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6   The role of error processing in the contextual interference effect during the training of

7   perceptual-cognitive skills

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Abstract

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

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

General Introduction

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

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

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.

<div align="center">**Results**</div>

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, η_p^2 = .01, error main effect, F (1, 22) = .58, p =

377   .46, η_p^2 = .03, or interaction, F (1, 22) = 3.10, p = .09, η_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, η_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, η_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, η_p^2 = .06, and no Group x Phase

390   interaction, F (1, 22) = .01, p = .99, η_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, η_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 $p > .05$.

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.

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.

<div align="center">

Results

</div>

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, $F (2, 52) = .01$, $p = .99$, η_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.

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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981 **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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1006   **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. *$p < .05$

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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)			
			Observation Phase		Feedback Phase	
	Errorless	Error	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.
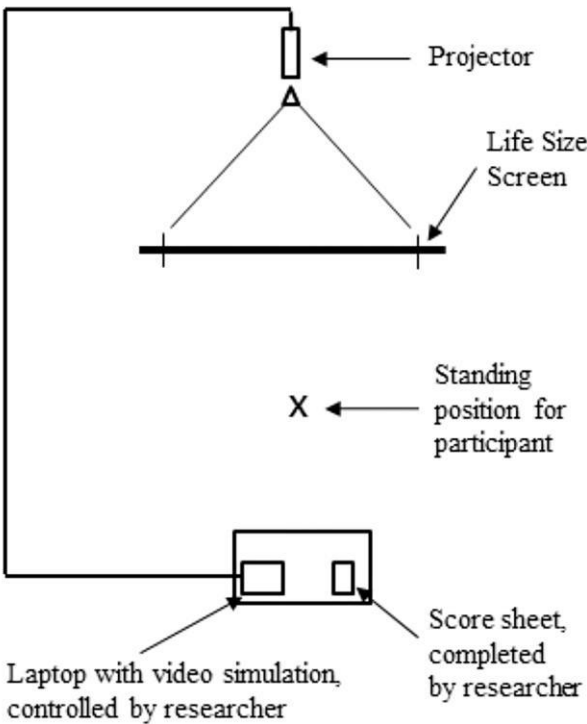
1035   Figure 2
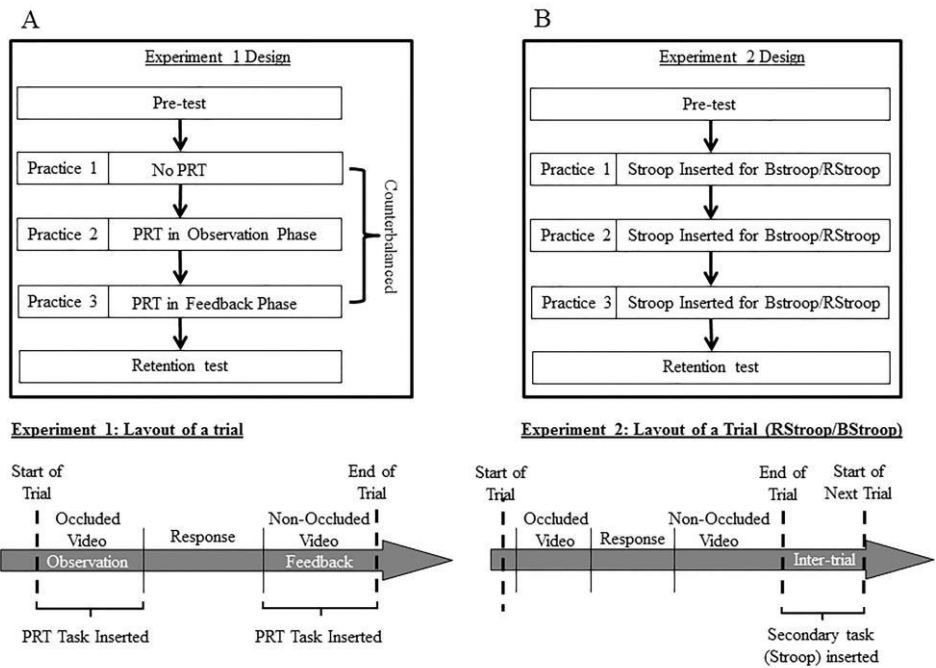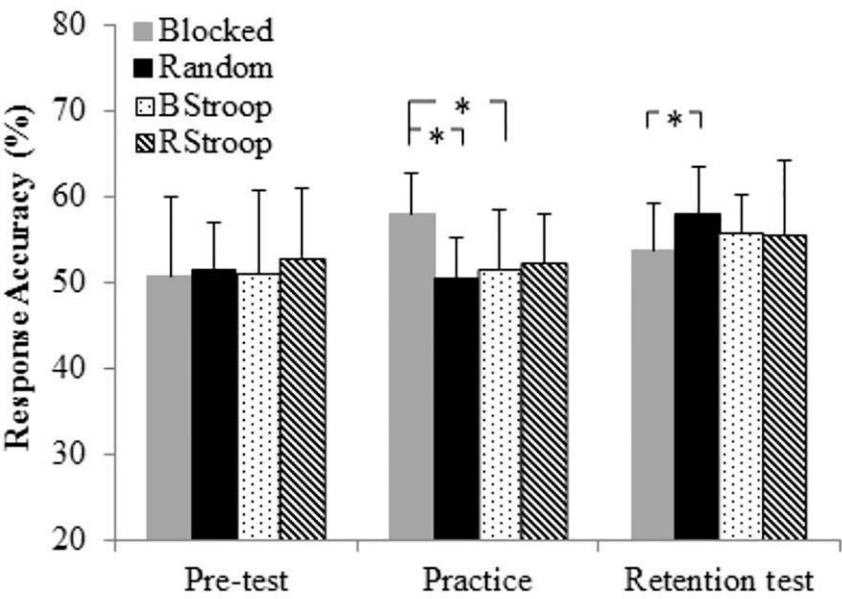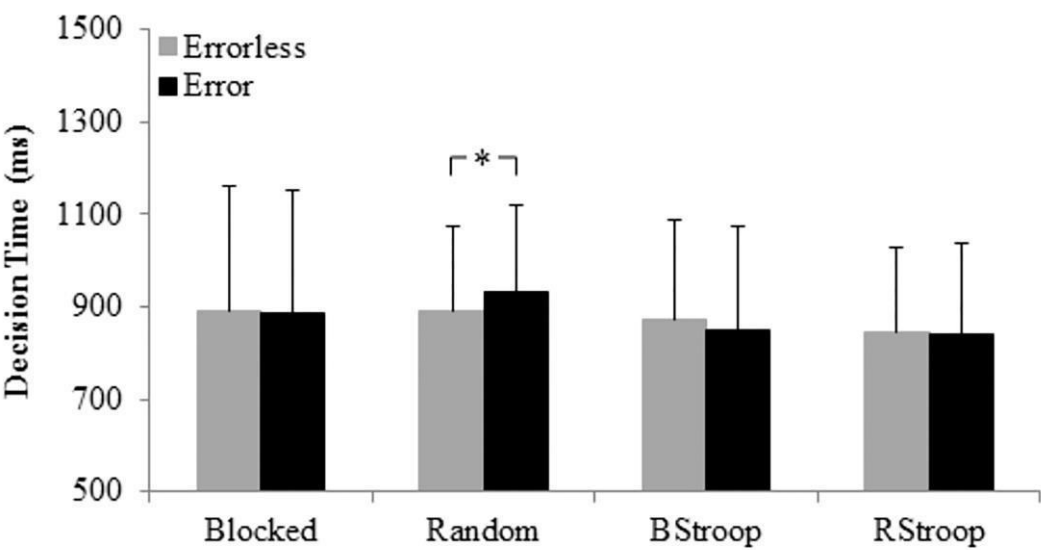
1036   Figure 3.

