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4 **Reflection-impulsivity in athletes: A cross-sectional and longitudinal investigation**

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6

7 Robert S. Vaughan & Jack D. Hagyard

8 York St John University, UK

9

10 Elizabeth J. Edwards

11 The University of Queensland, Australia

12 &

13 Robin C. Jackson

14 Loughborough University, UK

15

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20 Author Note

21 Correspondence concerning this article should be addressed to Robert Vaughan,

22 School of Education, Language, and Psychology, York St John University, Lord Mayors

23 Walk, York, UK, YO31 7EX, E-mail: r.vaughan@yorks.ac.uk

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Abstract

Reflection-impulsivity is a dimension of cognitive or decision-making style. We conducted two quasi-experimental studies to examine reflection-impulsivity in athletes using an information sampling task. In Study 1 ($n = 108$; $M_{age} = 22.7 \pm SD_{age} = 1.42$; 50% female), we used a cross-sectional design to compare performance across athletic expertise (super-elite, elite, amateur, novice or non-athlete) and sport type (external-paced or self-paced). In Study 2 (Time 1 $n = 106$; $M_{age} = 21.32 \pm SD_{age} = 5.77$; 53% female and Time 2 $n = 64$; $M_{age} = 21.19 \pm SD_{age} = 5.12$; 44% female), we examined changes in reflection-impulsivity across a 16-week playing season. Study 1 showed more accurate and more efficient performance as athletic expertise increased. Study 2 revealed better effectiveness and efficiency following sport participation, a 16-week playing season, most notably in elite-level performers. No sport-type differences were noted. Taken together, the studies demonstrate an association between reflection-impulsivity and athletic expertise, while also providing evidence that competitive sports participation leads to efficient decisions based on reflection, without sacrificing accuracy, which is often a consequence of impulsive decision-making.

Key Words: Reflection-Impulsivity, Decision-Making, Athlete Expertise

Highlights

Two samples with varying levels of athletic expertise completed the information sampling task to measure reflection-impulsivity.

Controlling for physical activity levels those with higher athletic expertise scored better on reflection-impulsivity effectiveness and efficiency using signal detection theory than those with lower athletic expertise.

No differences were found across sport type.

These findings were replicated and extended with effects increasing more for those with higher athletic expertise over a 16-week period compared to those with lower athletic expertise.

51 **Introduction**

52 Competitive sport environments are laden with situations that require athletes to
53 receive, process, and respond to external stimuli (Williams, Anshel, & Quek, 1997; Williams
54 & Jackson, 2019). Much of the research on individual differences in these abilities has
55 focused on the role of cognitive styles and researchers have used a variety of methodological
56 contexts. For example, elite level athletes have been shown to use a combination of cognitive
57 and affective styles to anticipate and respond to changing situations (e.g., Verburch, Scherder,
58 van Lange, Oosterlaan, 2014), avoid distractions and resolve interference in play (e.g., Furley
59 & Wood, 2016), and make more effective decisions (e.g., Vaughan, Laborde, & McConville,
60 2019). However, the link between individual differences in cognition and sports performance
61 remains poorly understood and continuing research is required to elucidate this complex
62 association.

63 **Reflection-Impulsivity in Sport**

64 Many sports require players to use complex cognitive processes on a second-to-second
65 basis (Walsh, 2014), that is, successful play requires a continuous stream of executive
66 processes (e.g., inhibition, shifting, updating, reflective and impulsive decision-making; Voss,
67 Kramer, Basak, Prakash, & Roberts, 2010). For example, in a game of soccer a sequence of
68 open play requires players to inhibit inappropriate actions or impulsive decisions (e.g.,
69 ignoring players calling for the ball who may not be clear from opposition), shift cognitive
70 resources between different information sources for potential pass options (e.g., keeping the
71 ball or passing to a team mate), and update available information to discard ineffective plans
72 (e.g., monitoring play based on proximity and readiness to kick at goal). We reason that the
73 ability to process information with regard to risk and reward may be particularly important for
74 decision-making in sport situations. In accord with Williams et al. (1997), we argue that
75 athletes may be more successful at optimising the balance between risk and reward in sporting
76 environments with intrinsic information overload. As such, we suggest that athletes might be

77 more efficient at assessing the situation and making correct choices with good speed, than
78 non-athletes. This notion, however, remains to be tested.

79 Researchers have identified three subtypes of behavioural impulsivity (Evenden,
80 1999): motor-impulsivity (or inhibitory control) refers to the inability to withhold a dominant
81 response; temporal-impulsivity refers to the inability to delay gratification; and reflection-
82 impulsivity refers to the degree to which an individual reflects on the validity of choices
83 (reflection) or makes decisions in times of uncertainty (impulsivity; see Kagan, 1966). To
84 date, there are no studies on reflection-impulsivity in athletes and no behavioural tests of
85 reflection-impulsivity in the context of sport. Indicative findings come from studies of
86 executive processes, some of which have shown that athletes outperform non-athletes on tests
87 of inhibitory control (e.g., Brevers et al., 2018; Wang et al., 2013) and decision-making (e.g.,
88 Vaughan et al., 2019), and that processing efficiency is impaired on an anticipation test under
89 heightened anxiety (Cocks, Jackson, Bishop, & Williams, 2016). Others have reported no
90 differences between athletes and non-athletes on measures of inhibition (e.g., Chang et al.,
91 2017) and decision-making (e.g., Jacobson & Matthaeus, 2014).

