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1 **Precision of the Integrated Cognitive Assessment for the assessment of neurocognitive**
2 **performance in athletes at risk of concussion**

3

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12

13 **Abstract**

14 Choice reaction time tests are commonly used for the assessment of cognitive function, and
15 may be useful to assess the effect of mild traumatic injuries or concussions. This study
16 investigated the precision of the Integrated Cognitive Assessment (ICA; Cognetivity
17 Neurosciences Ltd., Vancouver, Canada) test for the assessment of cognitive function in
18 athletes. Thirty-one participants volunteered to take part in this study, from both contact ($n =$
19 22) and non-contact sports ($n = 9$). Participants performed the ICA test consecutively both
20 before and after normal training session to simulate resting and post-sport conditions. Precision
21 errors were calculated for three variables, ICA Index (overall information processing ability),
22 ICA Speed (information processing speed) and ICA Accuracy (information processing
23 accuracy). ICA precision errors [root mean squared-standard deviation, RMS-SD (coefficient
24 of variation, %CV)] pre-sport were ICA Index: 5.18 (7.14%), ICA Speed: 3.98 (4.64%), and
25 ICA Accuracy: 3.64 (5.00%); and post-sport were ICA Index: 3.96 (4.94%), ICA Speed: 2.14
26 (2.32%), and ICA Accuracy 3.40 (4.25%). The ICA test demonstrates high in-vivo precision
27 with all variables, with all variables except ICA Index (7.14%) demonstrating an acceptable
28 precision error of $\leq 5\%$ %CV. The ICA test is suitable for the assessment of cognitive function
29 pre- and post-sport.

30

31 **Key words:** Choice Reaction, Information Processing, Reaction Time, Simple Reaction Time,
32 Concussion

33

34

35 **Introduction**

36 Cognitive decline is a troubling consequence of normal ageing, and evidence has demonstrated
37 links between mild traumatic brain injuries (mTBI) and persistent cognitive decline and long-
38 term neurodegeneration (1-3). A mTBI is commonly known as a concussion, and is the result
39 of a sudden movement of the brain within the cranium, and can arise from rapid rotational or
40 linear acceleration or deceleration of the head (4). People who play contact sports may be at a
41 higher risk of sustaining a concussion due to the nature of these sports and associated collisions
42 (5). In fact, sports-related concussion is one of the highest reported injuries in rugby union
43 players in the United Kingdom (1). A person with a concussion can experience symptoms such
44 as loss of consciousness, altered mental state, nausea, headaches, vertigo and amnesia (6).
45 However, concussion is currently difficult to objectively assess.

46 One proposed method to assess the effects of concussion and cognitive function is via
47 information processing and reaction time tests. An increase in reaction time (slower) is a
48 commonly used indicator of cognitive change following concussion (7, 8). Additionally,
49 information processing speed underpins several conditions of cognitive dysfunction, for
50 example, multiple sclerosis (9, 10) and Alzheimer's disease (11). Two common types of
51 reaction test include measurement of simple reaction time (SRT) or choice reaction time (CRT)
52 (12). SRT is recorded when there is only one possible stimulus (signal) and one possible
53 response (action), for example tapping anywhere on a screen when any image appears. In CRT
54 tasks there are two or more possible stimuli, each of which requires a quite different response,
55 for example, tapping on the left of the screen when an image of an object appears on the screen,
56 and tapping on the right when an image of an animal appears on the screen.

57 The Integrated Cognitive Assessment (ICA; Cognetivity Neurosciences Ltd., Vancouver,
58 Canada) (13, 14), is a newly developed method for the assessment of cognitive function, and

59 may be applicable to the assessment of concussion in athletic populations. The ICA is a short
60 computerised cognitive test of cognitive function via an assessment of information processing
61 (CRT) speed based on a rapid categorisation task, and is independent of language (13, 15). The
62 ICA test can be completed on a handheld device such as an iPad, and each test takes
63 approximately five minutes. The ICA has been shown to accurately detect mild cognitive
64 impairment and be moderately to highly correlated with other popular pen-and-paper cognitive
65 tests such as the Montreal Cognitive Assessment (Pearsons $r = 0.58$) and Addenbrooke's
66 Cognitive Examination (Pearsons $r = 0.62$) cognitive tests (13). There are no associated risks
67 with completing the ICA, and the test provides three variables, ICA Speed; information
68 processing speed, ICA Accuracy; information processing accuracy, and ICA Index; overall
69 information processing ability, a combination of ICA Speed and ICA Accuracy. There is a
70 speed-accuracy trade-off in reaction test performance, and often scoring higher in either speed
71 or accuracy is achieved at the expense of the other capacity (16, 17). To combat the potential
72 negative reflection on overall information processing ability from a poor speed or accuracy
73 score, a common solution is the inverse efficiency score (18), whereby speed and accuracy are
74 combined into a single score. In the case of the ICA, this concept is applied and manifests as
75 the ICA Index variable.