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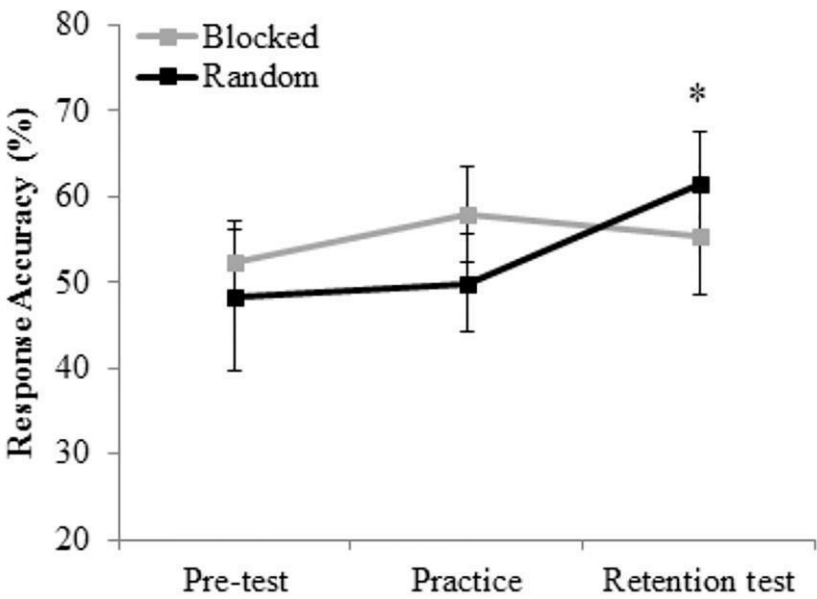
1038   Figure 4.

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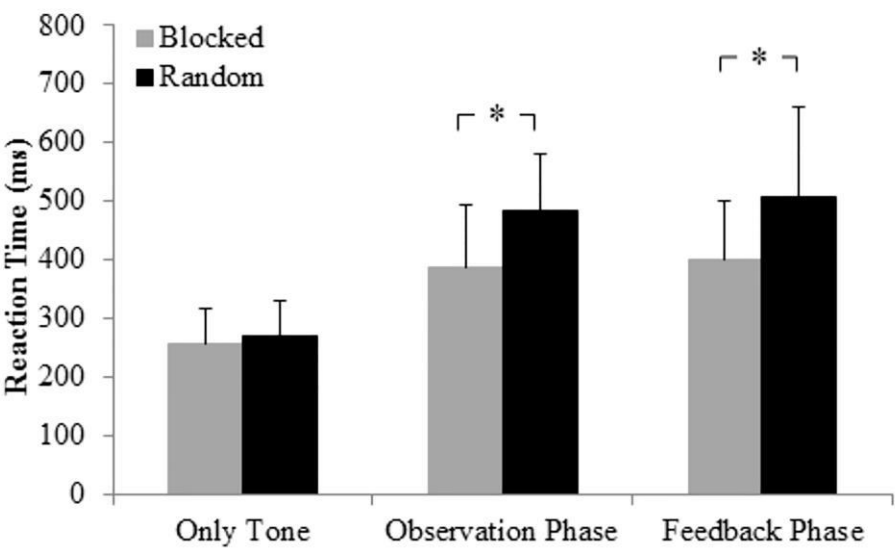
1040   Figure 5.

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1042   Figure 6.

1043   Figure 7.