92 Research on inhibition in sport is particularly relevant given its conceptual association
93 with impulsivity. Brevers et al. (2018) found that elite fencers and taekwondo competitors had
94 faster reaction times (RT) on a stop signal task, relative to non-athletes. Similar findings were
95 reported by Wang et al. (2013) with tennis players compared to non-athletes. Martin et al.
96 (2016) found that professional cyclists had faster RTs on a Stroop task, than recreational
97 cyclists. Chang et al. (2017), however, found no differences in RTs between endurance
98 athletes, martial arts athletes and non-athletes on their Stroop task. One reason for the
99 conflicting results between studies could be that there are inherent problems with interpreting
100 performance efficiency (e.g., RT) data without consideration of speed-accuracy trade-offs.
101 Specifically, the use of RT alone is only appropriate if all individuals perform with equal
102 accuracy. Given individual differences in performance, a more sensitive measure of efficiency

103 would be best indexed as a ratio of accuracy to RT (cf. Edwards, Moore, Champion &
104 Edwards, 2015). Another explanation for conflicting results between studies might be due to
105 individual differences such as sport type (Singer, 2000).

106 Jacobson and Matthaeus (2014) suggested that inhibition differed by sport type and
107 compared the performance of athletes from self-paced (e.g., swimming, running) and
108 externally-paced sports (e.g., soccer, basketball; see Singer, 2000) on tests of inhibitory
109 control and decision-making. They found athletes outperformed non-athletes on a modified
110 Stroop (inhibition), but not on a modified Tower of London (decision-making) task.
111 Importantly, self-paced athletes outperformed externally-paced athletes on inhibitory control,
112 yet externally-paced athletes scored higher on decision-making. It is possible that the
113 relationship differs for simple executive functions (inhibition), rather than complex executive
114 functioning (decision-making). Alternatively, following the notion that cognitive competence
115 predicts athletic success (Vestberg et al., 2017), and the idea that people enjoy doing what
116 they do well, Jacobson and Matthaeus (2014) concluded that it is probable that individuals
117 with high cognitive abilities might be drawn to sports because they have good executive
118 functioning, and their skills develop further with training in a reinforcing cycle. It is plausible
119 therefore, that self-paced sports may favour athletes who are more reflective and focus on
120 their decisions, whereas externally-paced sports favour athletes who perform with both
121 reflection and speed (efficiency).

122 The cause and effect relationship between cognition and athletic performance or vice
123 versa is an enduring question (Voss et al., 2010) and signals the need for designs that can
124 inform causality (e.g., longitudinal). Whilst more work is needed, empirical evidence alludes
125 to the existence of a causal relationship. For example, Hagyard, Brimmell, Edwards, and
126 Vaughan (2020) reported that those with more athletic expertise scored higher than those with
127 less expertise on a stop signal task of inhibitory control and this effect remained over a 16-
128 week period. They also reported that across a playing season, stop signal task performance

129 predicted athlete- and coach-ratings of performance and this relationship was moderated by
130 athletic expertise, such that those with more expertise demonstrated better inhibition and
131 sporting performance. These reported effects were independent of moderate to vigorous
132 physical activity (MVPA). Similar findings were reported by Vestberg et al. (2012) who
133 found that better inhibition was related to better performance over two seasons in elite and
134 sub-elite soccer players. Moreover, longitudinal work with children has reported increased
135 working memory performance in 6-11 year olds participating in a tennis play intervention
136 (Ishihara & Mizuno, 2018) and meta-analytic reviews of the relationship between executive
137 function and physical activity support the causal direction that sport performance enhances
138 cognitive performance (de Greef et al., 2018; Verbugh et al., 2014). Despite the problems
139 associated with individual differences in executive functions across the developmental
140 pathway in children (see Crone & Dahl, 2012, for review), taken together this research
141 suggests that it is likely that athletic expertise and executive functions may reciprocally
142 develop in tandem.

143 **Assessment of Reflection-Impulsivity**

144 The matching familiar figures task (MFF20; Cairns & Cammock, 1978) was designed
145 to index reflection-impulsivity. In the MFF20 participants select one of six visual stimuli to
146 match an original image. The test captures a total impulsivity score based on the standardised
147 mean RT minus the standardised total errors. Positive scores correspond to reflective
148 processing (fewer errors, but slow, deliberate performance) and negative scores indicate
149 impulsive processing (more errors, yet faster responses). The MFF20 has been used
150 extensively to index reflection-impulsivity in clinical populations (e.g., Morgan, Impallomeni,
151 Pirona, & Rogers, 2006), however, few studies have used the MFF20 with healthy adults. As
152 such, the reliability and validity of the MFF20 to capture reflection-impulsivity in a healthy
153 sample is unknown. Further, the MFF20 has been criticised for being confounded by other

154 cognitive processes such as visual processing and working-memory (see Clark, Robbins,
155 Ersche, & Sahakian, 2006).

156 The information sampling task (IST; Clark et al., 2006) was designed to be a relatively
157 process-pure measure of reflection-impulsivity. The IST has been used to measure reflection-
158 impulsivity in studies with healthy adults (e.g., Crockett, Clark, Smillie & Robbins, 2012) and
159 clinical samples (e.g., Irvine et al. 2013). In the IST, participants are presented with an array
160 of grey boxes from which they select one box at a time to reveal one of two colours. The
161 information revealed with each box choice is used to decide which of the colours is in the
162 majority behind the grey boxes. The IST produces three outcome measures: IST Correct is the
163 average number of boxes opened for each trial (i.e., in order to inform a decision); IST Errors
164 is the number of incorrect decisions across trials; and IST Latency is the RT (in milliseconds;
165 ms) of decision responses across trials. Individuals who gather information systematically and
166 have higher IST Correct scores display tendencies for reflection. Whereas, individuals who
167 make decisions with less information, consequently make more errors (IST Errors) and show
168 impulsive tendencies. Bennett and colleagues (2017), suggested that the IST Correct
169 calculation assumes equal probability that unopened box colours are unrelated to the boxes
170 already opened, yet in effect, the colours of the opened boxes provide vital information about
171 the box colours still to be revealed. Given the potential for IST Correct to overestimate
172 effectiveness (accuracy) of reflection-impulsivity performance, we argue for application of
173 signal detection theory (Stanislaw & Todorov, 1999) to provide a sensitivity score that
174 incorporates the number of correct box choices and errors (cf. Edwards, Edwards & Lyvers,
175 2017).

