Broadbent, DP, Causer, J, Ford, PR and Williams, AM

Contextual Interference Effect on Perceptual-Cognitive Skills Training

Article

Citation (please note it is advisable to refer to the publisher's version if you intend to cite from this work)

Broadbent, DP, Causer, J, Ford, PR and Williams, AM (2015) Contextual Interference Effect on Perceptual-Cognitive Skills Training. MEDICINE AND SCIENCE IN SPORTS AND EXERCISE, 47 (6). pp. 1243-1250. ISSN 0195-9131

Contextual interference effect in perceptual-cognitive skills training

David P. Broadbent [1], Joe Causer [1], Paul R. Ford [1], A. Mark Williams [2]

[1] Liverpool John Moores University

[2] Brunel University

Correspondence to:

David P. Broadbent

School of Exercise and Sport Science

Liverpool John Moores University

Liverpool

Merseyside

L3 3AF

Tel: 07891508468

E-mail: d.p.broadbent@2008.ljmu.ac.uk

Abstract

Introduction: The contextual interference (CI) effect predicts that a random order of practice for multiple skills is superior for learning compared to a blocked order. We report a novel attempt to examine the CI effect during the acquisition and transfer of anticipatory judgments from simulation training to an applied sport situation. **Method:** Participants were required to anticipate tennis shots under either a random or blocked practice schedule. Response accuracy was recorded for both groups at pre-test, during acquisition, and on a 7-day retention test. Transfer of learning was assessed through a field-based tennis protocol that attempted to assess performance in an applied sport setting. **Results:** The random practice group had significantly higher response accuracy scores compared to the blocked group on the 7-day laboratory retention test. Moreover, in the transfer to an applied sport situation the decision times of the random practice group were significantly lower compared to the blocked group. **Conclusion:** The CI effect was found to extend to the training of anticipatory judgments through simulation techniques. Furthermore, we demonstrate for the first time that the CI effect increases transfer of learning from simulation training to the applied sport task, highlighting the importance of using appropriate practice schedules during simulation training.

Key words: anticipatory judgment; practice structure; perceptual learning; video simulation; transfer of learning

Introduction

Paragraph Number 1 The key consideration when designing practice activity is the retention and transfer of learning from that activity to real-world performance (4). The manner in which practice activity is organized can affect the performance, learning, and transfer of the skills being practiced. The contextual interference (CI) effect predicts that practice scheduled in a random order (high CI) leads to more errors during practice, but superior learning and transfer of skill, when compared to practice scheduled in a blocked order (low CI) (31). A key skill possessed by expert performers in many domains is the ability to anticipate upcoming events (for a review, see 38). However, researchers have yet to examine the effect of practice order on the performance, learning, and transfer of anticipatory judgments. In this paper, we examine the CI effect during the practice of anticipatory judgments through simulation techniques and its transfer to applied sport performance in a dynamic, temporally constrained task involving tennis.

Paragraph Number 2 The CI effect has been extensively examined in a variety of motor learning tasks (25). Shea and Morgan (31) had participants practice three patterns of a simple barrier knockdown motor task under a blocked (e.g., AAA-BBB-CCC) or random (e.g., ACB-BCA-CAB) schedule of practice. After acquisition, participants completed retention tests in which half the trials were administered in a blocked order and the other half in a random order. Two transfer tests involving different barrier knockdown tasks were included. During the early acquisition trials, the blocked practice group had a significantly faster total movement time compared to the random group, indicating superior performance during practice. However, on the retention and transfer tests, the random practice group had a significantly faster total movement time compared to the blocked group, indicating superior learning and the CI effect (31). The CI effect has been replicated in many studies examining motor skill tasks across various contexts as described in several review articles (e.g. 20, 25, 28).

Paragraph Number 3 Two main theories have been forwarded to explain the CI effect. First, the reconstruction hypothesis proposes that a random practice order leads to interference between the tasks being practiced causing them to be forgotten in the short-term. As a consequence, participants are required to reconstruct an action plan in order to execute each attempt at a new task, promoting more memorable internal representations for the tasks. In contrast, in a blocked practice order the same task is practiced on consecutive trials and the same action plan used, removing the need to reconstruct an action plan each time (30). Second, the elaboration hypothesis proposes that a random practice order promotes more memorable representations through greater comparative and contrastive analyses between the tasks, compared to the repetitive nature of blocked practice (32). While both these theories differ in regards to the mechanisms that underpin the CI effect, they both attribute the robust finding to the greater cognitive effort and increased neural activity that occurs during random, as opposed to blocked practice (9, 18, 24).

