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Altering Pace Control and Pace Regulation: Attentional Focus Effects during Running

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17 **Abstract**

18 **Purpose:** To date there are no published studies directly comparing self-controlled and
19 externally-controlled pace endurance tasks. However, previous research suggests pace control
20 may impact on cognitive strategy use and effort perceptions. The primary aim of this study
21 was to investigate the effects of manipulating perception of pace control on attentional focus,
22 physiological, and psychological outcomes during running. A secondary aim was to
23 determine the reproducibility of self-paced running performance when regulated by effort
24 perceptions. **Methods:** Twenty experienced endurance runners completed four 3 km time-
25 trials on a treadmill. Subjects completed two self-controlled pace (SC), one perceived
26 exertion clamped (PE), and one externally-controlled pace (EC) time-trial. PE and EC were
27 completed in a counterbalanced order. Pacing strategy for EC and perceived exertion
28 instructions for PE replicated subjects' fastest SC time-trial. **Results:** Subjects reported a
29 greater focus on cognitive strategies such as relaxing and optimizing running action during
30 EC than SC. Mean heart rate was 2% lower during EC than SC despite an identical pacing
31 strategy. Perceived exertion did not differ between the three conditions. However, increased
32 internal sensory monitoring coincided with elevated effort perceptions in some subjects
33 during EC, and a 10% slower completion time for PE (13.0 ± 1.6 min) than SC (11.8 ± 1.2
34 min). **Conclusion:** Altering pace control and pace regulation impacted on attentional focus.
35 External control over pacing may facilitate performance, particularly when runners engage
36 attentional strategies conducive to improved running efficiency. However, regulating pace
37 based on effort perceptions alone may result in excessive monitoring of bodily sensations and
38 a slower running speed. Accordingly, attentional focus interventions may prove beneficial for
39 some athletes to adopt task-appropriate attentional strategies to optimize performance.

40

41 **Keywords:** Attentional strategies; perceived exertion; pacing; metacognition; endurance.

42 **Introduction**

43 Attentional focus during endurance activity is a dynamic process. To optimize
44 performance, athletes must monitor both internal (e.g. bodily states) and external (e.g.
45 environmental) stimuli and engage appropriate cognitive strategies to cope with task demands
46 (6). Much research underpins this contention, demonstrating that a focus on task-relevant
47 self-regulatory thoughts (e.g. relaxing, cadence/rhythm) may improve movement economy
48 (7) or optimize pace (8). Conversely, an excessive focus directed toward bodily sensations
49 (e.g. breathing, movement) may reduce movement efficiency (32) and diminish performance.

50 Alongside an appreciation of the isolated effects of attentional foci, an understanding
51 of the situational determinants of strategy selection is also important (6). Adapting
52 successfully to varying contexts requires cognitive control, or the intentional selection of
53 thoughts and actions based on task demands (12,27). Situational factors may also necessitate
54 differing forms of cognitive control; specifically proactive, goal-driven control (e.g. planning
55 a pacing strategy) or reactive, stimulus-driven processes (e.g. responding to environmental
56 changes) (4,6,10,27). Recently, Brick et al. (6) proposed a metacognitive framework to allow
57 a better understanding of these attentional operations during endurance activity.

58 Metacognition can be defined as an individual's insight into and control over their own
59 mental processes (15). The metacognitive framework (6) highlights the importance of
60 metacognitive skills (e.g. planning, monitoring, or reviewing one's thoughts) and
61 metacognitive experiences (e.g. feelings of task difficulty, or judgments about
62 effective/ineffective attentional foci) to cognitive strategy selection and implementation.

63 Highly developed metacognitive abilities may be a feature of experience and familiarity with
64 task demands, however (23). Accordingly, the ability of individuals to engage a focus of
65 attention appropriate to situational constraints deserves further exploration.

66 During self-paced endurance activity, including individual time-trials, perceptions of
67 exertion are considered central to pace-regulation (31,37). How perceptions of exertion are
68 generated is a topic of debate, however. Within some models, central regulation of pacing
69 strategy is the result of feedforward control in response to non-conscious processing of
70 afferent feedback from physiological systems (29,31,37). However, this contention has been
71 challenged by evidence that perceived exertion may be independent of afferent feedback (24).
72 An alternative approach, the psychobiological model, considers the role of corollary
73 discharge, or the conscious awareness of efferent signals believed to originate from premotor
74 and motor areas of the cortex (11,30,33). Within this model, the conscious regulation of pace
75 is determined by cognitive and motivational factors, including perception of effort, potential
76 motivation, knowledge of distance/time remaining, and previous experience of perception of
77 effort during exercise of varying intensity and duration (30,33).

78 Given the importance of effort perceptions to endurance performance, evidence
79 suggesting attentional focus may alter this relationship deserves further consideration (5,26).
80 In addition to understanding why attentional strategies are effective, recognizing situational
81 factors which dictate when particular foci are more useful is also important. One such context
82 relates to perception of control over pacing. In a recent review, Brick et al. (5) intimated that
83 control over pacing may impact on attentional focus and subsequent performance outcomes.
84 Specifically, in self-controlled pace designs performance tended to improve – without an
85 elevation in effort perception – when subjects engaged active self-regulatory strategies (8,22).
86 In contrast, during externally-controlled pace tasks an excessive focus on bodily sensations
87 tended to increase effort perceptions, while distractive strategies had the opposite effect (34).

88 Accordingly, the purpose of the current study was to present experienced endurance
89 runners with contexts where task constraints were modified. The primary aim was to
90 investigate the effect of manipulating perceptions of pace control on attentional focus,

91 physiological, and psychological measures during running. It was hypothesized that athletes
92 would adapt attentional focus to cope effectively with task demands. The use of effort
93 perceptions to regulate self-paced endurance activity, and the concomitant impact on
94 attentional foci was also of interest. Therefore, a secondary aim was to determine the
95 reproducibility of self-paced running performance when regulated by perceptions of effort.