176 **The Current Study**

177 In the present study we measured reflection-impulsivity using a computerised IST. We
178 operationalised effectiveness (accuracy) using the sensitivity index (d') from signal detection
179 theory (Stanislaw & Todorov, 1999), and efficiency as the ratio of accuracy to RT. We
180 predicted that performance would differ across athletic expertise (super-elite, elite, amateur,
181 novice and non-athletes; see Swann, Moran & Piggott, 2015) such that athletes with greater
182 expertise would perform with better effectiveness and efficiency than their lesser expert
183 counterparts. We also predicted that performance would vary across sport-type (externally-
184 paced, self-paced, non-athlete; see Singer, 2000), such that, externally-paced athletes would
185 be more efficient than self-paced athletes, or non-athletes. Given research that has showed
186 that MVPA enhances sport-specific cognitive performance (Chan et al., 2011; Williams &
187 Ericsson, 2005), we controlled for MVPA in our data analyses. Our investigation comprised
188 two studies.

189 **Study 1**

190 To test the hypotheses regarding differences across athlete expertise and sport type in
191 reflection-impulsivity we employed a cross-sectional design. We predicted that after
192 controlling for MVPA, athletes with higher expertise would demonstrate better reflection-
193 impulsivity performance effectiveness and efficiency, compared to athletes with less
194 expertise. Second, we hypothesised that externally-paced athletes would perform more
195 efficiently than self-paced athletes.

196 **Methods**

197 **Participants**

198 One hundred and eight volunteers aged 18 to 28 years, with a mean playing experience
199 of 9.74 years, participated ($M_{age} = 22.7 \pm SD_{age} = 1.42$; 50% female). Classification of athletic
200 expertise followed Swann et al.'s (2016) recommendation (i.e., non-athlete = 24, novice = 29,
201 amateur = 25, elite = 17 and super-elite = 13). Categorisation of externally-paced ($n = 62$) and

202 self-paced ($n = 44$) sports followed Singer (2000). Participants were recruited from the
203 university sport and psychology departments and volunteers were remunerated with research
204 participation credit points. G*Power sample size calculator for ANCOVA suggested a sample
205 size of 80 and 196 to detect large effects ($f = 0.4$) and medium effects ($f = 0.25$), respectively
206 ($1 - \beta = .80$, $\alpha = .05$; Faul, Erdfelder, Lang, & Buchner, 2007), with a sample size of 108
207 yielding sensitivity of $f = 0.34$.

208 **Materials**

209 **International Physical Activity Questionnaire** (IPAQ; Booth, 2000). The 9-item
210 (short form) of the IPAQ was used to index health-related physical activity in the last seven
211 days (i.e., MVPA). Items focus on the frequency and duration of vigorous and moderate-
212 intensity activities and indicators of sedentary behaviour (i.e., sitting and walking) e.g.,
213 *During the last 7 days, on how many days did you do moderate physical activities like*
214 *carrying light loads, bicycling at a regular pace, hiking? Do not include walking.* We used
215 the moderate and vigorous subscales, such that total scores were calculated as minutes x days
216 spent engaging in physical activity. Higher scores represented greater MVPA. Research
217 suggests the IPAQ is a reliable and valid measure for participants aged 18-59 years old (Nigg
218 et al., 2020).

219 **Information Sampling Task** (IST). The information sampling task from the
220 Cambridge Automated Neuropsychological Test Battery (CANTAB; Clark et al., 2006) was
221 used to measure reflection-impulsivity. Participants were presented with a 5 x 5 grid of grey
222 boxes on a screen and instructed that they are playing for points. They select grey boxes one
223 at a time to reveal one of two colours. Once a box has been selected, it remains open for the
224 duration of the trial. Participants are asked to decide which colour box is in the majority, by
225 indicating their choice on a panel at the bottom of the screen. Points are awarded for correctly
226 deciding which colour is in the majority. IST Correct, IST Errors, and IST Latency (RT in
227 ms) is captured. The task began with a single practice trial, followed by 20 test trials.

228 **Reflection-Impulsivity Performance**

229 **Effectiveness.** We followed other work that has calculated effectiveness or accuracy
230 on executive tasks using d' (e.g., Edwards et al., 2017). The following equation was used:

$$\text{Effectiveness } (d') = z(\text{IST Correct}) - z(\text{IST Errors})$$

231 **Efficiency.** Efficiency was operationalised as Effectiveness (d') divided by the Mean
232 IST Latency (ms). To aid interpretation we multiplied the ratio by 1000 (see Edwards et al.,
233 2017) in the following equation:

$$\text{Efficiency} = \left[\frac{d'}{\text{Mean IST Latency (ms)}} \right] \times 1000$$

235 **Procedure**

236 The study was approved by the University's ethics committee and signed informed
237 consent was collected prior to participation. Participants were tested individually in quiet,
238 designated laboratories and testing was completed on a GIGABYTE 7260HMW BN
239 touchscreen computer running a Pro Windows 8 operating system with a high resolution 12-
240 inch display. To begin, participants were briefed on the study protocol and ethical issues
241 pertaining to withdrawal and confidentiality and provided the opportunity to ask questions.
242 Next, participants provided demographic information (e.g., age, sex, and sport participation
243 details), and then completed the IPAQ followed by the IST. Finally, participants were
244 debriefed, thanked and released. Testing took approximately 20 minutes. Data were entered
245 onto SPSSv24 for analysis.

246 **Design and Data Analysis**

247 A two-way cross-sectional design was used. To isolate differences in MVPA across
248 athlete expertise, a one-way between subjects MANOVA model was constructed. Scores on
249 vigorous, moderate, and walking subscales of the IPAQ were entered as dependent variables
250 and athletic expertise as the independent variable. To test for differences in reflection-
251 impulsivity across athletic expertise and sport type, separate two-way ANCOVAs were

252 conducted for performance effectiveness and performance efficiency, with total MVPA
253 entered as the covariate. Significant effects were followed up with Bonferroni-corrected
254 pairwise comparisons.

