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Contextual Interference Effect on Perceptual–Cognitive Skills Training

AUTHOR

Broadbent, David P.; Causer, Joe; Ford, Paul R.; et al.

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The role of error processing in the contextual interference effect during the training of
perceptual-cognitive skills

David P. Broadbent^{1, 2}, Joe Causer¹, A. Mark Williams³ & Paul R. Ford⁴

¹ Research Institute of Sport and Exercise Sciences, Liverpool John Moores University

² Division of Sport, Health and Exercise, Department of Life Sciences, Brunel University
London

³ Department of Health, Kinesiology, and Recreation, University of Utah

⁴ Centre for Sport and Exercise Science and Medicine, University of Brighton

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Abstract

27

28 The contextual interference (CI) effect refers to the learning benefits that occur from a
29 random compared to blocked practice order. In this paper, the cognitive effort explanation for
30 the CI effect was examined by investigating the role of error processing. In two experiments,
31 a perceptual-cognitive task was used in which participants anticipated three different tennis
32 skills across a pre-test, three practice sessions, and retention test. During practice, the skills
33 were presented in either a random or blocked practice order. In Experiment 1, cognitive effort
34 was examined using a probe reaction time task. In Experiment 2, cognitive effort was
35 manipulated for two groups by inserting a cognitively demanding secondary task into the
36 inter-trial interval. The CI effect was found in both experiments as the random groups
37 displayed superior learning in the retention test compared to the blocked groups. Cognitive
38 effort during practice was greater in random compared to blocked practice groups in
39 Experiment 1. In Experiment 2, greater decrements in secondary task performance following
40 an error were reported for the random group when compared to the blocked group. The
41 suggestion is that not only the frequent switching of tasks in randomized orders causes
42 increased cognitive effort and the CI effect, but it is also error processing in combination with
43 task switching. Findings extend the cognitive effort explanation for the CI effect and propose
44 an alternative hypothesis highlighting the role of error processing.

44

45 **Keywords:** Cognitive effort; anticipatory judgement; practice structure; perceptual learning;
46 secondary task

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75 The CI effect is a robust finding for motor skill acquisition (for reviews, see Brady,
76 1998; 2008; Lee, 2012; Magill & Hall, 1990; Merbah & Meulemans, 2011; Wright, Verwey,
77 Buchanan, Chen, Rhee, & Immink, 2015). In the seminal paper by Shea and Morgan (1979),
78 participants performed three versions of a simple barrier knockdown motor task practiced in
79 either a random or blocked order. During practice, the blocked order group demonstrated
80 faster total movement times compared to the random order group. However, on the retention
81 and transfer test, the random practice group had a faster total movement time compared to the
82 blocked group, indicating superior learning. The CI effect has been shown in the acquisition
83 of a wide variety of laboratory-based (Pauwels, Swinnen, & Beets, 2014; Wright, Magnuson,
84 & Black, 2005; Lee, Wulf, & Schmidt, 1992; Magnuson & Wright, 2004), and applied motor
85 tasks (Goode & Magill, 1986; Ollis, Button, & Fairweather, 2005; Smith & Davies, 1995;
86 Hall, Domingues, & Cavazos, 1994).

87 Two theories have been proposed to explain the underlying mechanisms of the CI
88 effect, namely the *elaborative processing hypothesis* and the *action plan reconstruction*
89 *hypothesis*. Both theories detail how greater cognitive effort occurs during random compared
90 to blocked ordered practice due to task switching (Lee, 2012). Cognitive effort is the mental
91 work involved in selecting and executing decisions and actions (Lee, Swinnen, & Serrien,
92 1994). According to the elaborative processing hypothesis, a random practice order leads to
93 greater cognitive effort through intra- and inter-task comparisons because the skills differ
94 from trial to trial (Shea & Titzer, 1993; Wright, 1991; Wright, Li, & Whitacre, 1992). In
95 comparison, during blocked practice the opportunity for contrasting the different actions is
96 minimized to only intra-task comparisons due to the repetitive nature of the practice order
97 (Shea & Zimny, 1983; 1988). Lin and colleagues (Lin, Fisher, Winstein, Wu, & Gordon,
98 2008; Lin, Fisher, Wu, Ko, Lee, & Winstein, 2009; Lin, Winstein, Fisher, & Wu, 2010)
99 investigated the CI effect using transcranial magnetic stimulation (TMS). In one study,

100 novice participants practiced three different arm movement tasks in either a blocked or
101 random practice structure. Single TMS pulses were synchronized to each inter-trial interval to
102 reduce information processing during the two practice conditions. The typical CI effect was
103 found for groups without TMS. However, the random practice advantage was eliminated
104 when TMS was applied between random practice trials, as it was suggested to prevent them
105 from conducting elaborative processing (Lin et al., 2008).

106 According to the *action plan reconstruction hypothesis*, random practice requires
107 more effortful processing because the action plan for the next trial has been forgotten and
108 must be recalled. It is forgotten due to the interference of executing a different preceding
109 action and must be retrieved from working memory for the next action. In comparison,
110 blocked practice involves using the same action plan on each trial so no forgetting or
111 retrieval/reconstruction processes occur (Lee & Magill, 1983, 1985; Lee, Magill, & Weeks,
112 1985). One method to examine this hypothesis has been to prevent the forgetting that is
113 predicted to occur between trials in a random practice condition. For example, during the
114 inter-trial period participants observe a computer-generated demonstration of the movement
115 pattern to be performed (Lee, Wishart, Cunningham, & Carnahan, 1997). Observing a
116 congruent demonstration in the inter-trial period leads to similar performance from the
117 random practice groups compared to blocked practice groups in both practice and retention
118 tests, because it reduces forgetting and reconstructive processes. Cross, Schmidt, and Grafton
119 (2007) used a key-press task to examine the neural substrates of the CI effect with functional
120 magnetic resonance imaging. Consistent with the reconstruction hypothesis, the random
121 group showed greater activity in the planning regions of the brain, when compared to the
122 blocked practice group.

123 Both the elaboration and action plan reconstruction hypotheses have led to the highly
124 cited explanation that *task switching* causes the increased cognitive effort found during

125 random practice (Li & Wright, 2000). However, alternative explanations could provide a
126 greater insight into the mechanisms involved. Researchers from the motor learning domain
127 suggest that *error processing* increases cognitive effort through the demands associated with
128 success or failure on a task (Holroyd, Yeung, Coles, & Cohen, 2005; Koehn, Dickinson, &
129 Goodman, 2008). When errors occur, performers identify discrepancies between the actual
130 outcome and the desired goal (Rabbitt, 1966, 1967). In addition, they generate rules,
131 hypotheses and knowledge about future task requirements so as to improve subsequent
132 performance (Maxwell, Masters, Kerr, & Weedon, 2001). Therefore, an error trial leads to
133 greater cognitive effort due to the additional processing that takes place when compared to an
134 errorless trial (Lam et al., 2010). In the current paper, we examine the proposal that it is not
135 simply the switching of tasks that increases cognitive effort through elaborative and/or
136 reconstructive processes, but that error processing also has an important role in this
137 phenomenon by increasing the load in working memory during random practice when errors
138 occur. This finding may link to findings that random practice causes an implicit mode of
139 learning due an increased load in working memory (Rendell, Masters, Farrow, & Morris,
140 2011).

141 The CI effect has recently been extended to perceptual-cognitive skills training,
142 offering a new domain through to which investigate the underlying mechanisms of this
143 phenomenon (Broadbent et al., 2015a; Helsdingen, van Gog, & van Merriënboer, 2011a;
144 2011b). The CI effect originated from a non-motor task domain, the verbal learning literature,
145 where Battig (1972; 1979) referred to it first as ‘inter-task interference’. The elaborative
146 processing hypothesis is directly linked to this and other work on motor learning and, thus,
147 support for this hypothesis would be expected in the perceptual-cognitive skills domain
148 (Broadbent et al., 2015a; Memmert et al., 2009). In contrast, the definition for the action plan
149 reconstruction hypothesis states that for an upcoming task in random practice ‘a person must

150 retrieve the appropriate *motor program* representing that action and then add the parameters
151 specific to the constraints and goal of the task to be performed' (Magill & Hall, 1990, pp.
152 271). Finding the CI effect in verbal or perceptual-cognitive tasks contradicts this definition
153 of the action plan reconstruction hypothesis due to the absence of a physical action and an
154 associated motor program. However, there is strong evidence to suggest that observing a
155 movement can activate the brain via the mirror neuron system and excite the motor system
156 through resonant mechanisms (e.g., Denis, Rowe, Williams & Milne, 2016; Kilner, Vargas,
157 Duval, Blakemore & Sirigu, 2004). In previous research on the CI effect using a perceptual
158 task with skilled participants (Broadbent et al., 2015a), the perceived action might have
159 resonated within the individuals own motor system activating an action plan for completing
160 the skill and enabling the individual to anticipate, rather than react to, the actions of others
161 (Aglioti, Cesari, Romani & Urgesi, 2008). Alternatively, other researchers using non-motor
162 tasks (Carlson, Sullivan & Schneider, 1989; Carlson & Yaure, 1988; Helsdingen et al.,
163 2011a; 2011b) support the action plan reconstruction hypothesis explaining that random
164 practice forces learners to discard the task 'strategy' (Helsdingen et al., 2011a; 2011b) or
165 'processing plan' (Carlson & Yaure, 1988) between tasks and either retrieve or reconstruct a
166 new strategy/plan for successive tasks. This notion indicates that the term *action plan* is not
167 directly linked to a *motor* action plan, but rather suggests that for any task to be complete, be
168 it motor or perceptual, a plan must be placed into working memory for the task to be carried
169 out (Ericsson & Kintsch, 1995). The disparity around the definition of the action plan
170 reconstruction hypothesis is still yet to be fully acknowledged in the literature. The training
171 of perceptual-cognitive skill offers a novel domain to directly examine whether elaborative
172 and/or reconstructive processes take place during the CI effect and could allow for the
173 proposal of new terminology and definitions to encompass both motor and perceptual tasks.