Paragraph Number 4 In most domains, performance involves perceptual-cognitive skills, such as anticipatory judgments and decision making, as well as motor skill execution. Perceptual-cognitive skill refers to the ability of performers to search, identify, process, and integrate environmental information with existing knowledge and current motor capabilities to facilitate the selection of appropriate responses (26). Anticipation is the ability to recognize the outcome of the actions of other athletes prior to those actions being executed (38). Researchers have reported that experts are superior to novices based on their perceptual-cognitive skills in a range of domains, including law enforcement (37), medicine (6), the military (36), and sport (40). Moreover, perceptual and cognitive skills can be trained using simulation methods (8). For example, Smeeton, Williams, Hodges and Ward (33) investigated the relative effectiveness of video-based simulation training combined with various instructional techniques for enhancing anticipatory judgments in tennis. Participants viewed videos of tennis shots occluded at ball-racket contact and were required to predict shot direction. The training groups improved their anticipatory judgment performance from pre- to post-test compared with a control group, and these skills transferred to quicker decision times in a field-based transfer test (see also, 1).

Paragraph Number 5 Some researchers have examined the CI effect using perceptual-cognitive tasks, although they did not investigate how the CI effect transfers from training to the real-world. Del Rey and colleagues (10, 11) investigated the CI effect using an anticipatory judgment task involving predicting the arrival of moving lights at a final lamp. In retention and transfer tests, a random practice group had significantly lower error when anticipating the arrival of the lights to the final lamp when compared to the blocked group, supporting the CI effect. In contrast, Memmert, Hagemann, Althoetmar, Geppert and Seiler (27) used a more applied badminton simulation task to investigate the CI effect in anticipatory judgments, but did not find the classic CI effect. Participants sat in front of a computer screen that showed temporally occluded video footage of a player performing overhead badminton shots to different court locations. Participants were required to predict where the shuttlecock would land on an image of a badminton court, which was also on the computer screen. In six training sessions, one group received the occluded landing locations in a blocked practice order, whereas the other groups received the occluded landing locations in a random practice order. In training, feedback was provided after each trial, whilst learning was assessed in a post-test and a seven-day retention test. There were no differences in the accuracy of anticipatory judgments between random and blocked practice groups across acquisition, post-test, and retention. One possible explanation for this finding concerns the design of the representative task. A simplistic response to a small visual display was used in the task, both of which are thought to limit the expert advantage (39). Researchers have suggested that the coherence of a representative task with its real world version is vital for the appropriate processing to take place and, thus, decreasing the coherency of the task creates constraints on processing (12). Representative task design involves the use of large screens that allow life-size images to be projected, showing dynamic rather than static images. They allow the performer to complete a response that is the same, or as similar as possible, to that produced in the actual performance environment (4). The other possible explanation for the lack of group differences is that participants only practiced anticipatory judgments of the badminton overhead stroke, but to different landing locations. By definition, CI is the scheduling of practice for a number of different skills, not a single skill (30). Research is needed to examine how practice should be structured during perceptual-cognitive skills training requiring a complex movement response to a number of different skills on a large screen upon which life-size video is projected.

Paragraph Number 6 The retained transfer of learning from practice to real-world performance should be the key consideration when designing practice. To our knowledge, no researchers have examined how practice should be structured during simulation training so that the skills transfer more effectively to real-world performance, despite the widespread use of this method (8). For example, Helsdingen and colleagues (15, 16) showed the CI effect extended to complex police judgment tasks that involved prioritizing the urgency of different case descriptions. The random practice group was significantly more accurate at solving cases compared to the blocked group in a post-test. A transfer test was included in this study, but it was another simulation task in which only the structural and surface features differed from the training tasks, rather than a transfer to a real-world task. Consequently, there is a need to extend the research to judgments in an applied setting so as to extend the theory and verify the translational value of such interventions.

Paragraph Number 7 The current study examines the CI effect in simulation training of anticipatory judgments in a temporally constrained task in tennis and the retention and transfer of this ability to applied sport performance in the field. Anticipatory judgments of three different tennis skills were practiced across an acquisition phase in either a random or blocked practice order, with learning being measured across pre-, retention, and transfer tests. The three skills being anticipated were the forehand groundstroke, forehand smash, and forehand volley. It is expected that participants would improve the accuracy of their anticipatory judgments as a result of the training protocol and that this improvement would transfer to the field. In line with the CI effect, it is hypothesized that the blocked practice group will have more accurate anticipatory judgments during the acquisition phase compared to the random practice group. In contrast, the random practice group will have more accurate anticipatory judgments compared with the blocked practice group in the retention tests and in the transfer to a field-based protocol, indicating superior learning of the skills.