255 **Results**

256 **Descriptive Statistics and Baseline Modelling**

257 Measures of central tendency were tabulated for reflection-impulsivity across
258 expertise and sport type (see Table 1). MANOVA modelling indicated a significant
259 multivariate difference between athletes of varying expertise on MVPA, Wilks' $\lambda = .77$, F
260 $(15, 276.39) = 8.61$, $p = .001$; $\eta^2 = .18$. There was a significant group difference on the
261 measure of vigorous ($F(5, 102) = 5.67$, $p = .001$, $\eta^2 = .19$); moderate ($F(5, 102) = 5.18$, $p =$
262 $.001$, $\eta^2 = .17$); and walking activity ($F(5, 102) = 4.10$, $p = .003$, $\eta^2 = .14$). Results
263 indicated that higher levels of athletic expertise scored significantly higher on all measures of
264 MVPA, supporting the use of MVPA as a covariate in subsequent analyses.

265 Table 1 here

266 **Reflection-Impulsivity and Expertise**

267 Results of ANCOVA revealed a significant difference in reflection-impulsivity
268 effectiveness ($F(4, 102) = 5.88$, $p < .01$) and efficiency ($F(4, 102) = 1.87$, $p < .01$) by athletic
269 expertise, with higher scores across higher levels of expertise. More specifically, athletes were
270 able to focus and make correct decisions (reflection) and do so without an efficiency cost (that
271 would indicate an impulsive style). Post-hoc analyses indicated significantly higher scores in
272 elite and super-elite athletes compared to their non-elite counterparts with no difference
273 between novice and amateurs. Regarding sport type, no differences were noted for
274 effectiveness or efficiency between externally-paced, self-paced athletes and non-athlete
275 controls.

276 Table 2 here

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Discussion

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In Study 1 we examined differences in reflection-impulsivity performance (effectiveness & efficiency) across athletic expertise. Consistent with our hypothesis, higher-level athletes were more effective and more efficient than their lower-level counterparts. There is no existing data examining reflection-impulsivity in athletes, however, we agreed with previous research indicating positive associations between athletic expertise, and inhibition (Brevers et al., 2018), and decision-making (Vaughan et al., 2019). Our findings extend the current understanding of the relationship between cognitive performance and athlete expertise by demonstrating that those with more expertise make more deliberate decisions (based on reflection) without sacrificing the time taken to respond. Our pattern of results, however contrasts work that reported no association between athlete expertise and inhibition (Chang et al., 2017) or decision-making (Jacobson & Matthaeus, 2014). Given that the current study is the first to provide a direct test of reflection-impulsivity in sport, we suggest the most plausible explanation for differences between our results and that of Chang et al., (2017) and Jacobson and Matthaeus (2014) rests with task differences (i.e., Chang et al. used a Stroop task to assess inhibition; and Jacobson & Matthaeus used a Tower Test to index decision-making). We propose that despite being conceptually similar, reflection-impulsivity, and accordingly performance on the IST, requires distinctly different processes than those involved with performance of the Stroop (inhibition) and Tower Test (decision-making).

Study 1 was the first study to examine the association between sport-type and reflection-impulsivity. Our results revealed that sport-type was not associated with the effectiveness or efficiency of reflection-impulsivity performance. The present results contrast work that reported self-paced athletes have superior inhibition than externally-paced and externally-paced athletes are better decision-makers than self-paced athletes (Jacobson & Matthaeus, 2014). The reason for differences between our study and Jacobson and Matthaeus (2014) is puzzling. If sport-type was linked to performance on complex executive tasks (i.e.,

330 and generalisability of our findings, we retained our hypothesis that externally-paced athletes
331 would demonstrate greater efficiency than self-paced athletes, and that these effects would be
332 independent of MVPA. G*Power analysis for the within-between interaction (repeated
333 measures ANOVA, $f = 0.25$, $1 - \beta = .80$, $\alpha = .05$) yielded a suggested sample size of 55 and
334 34 for the Time x Expertise and Time x Sport type interactions, respectively. To allow for
335 attrition we recruited 106 participants for the study.

336 **Methods**

337 **Participants**

338 Table 2 shows the demographic characteristics of participants at Time 1 ($n = 106$; M_{age}
339 $= 21.32 \pm SD_{age} = 5.77$; 53% female) and Time 2 ($n = 64$; $M_{age} = 21.19 \pm SD_{age} = 5.12$; 44%
340 female), representing 39.7% attrition rate. Recruitment and ethical protocols followed Study
341 1, however, no participants completed both studies.

342 Table 2 here

343 **Materials**

344 The materials were the same as those used in Study 1.

345 **Reflection-impulsivity Performance**

346 The same measures of IST effectiveness and efficiency were used.

347 **Procedure**

348 The same procedures in Study 1 were used, with the inclusion of a 16-week follow up.
349 Testing procedures at Time 2 (end of season) followed the same as Time 1 (start of season).

350 **Design and Data Analytic Technique**

351 A two-way quasi-experimental design was used with a 16-week longitudinal follow-up
352 (Arday et al., 2014). Treatment of MVPA as a covariate was again analysed following Study
353 1 (e.g., one-way between subjects MANOVA). To assess the cross-sectional differences in
354 reflection-impulsivity across athletic expertise, after controlling for MVPA, separate
355 ANCOVA models were constructed to replicate study 1. Effectiveness and efficiency were

356 used as dependent variables, athlete expertise and sport type were entered as independent
357 variables, and MVPA as the covariate.