174 In this paper, we provide insight into the well-established explanations for the CI
175 effect, namely the elaborative processing hypothesis and the action plan reconstruction
176 hypothesis, by investigating them in the novel domain of perceptual-cognitive skills training.
177 Furthermore, an alternative hypothesis is examined to address whether the increased
178 cognitive effort found for random practice is as a consequence of task switching in
179 conjunction with error processing. Cognitive effort will be investigated across two
180 experiments in which novice tennis players anticipate three different skills shown on life-
181 sized video in either a random or blocked practice order. Anticipation performance will be
182 recorded during a pre-test, across three practice sessions, and on a retention test. It is
183 expected that the CI effect will occur in both experiments with the blocked group
184 outperforming the random group during practice, but in the retention test the random group
185 will show superior learning compared to the blocked group. Furthermore, it is predicted that
186 the random group will exhibit greater amounts of cognitive effort across practice compared to
187 the blocked group, either supporting one or both of the action plan reconstruction hypothesis
188 and the elaborative processing hypothesis from the CI literature. Moreover, cognitive effort is
189 predicted to be greater during random practice on error trials, compared to blocked practice
190 and errorless trials, as the combination between task switching and error processing increases
191 the load in working memory.

192

Experiment 1

193 Cognitive effort is a flexible capacity that can be subdivided among tasks so long as
194 the demands do not exceed the available capacity of attention (Kahneman, 1973). When a
195 task demands a high level of cognitive effort, there is a smaller capacity left available to
196 perform other tasks. Attentional capacity is often examined in both the CI and error literature
197 using the dual- or secondary-task paradigm, which involves performance of two tasks
198 simultaneously (Abernethy, Maxwell, Masters, van der Kamp, & Jackson, 2007). Discrete

199 secondary-tasks are often used, such as the probe reaction time (PRT), in which participants
200 respond to an auditory tone while performing the primary task (Abernethy et al., 2007). The
201 greater the cognitive demands of the primary task at any given moment, the slower the
202 reaction time on the secondary task (Goh, Gordon, Sullivan, & Winstein, 2014). PRT tasks
203 have been used to examine the underlying mechanisms of the CI effect in motor skill tasks
204 (Li & Wright, 2000; Rendell et al., 2011), providing support for both the reconstructive and
205 elaborative hypothesis. However, researchers are yet to examine these hypotheses for the
206 acquisition of perceptual-cognitive skills. PRT tasks have also been used to examine the
207 effect of errors on cognitive effort (Lam et al., 2010), showing that cognitive effort is greater
208 on trials involving an error when compared to errorless trials. No researchers to our
209 knowledge have examined the effects of errors on cognitive effort as a function of the CI
210 effect.

211 We examine the acquisition of anticipatory judgements under random or blocked
212 practice conditions and the role of cognitive effort from task switching and error processing
213 in the CI effect. Novice tennis players' anticipated three different tennis skills shown as life-
214 sized videos in either random or blocked schedules across a pre-test, three practice sessions,
215 and a retention test. In accordance with the CI effect, it is expected that the blocked group
216 will demonstrate superior response accuracy (RA) across practice compared to the random
217 group, but in the retention test the random group will demonstrate superior RA compared to
218 the blocked group (Shea & Morgan, 1979). During practice, cognitive effort will be examined
219 by inserting a PRT into two phases of a trial in accordance with the two hypotheses from the
220 CI literature. First, the action plan reconstruction hypothesis predicts greater cognitive effort
221 for the random group in the *observation phase* of a trial, when compared to the blocked
222 group. This phase is when participants are told the requirements of the upcoming task and
223 must retrieve and reconstruct an appropriate action plan (Li & Wright 2000). Second, the

224 elaborative processing hypothesis predicts greater cognitive effort for the random group
225 during the *feedback phase* of a trial. Feedback is gained on performance in this phase that is
226 compared, through intra- and inter-task comparisons, to previous successful and unsuccessful
227 trials (Li & Wright 2000). During practice, cognitive effort and error processing will be
228 analyzed using decision time (DT) from the secondary task in the observation and feedback
229 phase, and from the primary task in the response phase (Lam et al., 2010). DT will be
230 compared for a blocked and random schedule of practice following an error and an errorless
231 trial. It is expected that following an error the random practice group will exhibit significantly
232 greater cognitive effort in the observation, response, and feedback phase of a trial compared
233 to the blocked group and errorless trials.

234 **Method**

235 **Participants**

236 Participants were 24 undergraduate students who were novice tennis players with no
237 competition experience in the sport. They were randomly divided into either a blocked
238 practice group ($n = 12$; 4 females and 8 males; M age = 23.3 years, $SD = 4.5$) or a random
239 practice group ($n = 12$; 4 females and 8 males; M age = 23.5 years, $SD = 3.2$). No group
240 differences were found for the primary anticipation task at pre-test between the blocked ($M =$
241 52% , $SD = 4$) and random groups ($M = 48\%$, $SD = 9$), $p = .17$, $d = .60$. Informed consent was
242 obtained from the participants prior to participation. The research was conducted in
243 accordance with the ethical guidelines of the lead institution.

244 **Task and apparatus**

245 The task required participants to anticipate the landing location of tennis shots
246 executed by a player on-screen. To create the video footage, three different intermediate level
247 tennis players were filmed on a standard tennis court executing three shots: forehand
248 groundstroke; forehand smash; and forehand volley (Broadbent et al., 2015a). The video was

249 filmed from a camera placed on the center of the baseline of the tennis court at a height of 1.5
250 m to provide a representative view of the court from the participants' perspective. The
251 footage was made into clips using video editing software (Adobe Premier CS5, San Jose,
252 USA). Each video clip began with a black screen and the trial number, which appeared for 3
253 seconds. Subsequently, the tennis film began, which consisted of the onscreen player
254 standing at one of three central locations on the other side of the net, the ball arriving to the
255 player, the player moving to the ball, and swinging the racket. Clips were occluded at ball-
256 racket contact when the screen went black for 3 seconds, before the next trial began. Shots
257 landed in four locations on the participant's side of the court, which were occluded on the
258 video: left short; right short; left deep; and right deep.

259 The experimental apparatus and setup is shown in Figure 1. Participants stood 4 m
260 from the center of a 2.74 x 3.66 m projection screen (Cinefold Projection Sheet, Draper Inc.,
261 Spiceland, IN, USA) on which the test films were projected (Hitachi CP-X345, Yokohama,
262 Japan). The size of the image approximated the life-size proportions normally experienced in
263 game situations when players are positioned on the baseline of the court. Participants wore a
264 lapel microphone (Seinheisser EW 100 ENG G2 RF, Germany). They were required to
265 respond quickly and accurately to the onscreen shot by verbally stating a number between
266 one and four that corresponded to the area of the court where the ball could bounce (1 = left
267 short; 2 = right short; 3 = left deep; 4 = right deep). Participants did not perform a movement
268 response as in previous research (Broadbent et al., 2015a), but stood still with a tennis racket
269 in hand due to the movement restrictions caused by the secondary task. As stated previously,
270 the action plan reconstruction hypothesis states that the motor program for an action must be
271 retrieved and an action executed for interference to occur (e.g., Magill & Hall, 1990).
272 However, there is evidence to suggest that observing an action activates the individual's
273 motor system enabling anticipatory behavior (e.g., Denis et al., 2016; Kilner et al., 2004).

274 Therefore, it was predicted that a perceptual response would not cause differences in action
275 planning compared to previous research using motor responses, as similar processing will
276 occur due to resonant mechanisms in the brain (e.g., Aglioti et al., 2008).

277 A PRT secondary task was added to the clips shown during the practice phase. High
278 (2,500 Hz) and low frequency (300 Hz) tones that were 240 ms in duration were overlaid on
279 the clips using video editing software (Adobe Premier CS5, San Jose, USA). Probes were
280 presented in a way that their onset could not be predicted through randomizing inter-stimulus
281 intervals (Wulf, McNevin, & Shea, 2001) and inserting catch trials in which a probe did not
282 occur (Salmoni, Sullivan, & Starkes, 1976). Participants were required to react to the PRT
283 task on high, but not low, tones by pressing a button that was ergonomically attached to the
284 tennis racket. The microphone and the button press were synchronized and analyzed with a
285 developed algorithm through the computing environment MATLAB (Mathworks R2007,
286 UK). This latter procedure allowed the verbal anticipation response by the participant, the
287 onset of the high tones, and the moment the participant pressed the button on the racket to be
288 recorded, providing DT data on each button press to a high tone. There were 54 high tones,
289 54 low tones and 36 catch trials with two of these in each phase of each trial. The high tones
290 were present on approximately 40% of trials. Additionally, a different tone was added at the
291 beginning of each practice video, two seconds before the first trial began, which was used as
292 a reference point for analyzing DT in the verbal responses.