Methods

Participants

Paragraph Number 8 Based on previous perceptual research (7, 33) and taking into account the difficulty in recruiting and keeping participants over an extended period of time, we estimated that nine participants per group were required for this study. Participants were 18 intermediate-level, junior tennis players, who were divided into either a blocked practice group (n = 9; M age = 12.9 years, SD = 1.6) or a random practice group (n = 9; M age = 13.2 years, SD = 1.6). Participants in the two groups were matched by ensuring no between-group differences in prior tennis experience, the numbers of hours per week they currently played tennis, their laboratory pre-test accuracy scores, their field pre-test accuracy, and their field pre-test decision time (see Table 1). Separate independent t-tests on each of these variables showed no between-group differences (all $t < 1$). Written informed consent was obtained from the participants and their parent or legal guardian prior to participation and these documents were stored in the research department of the lead institution. The experiment was conducted in the country of residence and designed in accordance with the 1964 Declaration of Helsinki. Ethical approval was obtained from the lead institution's research ethics committee.

Test and Training Film Construction

Paragraph Number 9 Test and training films were developed for the simulation. Films were made for a pre-test, three training sessions, and a 7-day retention test. Video clips of tennis shots were edited using Adobe Premier CS5 software (San Jose, USA). Each clip began with a black screen and the trial number. Each film clip consisted of one of three intermediate level tennis players (age: *M* age = 19.7 years, SD = 1.2; *M* tennis experience = 8.7 years, SD = 1.2; *M* tennis hours per week = 6.3 hours, SD = 1.5) on the other side of the net of a standard indoor tennis court. The clips involved the ball arriving at the player from an off-camera feeder player, who was one of the two other players, the player moving to the ball, swinging the racket, and hitting the ball back over the net using a pre-defined shot. The video was filmed from a central position on the baseline of the tennis court at a height of 1.5 m to provide a representative view of the court from the participants' perspective. Shots were selected for the test film footage when they satisfied three criteria: 1) the ball fed to the player went over the net in a central area so that the player returning it performed similar body movements for each stroke; 2) the returned ball had to be struck cleanly by the player with the speed of return replicating a game situation; and 3) the returned ball had to bounce in the intended target location.

Paragraph Number 10 Players executed three offensive tennis shots: 1) forehand groundstroke; 2) forehand smash; and 3) forehand volley. These three shot types were selected as researchers have demonstrated that when a player executes them in an attacking manner it promotes the greatest need for anticipatory judgments by their opponent (34). The shots were played to one of four locations on the opponent's side of the court: 1) left front; 2) left back; 3) right front; and 4) right back. The three skills (groundstroke, volley, smash) have distinct invariant characteristics, so that certain elements of the skill are relatively fixed, such as movement patterns. However, variations are possible within the skills, such as the speed and height of ball flight, which are described as the parameters of the invariant skill (30). Within an applied sport setting it is difficult to control every parameter within an invariant skill. For example, Hall, Domingues, and Cavazos (13) demonstrated the CI effect in a baseball-hitting task using three invariant skills or pitches (fastballs, curveballs, and change-ups) received in either a blocked or random practice order. Within the three different types of pitches the parameters varied somewhat, such as the speed and height of each pitch. In our study, the blocked and random schedules of practice were created using the three different relatively invariant skills, as per the majority of other research in this area (e.g., 13, see also 14, 23), and not by the different parameters within a skill (e.g., 27).

Paragraph Number 11 For the test and training clips, the video occluded at three points that were selected based on previous research examining anticipatory judgments in sport (17, 34). The occlusion points were 80 ms before ball racket contact, at ball-racket contact (0 ms), and 80 ms after ball racket contact. At the occlusion point, the screen went black and the phrase 'Respond' appeared in large font, which allowed 3 seconds for the participant to respond before the next trial number appeared. Each trial lasted approximately 9 seconds. Across the pre-test (*n* = 108 trials), three training sessions (*n* = 72 trials per session), and 7-day retention test (*n* = 108 trials) the shot type, shot landing location, and occlusion condition were balanced so there was an equal number of each condition. To ensure that the structure of practice in the pre- and retention test did not favour either of the groups, both blocked and random practice structures (54 trials in each) were used, which were counterbalanced across participants. For the blocked practice group, the three skills were completed so that in each practice session all trials of one shot were completed before moving on to all trials for the next shot, with the order of the three shots being counterbalanced across participants. The server, end location of the shot, and occlusion point used varied across these blocks. For the random practice group, the quasi-random order meant that the same tennis shot was not played more than twice in a row. In the 7-day retention test, 50% of the clips were repeated from the pre-test and 50% were new clips. These new clips were used to ensure that participants were not completely familiar with the clips after completing the pre-test. The level of difficulty of the clips was kept constant between-tests. The old and new clips were balanced equally across both the blocked and random conditions.

Apparatus and Procedure

Paragraph Number 12 The experiment consisted of a pre-test in both the laboratory and field, three laboratory-based training sessions, separated by seven days, and a 7-day retention test in both the laboratory and field. All sessions were completed alongside the regular tennis training sessions of the participants. It was arranged with the coach that no other anticipation training would occur during the study period.