76 The ICA has been shown to accurately measure cognitive impairment in patients in the early
77 stages of dementia (13). However, to date, no known study has investigated the intra-day
78 precision of the ICA test. Therefore, the purpose of this study was to determine the same-day,
79 in-vivo precision of the ICA test to assess cognitive function.

80 **Materials and Methods**

81 Thirty-one participants volunteered to take part in this study. Participant characteristics are
82 presented in Table 1. Participants were eligible for participation if they were a current contact

83 sport or non-contact sport athletes (Table 2) aged 18-40 years, and healthy; having no
 84 underlying medical issues that affect participation in sport. Participants were excluded if they
 85 were injured, pregnant, or suffering from post-concussion syndrome. This study was approved
 86 by the Durham University Sport and Exercise Sciences Ethics Committee (reference: SPORT-
 87 2022-01-07T10_44_59-srhd22), and written informed consent was provided by each
 88 participant prior to participation.

89 Table 1: Participant Characteristics

	Age (Yr.)	Height (m)	Body Mass (kg)
Total ($n = 31$)	23.7 ± 5.7	1.78 ± 0.09	72.6 ± 8.3
Male ($n = 16$)	22.9 ± 4.7	1.82 ± 0.08	75.7 ± 7.4
Female ($n = 15$)	24.6 ± 6.6	1.71 ± 0.07	68.0 ± 9.9
Contact Sport ($n = 22$)	24.9 ± 6.3	1.80 ± 0.07	75.5 ± 6.0
Non-Contact Sport ($n = 9$)	20.6 ± 0.6	174.1 ± 8.3	77.2 ± 12.2

Data are presented as mean \pm standard deviation. Yr., Years; m, Metres; kg, Kilograms; n , Number.

90 Table 2: Sports Breakdown

Contact Sports ($n = 22$)		Non-Contact Sports ($n = 9$)	
Rugby Union ($n = 7$)	Semi-professional, Amateur	Touch Rugby ($n = 5$)	Amateur
Boxing ($n = 6$)	Amateur	Athletics ($n = 4$)	Amateur
Muay Thai (Kickboxing) ($n = 5$)	Professional, Amateur		
Indoor Football ($n = 4$)	Amateur		

n , Number.

91 To simulate resting- and post-sport conditions, participants performed the ICA test (version
 92 1.6.0 or 1.7.0) before and after a normal training session for their respective sports. Data
 93 collection was performed in a quiet room to minimise distractions. Prior to their sports training,
 94 participants completed two consecutive ICA tests. The participants then completed a normal
 95 training session and then two consecutive ICA tests again.

96 All data analysis was performed in Microsoft Excel (2016). Raw data for ICA Index, ICA
 97 Speed, and ICA Accuracy were extracted and exported to Microsoft Excel for analysis (19).

98 Precision of ICA scores and least significant change (LSC) were calculated at the 95%
99 confidence level. Precision was determined as root mean square standard deviation (RMS-SD),
100 coefficient of variation (CV), and percentage CV (%CV). RMS-SD represents the sample
101 standard deviation of the differences between predicted values and observed values, and is
102 calculated via the following formulae, where SD represents standard deviation and n represents
103 the number of participants:

$$104 \quad \sqrt{\left(\frac{\sum SD^2}{n}\right)}$$

105 The %CV expresses test variation relative to the mean of two tests and is corrected for small
106 sample bias, and was defined as acceptable <5% (20). The LSC represents a true meaningful
107 change was calculated from the precision errors (LSC = RMS-SD * 2.77).