293 **Procedure**

294 Participants took part in a pre-test, three practice sessions, and a 10 minute retention
295 test. The pre-test and practice blocks contained 36 trials each and the retention test consisted
296 of 36 trials in a blocked order and 36 trials in random order counterbalanced across
297 participants to ensure there was no bias towards either group (Broadbent et al., 2015a; Lin et
298 al., 2008; 2009; 2010). Participants were informed of the response requirements for the films

299 prior to testing. Pilot work ensured the clips were of similar difficulty and no clips were
300 repeated across the different phases. The 36 trials in each phase comprised of 12 forehand
301 groundstrokes, 12 forehand smashes, and 12 forehand volleys. Each set of 12 shot trials
302 comprised of three trials to each of four locations on the court, which were occluded on the
303 video: left short; right short; left deep; and right deep. The pre-test trials were structured in a
304 blocked order so that the three shots were in three separate sets each containing either
305 forehand groundstrokes, smashes, or volleys together.

306 For the practice phase, three different films were constructed corresponding to each of
307 the three practice sessions. For the blocked group, the clips were arranged in each session so
308 that all groundstrokes were together, all smashes were together, and all volleys were together.
309 For the random group, the clips were placed in a quasi-random order where none of the three
310 shot-types was repeated more than twice in a row. Participants received two presentations of
311 the same clip during each trial in the practice phase. The first video, termed the observation
312 phase, contained clips that were temporally occluded at ball-racket contact and that occurred
313 before the participant response. The second video, termed the feedback phase, occurred after
314 their response and was not occluded, so that participants viewed the full clip and received
315 feedback as to where the ball actually landed.

316 Participants were informed of the response requirements for the PRT task prior to
317 practice. For each participant, the three practice sessions were split into one practice block
318 with no tones, one block with tones across the first video (observation phase), and one block
319 with tones across the second video (feedback phase). These practice blocks were
320 counterbalanced across participants (see Figure 2a). Participants also completed a PRT task
321 alone prior to the experiment with no primary task so as to measure their base reaction time.
322 Base level RT did not differ between the blocked group ($M = 257$ ms, $SD = 61$) and random
323 group ($M = 272$ ms, $SD = 57$), $p = .54$, $d = .27$.

324 Data analysis

325 The dependent variables for the primary anticipation task were RA and DT. RA was
326 expressed as the percentage of successful trials in which the response was the same as the
327 location of the ball's landing on the court. DT (ms) was calculated as the difference between
328 the time of the verbal response on each trial and the time of ball-racket contact or temporal
329 occlusion. Responses initiated prior to ball-racket contact or occlusion received a negative
330 value. RA and DT in the primary task were analyzed using a 2 Group (blocked, random) x 3
331 Session (pre-test, practice, retention) mixed-design ANOVA, with repeated measures on the
332 last factor. For all ANOVAs partial-eta squared was calculated for effect size. Pairwise
333 comparisons were used to follow up any significant main effects. For significant interactions
334 a planned comparison was used to address the specific a priori hypotheses on the retention
335 test. For the planned comparison, Cohens d was calculated for effect size.

336 The role of errors on cognitive effort as a function of blocked and random schedules
337 of practice was examined using mean DT collapsed across all practice phases for the primary
338 task. Analysis was conducted on the trial *following* an error as error processing occurs
339 following feedback once the subject is aware of the error they have made and the nature of
340 the error (Lam et al., 2010). The blocked group had approximately 58% errorless trials and
341 42% errorful trials. The random group had approximately 50% errorless and errorful trials. A
342 2 Group x 2 Error (errorless, error) mixed design ANOVA with repeated measure on the last
343 factor was used to analyze DT in the primary anticipation task. Pairwise comparisons were
344 used for any significant main effects. For any interactions, planned comparisons were used to
345 address the specific a priori hypotheses. Updated alpha values are reported throughout.

346 The dependent variable for the secondary task was DT, which was calculated as the
347 difference between the onset of the high tone on each trial and the button press by the
348 participant. The role of errors was also analyzed for the secondary task in the observation and

349 feedback phase separately. Secondary task DT was analyzed using a 2 Group x 2 Phase
350 (observation phase, feedback phase) x 2 Error (errorless, error) ANOVA, with repeated
351 measures on the last factor. Pairwise comparisons were used for any significant main effects.
352 For any interactions, planned comparisons were used to address the specific a priori
353 hypotheses. In order to limit the potential inflation of Type-1 errors through multiple
354 comparisons, each alpha level was adjusted using the Bonferroni correction method. Updated
355 alpha values are reported throughout.

356 Results

357 Primary anticipation task

358 **Response accuracy.** Figure 3 shows mean RA for the two groups in the pre-test,
359 during practice, and in the retention test. A 2 Group x 3 Session ANOVA on RA revealed no
360 group main effect, $F(1, 22) = 1.23, p = .28, \eta_p^2 = .05$. There was a significant main effect for
361 session, $F(2, 44) = 12.16, p < .01, \eta_p^2 = .36$. RA in the pre-test ($M = 50\%, SD = 7$) and
362 practice ($M = 54\%, SD = 7$) were significantly lower than in the retention tests ($M = 58\%, SD$
363 $= 7$), $p < .01$ and $p = .01$ respectively. There was a Group x Session interaction, $F(2, 44) =$
364 $9.94, p < .01, \eta_p^2 = .31$. No differences were found for RA between the groups in the pre-test
365 as reported in the method section. Across practice the blocked group ($M = 58\%, SD = 6$) had
366 significantly greater accuracy compared to the random group ($M = 50\%, SD = 6$), $p < .01, d =$
367 1.33 . In the retention test, a planned comparison revealed that the random group ($M = 61\%,$
368 $SD = 6$) demonstrated significantly greater accuracy compared to the blocked group ($M =$
369 $55\%, SD = 6$), $p = .03, d = .92$.

370 **Decision time.** Table 1 shows mean DT in the primary task for the two groups across
371 the pre-test, practice, and retention test. A 2 Group x 3 Session ANOVA on DT revealed no
372 Group main effect, $F(1, 22) = .04, p = .85, \eta_p^2 < .01$, Session main effect, $F(2, 44) = .53, p =$
373 $.59, \eta_p^2 = .02$, or interaction, $F(2, 44) = 1.00, p = .36, \eta_p^2 = .04$.

374 **Error analysis.** Table 2 shows the mean DT of the two groups on trials following
375 error and errorless trials in the practice phase. A 2 Group x 2 Error ANOVA on DT revealed
376 no group main effect, $F(1, 22) = .14, p = .71, \eta_p^2 = .01$, error main effect, $F(1, 22) = .58, p =$
377 $.46, \eta_p^2 = .03$, or interaction, $F(1, 22) = 3.10, p = .09, \eta_p^2 = .12$.

378 **Secondary task**

379 **Decision time.** Figure 4 shows mean DT for the two groups on the PRT task across
380 the observation and feedback phases during practice. In order to assess whether the secondary
381 task had affected RA in the primary task, a one-way ANOVA on RA in the primary task
382 between tone conditions was used. RA was not different between the tone only condition (M
383 $= 54\%, SD = 10$), observation phase ($M = 53\%, SD = 9$), and the feedback phase ($M = 55\%,$
384 $SD = 6$), $F(2, 46) = .48, p = .62, \eta_p^2 = .02$, suggesting that the secondary task had not
385 affected RA in the primary task, supporting previous research (Goh et al., 2014).

386 A 2 Group x 2 Phase x 2 Error ANOVA revealed a significant group main effect for
387 DT, $F(1, 22) = 5.62, p = .03, \eta_p^2 = .21$. The blocked group ($M = 401$ ms, $SD = 94$) had a
388 significantly faster DT compared to the random group ($M = 507$ ms, $SD = 136$), $p = .03$.
389 There was no main effect for phase, $F(1, 22) = 1.33, p = .26, \eta_p^2 = .06$, and no Group x Phase
390 interaction, $F(1, 22) = .01, p = .99, \eta_p^2 < .01$, indicating that the random group had a
391 significantly slower DT across the observation and feedback phases during practice when
392 compared to the blocked group.

393 **Error analysis.** Table 2 shows mean DT for the secondary task of the blocked and
394 random groups as a function of performance success (errorless, error) in the previous trial.
395 The 2 Group x 2 Phase x 2 Error ANOVA on DT revealed a significant Phase x Error
396 interaction, $F(1, 22) = 5.28, p = .03, \eta_p^2 = .19$. The planned comparison showed that
397 differences in DT approached significance between an errorless trial in the feedback phase
398 ($M = 476$ ms, $SD = 154$) and the observation phase ($M = 425$ ms, $SD = 126$), $p = .07, d = .36$,

399 whereas there was no difference for error trials between the two phases ($p > .05$). A follow up
400 using Tukey's Honest Significance Test demonstrated the Phase x Error interaction was
401 explained by this difference between the feedback and observation phase following errorless
402 trials ($p = .04$), as all other comparisons were not significantly different ($p > .05$). No other
403 interactions were significant, all $p > .05$.