96 **Methods**

97 **Subjects, ethics, and informed consent**

98 Subjects were recruited via email to local running clubs. Twenty experienced
99 endurance runners (Table 1) volunteered to take part and were given no incentives for
100 participation. All subjects were healthy, free from injury, engaged in regular running training,
101 and were accustomed to treadmill running. The study was approved by the institutional
102 research ethics committee and all participants completed a medical history questionnaire and
103 gave written informed consent before taking part. The study requirements were outlined to
104 subjects but they were not informed of the aims and hypotheses. Subjects were also naive to
105 specific time-trial protocols and were requested not to discuss the study with other subjects.

106 **[INSERT TABLE 1 NEAR HERE]**

107 **Study design and procedures**

108 A repeated measures crossover design was used. Subjects visited the laboratory on
109 five occasions, each separated by 3-8 days to limit fatigue and training adaptations. Trials
110 were performed at the same time of day (+/-3 h). Subjects maintained normal training and
111 sleep patterns throughout the duration of the study and refrained from strenuous activity in
112 the 24 h preceding each trial. Before the first session, subjects recorded a 24 h food diary and
113 were asked to maintain similar dietary intake before subsequent visits. Subjects were asked to

114 avoid caffeine and food, and drink 500 ml of water in the 2 h before each session. Body mass
115 was recorded before each trial to indicate no significant variations in hydration status.

116 Maximal oxygen consumption (VO_{2max})

117 On the initial visit, subjects completed an incremental exercise test to volitional
118 exhaustion on a treadmill (h/p/cosmos quasar; h/p/cosmos Sports & Medical GmbH,
119 Traunstein, Germany) with continuous measurement of respiratory gas exchange using an
120 online metabolic cart calibrated before each test (Quark C-PET, Cosmed Srl, Rome, Italy).
121 Following a 5 min warm-up at a self-selected pace, subjects began at a light intensity based
122 on their ability, with the intention of reaching volitional exhaustion within 10-15 min. Stages
123 lasted 2 min, with $2 \text{ km}\cdot\text{h}^{-1}$ increments for each of the first 3 stages followed by $1 \text{ km}\cdot\text{h}^{-1}$
124 increments to volitional exhaustion. Treadmill gradient was maintained at 1%. Volitional
125 exhaustion was reached in 13.9 ± 1.4 min. Heart rate was measured continuously by wireless
126 telemetry (Cosmed HR monitor, Rome, Italy). VO_{2max} was determined as the highest value
127 for a 10 breath rolling average. In all tests two or more criteria for VO_{2max} were met (19).

128 Experimental measures

129 During visits 2-5, subjects completed a 3 km time-trial on the laboratory treadmill. On
130 arrival at the laboratory, subjects were informed of the protocol for the ensuing time-trial (see
131 *Time-trials*). Following a check for understanding, subjects completed the Brunel Mood
132 Scale (BRUMS; 36) on which they were instructed to “circle the answer which best describes
133 how you feel right now”. To determine potential motivation, subjects completed an adapted
134 state motivation questionnaire (25), and two 11-point Likert-type scales to determine
135 willingness to invest maximal physical, and mental effort (0 = not willing, 10 = willing;
136 38,39). Before the warm-up, subjects’ body mass (Seca 862, Hamburg, Germany) and resting
137 blood lactate concentration were recorded (Lactate Pro 2, Arkray Inc., Kyoto, Japan).

138 During each time-trial recordings of running speed, heart rate (Polar RS400, Kempele,
139 Finland), rating of perceived exertion (Borg RPE 6-20 scale; 3), and affective valence
140 (Feeling Scale; 17) were taken at 200 m, and at each 400 m distance interval thereafter. RPE
141 and affective valence scales were projected on a screen 3.5 m in front of the treadmill and
142 removed once subjects had indicated their RPE and affect over the preceding 200 m. Before
143 the PE time-trial, subjects were informed that their reported RPE could vary from the
144 instructed RPE if they perceived their actual exertion to be different.

145 Time-trials

146 Before each time-trial, subjects warmed up for 5 min at a pace equivalent to 70% of
147 the maximum heart rate recorded during the incremental test, followed by 2 min rest (38). To
148 provide knowledge of distance elapsed/remaining (30,33) only the treadmill distance display
149 was visible to the subjects. However, the user terminal was interfaced with a computer
150 (h/p/cosmos pc software) so that all time-trial data were visible to the experimenters. A video
151 camera was used to record data for later analysis. Subjects received no other feedback or
152 verbal encouragement throughout each time-trial. A fan was positioned at the front right of
153 the treadmill during each trial to ensure consistency of laboratory conditions.

154 Time-trials 1 and 2 were self-controlled pace trials. Before each trial, subjects were
155 instructed how to manipulate treadmill speed on the user terminal and were informed they
156 could pace the trial freely, but to complete it as quickly as possible. The first time-trial served
157 as a familiarization trial. The second trial replicated the familiarization trial. Paired-sample t-
158 tests indicated no differences between trials in running speed, completion time, heart rate,
159 post-trial blood lactate, perceived exertion, affective valence, or on frequency ratings for any
160 attentional focus category (see *Post time-trial measures and attentional focus interview*). The
161 fastest trial was used as each subject's self-controlled pace (SC) trial for subsequent analysis.

162 Time-trials 3 and 4 were completed in a randomized, counterbalanced order
163 (www.random.org). Time-trial 3 was a rating of perceived exertion clamped (PE) trial.
164 During PE, subjects were instructed to maintain varying perceptions of exertion, replicating
165 those self-reported during SC. Subjects were issued with an RPE instruction at each distance
166 interval (e.g. 200 m, 600 m, etc.) to attain by the next 200 m segment (e.g. 400 – 600 m, 800
167 – 1000 m, etc.). Subjects were informed beforehand and reminded during that RPE was in the
168 context of a 3 km time-trial they were attempting to complete as quickly as possible (30,33).
169 Subjects could manipulate the treadmill speed throughout. Time-trial 4 was an externally-
170 controlled (EC) pace trial during which the experimenter controlled treadmill speed using the
171 manufacturer’s software controls. Before EC, subjects were informed the trial would be
172 completed as quickly as possible but the experimenter would control the speed. Pacing
173 replicated the self-selected strategy adopted during SC. Subjects were blind to the origin of
174 the RPE instructions and the pacing strategy implemented during PE and EC respectively.

