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

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**Abstract**

26  
27       The contextual interference (CI) effect refers to the learning benefits that occur from a  
28 random compared to blocked practice order. In this paper, the cognitive effort explanation for  
29 the CI effect was examined by investigating the role of error processing. In two experiments,  
30 a perceptual-cognitive task was used in which participants anticipated three different tennis  
31 skills across a pre-test, three practice sessions, and retention test. During practice, the skills  
32 were presented in either a random or blocked practice order. In Experiment 1, cognitive effort  
33 was examined using a probe reaction time task. In Experiment 2, cognitive effort was  
34 manipulated for two groups by inserting a cognitively demanding secondary task into the  
35 inter-trial interval. The CI effect was found in both experiments as the random groups  
36 displayed superior learning in the retention test compared to the blocked groups. Cognitive  
37 effort during practice was greater in random compared to blocked practice groups in  
38 Experiment 1. In Experiment 2, greater decrements in secondary task performance following  
39 an error were reported for the random group when compared to the blocked group. The  
40 suggestion is that not only the frequent switching of tasks in randomized orders causes  
41 increased cognitive effort and the CI effect, but it is also error processing in combination with  
42 task switching. Findings extend the cognitive effort explanation for the CI effect and propose  
43 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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## 51 **General Introduction**

52 The manner in which practice is structured affects skill acquisition. The contextual  
53 interference (CI) effect refers to the differential impact on skill acquisition of a random  
54 versus blocked practice schedule. A random schedule, or high CI, involves switching  
55 between a number of tasks or actions during practice (e.g., CBA ACB BAC). In contrast, a  
56 blocked schedule of practice, or low CI, involves a number of tasks or actions being executed  
57 separately from one another in a repetitive manner (e.g., AAA BBB CCC). A random  
58 schedule of practice results in less improvement during practice, but promotes greater  
59 retention and transfer of skill, when compared to a blocked schedule of practice (Shea &  
60 Morgan, 1979).

61 While the CI effect is a robust finding, debate still remains around the underlying  
62 mechanisms of this phenomenon (Magill & Hall, 1990). In the current paper, the cognitive  
63 effort from task switching hypotheses for the CI effect is tested and an alternative hypothesis  
64 involving the processing of errors is examined. To our knowledge, the role of error  
65 processing and its effect on cognitive effort (Lam, Masters, & Maxwell, 2010) has not  
66 previously been investigated in conjunction with the CI effect and could provide a novel  
67 explanation for the mechanisms underpinning this phenomenon. Moreover, little attention has  
68 been given to the effects of different practice schedules on the learning of anticipatory  
69 judgements (for an exception, see Broadbent, Causer, Ford, & Williams, 2015a). Much of the  
70 research surrounding the CI effect appears to predict that the planning, selection, and  
71 execution of motor skill is essential for the interference caused between tasks (Magill & Hall,  
72 1990). We examined the CI effect using a perceptual-cognitive task rather than the typical  
73 perceptual-motor task in order to provide a unique insight into the mechanisms underpinning  
74 this phenomenon (Memmert et al., 2009).

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 (Sennheiser 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,

449 2002). Moreover, with regards to error processing, in the inter-trial interval the RStroop  
450 group are predicted to exhibit significantly greater cognitive effort following an error  
451 compared to an errorless trial. In contrast, the BStroop group is expected to show no  
452 differences in cognitive effort following an error and errorless trial due to the predicted lower  
453 amount of elaborative processing occurring in that practice structure.

## 454 **Method**

### 455 **Participants**

456 Participants were 56 undergraduate students who were novice tennis players with no  
457 competition experience in the sport. They were randomly divided into either a blocked group  
458 ( $n = 14$ ;  $M$  age = 20.7 years,  $SD = 1.6$ ), random group ( $n = 14$ ;  $M$  age = 20.9 years,  $SD = 1.1$ ),  
459 BStroop group ( $n = 14$ ;  $M$  age = 20.9 years,  $SD = 1.4$ ), or RStroop group ( $n = 14$ ;  $M$  age =  
460 21.1 years,  $SD = 1.1$ ). Each group had 11 males and 3 females. No group differences for  
461 response accuracy were found at pre-test between the four groups,  $p > .05$ . Informed consent  
462 was obtained from the participants prior to participation. The research was conducted in  
463 accordance with the ethical guidelines of the lead institution.

### 464 **Task and apparatus**

465 The film clips and the protocol were the same as in Experiment 1 with a pre-practice-  
466 retention design. No PRT measure was used in this experiment. For the BStroop and RStroop  
467 groups (see Figure 2b), a Stroop test was inserted in the inter-trial interval of practice trials  
468 using video editing software (Adobe Premier CS5 software, San Jose, USA). The Stroop test  
469 was selected due to the high cognitive demands it places on working memory (Kane & Engle,  
470 2003; Long & Prat, 2002). The Stroop test presents three color words, such as red, green, and  
471 blue, with a font color of text that is different to that of the word. On the video clips, a black  
472 screen appeared prior to the Stroop test on each trial that had either stated “color” or “word”  
473 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**



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.

### 665 **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**

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

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

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

**Figure Captions**

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Figure 1. The experimental set up.

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

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

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

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

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

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