404 **Discussion**

405 As predicted, in the primary anticipation task the traditional CI effect was found with
406 the random practice group displaying superior response accuracy in the retention test
407 compared to the blocked practice group (cf. Shea & Morgan, 1979). Moreover, the random
408 schedule of practice exhibited greater cognitive effort as shown by slower PRT compared to a
409 blocked schedule of practice. Greater cognitive effort was found in both the observation and
410 feedback phase of a trial for the random when compared to the blocked schedule of practice.
411 Findings suggest that additional cognitive processes are used before, and after, an executed
412 trial in a random compared to blocked schedule of practice, supporting the idea that both
413 reconstructive and elaborative processes underpin the CI effect (Li & Wright, 2000). With
414 regards to the role of error processing in the CI effect, the data provided no support for this
415 alternative hypothesis in either the observation or feedback phase. Findings suggest further
416 research is required to either support or dispute this alternative hypothesis, perhaps by
417 examining a different time-period during the practice trial such as the inter-trial interval.

418 **Experiment 2**

419 Researchers investigating the underlying mechanisms of the CI effect have often
420 referred to the *inter-trial interval* as a critical time period when cognitive effort occurs
421 (Magill & Hall, 1990). The elaboration hypothesis predicts that inserting a cognitively
422 demanding task during the inter-trial interval will disrupt the elaborative processes taking
423 place for a random schedule of practice and will diminish the superior learning of random

424 practice (Lin et al., 2008; Lin et al., 2010). In contrast, the action plan reconstruction
425 hypothesis predicts that a cognitively demanding task during the inter-trial interval will
426 promote forgetting in a blocked schedule of practice and inadvertently increase the
427 reconstructive processes, resulting in increased learning for blocked practice (Lee & Magill,
428 1983, 1985). In Experiment 1, evidence was not found for the hypothesis that error
429 processing for a random schedule of practice may contribute to the greater cognitive effort
430 compared to blocked schedule of practice. This hypothesis was investigated in the
431 observation and feedback phase of a trial, but not in the inter-trial interval.

432 In Experiment 2, we manipulate cognitive effort in the inter-trial interval using a
433 cognitively demanding task (Stroop test; Macleod, 1991). Including a secondary task allows
434 for the cognitive demands of the primary task to be analyzed. If the primary task is
435 cognitively demanding, the inclusion of a demanding secondary task will exceed the
436 available capacity of working memory and cause decrements in secondary task performance.
437 In comparison, if the primary task is less cognitively demanding, then both tasks can be
438 performed efficiently (Abernethy et al., 2007). Novice participants were divided into blocked,
439 random, blocked-Stroop (BStroop), and random-Stroop (RStroop) groups. It is expected that
440 the CI effect will occur in the primary anticipation task for the two groups without the Stroop
441 test. With regards to the two practice groups with the Stroop test inserted in the inter-trial
442 interval, the elaborative processing hypothesis predicts that the RStroop group will have
443 decrements in performance compared to the random group as the cognitively demanding task
444 will interfere with the intra-task comparisons made during a random schedule of practice (Lin
445 et al., 2008; Lin et al., 2010). Alternatively, the action plan reconstruction hypothesis predicts
446 that the BStroop group will demonstrate superior learning compared to the blocked group
447 because the secondary task in the interval will cause short-term forgetting, promoting
448 reconstructive activity for the BStroop group (Lee & Magill, 1983, 1985; Simon & Bjork,

2002). Moreover, with regards to error processing, in the inter-trial interval the RStroop group are predicted to exhibit significantly greater cognitive effort following an error compared to an errorless trial. In contrast, the BStroop group is expected to show no differences in cognitive effort following an error and errorless trial due to the predicted lower amount of elaborative processing occurring in that practice structure.

Method

Participants

Participants were 56 undergraduate students who were novice tennis players with no competition experience in the sport. They were randomly divided into either a blocked group ($n = 14$; M age = 20.7 years, $SD = 1.6$), random group ($n = 14$; M age = 20.9 years, $SD = 1.1$), BStroop group ($n = 14$; M age = 20.9 years, $SD = 1.4$), or RStroop group ($n = 14$; M age = 21.1 years, $SD = 1.1$). Each group had 11 males and 3 females. No group differences for response accuracy were found at pre-test between the four groups, $p > .05$. Informed consent was obtained from the participants prior to participation. The research was conducted in accordance with the ethical guidelines of the lead institution.

Task and apparatus

The film clips and the protocol were the same as in Experiment 1 with a pre-practice-retention design. No PRT measure was used in this experiment. For the BStroop and RStroop groups (see Figure 2b), a Stroop test was inserted in the inter-trial interval of practice trials using video editing software (Adobe Premier CS5 software, San Jose, USA). The Stroop test was selected due to the high cognitive demands it places on working memory (Kane & Engle, 2003; Long & Prat, 2002). The Stroop test presents three color words, such as red, green, and blue, with a font color of text that is different to that of the word. On the video clips, a black screen appeared prior to the Stroop test on each trial that had either stated “color” or “word” in a large white font to inform participants of their response requirement. Participants were

474 required to respond quickly and accurately by verbally stating either the word that was
475 printed or the color that the word was printed in, as directed. Three words appeared
476 consecutively following each trial of the primary task. Each word was presented on screen for
477 90 ms as pilot work demonstrated that this time allowed the task to be completed
478 successfully, but was still challenging for the participants. The order of presentation was
479 randomized so that participants were unaware of the response they had to provide prior to
480 each of the 36 trials of the Stroop test. The randomized presentation requires a new action
481 plan to be implemented into working memory on the subsequent trial, potentially causing
482 more interference to the primary task (for a review of Stroop effect theory, see Macleod,
483 1991; 1992).

484 **Procedure**

485 The experimental apparatus, set up and procedure was the same as in Experiment
486 1 (see Figure 2b), although there was no PRT task, and the pre-test contained a blocked ($n =$
487 18) and random ($n = 18$) structure of practice so as not to favor either group. In addition, the
488 Stroop test occurred after every trial in all three practice sessions for those two groups. The
489 lapel microphone was synchronized and analyzed with a developed algorithm through the
490 numerical computing environment MATLAB (Mathworks R2007, UK). It allowed the verbal
491 response by the participant on both the primary anticipation task and the Stroop test to be
492 recorded and later analyzed.

493 **Data analysis**

494 For the primary anticipation task, the dependent variables were the same as in
495 Experiment 1 and were analyzed separately using three separate ANOVAs. To replicate the
496 data analysis in Experiment 1, RA and DT in the primary task were analyzed using a 2 Group
497 (blocked, random) x 3 Session (pre-test, practice, retention) mixed-design ANOVA, with
498 repeated measures on the last factor. To analyze the additional groups, RA and DT in the

499 primary task were analyzed using a 2 Group (blocked, BStroop) x 3 Session (pre-test,
500 practice, retention) mixed-design ANOVA and a 2 Group (random, RStroop) x 3 Session
501 (pre-test, practice, retention) mixed-design ANOVA. For all ANOVAs partial-eta squared
502 was calculated for effect size. Pairwise comparisons were used to follow up any significant
503 main effects. For significant interactions a planned comparison was used to address the
504 specific a priori hypotheses on the retention test. For the planned comparison, Cohens d was
505 calculated for effect size.

506 Analysis of DT as a measure of cognitive effort on trials *following* errors was
507 conducted for the primary anticipation task. DT was analyzed following an errorless and error
508 response in the previous trial for the blocked and random groups. The percentages for
509 errorless and errorful trials for each group were: blocked group (58% errorless; 42% errorful
510 trials), random group (50% errorless; 50% errorful trials), BStroop group (52% errorless;
511 48% errorful trials), RStroop group (52% errorless; 48% errorful trials). To replicate the
512 analysis in Experiment 1, a 2 Group (blocked, random) x 2 Error mixed design ANOVA with
513 repeated measure on the last factor was used to analyze DT in the primary anticipation task.
514 To analyze the additional groups, DT was analyzed using a 2 Group (blocked, BStroop) x 2
515 Error mixed-design ANOVA and a 2 Group (random, RStroop) x 2 Error mixed-design
516 ANOVA

517 For the Stroop test, the dependent variables were RA and DT. RA refers to the
518 number of successful responses out of 108 trials and is defined as whether the color or word
519 verbalized by the participant matched the trial requirements for the color or word displayed.
520 DT (ms) was calculated as the difference between initiation of the verbal response on each
521 Stroop trial and the moment the slide appeared on the screen. All responses were initiated
522 after the slide appeared and received a positive value that was analyzed through MATLAB
523 with the software extrapolating all the data points for the verbal responses. Separate 2 Group

524 x 3 Practice mixed design ANOVAs with repeated measures on the last factor were used to
525 analyze RA and DT on the Stroop test. The role of errors was also analyzed for DT on the
526 Stroop test using a 2 Group x 2 Error mixed design ANOVA with repeated measure on the
527 last factor. Pairwise comparisons were used to follow up any significant main effects. For
528 significant interactions, planned comparisons were used to address any specific a priori
529 hypotheses. Alpha level was adjusted using the Bonferroni correction method. Updated alpha
530 values are reported throughout.