175 Post time-trial measures and attentional focus interview

176 Following each time-trial, participants completed the BRUMS, on which they were
177 instructed to “*circle the answer which best describes how you felt during the 3 km time-trial*”,
178 and the state motivation questionnaire as retrospective measures. As a manipulation check,
179 subjects rated their perception of control over pacing on an 11-point Likert-type scale (0 = no
180 control, 10 = complete control). During a post-trial interview, subjects rated how frequently
181 they focused on thoughts from attentional focus categories (5,6) during the time-trial on 11-
182 point Likert-type frequency scales (one item per category) with verbal descriptors (0 = never,
183 10 = always; 40). Subjects also recounted specific foci engaged, and were able to view
184 attentional focus category information to assist recall (see Supplemental Digital Content 1 for
185 attentional focus scales). All interviews were digitally recorded to check for accuracy.

186 Statistical analysis

187 The effect of condition (SC, PE, EC) on pre-trial states (i.e. body mass, resting blood
188 lactate, willingness to invest physical and mental effort, success and interest motivation),
189 time-trial performance (i.e. completion time, running speed), physiological (i.e. heart rate,
190 post-trial blood lactate), and psychological measures (i.e. RPE, affect, mood states), the
191 manipulation check, and attentional focus frequency ratings were analyzed using repeated
192 measures MANOVA. If assumptions of sphericity were violated, the Greenhouse-Geisser
193 correction was used to report analyses. Post hoc pairwise comparisons with Sidak-adjusted *P*
194 values were conducted where a significant F ratio was observed. Statistical significance was
195 accepted as $P < 0.05$ (two tailed). Reporting of analyses focused on comparisons between SC
196 and EC, and between SC and PE. Cohen's *d* (9) values are provided as an estimate of effect
197 size where relevant. Where appropriate, 95% confidence intervals (95% CI) are reported for
198 post hoc pairwise comparisons. All data analyses were conducted using the Statistical
199 Package for the Social Sciences (IBM Statistics 22.0, SPSS Inc., Chicago, IL).

200 Results

201 Reporting of within time-trial distance interval measures (i.e. speed, heart rate, affect
202 and RPE) will focus on mean time-trial values. A more detailed analysis is available on the
203 online digital content (see Supplemental Digital Content 2 for distance interval analyses).

204 Pre-trial state measures

205 Mean duration between SC and EC was 7.9 ± 4.2 days, and between SC and PE was
206 9.3 ± 4.6 days. Consistency of pre-trial states (Table 2) indicated no differences for body
207 mass, resting blood lactate, willingness to invest physical effort, willingness to invest mental
208 effort, or success motivation. Interest motivation was higher before EC than SC (Mean
209 difference, MD = 0.95, 95% CI = 0.03, 1.87; $P = 0.042$, $d = 0.44$). Retrospective measures

210 indicated no differences in success or interest motivation between conditions. As a
211 consequence, the effect of condition was further analyzed using a repeated measures
212 MANCOVA where appropriate, with pre-EC interest motivation controlled as the covariate.

213 **[INSERT TABLE 2 NEAR HERE]**

214 Time-trial performance

215 Mean running speed (Table 2 and Figure 1a) was slower during PE than SC (MD = -
216 1.33 km·h⁻¹, 95% CI = -2.01, -0.66; $P < 0.001$, $d = 0.94$), resulting in a slower completion
217 time for PE (MD = 1.18 min, 95% CI = 0.57, 1.78; $P < 0.001$, $d = 0.84$). Neither mean speed
218 nor completion time differed between SC and EC. During SC subjects made 12.1 ± 3.7 pace
219 adjustments, most occurring within the first 600 m (5.1 ± 2.6) and the last 400 m (2.6 ± 1.2).

220 **[INSERT FIGURE 1 NEAR HERE]**

221 Physiological measurements

222 Heart rate (Table 2 and Figure 1b) was higher during SC compared with both EC
223 (MD = 3.24 bpm, 95% CI = 1.51, 4.95; $P < 0.001$, $d = 0.35$) and PE (MD = 9.54 bpm, 95%
224 CI = 5.96, 13.12; $P < 0.001$, $d = 0.86$). A follow up Pearson's product moment correlation
225 revealed the difference in heart rate between SC and EC was negatively correlated with the
226 number of pace adjustments made during SC ($r = -0.513$, $P = 0.021$). Blood lactate (Table 2)
227 was lower following PE compared with SC (MD = -2.80 mmol·L⁻¹, 95% CI = -5.43, -0.159;
228 $P = 0.036$, $d = 0.67$). There was no difference in post-trial blood lactate between SC and EC.

229 Psychological measures and manipulation check

230 There was no main effect of condition for RPE on MANOVA or MANCOVA
231 outcomes (Table 2 and Figure 1d). Mean affective valence during PE (Table 2 and Figure 1c)
232 was more positive than SC (MD = 0.81, 95% CI = 0.06, 1.56; $P = 0.033$, $d = 0.52$). There

233 was no main effect of condition for any mood states reported pre-trial or retrospectively on
234 MANOVA or MANCOVA outcomes (Table 3). The post-trial manipulation check (Table 2),
235 revealed a reduced perception of control over pacing between EC than SC (MD = -7.50, 95%
236 CI = -9.27, -5.73; $P < 0.001$, $d = 3.64$) but not between SC and PE.