108 **Results**

109 Results of the precision analysis for each ICA variable pre- and post-sport are presented in
110 Table 3. All variables except for ICA Index pre-sport had a precision error of $\leq 5\%$ %CV. LSC
111 results are presented in Table 4.

112 Table 3: Precision Analysis Results

Variable	Precision ($n = 31$)		
	RMS-SD	CV	%CV
<i>Pre</i>			
ICA Index	5.18	0.07	7.14
ICA Speed	3.98	0.05	4.64
ICA Accuracy	3.64	0.05	5.00
<i>Post</i>			
ICA Index	3.96	0.05	4.94
ICA Speed	2.14	0.02	2.32
ICA Accuracy	3.40	0.04	4.25

n, Number; ICA, Integrated Cognitive Assessment; RMS-SD, Root Mean Square Standard Deviation; CV, Coefficient of Variation; %, Percentage.

113

114 Table 4: Least Significant Change Results

Variable	LSC ($n = 31$)		
	RMS-SD	CV	%CV
<i>Pre</i>			
ICA Index	14.36	0.20	19.78
ICA Speed	11.01	0.13	12.86
ICA Accuracy	10.09	0.14	13.9
<i>Post</i>			
ICA Index	10.96	0.14	13.7
ICA Speed	5.94	0.06	6.43
ICA Accuracy	9.43	0.12	11.78

LSC, Least Significant Change; n, Number; ICA, Integrated Cognitive Assessment; RMS-SD, Root Mean Square Standard Deviation; CV, Coefficient of Variation; %, Percentage.

115 Discussion

116 The purpose of this study was to determine on the same-day, in-vivo precision of the ICA test
117 to assess cognitive function. The results of this study support the ICA as a tool with acceptable
118 precision to measure changes in cognitive ability pre- and post-sport. All ICA variables in this
119 study, except for ICA Index pre-sport demonstrated a precision error of $\leq 5\%$ %CV.

120 The higher ICA Index precision score (7.14 %CV) pre-sport than post-sport (4.94 %CV) in
121 this study may be explained by a large difference between test one and test two pre-sport,
122 compared to a smaller difference in ICA scores between test three and test four post-sport. This
123 is exemplified by a larger ICA Index RMS-SD pre-sport than post-sport, which indicates more
124 variance in observed data around the mean. This result may be due to an increased level of
125 comfort with the test from the first pre-sport ICA test to the subsequent test, and possibly a
126 learning effect. However, this is in contrast to previous work which showed no learning effect
127 for the ICA test in healthy participants and those diagnosed with dementia (13).

128 All variables showed greater precision post-sport compared to pre-sport. This may be due to
129 the many positive physiological benefits that exercise has, such as an increase in blood flow to
130 muscles and brain (21), structural and functional changes in the brain (22), and increases

131 information processing ability (23). Indeed, improvements in cognitive function after a bout of
132 exercise is supported by previous research (24, 25).

133 Previous research looking at precision in a similar cognitive test to the ICA, the CogSport
134 choice reaction time test, has shown lower %CV for mean choice reaction time (speed) (1.4
135 %CV), and higher %CV for choice reaction time accuracy (11.4 %CV) (26). These results are
136 interesting as the ICA is shown to be less precise in measuring reaction speed (2.32 - 4.64 %CV
137 vs 1.4 %CV), however, the ICA test is shown to be more precise in terms of accuracy (4.25 –
138 5.00 %CV vs 11.4 %CV). These results may indicate that the test you adopt needs to be specific
139 to the variable of interest (i.e., speed or accuracy), however, this should be negated in the case
140 of the ICA via the ICA Index variable as an inverse efficiency score (18), whereby speed and
141 accuracy are combined into a single score. The contrasting results between the present study
142 and that of Straume-Naesheim, Andersen (26) may be due to the populations used; the
143 CogSport test was used in elite football players only, whereas only a small percentage of the
144 participants in the present study are practicing professionally (Table 2). Additionally, the
145 present study recruited participants from a variety of sports, each with their own decision
146 making and reaction characteristics, in comparison to only football.

147 In conclusion, the ICA is a practical test which can be used to measure cognitive function
148 before and after sport participation. The results of this study support the ICA as a precise
149 measure of information processing speed and information processing accuracy, and overall
150 information processing ability. The ICA can be used for the assessment of cognitive function,
151 and may be useful as a method to assess the effects of concussion.

152

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