358 Longitudinal effects were tested with regression-based modelling (Ishihara & Mizuno;
359 2018). Given that data was collected at two time points, inter-class-correlations were used to
360 determine test-retest reliability (Tabachnick & Fidell, 2007). All variables indicated
361 acceptable levels of stability ($\alpha = .78-.89$). The data were screened for multivariate outliers
362 via Mahalanobis distance which revealed no outliers > 3 degrees of freedom ($\chi^2(10) = 5.97, p$
363 $< .01$; Tabachnick & Fidell, 2007). Linear regression modelling assumes that all observations
364 in the data are independent of each other, which is violated in longitudinal data. Linear mixed
365 models (LMM) relax this assumption and allow for observations on the dependent variable to
366 have non-zero covariance and enable researchers to examine residual changes over time. Two
367 LMM's observing changes in effectiveness and efficiency (controlling for MVPA) across
368 athletic expertise were constructed (cf. West, 2009). There were two sources of variation;
369 over time and between athletes, thus, an unconditional model with no fixed effects provided
370 an estimate of variance at both levels. Subsequent fixed models with changes in impulsive
371 decision-making between Time 1 and Time 2 were added as predictor variables. The
372 restricted maximum likelihood estimation method was used to provide unbiased estimates of
373 the variance (West, 2009).

374 Results

375 Descriptive Statistics and Baseline Modelling

376 Measures of central tendency were tabulated for effectiveness and efficiency across
377 expertise and sport type at time 1 and time 2 (see Table 1). MANOVA modelling indicated a
378 significant multivariate difference between the athletes of varying expertise on MVPA,
379 Wilks' $\lambda = .63, F(12, 256.93) = 4.15, p = .001; \eta^2 = .15$. There was a significant group
380 difference on the measure of vigorous ($F(4, 99) = 4.90, p = .001, \eta^2 = .17$); moderate ($F(4,$
381 $99) = 4.59, p = .001, \eta^2 = .16$); and walking activity ($F(4, 99) = 3.37, p = .005, \eta^2 = .12$).

382 Results indicated that more expert athletes scored significantly higher on all measures of
383 MVPA, therefore MVPA was again entered as a covariate in subsequent analyses. To check
384 for speed-accuracy confounds in the data, we examined the relationship between IST Errors
385 and IST Latency. The bivariate correlation indicated that *more* errors were associated with
386 *longer* latencies ($r(62) = -.27, p = .01$) thus eliminating the possibility of a speed-accuracy
387 trade-off.

388 **ANCOVA Modelling**

389 Differences in reflection-impulsivity were analysed across sport type and expertise
390 entering MVPA as a covariate (see Table 3). Results indicated a significant variation on
391 effectiveness and efficiency by athletic expertise, with higher expertise predominantly
392 outperforming those of lesser expertise. Post-hoc analyses indicated significantly greater
393 performance in elite and super-elite athletes compared to their non-elite counterparts. No
394 significant differences were found with sport-type.

395 **Linear Mixed Models**

396 An initial unconstrained model over Time 1 and Time 2 revealed significant individual
397 variance in slopes and intercepts of reflection-impulsivity ($p < .01$) indicating that participants
398 varied in their performance at Time 1. Next, two main effect models examining reflection-
399 impulsivity changes over the 16-week period across athletic expertise controlling for MVPA
400 were tested (see Table 4). In both instances residual changes in the variance were significant
401 i.e., effectiveness ($\beta = 1.98, SE = .04, 95\% CI [1.35 - 2.34]$; see Figure 1) and efficiency ($\beta =$
402 $1.18, SE = .03, 95\% CI [.92 - 1.80]$; see Figure 2). In general, growth trajectories were
403 significantly different across expertise ($p < .01$), and typically larger in those with more
404 expertise compared to those with less expertise. Therefore, participants competing at higher
405 levels observed greater increases in their ability to make accurate and efficient deliberate
406 decisions from Time 1 to Time 2 independent of their MVPA levels.

407

Table 4 here

408 Discussion

409 Study 2 was an extension of Study 1. Cross-sectional findings at Time 1 concurred
410 with Study 1. Athletes with higher athletic expertise demonstrated better reflection-
411 impulsivity effectiveness and efficiency than those with less expertise, independent of MVPA
412 and no differences were found between externally- and self-paced athletes. Considering
413 longitudinal findings, as predicted, athletes demonstrated greater increases in ability to make
414 efficient decisions (without sacrificing accuracy) compared to non-athletes. The growth
415 trajectories at 16-weeks showed the largest increases in elite level athletes between Time 1
416 and Time 2. Our results concur with others who have found increases in executive function
417 across time in sports contexts (e.g., Hagyard et al., 2020; Vestberg et al., 2012; 2017; Ishihara
418 & Mizuno, 2018), nonetheless there are no comparative reflection-impulsivity data for these
419 longitudinal findings.

420 General Discussion

421 We have reported two studies that have examined differences in reflection-impulsivity
422 between athletes of varying expertise (i.e. super-elite, elite, amateur, novice, & non-athletes)
423 and sport-type (i.e. external- & self-paced athletes), whilst controlling for MVPA. In Study 2,
424 change in performance across a 16-week playing season was also tested. Akin to research
425 outside of sport, reflection-impulsivity is an important cognitive process across individual
426 differences (Irvine et al., 2013; Morgan et al., 2006). That is, the ability to better evaluate
427 information before making a decision is linked with greater athletic expertise (Williams et al.,
428 1997).

429 Results from Study 1 corresponded with Study 2 (Time 1). In the absence of existing
430 work examining reflection-impulsivity in sport, we highlight that our findings concurred with
431 studies reporting better inhibitory control and decision-making in elite athletes relative to non-
432 athletes (Brevers et al., 2018; Spindler et al., 2017; Vaughan et al., 2019). Study 2 is the first
433 to examine reflection-impulsivity across a playing season and provides support for the

434 assumption that differences are likely attributable to increased sports participation in a
435 competitive environment. For example, it is plausible that competitive sports environments
436 provide greater opportunity to elicit goal-oriented behaviour, whilst under distractions which
437 are dependent upon efficient decision-making (Williams & Ericsson, 2005). It is possible,
438 however, that the increased effect observed in elite athletes may be a practice effect from
439 participation in high-quality and cognitively demanding sports training (i.e., theory of
440 expertise; Ericsson & Smith, 1991) and the cognitive stimulation hypothesis (Tomprowski et
441 al., 2008). This explanation nonetheless, is beyond the scope of the current work.