237 **[INSERT TABLE 3 NEAR HERE]**

238 Post time-trial attentional focus frequency rating and qualitative interviews

239 Attentional focus frequency ratings are provided in Figure 2. Internal body sensations
240 were monitored more frequently during PE than both SC (MD = 1.55, 95% CI = 0.16, 2.94; P
241 = 0.026, $d = 0.83$) and EC (MD = 1.45, 95% CI = 0.39, 2.52; $P = 0.006$, $d = 0.90$). There was
242 no main effect of condition for active self-regulation ($P = 0.077$), outward monitoring ($P =$
243 0.262), or distraction ($P = 0.223$).

244 **[INSERT FIGURE 2 NEAR HERE]**

245 The primary active self-regulatory thoughts reported during SC were pacing/tactics
246 (95% of subjects), chunking (i.e. mentally breaking the 3 km distance down to smaller
247 segments; 80%) and improving running technique (65%). These were pacing/tactics (70%),
248 relaxing (55%), and improving running technique (40%) during PE, while during EC subjects
249 reported improving running technique (75%), relaxing (60%) and cadence/rhythm (55%).
250 Bodily sensations most frequently monitored were breathing, body movement/form, and
251 overall effort/feel. Breathing was monitored by 80% of subjects during SC, 65% during PE,
252 and 50% during EC. Body movement was monitored by 60% during SC, 65% during PE and
253 45% during EC, while overall effort/feel was monitored by 55% during SC, 80% during PE
254 and 45% during EC. The distance display was the most monitored outward source of
255 information, reported by 95% of subjects during SC, 85% during PE and 80% during EC.
256 Finally, 40% of subjects reported distraction during SC, 35% during PE and 55% during EC.

258 **[INSERT FIGURE 3 NEAR HERE]**

259 Further analysis of the RPE data suggested individual differences in response to the
260 EC trial (Figure 3). Specifically, nine individuals perceived exertion during EC to be higher
261 than SC, and eleven lower. Consequently, between-groups differences were analyzed using
262 MANOVA with increased/decreased RPE during EC as the between-groups factor. RPE
263 reported during SC did not differ, but there was a between-groups difference in RPE reported
264 during EC ($F_{1, 18} = 7.83$, $P = 0.012$, $d = 0.80$). Mean RPE increased from SC (12.7 ± 1.6) to
265 EC (13.9 ± 1.4) for those who reported EC harder, and decreased from SC (12.5 ± 1.9) to EC
266 (11.7 ± 2.0) for those who found EC easier. Furthermore, subjects who perceived an elevated
267 RPE during EC also reported a greater frequency of internal sensory monitoring than those
268 who reported a lowered RPE (Mean \pm SD; 7.2 ± 1.8 versus 5.6 ± 1.4 respectively; 95% CI =
269 0.08, 3.10; $P = 0.041$, $d = 0.99$). The groups did not differ on running experience or any other
270 attentional focus, physiological, or psychological variable.

271 **Discussion**

272 The primary aim of this investigation was to determine the effects of manipulating
273 perceptions of pace control on attentional focus, physiological, and psychological measures
274 during 3 km time-trial running. This study was the first to compare these outcomes under
275 self-controlled (SC) versus externally-controlled (EC) pace conditions. An important finding
276 was that externally-controlled pace running altered the content of subjects' self-regulatory
277 cognitions. Specifically, during EC subjects focused less attention on self-regulatory thoughts
278 related to pacing and more on relaxation and optimizing their running action. Heart rate was
279 also 2% lower during the EC trial than the SC trial despite an identical pacing strategy
280 between trials. The second aim was to determine the reproducibility of self-paced running
281 when regulated by perceptions of effort. Mean completion time was 10% slower during the

282 perceived exertion clamped (PE) time-trial, despite identical effort perceptions to the SC trial.
283 Subjects also reported a large increase in internal sensory monitoring during the PE trial.

284 Altering perceptions of pace control appeared to have a profound impact on runners'
285 focus of attention. During SC, for example, almost all subjects focused on pacing, monitoring
286 the distance display, and chunking (i.e. mentally breaking the 3 km distance down to smaller
287 segments to assist pacing decisions). In contrast, during EC the majority of subjects focused
288 on relaxing, and improving both running technique and cadence/rhythm. Furthermore, fewer
289 subjects reported monitoring breathing and body movement during EC in comparison with
290 SC. The altered focus of attention also coincided with a small reduction in heart rate during
291 the EC trial which cannot be explained by treadmill manipulations or a training effect (21).

292 The potentially beneficial impact of focusing on relaxing and optimizing running
293 action may have important implications for endurance running performance. Previous studies,
294 for example, have demonstrated improved running economy and/or reduced heart rate in
295 endurance athletes experienced at using relaxation strategies (7) or running at a preferred
296 cadence (20). Additionally, concentrating on improved movement technique has been shown
297 to optimize running performance (13). In contrast, monitoring highly automated processes
298 such as breathing or movement execution may increase heart rate and the oxygen cost of
299 running (32). The findings of the present study also emphasize the significance of
300 metacognitive processes to attentional focus within varying contexts (6). Specifically, the
301 data suggest that during the EC time-trial, task-relevant monitoring of situational variables
302 (e.g. bodily sensations) stimulated cognitive control and selection of cognitive strategies
303 more conducive to a lowered oxygen cost of running.

304 The differences in subjects' self-regulatory cognitions during the SC and EC time-
305 trials may have further significance. Focusing on pace-related thoughts during the SC trial

306 implies a need for proactive, goal-driven cognitive control (4,6,10). In such circumstances,
307 sustained activation of the prefrontal cortex is required to control cognition and guide
308 behavior, resulting in a greater demand on cognitive resources (4,27). Furthermore, study of
309 brain activity indicates that areas including the prefrontal, premotor, and sensorimotor
310 cortices are more active when changes in locomotion speed are prepared in advance (35), as
311 would occur during self-paced running. In contrast, during EC an identical pacing strategy
312 may not have required proactive cognitive control. Instead, reactive, or stimulus-driven
313 attentional control (4,6,10) may have been more appropriate, whereby subjects could
314 reactively employ cognitive strategies (e.g. to relax) based on periodic monitoring. While
315 reactive cognitive control may also have been prevalent during the SC trial, it was likely the
316 dominant form of control during the EC trial. Reactive control is considered less demanding
317 on cognitive resources than proactive control (4). Accordingly, a reduction in central
318 regulation (31) may represent an additional benefit of externally-controlled pace running.