Paragraph Number 13 **Laboratory pre-test and retention test.** Figure 1a presents an overhead illustration of the experimental setup. Participants stood 4 m from the centre of a large portable projection screen (2.74 x 3.66 m; Cinefold Projection Sheet, Draper Inc., Spiceland, IN, USA) on which the test films were back projected (Hitachi CP-X345, Yokohama, Japan). The size of the image was representative of the proportions normally experienced in game situations when participants are positioned on the baseline of the court. Participants were required to respond to the onscreen shot by moving to one of four markers that were 1 m from them in four directions corresponding to the four locations where the ball could bounce. The players held a tennis racket and were required to simulate a return shot. Hand notation was used to record the movement response from each trial. The laboratory pre-test and the 7-day retention test took approximately 15 minutes each to complete.

Paragraph Number 14 **Field pre-test and retention test.** Figure 1b presents an illustration of the experimental setup for the field test. Participants were required to respond to shots played by an opposing intermediate level tennis player (age: *M* age = 22 years, *M* tennis experience = 7 years; *M* tennis hours per week = 4 hours) on a standard indoor tennis court. The player was not part of the laboratory test or training film. The shots performed by the player were the same three as used in the laboratory test films. A second skilled tennis player who projected the ball to the player was positioned slightly off court to the right of the participant. Upon receiving the feed ball, the player on court was required to execute each shot to one of the four locations used in the film on the participant's side of the court. The lead experimenter briefed the feeder and player on which shots to be performed across the tests so that each skill was counterbalanced for all participants. There were 36 trials for each participant in the field-based protocol, which were divided into two sets of 18 trials. In one set, participants received the shots in a blocked order, where all trials on one skill were completed before starting all trials on the next skill. In the other set, they received the shots in a random order in which no shot type was repeated more than twice in a row. The order of presentation of the two sets was counterbalanced across participants. Any shots that did not reach the intended target or failed to go over the net were discarded and the trial was repeated at the end of the session, where they were placed in their respective practice orders.

Paragraph Number 15 Participant responses were filmed using a video camera (Canon XM-2, Tokyo, Japan) with wide-angled lens at a sampling frequency of 50 Hz. The camera was located behind and to the left of the participant. It recorded the moment of ball-racket contact and the movements of the participant. The field pre-test and the 7-day retention test took approximately 15 minutes each.

Paragraph Number 16 **Training phase.** The training phase consisted of three laboratory sessions that occurred once each week over a 3-week period between the pre- and the 7-day retention tests. Participants watched two presentations of the same shot during each trial. First, the video footage occluded at one of the three time points and they were required to respond to the anticipated location of the ball bounce, as in the pre- and retention tests. Second, the same video clip was shown in full enabling the participants to view the ball flight and shot outcome in terms of where on the court the ball bounced. No verbal instructions were given regarding the information on screen or participant movements and responses. Each training session consisted of 72 trials and took approximately 15 minutes to complete. The 72 trials consisted of 24 trials of each shot, with each shot equally divided into the three occlusion points and four locations.

Paragraph Number 17 **Dependant measures and statistical analysis.** For the laboratory tests and training, response accuracy (RA) was the primary dependent variable. Responses were deemed as being accurate when the movement response of the participant was to the same location as the bounce of the ball on the participant's side of the court. Data from the laboratory and field were analyzed separately. In the field, both RA and decision time (DT) were recorded. DT was defined as the time period from ball-racket contact by the opponent to the initiation of movement by the participant (ms). The movement initiation of the participant was used as their response. Movement initiation was defined as 'the first frame where there was an observable and significant lateral motion to the right or left of the racket, the hips, the shoulder or the feet, which was made in order to move to the future location of the next strike' (34; p.822). Movement initiation in tennis usually occurs during or just after a player executes a split-step/landing sequence (35). Responses initiated prior to ball contact received negative values. Footage of the field tests were analyzed through Adobe Premier CS5 software. A participant from each group dropped out from the field post-test due to an injury and a time scheduling issue, so they were excluded from the field test data set. Inter- and intra-observer reliability measures were obtained for DT by using intraclass correlation techniques (see 3) on the data from two participants (144 trials), one from each group. The obtained correlation coefficients for the inter- (.938) and intra-observer (.876) measures demonstrated the reliability of the data analysis.