442 In Study 2, we demonstrated reflection-impulsivity improvements over a 16-week
443 playing season. Noted improvements in elite-level athletes coincide with previous assertions
444 that expertise is highly dependent on attentional resources (Williams et al., 2011). It is
445 reasonable to suggest that performance in elite level sports requires participants to react, plan,
446 and execute responses, under severe temporal constraint, in times that are shorter than actions
447 (Walsh, 2014). It is plausible, therefore, that the ability to delay decision-making, consider
448 alternatives and make deliberate choices, may be facilitative of athlete expertise, thus more
449 successful performance. Whilst claims of causality between athletic expertise and executive
450 functions are beyond the scope of the current work, we believe that the current data adds to
451 evidence alluding to causality. For example, Crone and Dahl (2012) and de Greef et al. (2018)
452 highlight that the development of executive functions are modified by participation in sports
453 based activity in children and adolescents. These developmental trajectories may in part
454 explain the positive relationship between executive function and later athlete performance
455 (e.g., Hagyard et al., 2020; Ishihara & Mizuno; 2018; Vestberg et al., 2012; 2017).

456 Importantly, our findings remained significant after controlling for MVPA
457 demonstrating that differences in reflection-impulsivity across athletic expertise are
458 independent of physical activity. Whilst this finding has been observed in children and
459 adolescents (Ishihara & Mizuno; 2018) our findings are the first using an adult sample on a

460 reflection impulsivity task. Like Hagyard et al. (2020) who reported better inhibition via stop
461 signal task performance in those with more expertise independent of MVPA longitudinally, it
462 is likely that the present results represent skill acquisition or learning effects from sport (De
463 Luca et al., 2003), given that complex executive functions are instrumental to learning and
464 may share a reciprocal relationship with sports participation i.e. the increase observed in the
465 current research may be a result of coaching and learning new skills throughout the season (de
466 Greef et al., 2018).

467 Interestingly, the distinction between sport-type and reflection-impulsivity was not
468 validated. That is, our findings did not agree with differences in sport-type reported by
469 Jacobson and Matthaeus (2014). Despite some shared methodologies, there were also
470 differences. Jacobson and Matthaeus (2014) examined inhibitory control and decision-making
471 and we investigated reflection-impulsivity. As aforementioned, it is possible that sport-type is
472 uniquely associated with particular executive functions and not others or by removing the
473 variance related to MVPA we provided a more sensitive examination of the relationship
474 between sport-type and reflection-impulsivity which is potentially inconsistent or reflective of
475 other taxonomies relevant to executive functions such as static, interceptive and strategic
476 sports (Krenn, Finkenzeller, Würth, & Amesberger, 2018). It is understandable that athletes
477 participating in team sports must determine the position of fellow players and opposing
478 players and manipulate their actions to achieve their goal (Di Russo et al., 2010). By contrast,
479 self-paced sports (e.g. swimming) place different demands on athlete's cognition. Therefore,
480 another plausible account may rest with the assumption that the demands of playing in a team
481 environment may induce situational pressures that have consequences for performance. For
482 example, it has been shown that situational stress is linked to poorer inhibitory control (e.g.,
483 Edwards et al., 2017) and decision-making (e.g., Miu, Heilman, & Houser, 2008) in non-
484 athlete samples. However, no work has examined whether situational stress is linked to poorer
485 reflection-impulsivity. Further work is needed to elucidate and untangle the combined

486 relationship between situational stress, sport-type and reflection-impulsivity in the sport
487 context.

488 Despite numerous strengths, the current research is not without limitation. Collecting
489 data at two time points enabled a within samples comparison of changes in reflection-
490 impulsivity from Time 1 (beginning of a playing season) to Time 2 (end of a 16-week playing
491 season). Nonetheless, the study was not able to answer whether the improvements measured
492 across the 16-week playing period, were sustainable. Future research warrants additional
493 follow-up measures to determine whether reflection-impulsivity improvements are maintained
494 over time. Despite the benefits of a longitudinal approach, our study did fall short of including
495 assessment of training frequency and load, that is, details of sporting competition and training
496 completed across the 16-week period (Brush et al., 2016). Extension of method could
497 incorporate multiple time points over a longer period and further develop the longitudinal
498 design to include interventions to assess the impact of specific training regimes on sport
499 performance. New work may wish to combine sport-specific measures of reflection-
500 impulsivity alongside general measures to augment the current findings. Researchers may also
501 investigate the mediating effect of other variables (e.g., anxiety) on reflection-impulsivity
502 under pressure in a sports context (Eysenck et al., 2007).

503 **Conclusion**

504 The present findings indicated a substantial association between athletic expertise and
505 reflection-impulsivity, independent of MVPA. Our findings support the notion that long-term
506 participation in competitive sport may facilitate reflection-impulsivity, making more efficient
507 and deliberate decisions, which in turn may facilitate better sport performance (Hagyard et al.,
508 2020; Ishihara & Mizuno, 2018). We propose that the reported improvements across the
509 expertise continuum might implicate the trainability of reflection-impulsivity for the potential
510 benefit of athletes. It is for future work to explore this.

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Table 1.Mean Effectiveness and Efficiency (\pm SD) on the Information Sampling Task across Sport Type in Study 1 and Study 2

		<i>M (SD)</i>							
	Variable	Total	Self-Paced	Externally-Paced	Non-Athletes	Novice	Amateur	Elite	Super Elite
Study 1									
(N = 108)	Effectiveness (<i>d'</i>)	15.12 (1.36)	16.01 (1.48)	16.29 (1.31)	13.70 (1.47)	14.48 (1.41)	15.70 (1.10)	16.22 (1.21)	17.65 (1.02)
	Efficiency	.78 (.10)	.79 (.09)	.80 (.08)	.72 (.09)	.75 (.08)	.78 (.08)	.81 (.06)	.84 (.06)
Study 2									
(N = 106)	Time 1 Effectiveness (<i>d'</i>)	15.69 (1.96)	15.58 (1.72)	15.91 (1.78)	15.10 (1.94)	15.33 (1.87)	15.53 (1.54)	16.02 (1.59)	17.28 (.89)
	Time 1 Efficiency	.73 (.11)	.74 (.10)	.76 (.09)	.67 (.10)	.73 (.08)	.75 (.07)	.78 (.06)	.81 (.06)
(N = 64)	Time 2 Effectiveness (<i>d'</i>)	16.74 (1.41)	16.58 (1.19)	17.05 (1.31)	15.59 (1.43)	16.62 (1.33)	17.29 (.98)	18.11 (.91)	18.93 (.48)
	Time 2 Efficiency	.82 (.10)	.81 (.11)	.82 (.10)	.72 (.09)	.76 (.09)	.78 (.09)	.82 (.07)	.86 (.06)

Table 3.

