone screening tool for shoulder injury in overhead athletes, at least in synchronized

198   swimming and female handball athletes.

199   Despite its poor utility in identifying overhead athletes suffering from a shoulder injury,

200   the CKCUEST may have some utility if the objective is to assess upper extremity closed-kinetic

201   functional strength. Indeed, data obtained from the force platforms showed that higher RFDs

202   and peak GRFs were associated with higher CKCUEST score, as illustrated in Figure 2 and

203   confirmed by a supplementary correlation analysis (see Supplementary Table). Tucci et al. [19]

204   also reported high GFRs during the CKCUEST (up to 68 % of bodyweight) and suggested that

205   for this reason, the test may not be suitable for populations with severe shoulder dysfunction.

206   Furthermore, average contact time per repetition was 0.64 ± 0.11 s, which is even smaller than

207   contact times recorded during common plyometric push-up variations [26]. To that end, CKCUEST

208   could be regarded as an interesting PPM to assess plyometric performance of the upper

209   extremities, as suggested by Westrick et al. [27]. In sports such as American football, where most

210   shoulder injuries are caused by direct trauma to the shoulder [28] and main sport-specific actions

211   are closed-chain (pushing, tackling), higher functional strength in closed-kinetic chain

212   movements, like the CKCUEST, may have a protective effect. On the other hand, the most

213   common cause of shoulder injuries in synchronized swimmers and handball players is

214   overuse [1,2] and those sports involve mostly open-chain sport-specific movements (throwing,

215   sculling). This could explain why Pontillo et al. [20] observed that college football players with low

216   CKCUEST score were 18.75 more likely to get a shoulder injury than high performers while high

217   CKCUEST score was not protective of shoulder injury in the present study. The CKCUEST may

218   thus have some utility as a shoulder injury screening test in contact sports, such as football and

219   rugby, although further research is required. Alternative tests targeting open-chain movements,

220   such as the unilateral seated shot put [4] should be further explored in overhead athletes

221   populations.

222   The choice of using *k*-means clustering instead of using a cut-off value to classify

223   athletes based on their KJOC or CKCUEST score was motivated by the substantial overlap

224   previously reported in screening test scores between athletes with high and low risk of injury [5]. In

225   addition, cut-off criteria can vary from one population to another. For instance, optimal cut-off

226   criteria for the CKCUEST in the present study (maximizing the product of sensitivity and

227   specificity [29]) would have been 30 touches compared to the 21 touches suggested by Pontillo et

228   al. [20], yet it would have resulted in poor sensitivity and specificity of 29% and 26%, respectively.

229   *K*-means clustering aims to find similarities among data points through an iterative process and

230   can take in multiple variables at once. Considering the fact that no single PPM has sufficient test

231   properties to predict upper extremity injuries on its own [4,8], *k*-means clustering may provide an

232   advantage for analyzing numerous parameters at the same time. This method proved to be

233   highly accurate at identifying injured athletes using KJOC data. Cluster analysis using

234   CKCUEST data was not as successful, although the obtained diagnostic accuracy was superior

235   to using a cut-off criterion.

236   The present study has some limitations. Although our results show that the KJOC could

237   identify injured athletes with high accuracy, there is no assurance that it would be as accurate in

238   predicting future injuries. In fact, the self-responsive nature of the KJOC [8] and its high

239   responsiveness to shoulder function suggest it could be a better tool for diagnostic than

240   prediction. Only female athletes were included as part of this study which limits the

241   generalizability of our results to male athletic populations. Although our sample size was small

242   and only included 7 injuries, the prevalence rate was similar to those reported in the literature for

243   the populations of interest [1,2]. Future research involving different cohorts and bigger sample size

244   should be carried to validate our findings.

245   **Conclusions**

246   The current study showed that the KJOC questionnaire could be a valid and useful SRM

247   to assess shoulder function and differentiate between injured and non-injured athletes, in

248   synchronized swimming and team handball. On the other hand, the CKCUEST seemed to be a

249   poor screening test but appeared to be an interesting tool for evaluating upper extremity

250   functional strength and plyometric capacity. Therefore, contrary to the suggestion of Hegedus et

251   al. [8], we doubt that the CKCUEST can be considered an interesting PPM to be used in

252   combination with the KJOC when screening for shoulder injuries in overhead athletes. It may,

253   however, have some utility as a screening tool in contact sports such as football or rugby where

254   shoulder injuries are often caused by direct trauma rather than overuse. Finally, k-means

255   clustering appears to be an interesting method to group athletes with similarities over an

256   ensemble of parameters which could improve the accuracy of screening protocols in identifying

257   athletes at high or low risk of shoulder injury.