Paragraph Number 18 RA across training sessions was analyzed using a 2 Group (random, blocked) x 3 Training (training 1, training 2, training 3) x 3 Occlusion (80 ms before, ball-racket contact, 80 ms after) mixed-design analysis of variance (ANOVA), with repeated measures on the last two factors. To examine learning in the laboratory, RA was analyzed using a 2 Group (random, blocked) x 2 Test (pre-test, retention) x 3 Occlusion (80 ms before, ball-racket contact, 80 ms after) mixed-design ANOVA, with repeated measures on the last two factors. The Bonferroni post hoc procedure was used for any significant within-participant main effects. The Tukey HSD post hoc procedure was used for any significant interactions. Performance on the field-based protocol was analyzed using a factorial multivariate analysis of variance (MANOVA) in which group (blocked, random) was a between-participant variable, test (pre-test, retention) was the within-participant variable, and RA and DT were the dependent measures. Planned comparisons were carried out to compare the performance of both groups on each dependent measure, respectively. The alpha level for significance was set at $p < .05$ for all tests and partial eta squared ($\eta p2$) was used as a measure of effect size.

Results

Training

Paragraph Number 19 Figure 2 shows RA across the two groups on the three training sessions. A 2 Group x 3 Training x 3 Occlusion ANOVA revealed no main effect for group in RA during acquisition, F (1, 16) = .10, p = .76, η_p^2 = .01. There was a significant improvement in RA across the training phase, F (2, 32) = 10.25, p < .01, η_p^2 = .39. Tukey HSD *post hoc* analysis indicated that RA in the third training session (*M* = 54.8%, *SD* = 4.8) was significantly higher than in the first training session (*M* = 47.1%, *SD* = 3.4), p < .01. However, RA in the second training session (*M* = 51.2%, *SD* = 7.4) was not significantly different from either of the other two training sessions, all p > .05. Figure 3 shows RA at each occlusion point from the three training sessions. There was an occlusion main effect, F (2, 32) = 153.38, p < .01, η_p^2 = .91. *Post hoc* analysis indicated that RA in the trials occluded 80 ms after ball-racket contact (*M* = 66.6%, *SD* = 6.6) was significantly higher than in trials occluded at ball-racket contact (*M* = 48.2%, *SD* = 5.5) and 80 ms before ball-racket contact (*M* = 38.7%, *SD* = 3.0), p < .01. Furthermore, RA on trials occluded at ball-racket contact was significantly greater than on trials occluded 80 ms before ball-racket contact, p < .01. No interaction effects were observed.

Laboratory Pre- and Retention Test

Paragraph Number 20 Figure 2 shows RA across the two groups on the pre-test and 7-day retention test. A 2 Group x 2 Test x 3 Occlusion ANOVA revealed no main effect for group, F (1, 16) = 2.90, p = .11, η_p^2 = .15. However, RA significantly improved from pre-test (*M* = 50.9%, *SD* = 6.9) to retention-test (*M* = 67.5%, *SD* = 6.9), F (1, 16) = 113.74, p < .01, η_p^2 = .88. There was also a significant Group x Test interaction, F (1, 16) = 6.03, p = .03, η_p^2 = .27. *Post hoc* revealed no significant difference in RA in the pre-test between the blocked (*M* = 50.5%, *SD* = 8.6) and random group (*M* = 51.2%, *SD* = 5.6). However, in the retention test, the random group (*M* = 71.7%, *SD* = 5.3) had a significantly higher RA compared to the blocked group (*M* = 63.3%, *SD* = 6).

Paragraph Number 21 Figure 3 shows RA at each occlusion point on the pre-test and 7-day retention test. There was an occlusion main effect, F (2, 32) = 70.63, $p < .01$, $\eta_p^2 = .82$. *Post hoc* analysis indicated that RA was significantly higher in the trials occluded 80 ms after ball-racket contact (M = 70.7%, SD = 5.8) compared to trials occluded at ball-racket contact (M = 58.0%, SD = 8.2) and 80 ms before ball-racket contact (M = 48.8%, SD = 7.7), $p < .01$. Moreover, RA on trials occluded at ball-racket contact was significantly greater than on trials occluded 80 ms before ball-racket contact, $p < .01$. There was a Test x Occlusion interaction, F (2, 32) = 5.01, $p < .01$, $\eta_p^2 = .24$. *Post hoc* revealed that that in the pre-test, RA was not different between trials occluded at ball-racket contact (M = 47.7%, SD = 9.9) compared to trials occluded 80 ms before ball-racket contact (M = 42.8%, SD = 8.7). However, in the retention test, RA was significantly higher on trials occluded at ball-racket contact (M = 68.4%, SD = 9.0) compared to trials occluded 80ms before ball-racket contact (M = 54.8%, SD = 10.8). The Group x Test x Occlusion interaction was not significant.