319 While recognizing limitations of the present study (i.e. treadmill running and
320 subjective reporting of attentional focus), the potential reduction in both cognitive and
321 physiological demands when pace is set may have practical performance benefits. While Bath
322 et al. (1) reported no performance effect for subjects running with a pacemaker, the second
323 runner in that study adjusted their pace in reaction to the subject's strategy, thus not truly
324 acting as a pace-maker. However, a study of pack running during World Half Marathon
325 Championships (16) noted that athletes who ran in packs with similar ability opponents (i.e.
326 pacemakers) during the entire race increased pace over the final 1.1 km more than any other
327 group (e.g. solo runners, occasional pack runners). Whether this was a result of increased
328 competition (16,39) or reduced wind resistance (31) demands further study. It may be that
329 additional advantages are accrued when employing less resource demanding reactive
330 cognitive control and cognitive strategies conducive to increased running efficiency.

331 While stimulus-driven attentional control may be less demanding on cognitive
332 resources, a more in-depth analysis of the data suggests an excessive focus on some stimuli
333 may be counterproductive. Though mean RPE did not differ between EC and SC trials, large
334 individual differences in RPE responses were apparent (Figure 3). Specifically, nine subjects,
335 including all five females, perceived EC to be more difficult than SC. This group also
336 reported monitoring bodily sensations frequently during EC, while those who perceived EC
337 to be easier monitored occasionally/often. Increased monitoring of bodily sensations has been
338 reported to intensify perceptions of exertion (34). Thus, the findings partially support the
339 original hypothesis in that some, but not all subjects adapted attentional focus to cope with
340 the constraints imposed by the EC trial. This may be due to a lack of task-specific experience,
341 for example (23,30,33), while the influence of gender warrants further research attention.

342 The second aim was to determine the reproducibility of self-paced running when
343 regulated based on perceptions of effort. In this regard, a major finding was that, on average,
344 PE was completed 10% slower than SC. This was despite no reported difference in perceived
345 exertion or state motivation between SC and PE trials. The slower running speed (by 8.7%)
346 during PE resulted in a reduced heart rate (by 5.8%), and a lower post-trial blood lactate
347 concentration (by 25.5%). Affective valence was also more positive during EC, which may
348 reflect the slower running speed and decreased blood lactate (14). Collectively, the findings
349 support suggestions that effort perceptions may be independent of afferent feedback from
350 cardiovascular and metabolic stress (24). However, the slower running speed during PE
351 should, theoretically, also reduce efferent output and activity in premotor and motor areas of
352 the cortex, regions believed to be responsible for the corollary discharges generative of effort
353 perception (11). As with individual differences reported between SC and EC trials, however,
354 consideration of attentional focus responses may also resolve this apparent anomaly.

355 During the PE trial, subjects monitored bodily sensations most of the time as opposed
356 to often/frequently during SC (Figure 2). In addition, a greater number of athletes reported
357 monitoring overall effort/feel (80%) and body movement (65%) during PE. From an
358 attentional focus perspective (6) the findings suggest excessive internal sensory monitoring
359 without task-appropriate self-regulatory (8,22), outward (38,39) or distractive (34) foci may
360 amplify feelings of task difficulty. This may result from an increased conscious awareness of
361 corollary discharge and an attendant elevation in effort perceptions. Consequently, during PE
362 a decreased intensity was required to maintain the instructed RPE. The findings emphasize
363 the importance of a context-appropriate focus of attention during endurance activity (5,6).

364 **Conclusions and future recommendations**

365 This is the first study to directly compare self-controlled (SC trial) and externally-
366 controlled (EC trial) pace endurance tasks. An important finding was that subjects employed
367 attentional strategies (e.g. relaxing, optimizing running action) conducive to improved
368 running efficiency during the EC trial. Attentional control during externally-controlled pace
369 running may also be less demanding on cognitive resources. However, increased internal
370 sensory monitoring coincided with elevated effort perceptions in some runners during the EC
371 trial. Compared with the SC trial, excessive monitoring of bodily sensations (e.g. overall
372 effort/feel, body movement) was also accompanied by a slower running speed and
373 completion time during the perceived exertion clamped (PE) trial. This study highlights the
374 need for a task-appropriate focus of attention during running and supports suggestions that
375 attentional focus may be an important determinant of endurance performance (2,26).

376 Based on the present findings, further research is required to explore the performance
377 implications of externally-controlled pace running in an ecologically valid setting (e.g.
378 running with pacemakers). Given that all five female subjects reported increased effort

379 perceptions during the EC trial, the potentially moderating influence of gender should also be
380 investigated. Future research is also needed to determine the cortical activity involved during
381 externally-controlled versus self-controlled pace endurance tasks. Finally, from an applied
382 practice perspective, the findings suggest attentional focus interventions may prove beneficial
383 for some athletes to adapt successfully to task demands. Performance advantages may be
384 accrued by those athletes adopting a context-appropriate focus of attention.

385 **Conflicts of interest, source of funding and acknowledgements**

386 The authors have no conflicts of interest. This study received no sources of funding.
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500

501 Table 1. Demographic and training characteristics of subjects ($n = 20$).

502 Table 2. Measures for pre-trial variables, time-trial data, and manipulation check for SC, PE
503 and EC.

504 Table 3. Mean \pm SD for mood states (BRUMS) reported pre-trial and retrospectively post-
505 trial.

506 Figure 1. Running speed (a), heart rate (b), affective valence (c), and ratings of perceived
507 exertion (d) during 3 km time-trials. Error bars illustrate SEM. Symbols denote main effect of
508 condition: (#) Mean speed slower for PE than SC ($P < 0.001$). (*) Heart rate higher for SC
509 than both EC ($P < 0.001$) and PE ($P < 0.001$). (^) Affective valence more positive for PE
510 than SC ($P = 0.033$).