531 Results

532 Primary anticipation task

533 **Response accuracy.** Figure 5 shows mean RA for the four groups on the pre-test,
534 three practice sessions, and the retention tests. A 2 Group (blocked, random) x 3 Session
535 ANOVA revealed no group main effect, $F(1, 26) = .30, p = .59, \eta_p^2 = .01$. There was a
536 significant main effect for session, $F(2, 52) = 5.23, p = .01, \eta_p^2 = .17$. RA in the retention test
537 ($M = 56\%, SD = 6$) was significantly greater compared to the pre-test ($M = 51\%, SD = 8$), $p =$
538 $.02$, whereas RA in practice ($M = 54\%, SD = 6$) did not differ to the pre- and retention test.
539 There was a significant Group x Session interaction, $F(2, 52) = 8.47, p < .01, \eta_p^2 = .25$. No
540 between-group differences were found in the pre-test as shown in the methods section.
541 Across practice the blocked group ($M = 58\%, SD = 5$) were significantly more accurate than
542 the random group ($M = 50\%, SD = 5$), $p < .01, d = 1.60$. In the retention test, the random
543 group ($M = 58\%, SD = 6$) had significantly greater RA compared to the blocked group ($M =$
544 $54\%, SD = 5$), $p = .05, d = .77$.

545 A 2 Group (blocked, BStroop) x 3 Session ANOVA revealed no group main effect, F
546 $(1, 26) = .43, p = .52, \eta_p^2 = .02$. There was a significant main effect for session, $F(2, 52) =$
547 $4.94, p = .01, \eta_p^2 = .16$. RA in the retention test ($M = 55\%, SD = 5$) was significantly greater
548 compared to the pre-test ($M = 51\%, SD = 9$), $p = .05$, whereas RA in practice ($M = 54\%, SD$

549 = 7) did not differ to the pre- and retention test. There was a significant Group x Session
 550 interaction, $F(2, 52) = 4.95, p = .01, \eta_p^2 = .16$. No between-group differences were found in
 551 the pre-test as shown in the methods section. The blocked group ($M = 58\%, SD = 5$)
 552 demonstrated superior RA across training compared to the BStroop group ($M = 52\%, SD =$
 553 $7), p = .01, d = 1.07$, but there were no between-group differences in RA in the retention test,
 554 $p = .27, d = .44$. The 2 Group (random, RStroop) x 3 Session ANOVA revealed no group
 555 main effect, $F(1, 26) = .03, p = .86, \eta_p^2 < .01$. There was a significant main effect for session,
 556 $F(2, 52) = 8.25, p < .01, \eta_p^2 = .24$. RA in the retention test ($M = 57\%, SD = 7$) was
 557 significantly greater compared to the pre-test ($M = 52\%, SD = 7$) and in practice ($M = 51\%,$
 558 $SD = 5), p = .01$ and $p < .01$ respectively. There was no Group x Session interaction, $F(2, 52)$
 559 $= 1.30, p = .28, \eta_p^2 = .05$.

560 **Decision time.** A 2 Group (blocked, random) x 3 Session ANOVA revealed no group
 561 main effect, $F(1, 26) = .69, p = .41, \eta_p^2 = .03$. There was a significant main effect for session,
 562 $F(2, 52) = 5.01, p = .01, \eta_p^2 = .16$. DT in the retention test ($M = 890$ ms, $SD = 227$) and in
 563 practice ($M = 895$ ms, $SD = 241$) was significantly greater compared to the pre-test ($M = 805$
 564 ms, $SD = 185), p = .03$ and $p = .01$ respectively. There was no Group x Session interaction, F
 565 $(2, 52) = .56, p = .57, \eta_p^2 = .02$.

566 A 2 Group (blocked, BStroop) x 3 Session ANOVA revealed no group main effect, F
 567 $(1, 26) = .07, p = .79, \eta_p^2 < .01$. There was a significant main effect for session, $F(2, 52) =$
 568 $6.96, p < .01, \eta_p^2 = .21$. DT in practice ($M = 870$ ms, $SD = 226$) was significantly greater
 569 compared to the pre-test ($M = 762$ ms, $SD = 224), p < .01$, whereas DT in the retention test
 570 ($M = 832$ ms, $SD = 237$) did not differ to pre-test and practice. There was no Group x Session
 571 interaction, $F(2, 52) = .60, p = .55, \eta_p^2 = .02$. The 2 Group (random, RStroop) x 3 Session
 572 ANOVA revealed no group main effect, $F(1, 26) = 1.51, p = .23, \eta_p^2 = .06$. There was no

573 main effect for session, $F(2, 52) = 1.93, p = .16, \eta_p^2 = .07$ and no Group x Session
574 interaction, $F(2, 52) = .12, p = .89, \eta_p^2 = .01$.

575 **Error analysis.** Figure 6 shows mean DT in the primary task following an errorless
576 or error response across the practice phase for the four groups. A 2 Group (blocked, random)
577 x 2 Error mixed design ANOVA revealed no group main effect, $F(1, 26) = .06, p = .80, \eta_p^2 <$
578 $.01$ and no Error main effect, $F(1, 26) = 3.34, p = .08, \eta_p^2 = .11$. However, there was a
579 significant Group x Error interaction, $F(1, 26) = 8.32, p = .01, \eta_p^2 = .24$. The random
580 practice group had significantly slower DT following an error ($M = 930$ ms, $SD = 225$)
581 compared to following an errorless trial ($M = 893$ ms, $SD = 217$), $p = .02, d = 0.81$. In
582 contrast, the blocked group showed no difference in DT following an error ($M = 883$ ms, SD
583 $= 269$) compared to following an errorless trial ($M = 892$ ms, $SD = 268$), $p = 1.00, d = 0.22$.

584 A 2 Group (blocked, BStroop) x 2 Error mixed design ANOVA revealed no group
585 main effect, $F(1, 26) = .10, p = .75, \eta_p^2 < .01$. There was a significant main effect of Error, F
586 $(1, 26) = 6.46, p = .02, \eta_p^2 = .20$. DT was significantly slower following an errorless trial (M
587 $= 882$ ms, $SD = 225$) compared to an error ($M = 865$ ms, $SD = 229$), $p = .02$. There was no
588 Group x Error interaction, $F(1, 26) = 1.66, p = .21, \eta_p^2 = .06$. A 2 Group (random, RStroop)
589 x 2 Error mixed design ANOVA revealed no group main effect, $F(1, 26) = .79, p = .38, \eta_p^2 =$
590 $.03$. There was a significant main effect of Error, $F(1, 26) = 4.61, p = .04, \eta_p^2 = .15$. DT was
591 significantly slower following an error ($M = 885$ ms, $SD = 212$) compared to an errorless trial
592 ($M = 867$ ms, $SD = 201$), $p = .04$. There was also a significant Group x Error interaction, F
593 $(1, 26) = 5.26, p = .03, \eta_p^2 = .17$. The random practice group had significantly slower DT
594 following error compared to errorless trials, whereas the RStroop group showed no
595 significant difference in DT following an error ($M = 841$ ms, $SD = 195$) compared to an
596 errorless trial ($M = 843$ ms, $SD = 188$), $p = 1.00, d = 0.01$.

597 **Stroop test**

598 **Response accuracy.** Table 3 shows the mean RA on the Stroop test for the BStroop
 599 and RStroop groups across the three practice sessions. A 2 Group x 3 Practice ANOVA
 600 revealed no Group main effect, $F(1, 26) = 1.23, p = .28, \eta_p^2 = .05$. There was a Practice main
 601 effect, $F(2, 52) = 4.48, p = .02, \eta_p^2 = .15$. RA in practice 3 ($M = 105, SD = 4$) was
 602 significantly greater than in practice 1 ($M = 104, SD = 4$), $p = .02$, whereas RA in practice 2
 603 ($M = 105$ ms, $SD = 3$) did not differ to pre-test and practice. No Group x Practice interaction
 604 occurred, $F(2, 52) = .60, p = .55, \eta_p^2 = .02$.

605 **Decision time.** Table 3 shows the mean DT in the Stroop test for the BStroop and
 606 RStroop groups across the three practice sessions. A 2 Group x 3 Practice ANOVA revealed
 607 no group main effect, $F(1, 26) = .014, p = .91, \eta_p^2 < .01$, no main effect for Practice, $F(2,$
 608 $52) = 1.30, p = .28, \eta_p^2 = .05$, and no Group x Practice interaction, $F(2, 52) = .01, p = .99, \eta_p^2$
 609 $< .01$.