Between-Subjects Analysis of Covariance for the Association between Athletic Expertise and Performance on the Information Sampling Task.

	IV	DV	<i>F</i>	df	η^2	Post Hoc
Study 1 (<i>N</i> = 108)	Expertise	Effectiveness (<i>d'</i>)	5.88**	(4,102)	.19	NA, N, A < E, S
		Efficiency	1.87**		.17	NA, N, A < E, S
	Sport Type	Effectiveness	1.45	(4,102)	.03	SP = EP
		Efficiency	.21		.01	SP = EP
Study 2 (<i>N</i> = 106)	Expertise	Effectiveness	4.51**	(4,100)	.17	NA, N, A < E, S
		Efficiency	2.87**		.15	NA, N, A < E, S
	Sport Type	Effectiveness	.87	(4,100)	.02	SP = EP
		Efficiency	.13		.01	SP = EP

Note. Covariate Physical Activity insignificant across all models ($p > .05$). IV = Independent Variables, DV = Dependent Variables. SP = Self-Paced Athlete, EP = External-

Paced Athlete, NA = Non-Athlete, N = Novice, A = Amateur, E = Elite, S = Super-Elite. IST = Information Sampling Task; $p < .01^{**}$, $p < .05^*$

Table 2.

Demographic Characteristics of Study 2 Participants at Time 1 and Time 2.

		Athletes at T1 (<i>n</i> = 69)		Athletes at T2 (<i>n</i> = 50)		Non-athletes at T1 (<i>n</i> = 37)	Non-athletes at T2 (<i>n</i> = 14)	Total (<i>N</i> = 106)
		Self-Paced (<i>n</i> = 43)	Externally-Paced (<i>n</i> = 26)	Self-Paced (<i>n</i> = 30)	Externally-Paced (<i>n</i> = 20)			
Age	<i>M</i> (<i>SD</i>)	22.72 (8.35)	20.92 (2.95)	22.13 (7.25)	21.24 (3.05)	19.97 (2.36)	20.21 (2.67)	21.32 (5.77)
<i>(18- 37 years)</i>								
Expertise	Novice	10	4	7	4			
	Amateur	5	10	2	7			
	Elite	21	9	16	7			
	Super-Elite	6	4	5	2			
Years	<i>M</i> (<i>SD</i>)	10.70 (7.65)	12.38 (5.76)	11.00 (7.17)	12.29 (5.95)			

Note: Years = Mean Length of Time Participating in Sport.

Table 4.

Summary of Linear Mixed Models Results.

Variable	Descriptives of Model Summary			Test of Fixed Effect	Covariance	
	Time 1	Time 2	<i>t</i>	<i>F</i> ^(4,59)	β (CI)	Wald Z
Effectiveness (<i>d'</i>)	15.69	16.64	5.16**	10.36**	1.98 (1.35-2.34)	5.61**
Efficiency	.73	.82	2.89**	5.74**	1.18 (.92-1.80)	5.65**

Note. CI = 95% Confidence Intervals. IST = Information Sampling Task. *N* = 64. *p* < .05*, *p* < .01**