511 Figure 2. Attentional focus frequency ratings for each condition. Error bars illustrate SEM.
512 Symbol denotes Sidak-adjusted pairwise difference: (*) ISM higher during PE than SC ($P =$
513 0.026) and EC ($P = 0.006$).

514 Figure 3. Individual subject data (*grey lines*) for differences in RPE reported during SC and
515 EC time-trials. Thicker black lines represent mean RPE \pm SEM for subjects perceiving EC
516 easier (full lines), and more difficult (dashed lines) than SC. (*) Difference between groups in
517 mean RPE reported during EC ($P = 0.012$).

518

519 Supplemental Digital Content 1. Attentional focus rating scales and checklist (.pdf)

520 Supplemental Digital Content 2. Distance interval analyses (.pdf)

Table 1. Demographic and training characteristics of subjects ($n = 20$).

<hr/>	
Variable	
Age	40.3 ± 8.1 yr
Gender	15 M, 5 F
Body Mass (Session 1)	69.2 ± 10.8 kg
Height	1.73 ± .09 m
VO_{2max} (all)	53.1 ± 5.0 mL·kg ⁻¹ ·min ⁻¹
Males ($n = 15$)	54.3 ± 4.3 mL·kg ⁻¹ ·min ⁻¹
Females ($n = 5$)	49.5 ± 5.5 mL·kg ⁻¹ ·min ⁻¹
Running experience	9.7 ± 10.6 yr
Weekly training volume	62.9 ± 15.6 km
Training intensity* (No. sessions p.w.)	2.2 ± 0.6 high, 3.0 ± 0.8 medium/low
Primary events	Ultra-distance ($n = 3$) 10km – Marathon ($n = 7$) 800m – 10km ($n = 10$)

**Note: training intensity self-reported by participants. High intensity training identified as high-intensity interval and tempo running*

Table 2. Measures for pre-trial variables, time-trial data, and manipulation check for SC, PE and EC.

	SC	PE	EC
<i>Pre-trial variables</i>			
Body Mass (kg)	69.4 ± 10.8	69.2 ± 10.5	69.5 ± 10.7
Resting Blood Lactate (mmol·L ⁻¹)	1.6 ± 0.5	1.8 ± 0.8	1.8 ± 0.8
<i>Willingness to invest effort</i>			
Physical	9.4 ± 0.9	9.6 ± 0.8	9.7 ± 0.6
Mental	9.3 ± 1.1	9.6 ± 0.6	9.6 ± 0.7
<i>Motivation (Pre-trial)</i>			
Success	20.2 ± 5.4	20.1 ± 5.1	20.4 ± 4.9
Interest	24.9 ± 2.3	25.6 ± 2.5	25.9 ± 2.0 ^a
<i>Motivation (Retrospective)</i>			
Success	21.3 ± 4.0	20.4 ± 5.3	20.1 ± 5.0
Interest	25.7 ± 2.4	26.2 ± 2.2	25.9 ± 2.5
<i>Time-trial data</i>			
Completion Time (min)	11.8 ± 1.2	13.0 ± 1.6 ^b	11.9 ± 1.2
Mean Speed (km·h ⁻¹)	15.3 ± 1.4	14.0 ± 1.5 ^b	15.3 ± 1.4
Mean Heart Rate (bpm)	163.3 ± 9.3 ^c	153.8 ± 12.6	160.1 ± 9.2
Post-trial Blood Lactate (mmol·L ⁻¹)	11.0 ± 4.2	8.2 ± 4.2 ^d	10.2 ± 3.7
Mean RPE	12.6 ± 1.7	12.8 ± 1.6	12.7 ± 2.1
Mean Affect	1.7 ± 1.6	2.6 ± 1.5 ^e	1.8 ± 1.9
<i>Manipulation check</i>			
Perceived control pacing	8.7 ± 1.8	8.2 ± 2.0	1.2 ± 2.3 ^f

Data are presented as Mean ± SD. Symbols denote significant pairwise differences: ^a Higher than SC ($P = 0.042$). ^b Slower than SC ($P < 0.001$). ^c Higher than PE ($P < 0.001$) and EC ($P < 0.001$). ^d Lower than SC ($P = 0.036$). ^e More positive than SC ($P = 0.033$). ^f Lower than SC ($P < 0.001$).

Table 3. Mean \pm SD for mood states (BRUMS) reported pre-trial and retrospectively post-trial.

		Tension	Depression	Anger	Vigor	Fatigue	Confusion
SC	Pre-trial	1.7 \pm 1.8	0.2 \pm 0.4	0.2 \pm 0.7	10.0 \pm 3.2	2.0 \pm 2.1	0.5 \pm 0.8
	Post-trial	1.3 \pm 1.9	0.01 \pm 0.3	0.1 \pm 0.3	12.5 \pm 2.8	2.0 \pm 2.4	0.5 \pm 1.2
PE	Pre-trial	1.9 \pm 2.0	0.0 \pm 0.0	0.0 \pm 0.0	9.7 \pm 3.7	1.2 \pm 1.5	0.6 \pm 1.1
	Post-trial	1.3 \pm 2.4	0.2 \pm 0.5	0.1 \pm 0.2	11.4 \pm 3.9	1.2 \pm 1.5	1.0 \pm 2.0
EC	Pre-trial	2.7 \pm 2.8	0.2 \pm 0.5	0.01 \pm 0.5	9.8 \pm 3.9	2.0 \pm 2.5	0.8 \pm 1.2
	Post-trial	1.5 \pm 1.8	0.3 \pm 1.1	0.0 \pm 0.0	10.8 \pm 3.3	1.4 \pm 1.8	0.9 \pm 1.4

No main effect of condition for mood states reported pre-trial or retrospectively on MANOVA or MANCOVA outcomes.