610 **Error analysis.** Figure 7 shows mean DT for the BStroop and RStroop group in the
 611 secondary Stroop task following an error and an errorless trial across practice. A 2 Group x 2
 612 Error ANOVA revealed no group main effect, $F(1, 26) = .01, p = .91, \eta_p^2 < .01$. There was a
 613 significant error main effect, $F(1, 26) = 12.16, p < .01, \eta_p^2 = .32$. DT was significantly
 614 slower following an error ($M = 681$ ms, $SD = 87$) compared to following an errorless trial (M
 615 $= 664$ ms, $SD = 85$), $p < .01$. There was also a significant Group x Error interaction, $F(1, 26)$
 616 $= 4.25, p = .05, \eta_p^2 = .14$. DT for the RStroop was significantly slower following an error (M
 617 $= 687$ ms, $SD = 85$) compared to an errorless trial ($M = 661$ ms, $SD = 81$), $p < .01, d = 1.68$.
 618 In comparison, DT for the BStroop group was not different following error ($M = 674$ ms, SD
 619 $= 91$) and errorless trials ($M = 667$ ms, $SD = 91$), $p = .88, d = .21$.

620

Discussion

621 As expected, for the two practice structure groups *without* the secondary task the
 622 traditional CI effect was found (Shea & Morgan, 1979). In the retention test, the random

623 group was significantly more accurate compared to the blocked group, whereas in the pre-test
624 there was no between-group difference in accuracy. With regards to the performance in the
625 primary anticipation task for the two groups with the secondary Stroop test, no support was
626 provided for either the elaboration hypothesis or the action plan reconstruction hypothesis.
627 RA for the RStroop group in the retention test was not significantly different to the random
628 group, suggesting that the participants were able to cope with the additional cognitive effort
629 caused by the secondary task or they prioritized effort to maintain performance on the
630 primary task at the cost of secondary task performance (Abernethy et al., 2007). Moreover,
631 while the BStroop group were descriptively more accurate than the blocked group in the
632 retention test as predicted and a significant interaction was found, the planned comparison did
633 not reach significance. The suggestion is that the task did not cause a sufficient amount of
634 forgetting, retrieval and reconstructive processes during practice compared to methods used
635 in previous studies (Lin et al., 2008; 2010).

636 DT in the primary anticipation task was slower following an error compared to an
637 errorless trial for the random group, but not for the other three groups. This finding suggests
638 that following an error, greater cognitive effort is required using a random schedule of
639 practice to generate an appropriate response compared to a blocked schedule of practice (Lam
640 et al., 2010). However, contrary to predictions, DT in the primary anticipation task was not
641 different between errorless and error responses for the RStroop group, suggesting that the
642 secondary task affected the cognitive processes taking place. Performance on the Stroop task
643 allowed for more of an insight into the effect of error processing on working memory for the
644 RStroop and BStroop groups. The RStroop group had a slower RT in the Stroop test
645 following an error compared to following an errorless trial. In comparison, RT for the
646 BStroop group was not different following both errorless and error trials. It appears that
647 performance decrements occurred on the secondary task for the RStroop group in order to

648 maintain performance in the primary task. In contrast, the BStroop group could maintain
649 performance in both the primary and secondary task due to lower cognitive demands of the
650 primary task. The data show that this performance decrement in the secondary task for the
651 RStroop group was not across every trial, but rather only following an error. This finding
652 provides support for the alternative hypothesis that it is not just task switching that increases
653 the load in working memory for the random group, but a combination of task switching in
654 conjunction with error processing.

655

General Discussion

656 In this paper, we presented two experiments that examined the cognitive processes
657 underlying the CI effect during the learning of anticipation judgments in tennis, specifically
658 examining the role of error processing. In Experiment 1, we used a PRT task to measure
659 cognitive effort in the observation and feedback phase of a trial during blocked and random
660 practice. Cognitive effort was examined following errorless and error trials for blocked and
661 random practice orders. In Experiment 2, we investigated the effects of inserting a
662 cognitively demanding secondary task into the inter-trial interval of blocked and random
663 practice, while again investigating the effects of errors on performance of the primary and
664 secondary task.

Contextual interference effect and the underlying mechanisms

666 As predicted, in both experiments the anticipation accuracy of the random practice
667 group was not different in the pre-test but significantly more accurate in the retention test
668 when compared to the blocked group. Our findings support previous research on the CI effect
669 in the motor skills literature (Shea & Morgan, 1979) and provide confirmation that the effect
670 extends to perceptual-cognitive skills training (Broadbent et al. 2015a; Memmert et al.,
671 2009). The data demonstrate the generalizability of the CI effect to perceptual-cognitive as
672 well as perceptual-motor skills training, as the phenomenon has now been found to extend to

673 skilled (Broadbent et al., 2015a) and novice participants using both complex movement
674 responses (Broadbent et al., 2015a) and no movement responses. These findings indicate that
675 a motor response may not be necessary to induce a CI effect; rather it is the cognitive
676 processes that are key (Battig, 1972; Blandin, Proteau, & Alain, 1994). For decision time in
677 the primary task, no differences were found between the two groups in any phase, contrary to
678 previous research by Broadbent et al. (2015a). This contradictory finding is potentially due to
679 the different tasks used in the two papers. Broadbent et al. (2015a) used a field-based transfer
680 test with no temporal occlusion paradigm. In the current study, a laboratory-based setting was
681 used and the footage was occluded around ball-racket contact. The temporal occlusion
682 paradigm forces participants to respond to the footage earlier than they usually would, so a
683 floor effect is found for the decision time data (Broadbent, Causer, Williams, & Ford, 2015b).

684 The two experiments examined the underlying cognitive mechanisms of the CI effect
685 using the novel domain of perceptual-cognitive skills training. The majority of previous
686 research has examined the CI effect using a motor task and debate still remains around the
687 underlying mechanisms of this phenomenon. To provide further insight into the mechanisms
688 involved, different secondary task protocols were used in the two experiments. These
689 protocols enabled investigation of the cognitive effort involved at specific time points across
690 an anticipation trial, examining both the elaborative processing hypothesis and the action plan
691 reconstruction hypothesis (Magill & Hall, 1990).

692 **Elaborative processing hypothesis.** Support for the elaborative processing
693 hypothesis was expected in a perceptual-cognitive skills task as the early work on the CI
694 effect used a non-motor skill task to propose that inter-task comparisons were the source of
695 interference in random practice (Battig, 1972; 1979). In Experiment 1, we showed that
696 cognitive effort was greater in the feedback phase of a trial for a random compared to blocked
697 schedule of practice. The feedback phase has previously been linked to the elaborative

698 processing hypothesis as comparisons between trials can only occur once the participant is
699 aware of the outcome of the trial (Li & Wright, 2000). This finding supports the elaborative
700 processing hypothesis as the increased cognitive effort of the random group indicates that
701 inter-task comparisons occurred in this practice condition but not in the blocked group (Shea
702 & Zimny, 1983; 1988). However, the findings reported in Experiment 2 did not support the
703 elaborative processing hypothesis. Inserting a cognitively demanding secondary task into the
704 inter-trial interval did not affect learning in a random structure of practice, thereby
705 contradicting previous research that has shown this effect (Lin et al., 2008). However,
706 previously, researchers did not use a secondary task, but rather used TMS to disrupt
707 elaborative processes (Lin et al., 2008; Lin et al., 2010). It may have been that the Stroop task
708 was not disruptive enough to interfere with the between task comparisons taking place.

709 **Action plan reconstruction hypothesis.** While the elaborative processing hypothesis
710 provides a plausible explanation for the acquisition of perceptual-cognitive skills, the action
711 plan reconstruction hypothesis seems more precariously linked to this domain due to the idea
712 that a motor program must be present in this process (Magill & Hall, 1990). The current data
713 provided mixed support for this hypothesis. Experiment 2 provided only tentative evidence
714 for the action plan reconstruction hypothesis. While the BStroop group did increase response
715 accuracy in the retention test compared to the blocked group, this change did not reach
716 conventional levels of significance. The suggestion is that the Stroop test may not have been
717 as cognitively demanding as task switching and did not cause total forgetting of an action
718 plan (Lee & Magill, 1983; 1985; Simon & Bjork, 2002). Alternatively, the Stroop task may
719 have been too similar to the primary task, as both were perceptual in nature, and between-task
720 similarity is negatively related to the CI effect (Boutin & Blandin, 2010).

721 In contrast, evidence from Experiment 1 supported the action plan reconstruction
722 hypothesis and contradicts the notion that this hypothesis only applies to motor tasks

723 (Broadbent et al., 2015a; Carlson et al., 1989; Carlson & Yaure, 1988; Helsdingen et al.,
724 2011a, 2011b). Greater cognitive effort was found in the observation phase of the trial for
725 random compared to blocked practice. The observation phase has been linked to the action
726 plan reconstruction hypothesis because an action plan can only be retrieved and reconstructed
727 once participants are aware of the requirements of the upcoming task (Li & Wright, 2000).
728 There are a few plausible explanations as to why the action plan reconstruction hypothesis is
729 still applicable to a non-motor task. The evidence concerning *action anticipation* suggests
730 that the motor system becomes activated through resonant mechanisms when observing an
731 action (e.g., Aglioti et al., 2008). Therefore an action plan, as understood in the CI literature,
732 is still implemented for the observed action. However, the current experiment used novice
733 tennis player without a fine-tuned motor resonance system for the observed task, which
734 suggests that this is not a fully valid argument (Broadbent et al., 2015). Alternatively, it may
735 be that the definition and terminology currently used needs to be adjusted to acknowledge
736 non-motor tasks. Previously, researchers have suggested that ‘strategies’ and ‘processing
737 plans’ will still need to be retrieved and reconstructed similar to a motor program (Carlson &
738 Yaure, 1988; Helsdingen et al., 2011a; 2011b). We propose that to provide an explanation
739 consistent for both motor and non-motor tasks the terminology should be changed from the
740 action plan reconstruction hypothesis to the *response plan reconstruction hypothesis*. As
741 such, the definition for this hypothesis must state that for an upcoming task a person must
742 retrieve and reformulate the appropriate *response plan* on each attempt as it has been
743 forgotten by intervening responses. The individual under a random schedule of practice
744 engages in more effortful reconstructive process to regenerate the *response plan* for
745 subsequent performances.