Field Pre- and Transfer Test

Paragraph Number 22 Figure 4 shows the RA and DT across the two groups on the pre-test and 7-day retention test. The results of the MANOVA used to analyze performance on the field-based protocol with RA and DT as the dependent measures are presented in Table 2. Planned comparisons indicated that there was no significant difference in RA or DT between-groups at the pre-test, all $p > .05$. Furthermore, in the retention test, no significant difference was found for RA between the blocked (M = 88.5%, SD = 7.0) and random group (M = 88.0%, SD = 3.3), F (1, 14) = .03, $p = .86$, $\eta_p^2 = .02$. However, there was a significant difference for DT in the retention test, F (1, 14) = 7.19, $p = .02$, $\eta_p^2 = .34$. The random group (M = 98 ms, SD = 89) had a significantly faster DT in the retention test compared to the blocked group (M = 238 ms, SD = 118) and the pre-test, suggesting greater transfer of learning.

Discussion

Paragraph Number 23 We investigated the CI effect on the acquisition of anticipatory judgments in a dynamic, temporally constrained environment. Furthermore, we reported a novel attempt to examine whether the structure of practice during simulation training affects the transfer of these skills to an applied sport setting. Specifically, we investigated the effects of a random and blocked schedule of practice on the acquisition, retention, and transfer of anticipatory judgments in tennis acquired through simulation training. The main hypothesis of the CI effect was that in the laboratory-based protocols the random group would demonstrate significantly greater improvements in judgments from the pre- to retention test compared to the blocked group. Our data provides evidence for the CI effect as the random group demonstrated significantly more accurate judgments in the 7-day laboratory-based retention test compared to the blocked group and the pre-test. These data provide support for previous research investigating the CI effect with motor and perceptual-cognitive skills (10, 11, 15, 16, 31). However, these findings contradict those of Memmert et al. (27), who did not provide any support for the CI effect in this domain. Therefore, the current findings provide the first indication that the structure of practice affects the acquisition of anticipatory judgments during simulation training.

Paragraph Number 24 It was hypothesized that in a transfer test to an applied sport situation the random group would demonstrate more accurate and faster anticipatory judgments when compared to the blocked group. In the 7-day transfer test, while RA did not differ between groups, participants in the random group had significantly faster DT compared to the blocked group and the pre-test, indicating superior learning. The lack of between-group difference in RA in the transfer tests may be because scores were relatively high across all field tests. In the field-based protocol, participants had access to all of the ball flight information, providing an advantage over the laboratory where vision of ball flight was not available due to the occlusion paradigm. However, findings for DT indicate that the training intervention led to earlier cue use and this transferred onto the field, as both groups reduced their DT significantly. Furthermore, the data suggest that the random group were better able to learn early cue usage than the blocked group, as they made significantly faster anticipatory judgments in the field-based protocol. Data provide novel evidence that the CI effect transfers from simulation training to an applied sport setting. Our findings provide support for previous literature (13) and extend current understanding by showing that principles from the motor skills literature regarding the CI effect apply to simulation training to improve anticipatory judgments (8).

Paragraph Number 25 In line with the CI effect, we hypothesized that during the acquisition phase the blocked group would have more accurate anticipatory judgments compared to the random group. However, contrary to this hypothesis, RA was not significantly different between the two groups during the three acquisition sessions. These data contradict the majority of previous researchers who have investigated the CI effect (25, 28). However, some researchers have reported a lack of difference between blocked and random practice groups during acquisition, but have still found the hypothesized differences in the retention and transfer phase (i.e. 16), somewhat contradicting the "typical" CI effect (20). A possible explanation for this finding is that the three invariant tennis skills contained variable parameters, such as shot location. Other researchers in both applied (13) and laboratory-based settings (23) have examined blocked and random schedules of practice that contain variable parameters, as opposed to constant parameters. Similar to our study, they have shown a lack of differences between practice groups across acquisition, whereas the random practice group is superior in retention and transfer when compared to the blocked practice group.

Paragraph Number 26 The two main theories forwarded to explain the CI effect are the forgetting/reconstruction hypothesis (21, 22) and the elaboration/distinctiveness hypothesis (31). They both predict greater cognitive effort during random compared with blocked practice, either prior to or after skill execution, respectively. Another theory is that random practice conditions lead to greater cognitive effort and increased neural activity across practice simply because the task changes often when compared to blocked practice (9, 18, 24). Anticipatory judgments are a perceptual-cognitive process that sometimes may not involve constructing an action plan and executing a motor skill, so the advantage of random practice in these cases may be explained by the elaboration hypothesis. Alternatively, anticipation in sport may be related to the embodiment of actions, which suggests motor regions of the brain activate via the mirror neuron system when observing a movement (29). Furthermore, the mere knowledge of an upcoming movement is suggested to excite the motor system through a resonant mechanism, enabling people to anticipate, rather than react to others actions (19). Therefore, for experienced tennis players who have the necessary motor skill to perform the observed strokes, anticipation may not just be a perceptual-cognitive process (5). The anticipated opponent action might resonate within the individual's own motor system, activating an action plan for completing that skill (2). If so, then random practice would be hypothesized to lead to greater cognitive effort through reconstructing actions plans when compared to blocked practice (21, 22). Further research is required to reveal the underlying cognitive mechanisms that lead to the CI effect in anticipatory judgments, perhaps by comparing between skilled participants, who have fine-tuned motor-resonance systems, and novice participants, who do not.