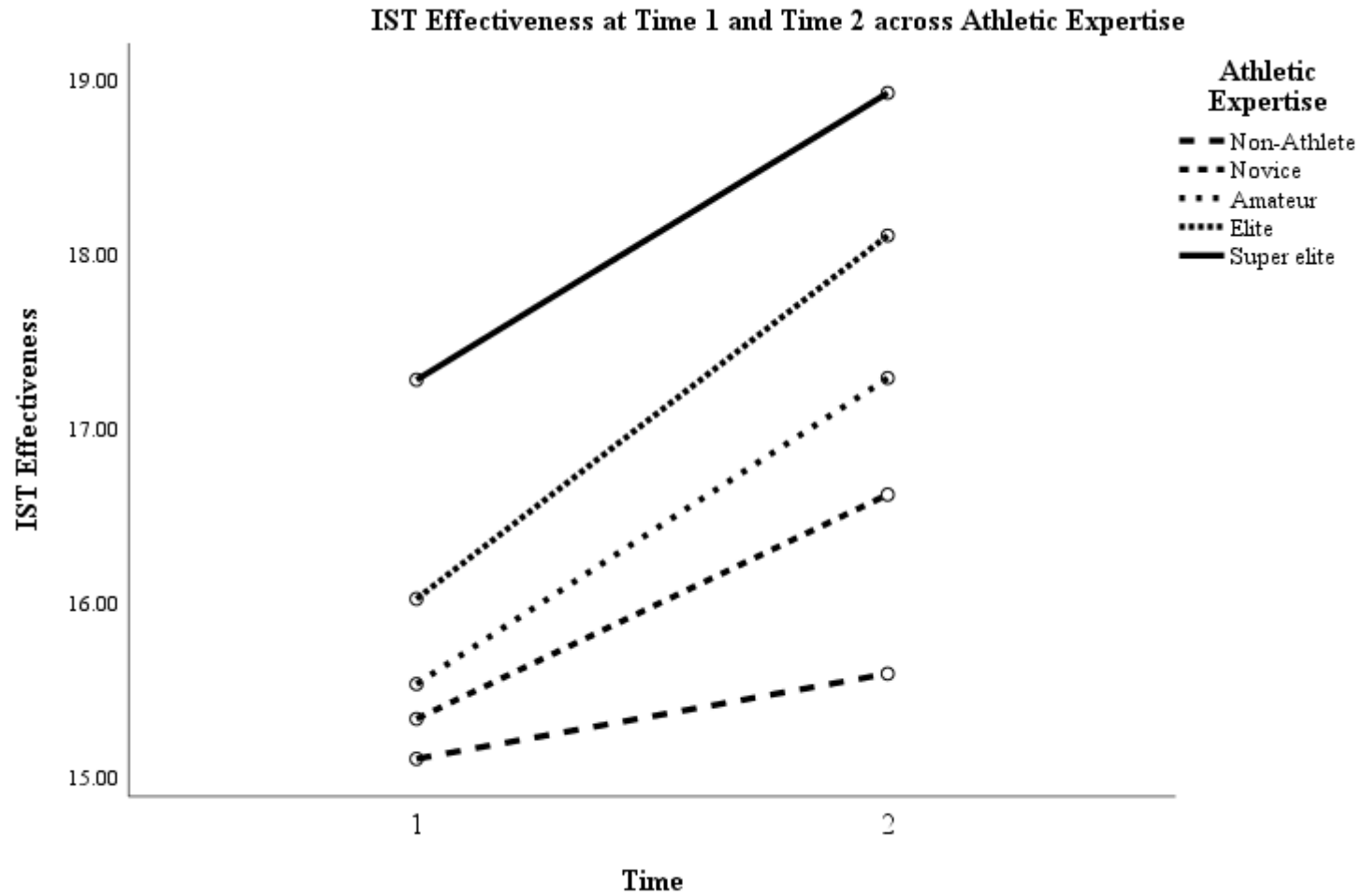


Figure 1. Plots for Linear Mixed Model of IST Effectiveness at Time 1 and Time 2 across Athletic Expertise.

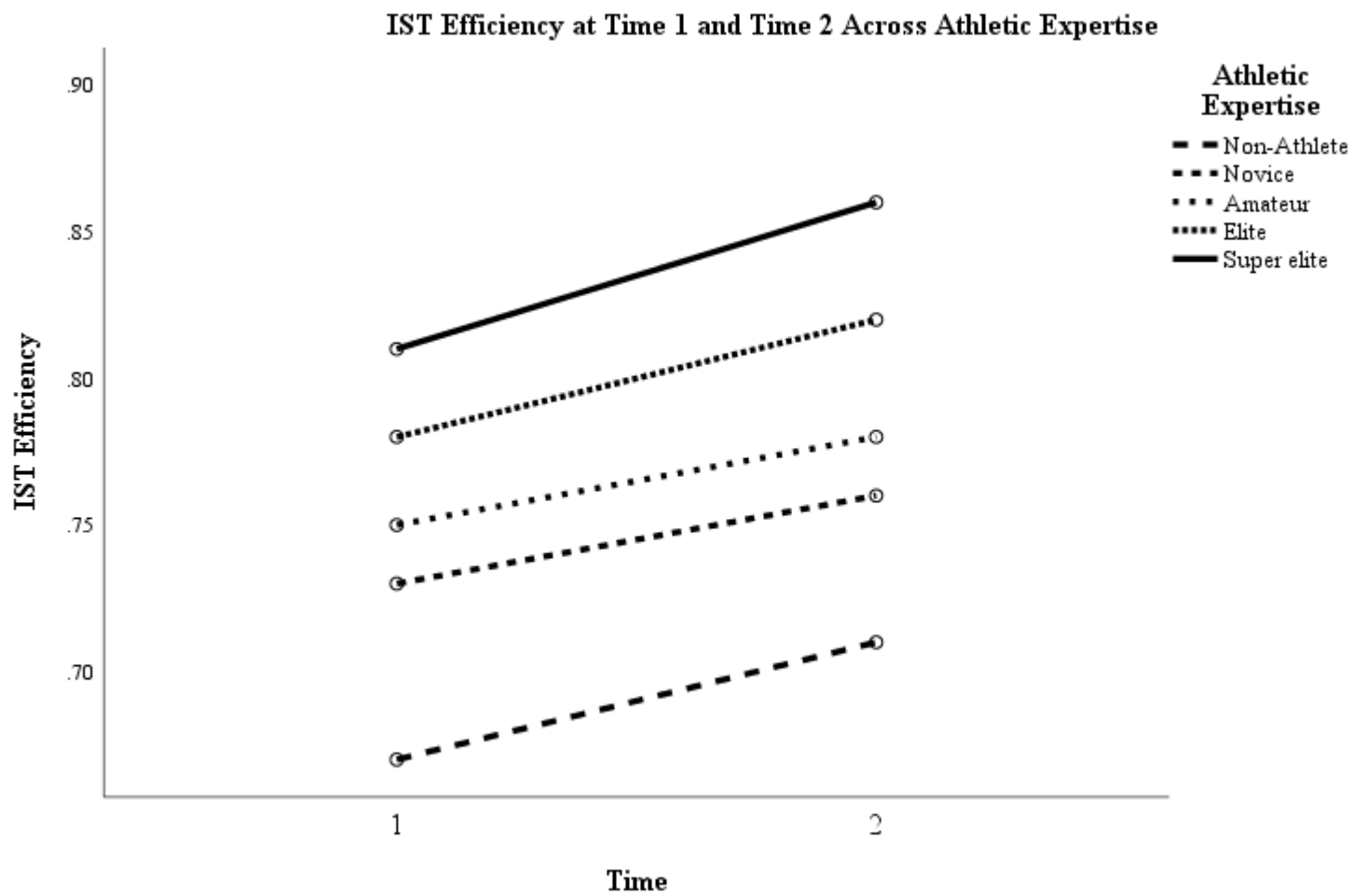


Figure 2. Plots for Linear Mixed Model of IST Efficiency at Time 1 and Time 2 across Athletic Expertise.