746 Overall the current data showed some evidence for both the elaborative processing
747 and action plan reconstruction hypothesis (Magill & Hall, 1990). Data from Experiment 1

748 indicate that elaborative and reconstructive processes occur in the observation and feedback
749 phase, respectively. This finding suggests that the two hypotheses might not be viewed as
750 being separate, but rather as an integrated hypothesis involving greater cognitive effort across
751 the whole of the trial. In contrast, data from Experiment 2 examining the hypothesis led to
752 null effects, suggesting an alternative hypothesis may have to be considered to explain this
753 phenomenon.

754 **Alternative hypothesis: Error processing**

755 We investigated error processing as an additional explanation for the increased
756 cognitive effort underlying random practice. Previously, researchers have suggested it is the
757 switching of tasks that increases the load in working memory and underlies the learning
758 benefits of random compared to blocked practice (Rendell et al., 2011). The current data
759 provided some support for the proposal that task switching in conjunction with error
760 processing underpins the CI effect. In Experiment 2, we demonstrated that RStroop group
761 performance on the secondary task was negatively affected following an error compared to an
762 errorless trial, supporting the error-processing hypothesis. Participants allocated more
763 resources to the primary task on these trials to process errors in addition to the elaborative
764 processing and response plan reconstruction caused by task switching. This finding shows
765 some support for the idea that random practice increases the load in working memory similar
766 to a secondary task and may create a form of implicit learning (Rendell et al., 2011).
767 Moreover, in Experiment 2, support for the error-processing hypothesis was shown as the
768 random group demonstrated slower decision times on the primary task following an error
769 compared to an errorless trial, suggesting that the monitoring and controlling of a response
770 increases following an error for the random, but not the blocked, practice group (Holroyd et
771 al., 2005; Lam et al., 2010).

772 An alternative hypothesis is outlined combining ideas and concepts from the CI
773 literature (Magill & Hall, 1990) and the error processing literature (Lam et al., 2010). The
774 hypothesis suggests that error processing in conjunction with task switching may underpin
775 the increased cognitive effort found for a random compared to blocked structure of practice.
776 The greater cognitive effort following an error for a random schedule of practice could be due
777 to participants having to both update the current rules for the previous task and store these
778 (error processing), as well as retrieving the response plan for the upcoming task
779 (reconstructive processes). The updating of responses would occur through inter- and intra-
780 task comparisons (elaborative processing) made to identify discrepancies between the actual
781 outcome and the desired goal (error processing). In contrast, following an error, a blocked
782 structure of practice would not require the retrieval of a response plan (reconstructive
783 processes) due to the repetitive nature of the trials, so would merely require the rules for the
784 task to be updated (error processing) and this would not involve inter-task comparisons
785 (elaborative processes), hence less cognitive effort would be required. This hypothesis is
786 made tentatively and is to allow for clear hypotheses to be tested in future research to either
787 support or contradict the potential role of error processing in the CI effect.

788

Conclusions

789 In this paper, we report two experiments that provided confirmation of the CI effect
790 for the acquisition of perceptual-cognitive skills and some support for both the elaborative
791 processing hypothesis and the newly termed response plan reconstruction hypothesis.
792 Moreover, the experiments provide a novel insight into the role of error processing as a
793 potential underlying mechanism in the CI effect. The current literature suggests that cognitive
794 effort is greater for random practice compared to blocked practice due to task switching,
795 specifically through elaborative and reconstructive processes. However, the current data
796 further suggests that it may not be solely the switching of the tasks that underpins the CI

797 effect, but error processing in conjunction with the task switching that causes greater
798 cognitive effort for a random schedule of practice. In future, researchers should seek to
799 examine error processing as an additional underlying mechanism of the CI effect.
800 Furthermore, the extent to which task switching and error processing increase the load in
801 working memory and potentially create a type of implicit learning should be examined
802 (Rendell et al., 2010). The CI effect has been shown to extend to a range of domains and
803 conditions from simple motor skill tasks with novice participants (e.g., Shea & Morgan,
804 1979) to complex sporting tasks with expert athletes (e.g., Hall, Domingues, & Cavazos,
805 1994). Further research is required to assess the role of error processing in conjunction with
806 task switching in a variety of domains and conditions to determine the generalizability of the
807 alternative theory proposed in this paper.

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Table Captions

982 Table 1. Experiment 1: Mean (SD) decision time (ms) in the primary anticipation task for the
983 Blocked and Random groups across the pre-test, practice, and retention test.

984

985 Table 2. Experiment 1: Mean (SD) decision time (ms) in the primary anticipation task, and
986 mean (SD) reaction time (ms) in the secondary task, for the Blocked and Random groups on
987 errorless and error responses in the previous trial.

988

989 Table 3. Experiment 2: Mean (SD) response accuracy (number of correct trials) and decision
990 time (ms) in the Stroop test for the BStroop and RStroop groups across the three practice
991 sessions.

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Figure Captions

1007 Figure 1. The experimental set up.

1008

1009 Figure 2. The experimental design and layout of an individual trial for (a) Experiment 1 and
1010 (b) Experiment 2.

1011

1012 Figure 3. Experiment 1: Mean (SD) response accuracy (%) in the primary anticipation task
1013 for the Blocked and Random group in the pre-test, practice, and retention test. $*p < .05$

1014

1015 Figure 4. Experiment 1: Mean (SD) response time (ms) for the probe reaction time (PRT) for
1016 the Blocked and Random group in tone only, observation phase, and feedback phase. $*p < .05$

1017

1018 Figure 5. Experiment 2: Mean (SD) response accuracy (number of correct trials) in the
1019 primary anticipation task for the Blocked, Random, BStroop, and RStroop groups in the pre-
1020 test, practice, and retention test. $*p < .05$

1021

1022 Figure 6. Experiment 2: Mean (SD) decision time (ms) in the primary anticipation task for the
1023 Blocked, BStroop, Random group and RStroop groups following error and errorless trials. $*p$ 1024 $< .05$

1025

1026 Figure 7. Experiment 2: Mean (SD) decision time (ms) in the secondary Stroop task BStroop
1027 and RStroop groups following error and errorless trials for the. $*p < .05$

1028

1029

1030

1031 Table 1.

	Decision Time (ms)		
	Pre-Test	Practice	Retention
Blocked	910	861	930
(SD)	(446)	(225)	(272)
Random	952	893	790
(SD)	(591)	(186)	(150)

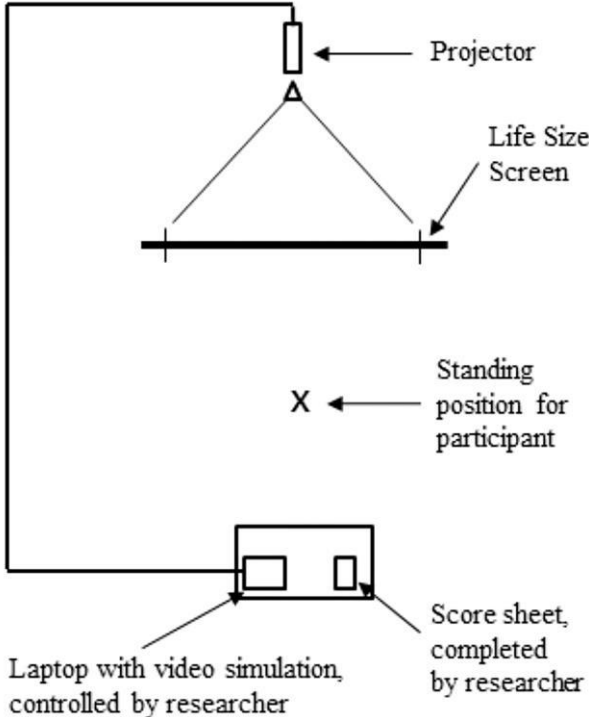
1032 Table 2.