Figure 1

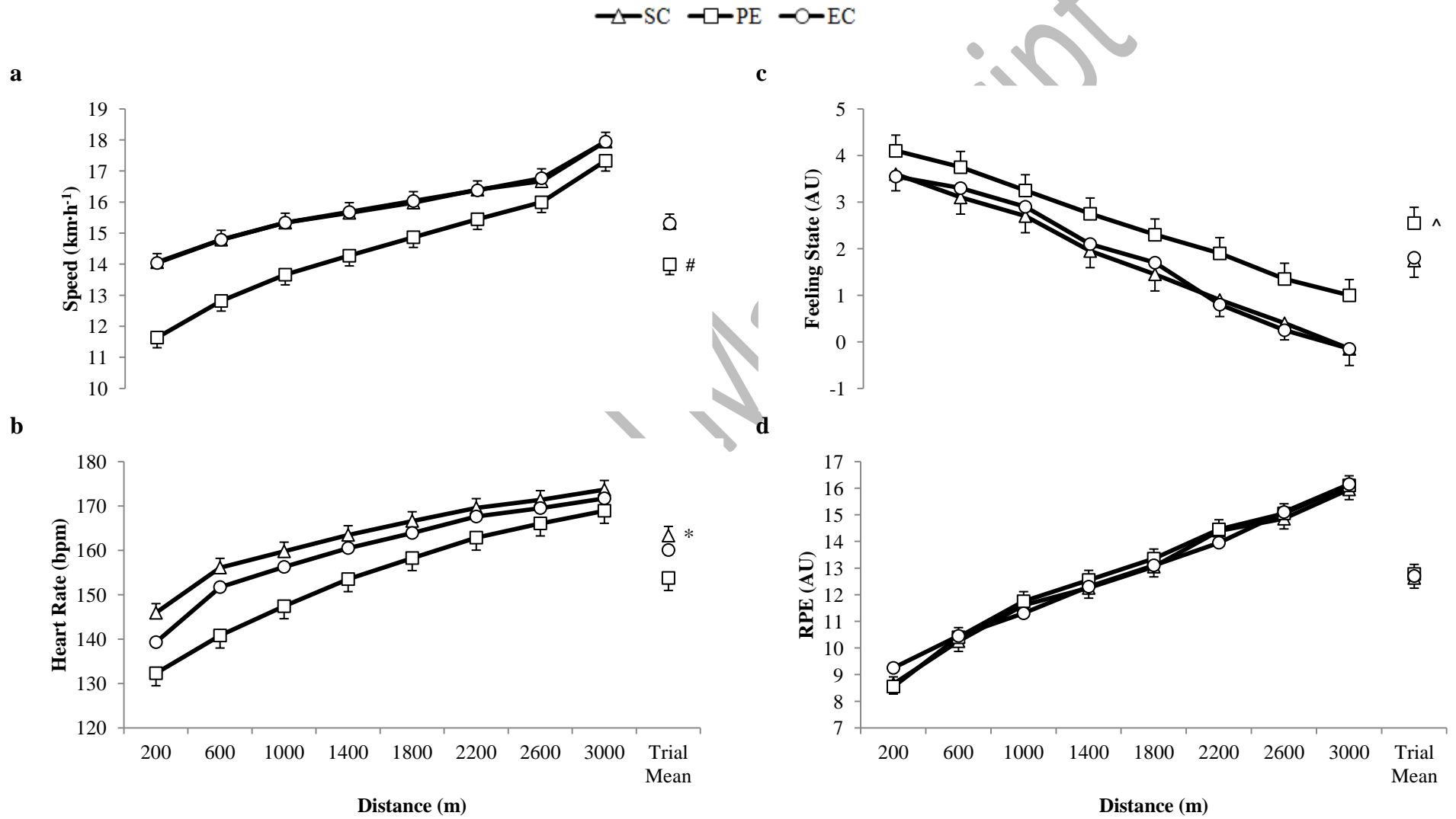


Figure 2