Paragraph Number 27 In summary, we report novel data to suggest that the robust CI effect in perceptual-motor skills extends to the development of perceptual-cognitive skills through simulation training and to the transfer of these skills to an applied sport setting. A random practice schedule during simulation training resulted in improved anticipatory judgment accuracy on a 7-day retention test in the laboratory when compared to a blocked schedule of practice. Furthermore, the positive changes in anticipatory judgment transferred to a field-based condition where the random schedule of practice resulted in faster DT in the field during the 7-day transfer test compared to a blocked schedule of practice. Overall, the findings support previous researchers (31) by demonstrating that a random schedule of practice leads to superior learning compared to a blocked schedule of practice and extends this principle to the training of anticipatory judgments through a video simulation technique.

Acknowledgements

The authors declare no additional funding sources.

The authors declare no conflicts of interest.

The results of this study do not constitute an endorsement by the American College of Sports Medicine.

References

1. Abernethy B, Schorer J, Jackson RC, Hagemann N. Perceptual training methods compared: the relative efficacy of different approaches to enhancing sport-specific anticipation. *J. Exp. Psychol.-Appl.* 2012;18(2):143-53.
2. Aglioti SM, Cesari P, Romani M, Urgesi C. Action anticipation and motor resonance in elite basketball players. *Nat Neurosci*. 2008;11(9):1109-16.
3. Atkinson G, Nevill AM. Statistical methods for assessing measurement error (reliability) in variables relevant to sports medicine. *Sports Med*. 1998;26:217-38.
4. Broadbent DP, Causer J, Williams AM, Ford PR. Perceptual-cognitive skill training and its transfer to expert performance in the field: Future research directions. *Eur. J. Sport Sci.* in press.
5. Bruce L, Farrow D, Raynor A, Mann D. But I can't pass that far! The influence of motor skill on decision making. *Psychol. Sport Exerc.* 2012;13(2):152-61.
6. Causer J, Barach P, Williams AM. Expertise in medicine: using the expert performance approach to improve simulation training. *Med. Educ.* 2014;48(2):115-23.
7. Causer J, Holmes PS, Williams AM. Quiet Eye Training in a Visuomotor Control Task. *Medicine and science in sports and exercise*. 2011;43(6):1042-9.
8. Causer J, Janelle CM, Vickers JN, Williams AM. Perceptual expertise: What can be trained? In: NJ Hodges, AM Williams editors. *Skill acquisition in sport: research, theory and practice*. New York: Routledge; 2012, pp. 306-24.
9. Cross ES, Schmitt PJ, Grafton ST. Neural substrates of contextual interference during motor learning support a model of active preparation. *J. Cognitive Neurosci.* 2007;19:1854-71.
10. Del Rey P. Training and contextual interference effects on memory and transfer. *Res. Q. Exerc. Sport*. 1989;60:342-7.

11. Del Rey P, Wughalter E, Du Bois D, Carnes MM. Effects of contextual interference and retention intervals on transfer. *Percept. Motor Skills*. 1982;54:467-76.

12. Glockner A, Betsch T. Decisions beyond boundaries: When more information is processed faster than less. *Acta psychologica*. 2012;139(3):532-42.

13. Hall KG, Domingues DA, Cavazos R. Contextual interference effects with skilled baseball players. *Percept. Motor Skills*. 1994;78:835-41.

14. Hall KG, Magill RA. Variability of practice and contextual interference in motor skill learning. *J. Motor Behav.* 1995;27:299-309.

15. Helsdingen A, van Gog T, van Merriënboer J. The effects of practice schedule and critical thinking prompts on learning and transfer of a complex judgment task. *J. Educ. Psychol.* 2011;103:383-98.

16. Helsdingen A, van Gog T, van Merriënboer J. The effects of practice schedule on learning a complex judgment task. *Learn. Instr.* 2011;21:126-36.

17. Jackson RC, Warren S, Abernethy B. Anticipation skill and susceptibility to deceptive movement. *Acta Psychol.* 2006;123:355-71.

18. Kantak SS, Sullivan KJ, Fisher BE, Knowlton BJ, Winstein CJ. Neural substrates of motor memory consolidation depend on practice structure. *Nat Neurosci*. 2010;13:923-5.

19. Kilner JM, Vargas C, Duval S, Blakemore SJ, Sirigu A. Motor activation prior to observation of a predicted movement. *Nat Neurosci*. 2004;7(12):1299-301.

20. Lee TD. Contextual interference: Generalizability and limitations. In: NJ Hodges, AM Williams editors. *Skill acquisition in sport: research, theory and practice*. New York: Routledge; 2012, pp. 79-93.

21. Lee TD, Magill RA. The locus of contextual interference in motor-skill acquisition. *J. Exp. Psychol.-Learn. Mem. Cogn.* 1983;9:730-46.

22. Lee TD, Magill RA, Weeks DJ. Influence of practice schedule on testing schema theory predictions in adults *J. Motor Behav.* 1985;17:283-99.

23. Lee TD, Wulf G, Schmidt RA. Contextual Interference in Motor Learning: Dissociated Effects Due to the Nature of Task Variations. *The Quarterly Journal of Experimental Psychology Section A*. 1992;44(4):627-44.

24. Lin C-H, Fisher BE, Winstein CJ, Wu AD, Gordon J. Contextual interference effect: Elaborative processing or forgetting-reconstruction? A post hoc analysis of transcranial magnetic stimulation-induced effects on motor learning. *J. Motor Behav.* 2008;40:578-86.

25. Magill RA, Hall KG. A review of the contextual interference effect in motor skill acquisition. *Hum. Mov. Sci.* 1990;9:241-89.

26. Marteniuk RG. *Information processing in motor skills*. New York: Holt, Rinehart, and Winston; 1976, 244 p.

27. Memmert D, Hagemann N, Althoetmar R, Geppert S, Seiler D. Conditions of practice in perceptual skill learning. *Res. Q. Exerc. Sport*. 2009;80:32-43.

28. Merbah S, Meulemans T. Learning a motor skill: Effects of blocked versus random practice a review. *Psychol. Belg.* 2011;51:15-48.

29. Rizzolatti G, Craighero L. The mirror-neuron system. *Annu Rev Neurosci*. 2004;27:169-92.

30. Schmidt RA, Lee TD. *Motor control and learning: A behavioural emphasis*. 5th ed. Champaign, IL: Human Kinetics; 2011, 488 p.

31. Shea JB, Morgan R. Contextual interference effects on the acquisition, retention, and transfer of a motor skill. *J. Exp. Psychol.-Hum.* . 1979;5:179-87.

32. Shea JB, Zimny ST. Knowledge incorporation in motor representation. In: ON Meijer, K Roth editors. *Complex movement behaviour: The motor-action controversy*. Amsterdam: North Holland1988, pp. 289-314.

33. Smeeton NJ, Williams AM, Hodges NJ, Ward P. The relative effectiveness of various instructional approaches in developing anticipation skill. *J. Exp. Psychol.-Appl.* 2005;11:98-110.

34. Triolet C, Benguigui N, Le Runigo C, Williams AM. Quantifying the nature of anticipation in professional tennis. *J. Sports Sci.* . 2013;31:820-30.

35. Uzu R, Shinya M, Oda S. A split-step shortens the time to perform a choice reaction step-and-reach movement in a simulated tennis task. *J. Sports Sci.* . 2009;27:1233-40.

36. Ward P, Farrow D, Harris KR, Williams AM, Eccles DW, Ericsson KA. Training perceptual-cognitive skills: Can sport psychology research inform military decision training? *Mil. Psychol.* 2008;20:S71-S102.

37. Ward P, Suss J, Eccles DW, Williams AM, Harris KR. Skill-based differences in option generation in a complex task: a verbal protocol analysis. *Cognitive processing*. 2011;12:289-300.

38. Williams AM, Ford PR. 'Game intelligence': Anticipation and decision making. In: AM Williams editor. *Science and soccer: Developing elite performers*. Oxon, UK: Routledge; 2013, pp. 105-21.

39. Williams AM, Grant A. Training perceptual skill in sport. *International Journal of Sport Psychology.* 1999;39:194-220.

40. Williams AM, Ward P, Knowles JM, Smeeton NJ. Anticipation skill in a real-world task: Measurement, training, and transfer in tennis. *J. Exp. Psychol.-Appl.* 2002;8:259-70.

Figure Captions

Figure 1. The experimental set up used in (a) the laboratory based protocol and (b) the field based protocol.

Figure 2. Mean (and standard deviation) response accuracy percentage (RA; %) in the laboratory pre-test, training 1-3, and 7-day retention tests for the blocked and random group.*$p < .05$.

Figure 3. Mean (and standard deviation) response accuracy percentage (RA; %) in the laboratory pre-test, training 1-3, and 7-day retention tests for footage occluded 80ms prior to ball-racket contact (-80), at ball-racket contact (0), and at 80ms after ball-racket contact (80).

Figure 4. Mean (and standard deviation) response accuracy percentage (RA; %) and decision time (DT; ms) in the field pre-test and 7-day transfer tests for the blocked and random group.*$p < .05$.