	Decision Time (ms)		Probe Reaction Time (ms)			
	Errorless	Error	Observation Phase		Feedback Phase	
			Errorless	Error	Errorless	Error
Blocked	869	858	380	399	422	402
(SD)	(220)	(228)	(129)	(85)	(104)	(89)
Random	880	910	471	521	530	505
(SD)	(197)	(186)	(109)	(147)	(180)	(172)

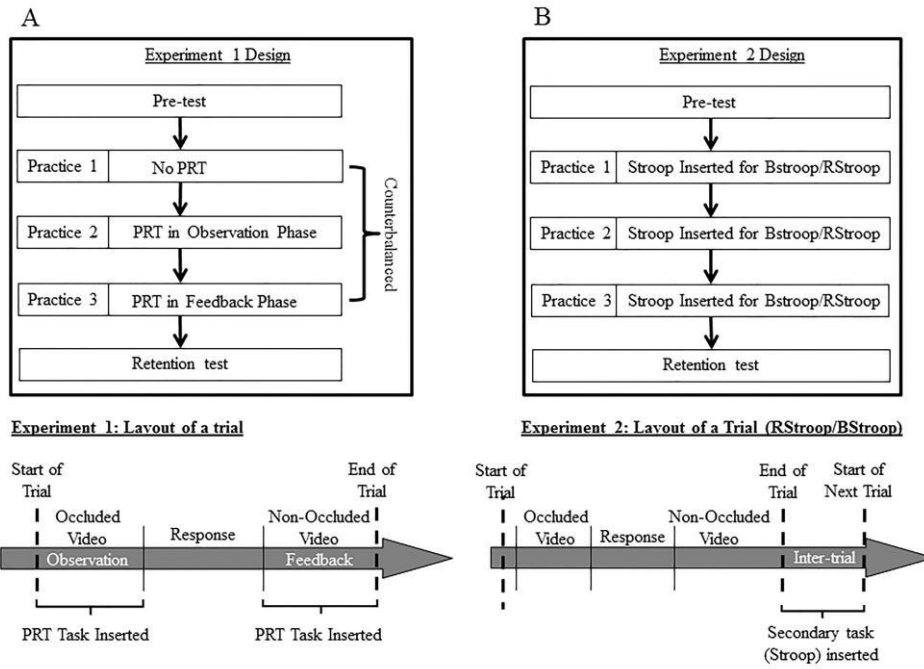
1033 Table 3.

	Practice 1		Practice 2		Practice 3	
	RA (n)	DT (ms)	RA (n)	DT (ms)	RA (n)	DT (ms)
BStroop	104	691	105	668	104	662
(SD)	(4)	(71)	(4)	(100)	(4)	(120)
RStroop	104	685	106	664	106	661
(SD)	(4)	(74)	(3)	(98)	(3)	(126)

1034 Figure 1.

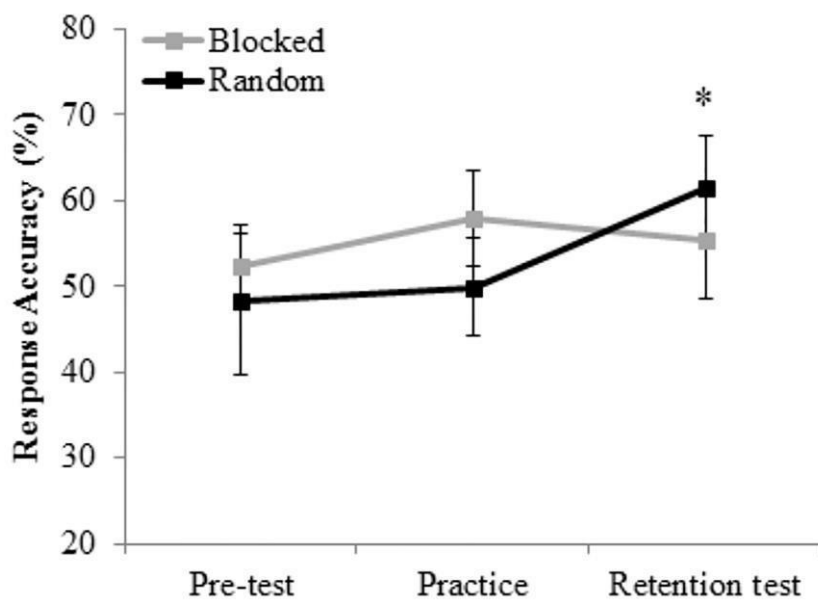


1035 Figure 2



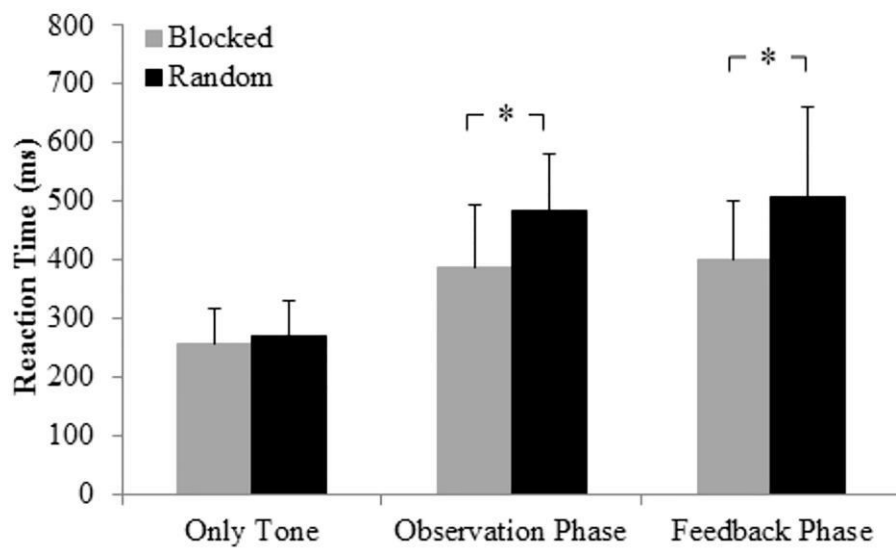
1036 Figure 3.

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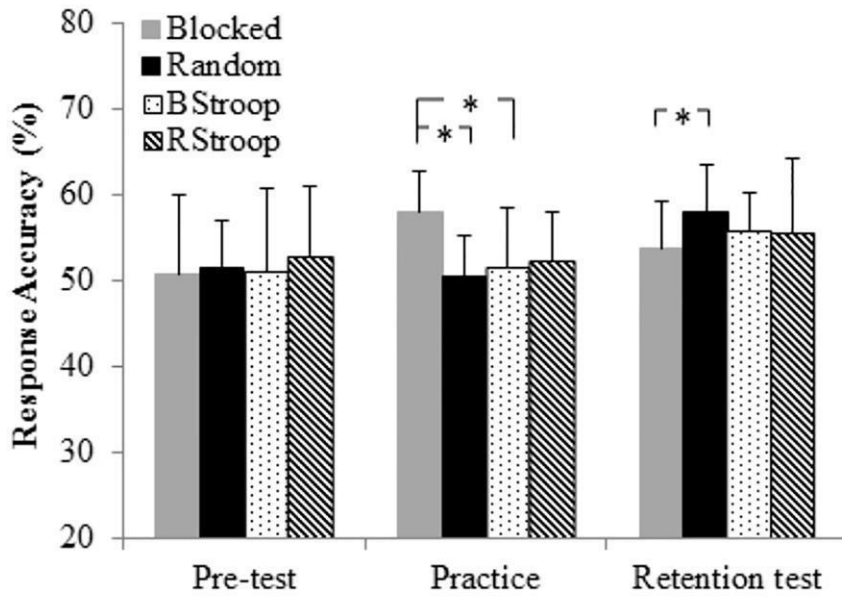
1038 Figure 4.

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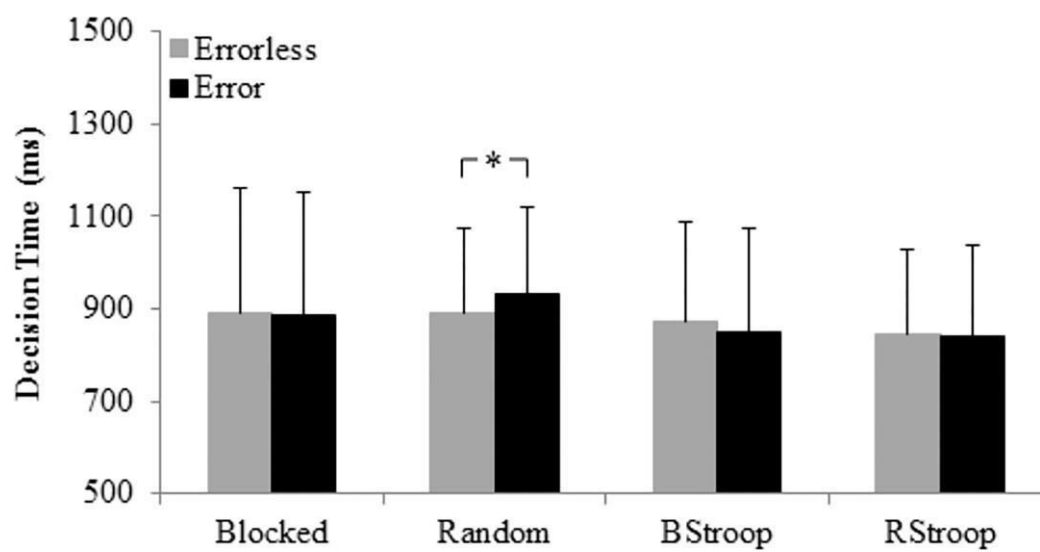


1040 Figure 5.

1041



1042 Figure 6.



1043 Figure 7.