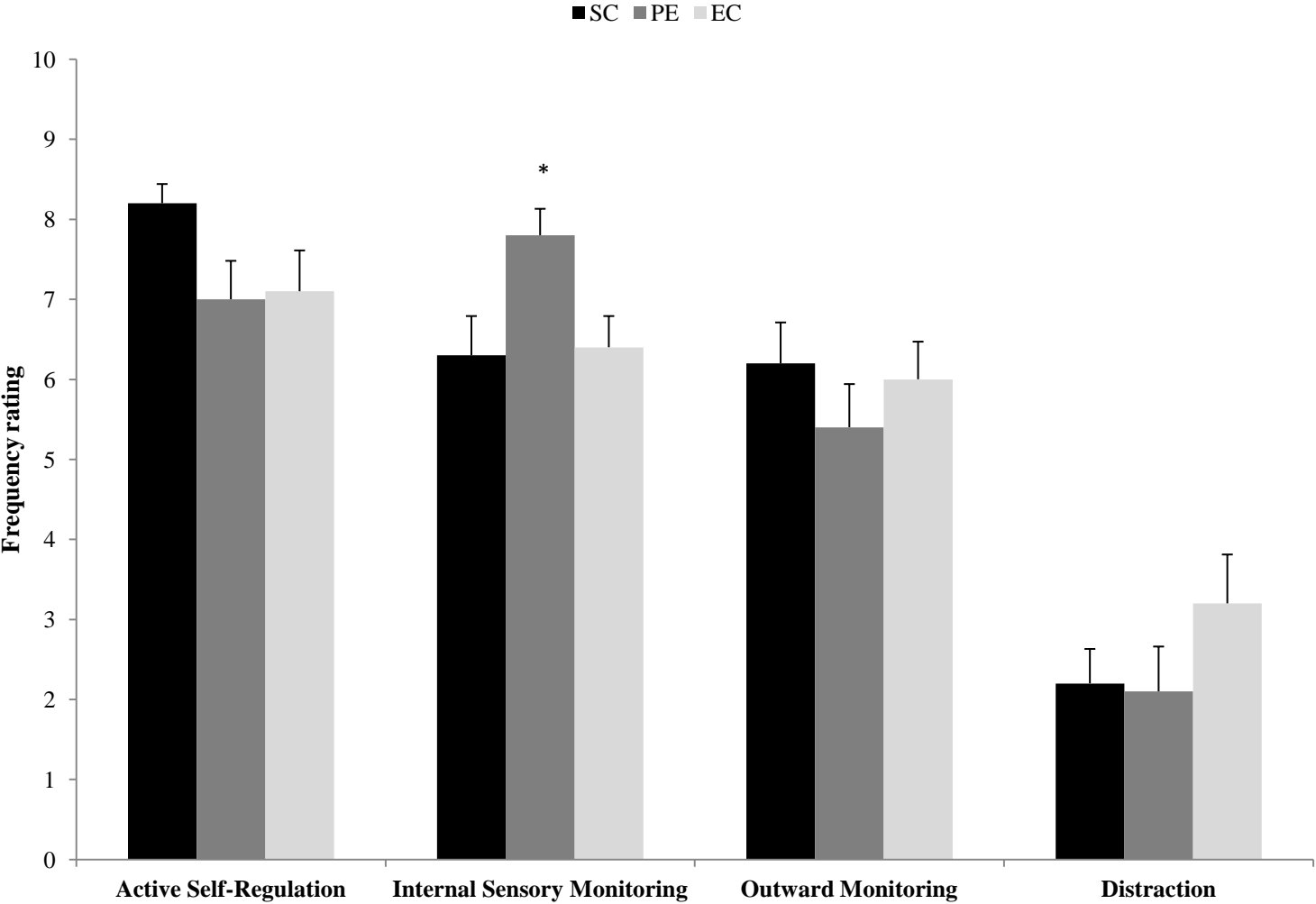
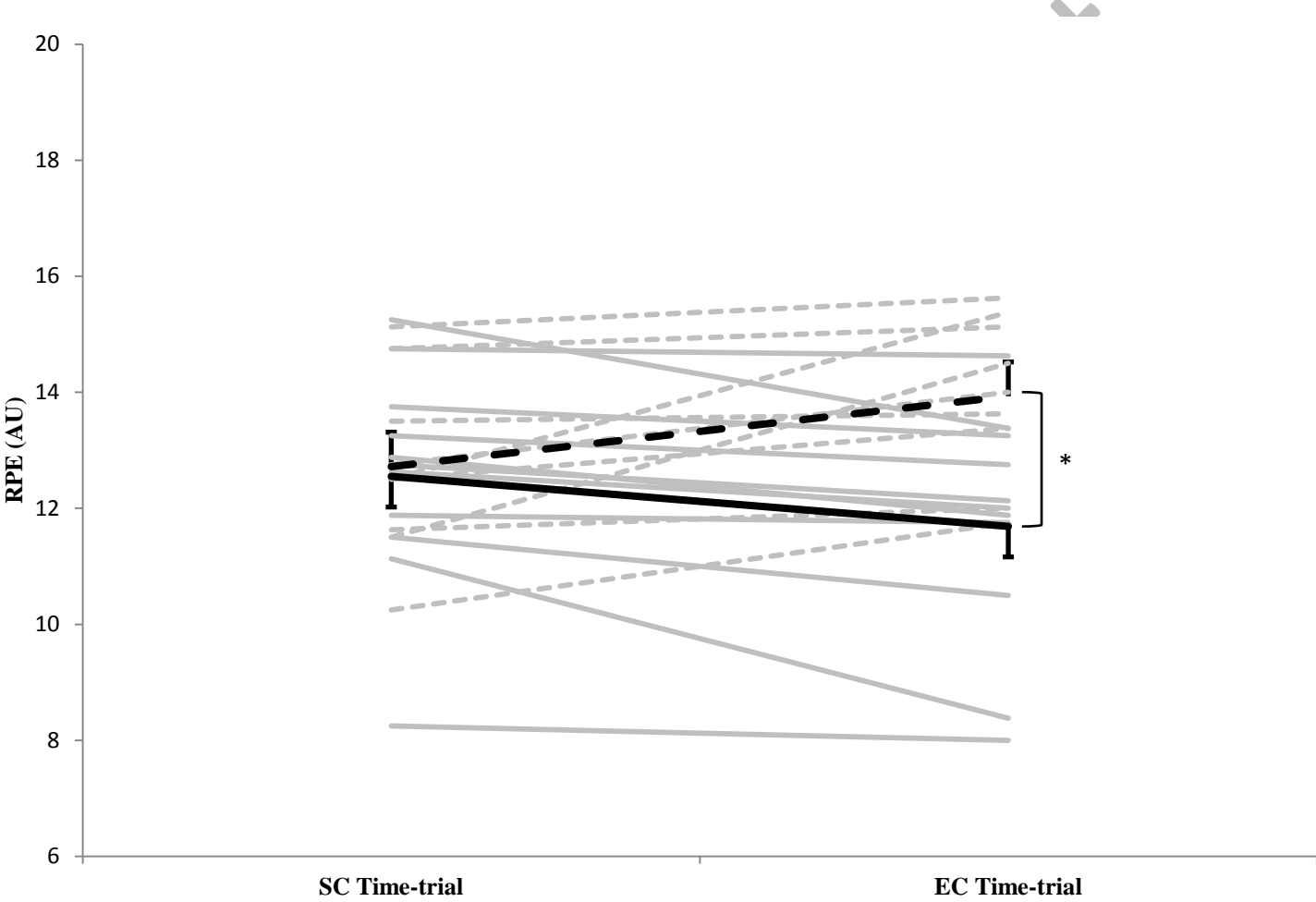


Figure 3



AC