258   **Practical implications**

259   •   The KJOC questionnaire is a valid and useful screening tool to identify athletes competing
260   with a shoulder injury.

261   •   The CKCUEST should not be used as a stand-alone screening tool in identifying injured
262   athletes but appears to be an interesting test for evaluating upper extremity functional
263   strength and plyometric capacity.

264   •   Unsupervised learning such as k-means provides an advantage over the use of cut-off
265   criteria as it can take into account multiple parameters to identify injured athletes which in
266   turn improves sensitivity and specificity.

13

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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	CKCUEST	Injury	Healthy
Injured	6	0	Injured	6	17
Not Injured	1	26	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.
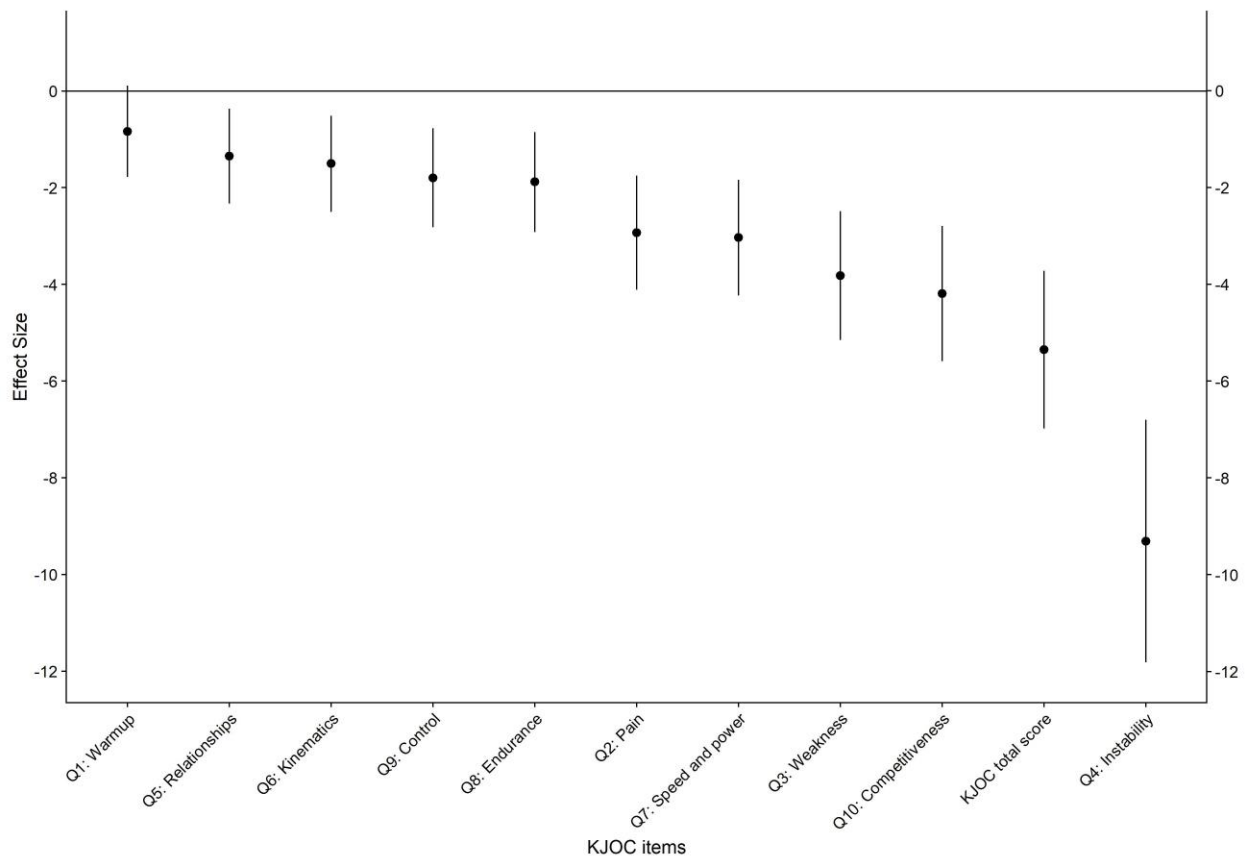
FIGURE 1:

FIGURE 2: