CONDITIONS OF PRACTICE FOR

PERCEPTUAL-COGNITIVE SIMULATION TRAINING IN SPORT

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Contents

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Abstract

In this thesis, two concepts concerning conditions of practice were examined for the practice, retention and transfer of perceptual-cognitive skill, specifically anticipation in tennis. First, from the motor skills literature, the contextual interference (CI) effect was investigated for the first time in perceptual-cognitive skill training. A blocked and random schedule of practice was used to train anticipation skills in tennis using video simulation techniques with transfer of learning assessed using a field-based task. Results showed support for the CI effect in this new domain as random practice had significantly greater response accuracy in the retention test, and significantly reduced decision time in the field-based transfer test, when compared to the blocked group. Subsequently, the underpinning mechanisms of the CI effect were examined focusing on cognitive effort and error processing. Across two experiments results showed that following errors, the random groups exhibited greater cognitive effort compared to errorless trials, whereas the blocked groups showed no difference between errorless and error trials. These results provided an alternative account for the CI effect by suggesting that it is not solely the switching of the tasks during random practice, but the role of error processing in conjunction with the switching tasks that result in greater cognitive effort and the CI effect. Second, the role of contextual information in perceptual-cognitive skills training was examined. Tennis shots were displayed to participants in either a smart-random structure, which showed shots in a tactically relevant manner, or in a random order so that no contextual information was available, just postural cue information. The smart-random structure group showed superior response accuracy in retention and reduced decision time in a field-based transfer test. Results demonstrated the benefits of contextual information for the retention and transfer of perceptual-cognitive skills in tennis. The overall findings extend the research in perceptual-cognitive skill training and have several theoretical and applied implications.

Chapter 1:

Review of Perceptual-Cognitive Skills Training and Conditions of Practice

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Expert performance by athletes during competition, such as in the Olympic Games, is revered by most people that observe it. Expertise in any domain, including sport, is achieved through extensive practice. In their theory of deliberate practice, Ericsson, Krampe, and Tesch-Römer (1993) argued that the level of attainment of an individual is directly proportional to the amount of practice hours accumulated. However, the mere accumulation of experience or repetitive execution of routine work is not sufficient for attaining expertise. Instead, continued improvements in performance depend on deliberate efforts to change important aspects of performance, with the availability of informative feedback, and opportunities for error detection, corrections, and refinements (Ericsson, 2008). Researchers examining the acquisition of motor skills have revealed further conditions of practice that promote skill acquisition, such as the advantage of practicing motor skills in a random order, as opposed to blocked orders of the same skill (for a review, see Lee, 2012). However, expert performance in domains such as sport, involves a combination of *both* motor and *perceptual-cognitive* skills (Williams & Ericsson, 2005). Perceptual-cognitive skill refers to the ability of an individual to locate, identify and process environmental information so as to integrate it with existing knowledge and current motor capabilities in order to select and execute appropriate actions (Marteniuk, 1976). In sport, coaches predominantly focus on developing physical and technical motor skills and tend to neglect perceptual-cognitive skill training, despite its known importance (Williams & Ward, 2007). Moreover, work is still required to investigate the conditions of practice that are most beneficial to the training, retention, and transfer, of perceptual-cognitive skills in sport.

This thesis aims to investigate various conditions of practice to examine the effect they have on the acquisition of anticipation skills in tennis using video simulation techniques. Conditions of practice associated with *context* will be examined to identify their role in the retention and transfer of perceptual-cognitive skill. Context refers to the conditions that exist where and when something occurs, such as a sports competition. First, the contextual interference (CI) effect will be investigated across three studies to confirm and extend the literature concerning this phenomenon. CI refers to how the context of a task can be manipulated and displayed in different formats, which causes different levels of interference during practice and effects the levels of learning. Second, the role of contextual information during practice and the effect it has on anticipation and its transfer to the field will be examined. Contextual information refers to how additional information is available to athletes when the context a skill is learnt in is sport specific. Specifically, the practice structures examined throughout this thesis are a blocked, random, and smart-random order. They seek to produce the optimal challenge point for individuals during practice by simplifying (blocked), randomising (random), or recreating (smart-random) the pattern of skill executions experienced when physically playing the sport. This introductory chapter provides an overview of the perceptual-cognitive skill literature, as well as a review and discussion of the research concerning CI and contextual information. The rationale for the research conducted in this thesis will be outlined throughout the chapter and a summary of the subsequent chapters will be provided.

Perceptual-cognitive skills

Researchers have shown that perceptual-cognitive skills are an essential part of expertise in a variety of domains, including law enforcement (Ward, Suss, Eccles, Williams, & Harris, 2011), medical procedures (McRobert et al., 2013), military operations (Ward et al., 2008) and sport (Williams & Ward, 2007). The majority of researchers investigating perceptual-cognitive skills have used the expert-novice paradigm to isolate several important attributes that differentiate skilled from less-skilled performers (Abernethy & Russell, 1987a). Firstly, experts demonstrate a more efficient and effective use of vision to scan the performance environment in order to extract relevant information (Williams, Davids, & Williams, 1999). Evidence for this was shown through the meta-analysis conducted by Mann, Williams, Ward, and Janelle (2007), which revealed that experts consistently exhibit fewer visual fixations of longer durations compared to their novice counterparts. Another attribute that researchers have revealed is that expert performers have the ability to better recognise and recall sport-specific patterns of play (North, Williams, Hodges, Ward, & Ericsson, 2009). They acquire this ability from task-specific practice that enables experts to change the limits on working memory and promotes the rapid encoding of information in long-term memory (Ericsson & Kintsch, 1995; Ericsson & Lehmann, 1996). Experts also have a superior ability to pick up the early or advance postural cues emanating from opponents movements (Williams & Ward, 2007). This ability has been shown in sports such as soccer penalty kicks (Williams & Burwitz, 1993), squash (Abernethy, 1990), and tennis (Jones & Miles, 1978). Finally, experts are able to generate accurate options and choose the most appropriate likely outcomes in any given situation based on the refined use of situational probabilities (Gottsdanker & Kent, 1978). For example, Alain and colleagues (Alain & Proteau, 1980; Alain & Sarrazin, 1990) showed that expert athletes in various racket sports can use their superior knowledge base to dismiss highly improbable events and allocate attention to the most likely occurring events (see also Ward & Williams, 2003). These perceptual-cognitive skills combine to produce two judgments, namely, *decision making* and *anticipation* (Williams, Ward, & Smeeton, 2004). Decision making is the ability to plan, select and execute an action based on the current situation and the knowledge possessed. Anticipation is the ability to recognise the outcome of other athletes' actions during and prior to those actions being executed (Williams & Ford, 2013). The majority of research conducted in this area has focused on anticipation skills using various protocols to understand the mechanisms involved, as well as the training of these skills.

Representative task design and the expert performance approach

The environments used to examine and train perceptual-cognitive skills have included real-life settings and representative tasks in the field or in the laboratory (Broadbent, Causer, Williams, & Ford, 2014). Studies conducted in real-life settings have involved methods such as collecting verbal reports during actual competition (McPherson & Thomas, 1989) or conducting analysis on competition video footage after the event (Triolet, Benguigui, Le Runigo, & Williams, 2013). Representative tasks in the field include procedures such as simulated match play or participants physically performing the skills during practice. These two procedures are thought to be a more ecologically valid method compared to laboratory-based protocols (Dicks, Button, & Davids, 2010; Hagemann & Memmert, 2006). However, in both these methodologies, each participant will encounter unique challenges that make it extremely difficult to repeat conditions and compare levels of performance and generate results that can be generalised to a population (Ericsson & Ward, 2007).

The main challenge when investigating expert performance is to create a representative environment that recreates the same task constraints as when actually competing in the sport, but under repeatable and standardised conditions for everyone tested (Ericsson & Williams, 2007). To address this problem, Ericsson & colleagues (Ericsson, 2003; Ericsson & Kintsch, 1995; Ericsson & Lehmann, 1996; Ericsson & Smith, 1991) developed the *expert performance approach*. It is a three-stage model for the empirical analysis of expertise. In the first stage, naturally occurring domain-specific tasks that enable superior performance to be captured are identified and presented in a standardised and realistic form as representative and reproducible experimental tasks (Ericsson & Ward, 2007). The second stage is to use the representative tasks to identify the mediating mechanisms underlying superior performance by recording process-tracing measures, such as eye movement recording, verbal protocol analysis, and/or representative task manipulations (Williams & Ericsson, 2005). Finally, the third stage then examines how the mediating mechanisms are acquired and the effects of different practice conditions on their acquisition (Ericsson, 2003), and it is this final stage that is the focus of this thesis.

Following the expert-performance approach, the testing and training of perceptual-cognitive skills have, in the most part, used laboratory-based representative tasks, such as video simulations (Causer, Janelle, Vickers, & Williams, 2012; Williams & Grant, 1999). Video simulations recreate key situations normally encountered in the performance environment, so that experts are able to reproduce their superior performance in a shorter space of time under standardised and repeatable conditions (Ericsson, 2003; Pinder, Davids, Renshaw, & Araujo, 2011b). However, some researchers have raised concerns over the use of video simulations and how well the skills acquired transfer to the applied setting. Specifically, the concerns raised refer to how closely the actions in the training environment replicate those in the performance environment (Pinder et al., 2011b; Van der Kamp, Rivas, Van Doorn, & Savelsbergh, 2008). Early methods were criticised for using simplistic responses to small and static visual displays, all of which were thought to limit the expert advantage (Williams & Grant, 1999). The size of the visual display may be more important for research on certain perceptual-cognitive skills, such as the use of postural cues, compared to some other skills, such as recognition where experts perceive relative motion within the display (Williams, North, & Hope, 2012). Many researchers now use large screens that allow life-size images to be projected and show dynamic rather than static images. However, some studies in this area are still criticised for the use of simplistic responses, such as button pressing and written or verbal responses (Savelsbergh, van der Kamp, Williams, & Ward, 2005).

Two critical components proposed in the design of representative training environments are *task functionality* and *action fidelity* (Pinder et al., 2011b). Functionality refers to whether the constraints a performer is exposed to, and must act upon in the task, match those that they will be exposed to in the performance environment. Similarly, action fidelity requires that the performer is allowed to complete a response that is the same as that produced in the performance environment. Central to these ideas is the reciprocal relationship between perception and action, as well as the complementary contributions of the ventral and dorsal cortical visual systems to performance (Goodale & Milner, 2006; Milner & Goodale, 2008; Van der Kamp et al., 2008). Therefore, researchers advocate that practice should involve athletes processing and executing these perceptual-cognitive skills in the manner they would in the competition format of the sport (Ford, Low, McRobert, & Williams, 2010; Ford & Williams, 2013; Low, Williams, McRobert, & Ford, 2013). These proposals support those of researchers who suggest the maintenance of both functionality and action fidelity in practice is critical to accurately capture the action of interest (Pinder, Davids, Renshaw, & Araujo, 2011a). Performance differences between studies using complex movement responses or simple responses, and video simulations or field-based protocols, have been shown for some perceptual-cognitive processes underpinning expert performance (Dicks et al., 2010; Dicks, Davids, & Button, 2009; Farrow & Abernethy, 2003; Mann, Abernethy, & Farrow, 2010; Mann et al., 2007; Van der Kamp et al., 2008). A recent meta-analysis indicated that the advantages of expert over novice performers in perceptual-cognitive skills studies are directly proportional to how close the action completed in a simulated environment is to the actual action required in sport (Travassos et al., 2013). However, other researchers have contradicted these findings by showing that anticipation skills can be acquired through verbal responses, indicating the benefits of simulation training with simple responses (Williams, Ward, Smeeton, &

Allen, 2004). Therefore, it seems a representative task should allow individuals to search the environment for reliable information, integrate this information with existing knowledge, and complete an appropriate response.

The occlusion paradigm

A benefit of using video simulation techniques in a laboratory setting is that they can be manipulated using occlusion techniques to identify the cues that are critical to anticipation, as well as the evolution of these cues over time. Researchers have used the temporal occlusion paradigm in order to occlude video at different time points around key events within the actions of an opposing player on screen, such as racket-ball contact in tennis (Farrow, Abernethy, & Jackson, 2005). Researchers using temporal occlusion techniques have consistently demonstrated expert-novice differences in anticipating outcomes from opponent movement patterns, particularly at earlier occlusion time points (Abernethy & Russell, 1987b; Farrow et al., 2005; Jackson & Mogan, 2007; Jackson, Warren, & Abernethy, 2006; Jones & Miles, 1978; Williams & Burwitz, 1993; Williams, Ward, Knowles, & Smeeton, 2002). Researcher's use of progressive temporal occlusion, in which there are multiple occlusion conditions that occur earlier or later has demonstrated the expert advantage, but only at earlier time points. For example, the paper by Williams and Burwitz (1993) investigated anticipation skills in skilled and less-skilled soccer goalkeepers across four occlusion conditions: 120 ms before foot-ball contact; 40 ms before foot-ball contact, at foot-ball contact (0 ms); and 40 ms after foot-ball contact. Skilled soccer goalkeepers were significantly more accurate in their responses compared to the less-skilled participants, but only in the occlusion conditions with the earliest occlusion points. Their domain-specific knowledge allowed them to identify and extract key pieces of information from early in the display. No difference was found between skill levels in the later occlusion conditions as there was more information available for the less-skilled participants to use and a ceiling effect is found for both groups (Williams & Burwitz, 1993).

Whilst the temporal occlusion paradigm demonstrates the expert advantage in anticipation, it does not show the sources of information used when making these predictions (Causer & Williams, 2013). Researchers have used the spatial occlusion paradigm to reveal the sources of information used by experts during anticipation. Spatial occlusion involves editing video to remove or neutralise particular areas or information sources from the opponent, such as an arm (Causer & Williams, 2015; Huys et al., 2009; Smeeton, Huys, & Jacobs, 2012, 2013). It enables researchers to infer which body region provides information that cannot be picked up elsewhere, through decrements in anticipation occurring when that body region is occluded (Williams & Davids, 1998). However, this does not necessarily mean that the body region or cue in isolation is critical. It may be the removal of the cue that distorts or removes the relative motion between regions of the body. Alternatively, it may be that removal of a critical cue does not impact on performance, as expert performers are able to extract information from several different sources. Using the temporal and spatial occlusion methodologies researchers have identified expert-novice differences in key perceptual-cognitive skills (Causer et al., 2012; Williams & Grant, 1999).

Training perceptual-cognitive skill: retention and transfer

Perceptual-cognitive skill training using representative tasks such as video simulation attempt to find a suitable balance between the need to maintain ecological validity on the one hand and the desire for internal validity and experimental control on the other (Causer, Barach, & Williams, 2014). Review papers spanning the last 15 years have highlighted key future research areas for individuals examining perceptual-cognitive skill and its training (Broadbent, Causer, Williams, et al., 2014; Causer et al., 2012; Vine, Moore, & Wilson, 2014; Williams & Grant, 1999). The majority of training studies in sport have concentrated on anticipation skills and utilised video simulation techniques. These training programmes attempt to highlight the links between important environmental cues and eventual outcome using various forms of instruction and feedback (Abernethy, 1990; Abernethy & Russell, 1987b; Christina, Barresi, & Shaffner, 1990; Farrow et al., 2005; Hagemann, Strauss, & Cañal-Bruland, 2006; Savelsbergh, Van Gastel, & Van Kampen, 2010; Singer et al., 1994; Smeeton, Williams, Hodges, & Ward, 2005; Williams & Burwitz, 1993; Williams, Ward, & Chapman, 2003; Williams et al., 2002).

For example, Williams et al. (2002) completed two experiments investigating anticipation skills in tennis. The first experiment examined anticipation in skilled and less-skilled tennis players. A projector screen was used to show a near full size image of an opponent, from a first person perspective. Participants were required to anticipate where the opponent shot would land on their side of the court. Visual search strategies were recorded using an eye movement registration system throughout the experiment. Skilled players had superior anticipation skills compared to their less-skilled counterparts. Furthermore, skilled participants showed an enhanced ability to use vision to search for and utilise cues emanating from the display compared to less-skilled participants (Williams et al., 2002). In the second experiment, knowledge derived from the first experiment regarding visual search strategies of skilled performers, was used to train less-skilled performers. Two groups of less-skilled players received either explicit instruction or guided discovery instruction during video simulation training. After the training, participants were tested using the same video simulation test in the laboratory as the first experiment, as well as a field-based transfer test of anticipation. Both groups improved their anticipation performance from pre- to post-test in both the laboratory and the field-based transfer test. These findings provide evidence of the practical use of video simulation techniques as representative tasks in developing anticipatory performance and its underlying knowledge structures, processes and skills in sport. It also demonstrates that these tasks facilitate the acquisition, retention, and transfer of perceptual-cognitive skills (see also Smeeton et al., 2005).

Researchers have demonstrated that perceptual-cognitive skills can be trained using video simulations in other sports, including soccer (e.g. Savelsbergh et al., 2010), badminton (e.g. Hagemann et al., 2006), and tennis (e.g. Smeeton et al., 2005). However, evidence is lacking as to how well the aspects of performance being trained are *retained* across a long period or *transfer* to improved performance in the competition format of the sport (Broadbent, Causer, Williams, et al., 2014; Rosalie & Mueller, 2012). Researchers examining video simulation training for perceptual-cognitive skills have started to include retention conditions, as opposed to just a post-test. Some researchers have shown that video simulation training has led to improved anticipation and decision making that has been retained after periods of 14 days (Gorman & Farrow, 2009), four weeks (Gabbet, Rubinoff, Thorburn, & Farrow, 2007; Raab, 2003) and five months (Abernethy, Schorer, Jackson, & Hagemann, 2012).

However, much of the previous research on video simulation training for perceptual-cognitive skills does not assess whether improvements during acquisition actually transfer to more ecologically valid scenarios (Rosalie & Mueller, 2012). In the previously mentioned studies, only the paper by Gabbet et al. (2007) demonstrated significant improvements to a field setting following a retention period. Other researchers either failed to include a transfer test (Raab, 2003), administered a laboratory-based transfer test to a stressful condition (Abernethy et al., 2012), or found no significant improvement to performance in the field-based protocol (Gorman & Farrow, 2009). A few researchers have assessed the transfer of perceptual-cognitive skills from laboratory-based training to the field (e.g. Farrow & Abernethy, 2002; Smeeton et al., 2005; Williams et al., 2002). While these studies have shown successful transfer, the field-based protocol is administered as part of a pre- and post-test occurring close to the practice phase and so does not assess the retention of these transferrable skills.

While the retention and transfer of performance is the most important outcome of any training protocol, research on perceptual-cognitive skills is yet to confirm the most beneficial condition of practice for video simulation training to achieve retained transfer of performance. In the following section, two conditions of practice that will be the focus of this thesis will be reviewed from an applied and theoretical perspective.

Conditions of Practice

The contextual interference effect

A robust finding in the motor learning literature is the CI effect (Magill & Hall, 1990). It originated from the verbal learning literature, where Battig and colleagues (Battig, 1972, 1979; Schild & Battig, 1966) referred to it first as 'inter-task interference'. Battig and colleagues argued against the popular and established standpoint that interference leads to negative transfer, by suggesting that in certain circumstances, interference could actually result in positive transfer. They demonstrated an inverse relationship between practice and retention/transfer performance as a function of interference (Schild & Battig, 1966). High levels of within-task interference typically led to poor performance during acquisition trials compared to low levels of interference. However, when transfer or retention trials were included in the experiment, positive transfer or better retention was found, suggesting superior learning under inter-task interference. Battig (1979) referred to contextual interference as functional interference that produces improvement in memory, which alters the inter-task context to produce contextual variety.

On the basis of these proposals, Shea and Morgan (1979) investigated the effects of CI on motor skill learning. The task used was a simple motor task that involved using a tennis ball to knock down four small barriers in three orders prescribed by a light stimulus, across multiple trials under a low interference (blocked) or high interference (random) schedule of trials. The blocked practice group completed all the trials for one version of the task before starting another block of trials on a different version of the task (i.e., AAA-BBB-CCC). In comparison, the random practice order group completed only one trials, or a maximum of two trials, for any one task before a trial on another task was undertaken, creating inter-task interference (i.e., ACB-BCA-CAB). After practice, participants completed retention tests to the same structure of practice (i.e. random group retention test under a random structure of trials) and transfer tests to the opposite structure of practice (i.e. random group transfer test under a blocked structure of trials). The blocked group had a faster total movement time compared to the random group during the early practice trials, indicating superior performance (see Figure 1.1). However, in line with Battig's (1972, 1979) predictions, on the transfer tests, the random group had faster total movement time compared to blocked practice, indicating superior learning (Shea & Morgan, 1979).

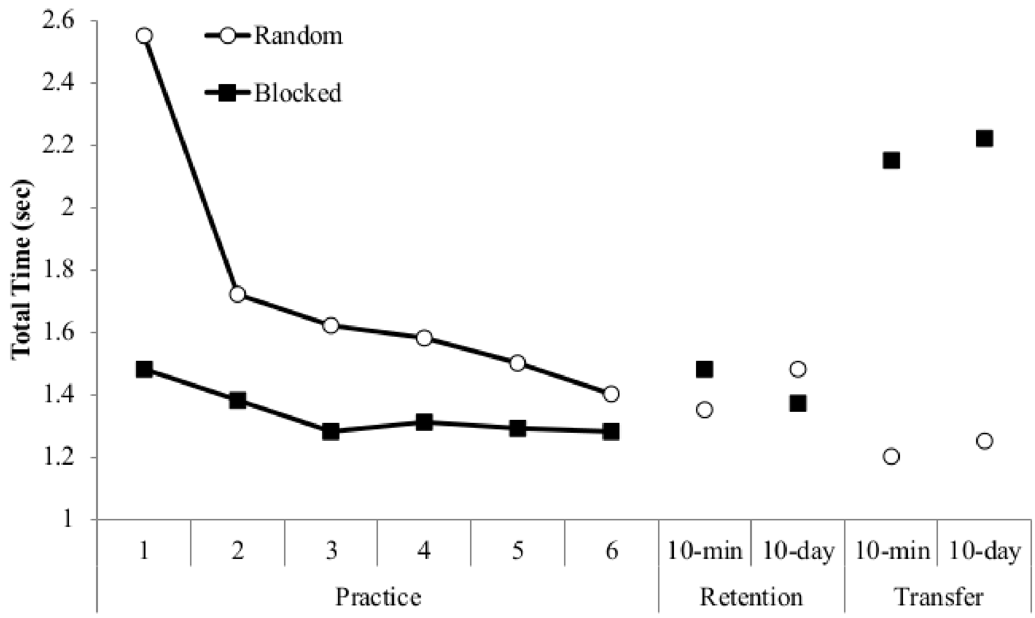

Figure 1.1: Total movement time (sec) in three barrier knock down tasks for the blocked and random groups during practice, retention and transfer tests. Adapted from Shea and Morgan (1979)

Since Shea & Morgan's (1979) classic paper, researchers have attempted to explain the underlying mechanisms of the CI effect. Two theories have been forwarded: the elaborative processing hypothesis (Shea & Morgan, 1979; Shea & Zimny, 1983) and the action plan reconstruction hypothesis (Lee & Magill, 1983, 1985). The elaborative processing hypothesis suggests that random practice promotes more comparative analysis between the different tasks as participants switch between them. In comparison, during blocked practice the tasks are practiced in a repetitive nature and are all the same. It proposes two distinct cognitive processing modes, intra-task and inter-task, and the differential use of these processes during blocked and random practice, respectively (Shea & Zimny, 1983, 1988). Blocked practice learners rely almost exclusively on intra-task processing, which is limited because only one skill is practiced. In comparison, random practice contains both intra-task and inter-task processing allowing for detailed task representations to be formulated (Immink & Wright, 1998). Therefore, the suggestion is that the CI effect is caused by the contrast that occurs between the multiple tasks in random practice, which results in a more memorable representation of each task (Shea & Zimny, 1983, 1988).

While there are differences between the two hypotheses, the action plan reconstruction hypothesis does share commonalities with the elaborative processing hypothesis. For example, the role of memory processes as the foundation for the learning differences in random and blocked practice schedules. However, the action plan reconstruction hypothesis suggests that rather than random practice promoting comparative analysis, it actually promotes short-term forgetting due to memory decay and interference. Therefore, participants in the random group must undertake planning operations and reconstructive processes in order to execute a skill that differs to the trial before (Lee, Wishart, Cunningham, & Carnahan, 1997). In comparison, short-term forgetting is minimised in blocked practice because of the repeated trials on the same skill. According to this hypothesis, using the action plan from a previous trial for the upcoming trial, as in blocked practice, promotes performance in acquisition, but consistently reconstructing action plans for the forthcoming trial, as in random practice, promotes learning and retention (Lee & Magill, 1983, 1985).

The CI effect has been replicated in many studies across various contexts and domains as described in several review articles (Brady, 1998, 2008; Lee, 2012; Magill & Hall, 1990; Merbah & Meulemans, 2011). The generalizability of the CI effect into the applied sporting setting has been shown for the acquisition of badminton (Goode & Magill, 1986) and baseball hitting motor skills (Hall, Domingues, & Cavazos, 1994). Moreover, researchers have shown the CI effect transfers to the acquisition of perceptual and cognitive skills in a variety of domains, such as a coincidence timing task (Del Rey, 1982, 1989; Del Rey, Wughalter, & Carnes, 1987; Del Rey, Wughalter, Du Bois, & Carnes, 1982) and a complex decision making task (Helsdingen, van den Bosch, van Gog, & van Merriënboer, 2010; Helsdingen, van Gog, & van Merriënboer, 2011a, 2011b).

However, researchers have yet to sufficiently determine how practice should be structured during video simulation training so that learners acquire fast and dynamic perceptual-cognitive skills in sport that transfer to the field (Memmert, Hagemann, Althoetmar, Geppert, & Seiler, 2009). Furthermore, disagreements are still present in the motor learning literature as to the mechanisms underpinning the CI effect. These shortcomings in the literature are surprising given the practical utility of such information in guiding the design of perceptual-cognitive training programmes across domains (Causer et al., 2012). Therefore, research is required to examine how practice should be structured to optimise the acquisition of perceptual-cognitive skills during video simulation training to best allow the transfer of these skills to the field. Moreover, the underlying mechanisms of the CI effect are yet to be confirmed in the motor skill literature and have not been extended to the perceptual-cognitive skills literature.

Contextual information

The term *contextual interference* was used later by Battig (1979) instead of inter-task interference because it draws attention to the influence of the entire practice context, including factors that are within and extraneous to the task being learned. The task, practice schedule, and the processing engaged in by the learner were seen as potential sources of contextual interference that could enhance learning (Battig, 1979). However, research on CI rarely takes into account the processing of other context-specific information. In sport, contextual information is an essential component of expert performance as it may act as an informational constraint on performance, increasing the functionality of the task (Vicente & Wang, 1998). Contextual variables include factors such as: the pitch surface; the weather; the time in the game; the score of the game; and the opponent characteristics, tactics and tendencies (McPherson & Kernodle, 2003). When performing in sport competition, perceptual-cognitive skills are constrained not only by the level of expertise of the athlete and the current situation in the performance, but also by the contextual information within the situation (McRobert, Ward, Eccles, & Williams, 2011). Therefore, the practice environment should allow athletes to adapt to the specific contextual constraints imposed on them by the performance environment (Williams & Ford, 2008). To incorporate context-specific variables during practice researchers have used “smart combinations” where separate skills are combined in a tactically relevant way to simulate the conditions found in a competitive setting (Vickers, 2007). These conditions have similarities to two concepts from the motor learning literature termed *specificity of practice* or *transfer appropriate processing* (Barnett, Ross, Schmidt, & Todd, 1973; Lee, 1988). These hypotheses hold that skills are very specific to the practice conditions, so changing the conditions under which a task is performed will require a substantial shift in the underlying abilities. Therefore, information processing during practice should be the same as that in the retention and transfer test, which in sports is the competition activity.

Researchers have shown that contextual information surrounding a task facilitates a more efficient and accurate response when compared to low context in both sport (Crognier & Féry, 2005; MacMahon & Starkes, 2008; MacMahon, Starkes, & Deakin, 2009; McPherson & Kernodle, 2007; McRobert et al., 2011; Paull & Glencross, 1997) and medicine (McRobert et al., 2013; Verkoeijen, Rikers, Schmidt, van de Wiel, & Kooman, 2004). McRobert et al. (2011) investigated context-specific information and its effect on anticipation performance in cricket. Skilled and less-skilled batters were required to respond, with a simulated shot, to two sets of 24 ball deliveries by bowlers shown as video on a life-sized screen. In the low-context condition, the 24 deliveries from different bowlers were presented to the participants in a random order. In the high-context condition, participants responded to four bowlers who each delivered six balls in one block. The high-context condition replicated an actual match condition known as an “over” in cricket. It exposed participants to contextual variables linked to their opponent’s characteristics, tactics and tendencies. The high-context condition led to greater response accuracy scores for both groups when compared to the low-context condition. Moreover, visual search data revealed that fixation duration was shorter in the high- compared to the low-context condition, suggesting that the additional pre-performance information allowed the skilled batters to extract the information from the display more efficiently. In addition, verbal report data showed that the skilled batters made more predictions and plans for upcoming deliveries in the high- compared to low-context condition, and compared to the lesser-skilled batters.

In tennis, Crognier and Féry (2005) examined anticipation skills when facing a ‘live’ opponent on court during three different delivery situations ranging from high- to weak-initiative situations which refers to how much the participant could affect the final shot. Participants were positioned at the net to receive a volley and wore liquid crystal goggles, which were manually occluded during the early stages of opponent skill execution. The weak-initiative situation involved the opponent dropping the ball and playing a passing shot, so no contextual information was available to participants. In the moderate-initiative situation, there was still no rally, but the participant now started with the ball and put the ball into play by directing to one of three defined areas of the court. In the high-initiative situation, participants were able to impose their playing intent through a rally, thus, creating an opportunity to speculate the probability of certain types of shot being played at the end. As in the previous conditions, the opponent played the final shot and attempted a passing shot with the participant at the net. Participants in the high-initiative situation accurately predicted the direction of approximately 80% of shots. In comparison, in the low- and moderate-initiative situation the accuracy level was around chance level at 50%, suggesting that the direction in which the participant moved was chosen randomly. These findings demonstrate the importance of contextual information in a rally for expert tennis players (Crognier & Féry, 2005).

Other researchers have shown how sport-specific contextual information is stored in memory and utilised during performance. McPherson and colleagues (McPherson, 1999a, 1999b, 2000; McPherson & Thomas, 1989) examined the higher-order processing taking place in high- and low-skilled players during simulated and actual tennis competition using a verbal report methodology. High-skilled players were shown to plan and perform actions based on the current environmental situation (e.g. player positions, ball location), together with past events, such as opponent behaviours (e.g. strengths, tendencies, prior shot). In contrast, low-skilled players generated few plans based on current and past events and their weak problem representations consisted of goals related to their executions, failed actions, or reactions to game events. It was proposed that the superior decision skills of highly skilled players are due to two adaptations to long-term memory termed *action plan profiles* and *current event profiles* (French & McPherson, 2004; McPherson & Kernodle, 2003; Tenenbaum, 2003). Action plan profiles are rule-governed prototypes, which contain cognitive skills for monitoring current conditions, such as player positions, ball placement, or coordination patterns of opponents to make accurate response selections. They match certain current conditions with the appropriate visual and motor actions. In comparison, current event profiles are tactical scripts that guide the continuous building and modifying of concepts to monitor and utilise during the task. These profiles are built from previous performances and the current task as it progresses, and include contextual factors, such as what to do in relation to the current time or score in the game, and the opponent characteristics, tactics and tendencies (McPherson & Kernodle, 2003). They are used to keep relevant sport-specific contextual and tactical information active with potential past, current, and possible future events (McPherson, 2008). Both profiles are predicted to allow elite players easy access to, and retrieval of, important information to make decisions during a task.

Ericsson and Kintsch (1995) proposed the long-term working memory (LTWM) theory to explain the encoding and retrieval processes that take place during expert performance. It proposes that experts are able to bypass the limitations of short-term memory (STM) and long-term memory (LTM) by acquiring retrieval structures, such as action plan profiles and current event profiles, which encode information along with elaborate retrieval cues related to prior knowledge. Retrieval structures encode information in LTM with an associated retrieval cue, which through extended periods of deliberate practice reduces the time required to encode and retrieve information (Ericsson et al., 1993). These mechanisms are predicted to develop with expertise alongside the increase of domain-specific knowledge (McPherson & Kernodle, 2007).

Furthermore, these retrieval structures can be updated with contextual information during the task and allow for future retrieval demands to be anticipated.

McPherson and Kernodle (2007) suggest that future research should examine how the type of processing players encounter during actual competition can be acquired across periods of deliberate practice, so that the time required to encode and retrieve information from LTM can be reduced (Ericsson et al., 1993). While the significance of contextual information for expert performance is apparent, the role of such information during skill acquisition and the training of perceptual-cognitive skills has rarely been investigated. Furthermore, research has not considered the role of contextual information for the optimal transfer of perceptual-cognitive skills from video simulation protocols to simulated match play, which is the main goal of any practice activity.

Cognitive effort and the challenge point

Different conditions of practice can alter task difficulty, which in turn affects the cognitive effort required to complete the task. Cognitive effort is the processing resources required to make a decision (Lee, Swinnen, & Serrien, 1994). Early theoretical views from the motor learning literature suggested that thinking was less important for the purpose of learning, as all that needed to be stored was the motor commands for a movement and the sensory feedback resulting from it (Adams, 1971). In contrast, recent views stress the role of cognition for learning, which in general refers to a collective group of thought process surrounding decision making including anticipation, planning, regulation, and interpretation of performance (Lee et al., 1994). As the difficulty of the task increases, so does the information available, which results in greater processing resources required to make a decision (Guadagnoli & Lee, 2004). Researchers have yet to identify the level of cognitive effort that is most beneficial to learning (Rendell, Masters, Farrow, & Morris, 2011).

Cognitive effort directly links to a concept termed the *challenge point* *hypothesis*, from the motor learning literature. This hypothesis suggests that different conditions of practice provide different challenges for participants and the key is to provide the *optimal challenge point* during practice (Guadagnoli & Lee, 2004). The challenge point hypothesis provides a framework for creating practice conditions that promote learning. It is based on manipulating the difficulty of the task taking into account the ability of the participants. The framework contains two types of task difficulty. *Nominal task difficulty* takes into account the difficulty of the task, irrespective of the person performing it. *Functional task difficulty* not only includes the difficulty of the task, but also how challenging it is to the individual who is performing it. Functional task difficulty is directly related to the amount of available information in the task. Furthermore, functional task difficulty is directly linked to cognitive effort. The greater the functional task difficulty, the greater the cognitive demands of the task (Lee et al., 1994). In this framework, if a practice task is too easy or too difficult for a performer of certain ability, then either no or minimal learning may occur. Therefore, the practice task must place certain cognitive demands on the participant to reach the *optimal challenge point* so as to promote learning (Figure 1.2). As Figure 1.2 shows, the effect of task difficulty on the potential benefit for learning is illustrated as an inverted-U function with the optimal challenge point highlighted. The figure suggests that the optimal challenge point can be found where the task provides enough difficulty (i.e. cognitive effort) across practice to yield performance benefits but not too much such that learning is reduced. This supports Marteniuk (1976), who stated that after a point the amount of information available would exceed the capacity of the individual to process it efficiently thereby diminishing the potential benefit to learning. For novice participants, the challenge point for their practice should be set relatively low, whereas the challenge point can be higher for more skilled participants.

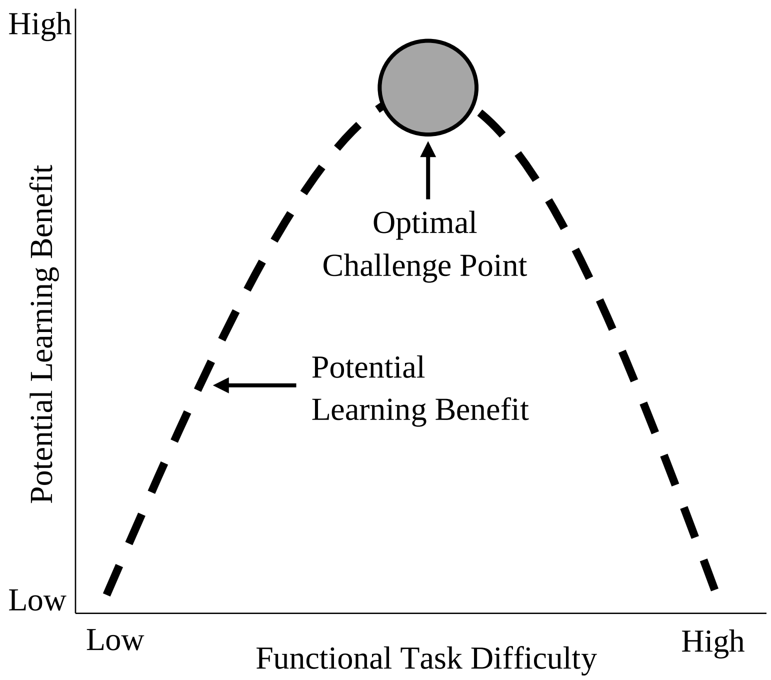

Figure 1.2: The relation between functional task difficulty and potential learning benefit to provide the optimal challenge point (adapted from Guadagnoli & Lee, 2004)

Aims of Thesis

The overall aim of the current thesis is to examine the optimal conditions of video simulation training for the retention and transfer of anticipation skills in tennis. Specifically, the CI effect and the role of contextual information during video simulation training will be examined using retention and field-based transfer tests. Furthermore, this thesis will use perceptual-cognitive simulation training as a tool to propose and investigate an alternative explanation to the underlying mechanisms of the CI effect: error processing.

Currently, there is no research to verify that the CI effect occurs for video simulation training for perceptual-cognitive skills (see Memmert et al., 2009) and its effects on the transfer of these skills from practice to the field. In Chapter 2, intermediate tennis players will undergo video simulation training to improve anticipation of three distinct tennis strokes. Participants will complete the training in either a blocked or random schedule of practice, and learning will be examined through a retention and transfer test to a field-based protocol. It is expected that the CI effect will be found with the blocked practice group showing superior performance across practice, whereas in the retention and transfer test the random group will demonstrate superior learning.

Chapter 3 will examine the underlying mechanisms of the CI effect using the same video simulation task as used in the previous chapter to train perceptual-cognitive skills. Across two experiments, the role of cognitive effort in the CI effect will be investigated and the hypotheses from the CI literature examined: the elaborative processing and action plan reconstruction hypotheses (Magill & Hall, 1990). In the first experiment, cognitive effort will be measured in the preparation and feedback phase of a trial, whereas in the second experiment the effects of inserting a cognitively demanding task on the CI effect will be investigated. Moreover, error processing has not previously been discussed with regards to the CI effect, but will be examined in this chapter as an additional hypothesis explaining the CI effect. Theories surrounding error processing will be linked to the previous hypotheses from the CI literature to provide an alternative account for the CI effect. It is predicted that cognitive effort will be a determining factor in the learning potential of a condition, with random practice being more cognitively demanding compared to a blocked schedule of practice.

While the CI effect promotes the use of a random compared to blocked schedule of practice, Chapter 4 will investigate the benefits of smart-random practice conditions compared to normal random conditions. Smart-random practice conditions occur when separate skills are ordered in a tactically relevant way to simulate actual match play (Vickers, 2007). In comparison, random practice is the same shots but in an order that does not resemble the conditions found in a competitive setting. Therefore, smart-random structure of practice has additional contextual information available to participants when compare to normal random practice. The aim of this study is to examine the role of smart-random, compared to random practice conditions, in the retention and transfer of anticipation skills in tennis for intermediate tennis players. The different mechanisms underpinning these schedules of practice will also be discussed. It is expected that both a smart-random and random structure of practice will result in learning benefits, but that the additional contextual information in a smart-random structure of practice will lead to greater learning benefits in the retention and transfer tests.

Finally, Chapter 5 will collate and synthesise the findings from the thesis to provide a concise summary. Implications of the programme of work will be discussed from theoretical and applied perspective, with limitations of the current research identified. Future research directions will be outlined, providing a clear path for research investigating the transfer benefits of different conditions of practice in video simulation training for perceptual-cognitive skills in sport.

Chapter 2:

Contextual interference effect in perceptual-cognitive skills training

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Abstract

The CI effect predicts that a random order of practice for multiple skills is superior for learning compared to a blocked order. This chapter outlines a novel attempt to examine the CI effect during the acquisition and transfer of anticipation skills from video simulation training to a field-based setting. Participants were required to anticipate three different tennis shots under either a random or blocked practice schedule. Response accuracy was recorded for both groups at pre-test, during practice, and on a retention test. Transfer of learning was assessed through a field-based tennis protocol that attempted to assess performance in a more ecologically valid sport setting. The random practice group had significantly higher response accuracy scores compared to the blocked group on the laboratory retention test. Moreover, in the field-based transfer test the decision times of the random practice group were significantly lower compared to the blocked group. The CI effect was found to extend to the training of anticipation skills through video simulation techniques. Furthermore, for the first time, the CI effect was found to increase transfer of learning from video simulation training to the field-based setting, highlighting the importance of using appropriate practice schedules during simulation training.

Introduction

The key consideration when designing practice activity is the retention and transfer of learning from that activity to real-world performance (Broadbent, Causer, Williams, et al., 2014). The manner in which practice activity is organised can affect the performance, learning, and transfer of the skills being practiced. The CI effect from the motor learning literature, predicts that practice scheduled in a random order leads to more errors during practice, but superior learning and transfer of skill, when compared to practice scheduled in a blocked order (Shea & Morgan, 1979). A key skill possessed by expert performers in many domains is the ability to anticipate upcoming events (for a review, see Williams & Ford, 2013). However, researchers have yet to examine the effect of practice order on the performance, learning, and transfer of anticipation skills. In this paper, we examine the CI effect during the practice of anticipation skills in a dynamic, temporally constrained task involving tennis.

The CI effect has been extensively examined in a variety of motor learning tasks following the seminal study conducted by Shea and Morgan (1979) (see Figure 1.2). Two main theories have been forwarded to explain the CI effect. As discussed in Chapter 1, these are the elaborative processing hypothesis (Shea & Zimny, 1988) and the action plan reconstruction hypothesis (Lee & Magill, 1983). 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 (Cross, Schmitt, & Grafton, 2007; Kantak, Sullivan, Fisher, Knowlton, & Winstein, 2010; Lin et al., 2009).

While the CI effect has been concentrated on in the motor learning literature, expert performance involves perceptual-cognitive skills, such as anticipation and decision making, as well as motor skill execution (Broadbent, Causer, Williams, et al., 2014). Researchers have reported that experts are superior to novices based on their perceptual-cognitive skills in a range of domains (Williams, Ford, Eccles, & Ward, 2011). Moreover, perceptual-cognitive skills can be trained using video simulation methods (Broadbent, Causer, Williams, et al., 2014; Causer et al., 2012). For example, Smeeton et al. (2005) investigated the relative effectiveness of video simulation training combined with various instructional techniques for enhancing anticipation skills 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 anticipation skills 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, Abernethy et al., 2012).

The CI effect has been replicated in many studies examining motor skill tasks across various contexts as described in several review articles (e.g. Lee, 2012; Magill & Hall, 1990; Merbah & Meulemans, 2011). Furthermore, some researchers have examined the CI effect using perceptual and cognitive tasks. Del Rey and colleagues (Del Rey, 1989; Del Rey et al., 1982) investigated the CI effect using an anticipatory timing 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. More recently, Helsdingen and colleagues (Helsdingen et al., 2010; Helsdingen et al., 2011a, 2011b) examined the effect of practice structure on complex police decision making tasks. The tasks involved prioritising different case descriptions of crimes in order of their urgency for the police to deal with them. The random group were significantly more accurate with their decisions compared to the blocked group in a post-test of similar tasks and a transfer test consisting of traffic offence tasks that differed in both structural and surface features from the training tasks (see also, Holladay & Quinones, 2003).

In contrast, Memmert et al. (2009) used a video simulation task to investigate the CI effect for anticipation skills in badminton, but did not find the classic CI effect. Participants were seated 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. There were three groups; a random perceptual training group, a blocked perceptual training group (depth before lateral), and another blocked perceptual training group (lateral before depth). The perceptual training schedule of the blocked training groups was based on the two directional dimensions of badminton shots, i.e. the depth dimension (length of shot) and the lateral dimension (direction of shots). Therefore, the blocked training programs consist of badminton shots that each vary in only one of the two dimensions. In training, feedback was provided after each trial, whilst learning was assessed in a post-test and a retention test. Contradictory to the CI effect, there were no differences in the accuracy of anticipation skills between the random and blocked practice groups across practice, 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 (Williams & Grant, 1999). 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 (Glockner & Betsch, 2012). Representative task design should involve the use of large screens that allow life-size images to be projected, showing dynamic rather than static images. They should also allow the performer to complete a response that is the same, or as similar as possible, to that produced in the actual performance environment (Broadbent, Causer, Williams, et al., 2014). The other possible explanation for the lack of group differences is that participants only practiced anticipation 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, so this paper perhaps had more relevance to the variable practice literature (Shea & Morgan, 1979). Research is needed to examine how practice should be structured during video simulation training for perceptual-cognitive skills requiring a complex movement response to a number of different skills on a large screen upon which life-size video is projected (Memmert et al., 2009).

In all of the above studies investigating the CI effect in perceptual and cognitive tasks, a transfer test was included but it was to 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 (e.g. Helsdingen et al., 2011a, 2011b). 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 video simulation training so that the skills transfer more effectively to field-based tasks, despite the widespread use of this method (Causer et al., 2012). Consequently, there is a need to extend the research to anticipation skills in an applied setting so as to extend the theory and verify the translational value of such interventions.

The current study examines the CI effect in video simulation training of anticipation skills in a temporally constrained task in tennis and the retention and transfer of this ability to performance in the field. Anticipation of three different tennis skills were practiced across an acquisition phase in either a random or blocked practice order, with learning being measured across a pre-, retention, and field-based transfer test. 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 anticipation skills as a result of the video simulation training protocol and that this improvement would transfer to the field. In line with the CI effect, it is hypothesised that the blocked practice group will have more accurate anticipation skills during the practice phase compared to the random practice group. In contrast, the random practice group will have more accurate anticipation skills compared with the blocked practice group in the retention test and in the transfer to a field-based protocol, indicating superior learning of the skills.

Methods

Participants

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 and field pre-test accuracy scores, and their field pre-test decision time (see Table 2.1). 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 Liverpool John Moores University. 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 Practice Film Construction

Test and practice films were developed for the video simulation. Films were made for a pre-test, three practice sessions, and a 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

Table 2.1: Mean (and standard deviation) prior tennis experience, current tennis experience, laboratory pre-test accuracy scores, field pre-test accuracy scores, and field pre-test decision time between the two groups (blocked, random)

	n	Experience (years)	Hours per week (hrs/wk)	Pre-test		
				Laboratory	Field	
				RA (%)	RA (%)	DT (ms)
Blocked	9	5.3	10.7	50.6	92.0	321
(SD)		(2.2)	(4.6)	(8.7)	(5.6)	(60)
Random	9	5.9	9.8	51.3	95.8	333
(SD)		(3.1)	(3.5)	(5.6)	(4.2)	(40)

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.

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 anticipation by their opponent (Triolet et al., 2013). The shots were played to one of four locations on the opponent's side of the court: 1) left short; 2) left deep; 3) right short; and 4) right deep. The three skills (groundstroke, volley, smash) are assumed to each have *invariant characteristics*, such that their kinematics are relatively fixed, but differ between the three skills. However, variations are possible within the skills, such as the speed, direction, and height of ball flight, which can be described as the *parameters* of the invariant skill. The invariant characteristics of each skill are scaled according to the parameters assigned to that trial (Wulf & Shea, 2005). For example, Shim, Carlton, & Kwon (2006) conducted a kinematic analysis of a groundstroke and a lob shot in tennis. They showed that kinematics from the racket and forearm were different between the two strokes, but there were no reliable kinematic differences within either stroke when shot directions varied. Within an applied sport setting it is difficult to control every parameter within an invariant skill. For example, Hall et al. (1994) 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 invariant skills, as per the majority of other research in this area (e.g. Hall et al., 1994; Hall & Magill, 1995; Lee, Wulf, & Schmidt, 1992), and not by the different parameters within a skill which has been shown not to promote the CI effect (e.g. Memmert et al., 2009).

For the test and training clips, the video occluded at three points that were selected based on previous research examining anticipation skills in sport (Jackson et al., 2006; Triolet et al., 2013). 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 practice sessions (n = 72 trials per session), and 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 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

The experiment consisted of a pre-test in both the laboratory and field, three laboratory-based practice sessions, separated by seven days, and a retention test seven days after the final practice session 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.

Laboratory pre-test and retention test. Figure 2.2a 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 retention test took approximately 15 minutes each to complete.

Field pre-test and transfer test. Figure 2.2b presents an illustration of the experimental setup for the field-based 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.

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 retention test took approximately 15 minutes each.

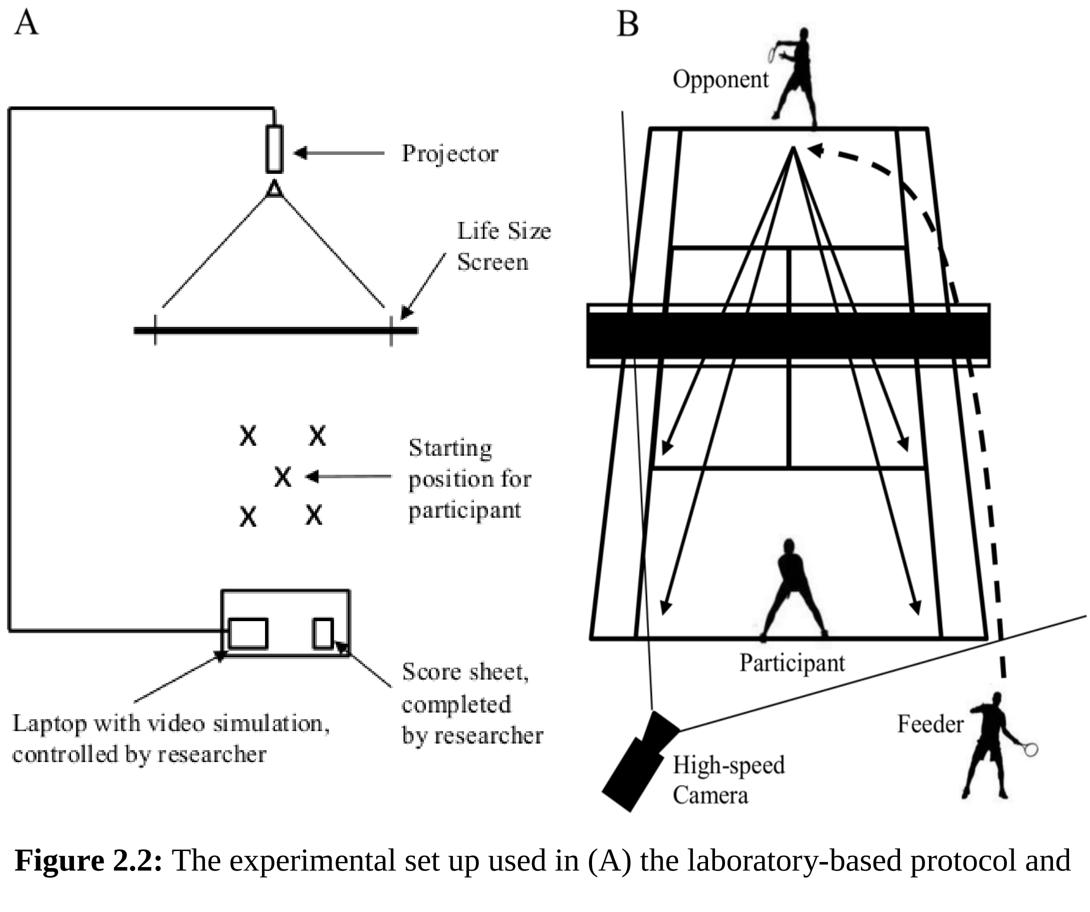

Figure 2.2: The experimental set up used in (A) the laboratory-based protocol and (B) the field-based protocol

Practice phase. The video simulation training consisted of three laboratory practice sessions that occurred once each week over a 3-week period between the pre-and the retention test. 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.

Dependent measures and statistical analysis. For the laboratory tests and practice sessions, 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 analysed 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' (Triolet et al., 2013, p.822). Movement initiation in tennis usually occurs during or just after a player executes a split-step/landing sequence (Uzu, Shinya, & Oda, 2009). Responses initiated prior to ball contact received negative values. Footage of the field-based transfer tests were analysed 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, Atkinson & Nevill, 1998) 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.

RA across practice sessions was analysed using a 2 Group (random, blocked) x 3 Practice (practice 1, practice 2, practice 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 analysed 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 analysed 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. Bonferroni pairwise 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 (η_p^2) was used as a measure of effect size.

Results

Practice

Figure 2.3 shows RA across the two groups on the three practice sessions. A 2 Group x 3 Practice 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 practice phase, F (2, 32) = 10.25, p < .01, η_p^2 = .39. *Post hoc* analysis indicated that RA in the third practice session (M = 55%, SD = 5) was significantly higher than in the first practice session (*M* = 47%, *SD* = 3), $p < .01$. However, RA in the second practice session (*M* = 51%, *SD* = 7) was not significantly different from either of the other two practice sessions, all $p > .05$. Figure 2.4 shows RA at each occlusion point from the three practice sessions. There was an occlusion main effect, F (2, 32) = 153.38, $p < .01$, $\eta_p^2 = .91$. *Post hoc* analysis indicated that RA in the trials occluded 80 ms after ball-racket contact (*M* = 67%, *SD* = 7) was significantly higher than in trials occluded at ball-racket contact (*M* = 48%, *SD* = 6) and 80 ms before ball-racket contact (*M* = 39%, *SD* = 3), $p < .01$. 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

Figure 2.3 shows RA across the two groups on the pre-test and retention test. A 2 Group x 2 Test x 3 Occlusion ANOVA revealed no main effect for group, F (1, 16) = 2.90, $p = .11$, $\eta_p^2 = .15$. However, RA significantly improved from pre-test (*M* = 51%, *SD* = 7) to retention test (*M* = 68%, *SD* = 7), F (1, 16) = 113.74, $p < .01$, $\eta_p^2 = .88$. 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* = 51%, *SD* = 9) and random group (*M* = 51%, *SD* = 6). However, in the retention test, the random group (*M* = 72%, *SD* = 5) had a significantly higher RA compared to the blocked group (*M* = 63%, *SD* = 6).

Figure 2.4 shows RA at each occlusion point on the pre-test and 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* = 71%, *SD* = 6) compared to trials occluded at ball-racket contact (*M* = 58%, *SD* = 8) and 80 ms before ball-racket contact (*M* = 49%, *SD* = 8), $p < .01$. Moreover, RA on trials occluded at ball-racket contact was significantly greater than on

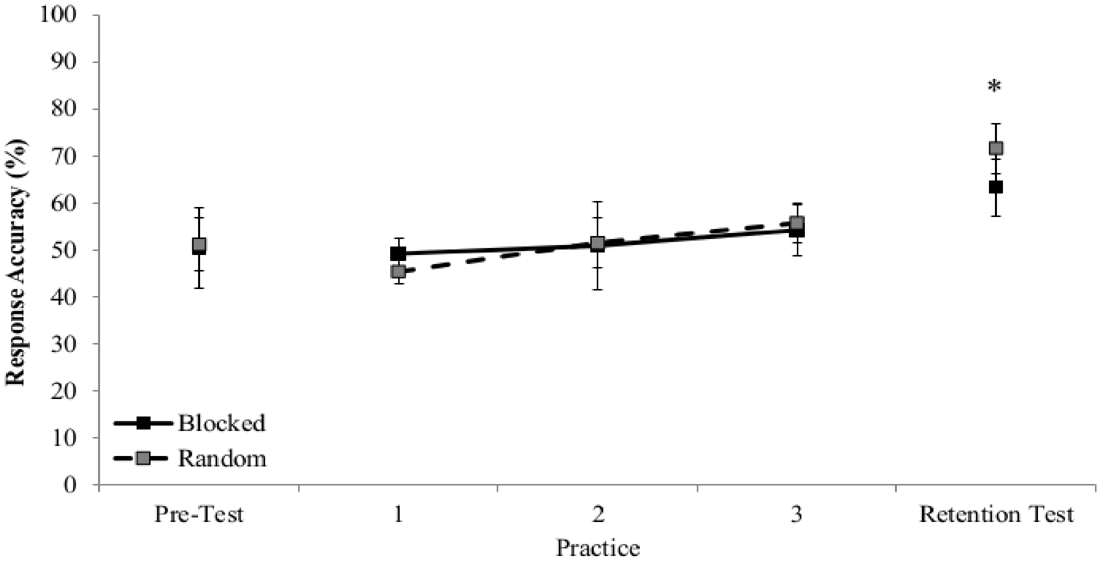

Figure 2.3: Mean (and SD) response accuracy (RA; %) in the laboratory pre-test, practice 1-3, and retention tests for the blocked and random group.*p < .05

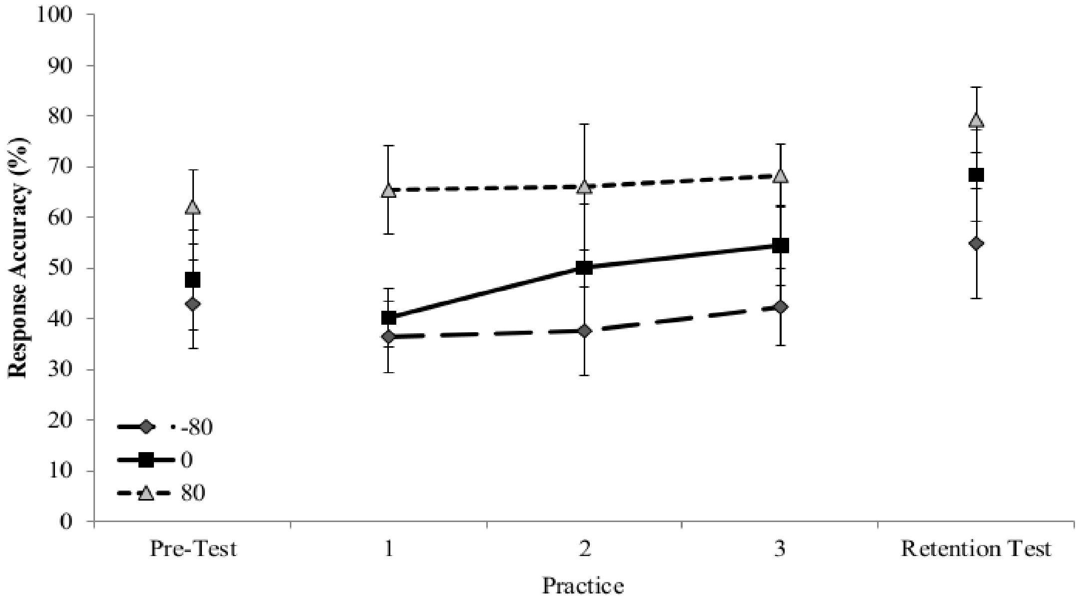

Figure 2.4: Mean (and SD) response accuracy (RA; %) in the laboratory pre-test, practice 1-3, and retention tests for occluded 80ms prior to ball-racket contact (-80), at ball-racket contact (0), and at 80ms after ball-racket contact (80)

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 = 48%, SD = 10) compared to trials occluded 80 ms before ball-racket contact (M = 43%, SD = 9).

However, in the retention test, RA was significantly higher on trials occluded at ball-racket contact (*M* = 68%, *SD* = 9) compared to trials occluded 80ms before ball-racket contact (*M* = 55%, *SD* = 11). No other interaction effects were observed.

Field Pre- and Transfer Test

Figure 2.5 shows the RA and DT across the two groups on the pre-test and retention test. The results of the MANOVA used to analyse performance on the field-based protocol with RA and DT as the dependent measures are presented in Table 2.6. Bonferroni pairwise 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* = 89%, *SD* = 7) and random group (*M* = 88%, *SD* = 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 to the field.

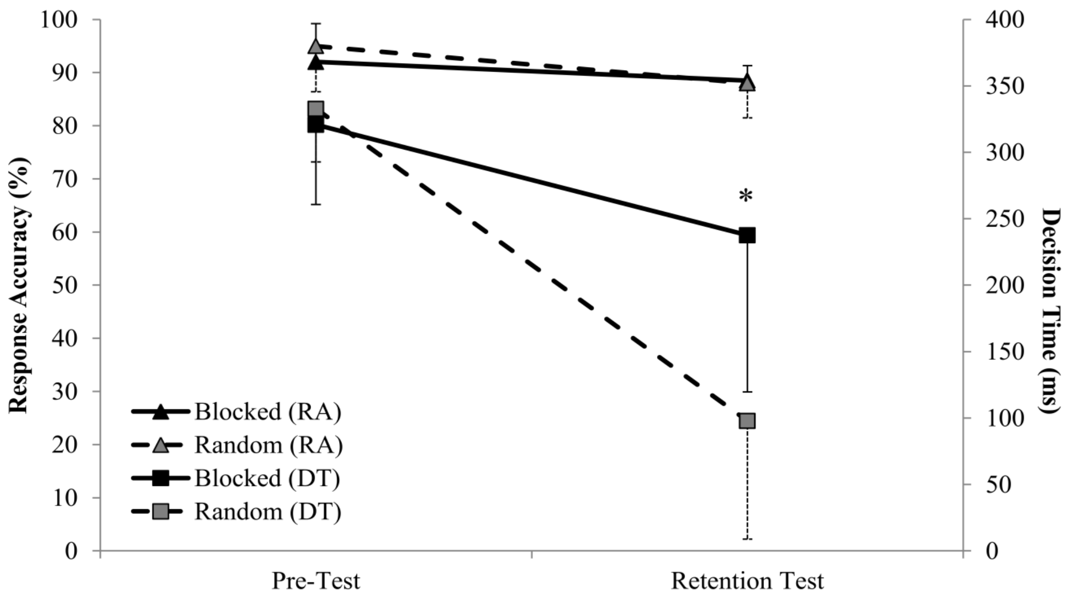

Figure 2.5: Mean (and SD) response accuracy (RA; %) and decision time (DT; ms) in the field pre-test and transfer tests for the blocked and random group.*p < .05

Table 2.6: MANOVA test results for the field-based protocol. *p< .05

Effect	Λ	*F*	*df*	η_p^2
Group	.49	6.91*	2, 13	.52
Test	.22	22.54*	2, 13	.78
Group x Test	.55	5.28*	2, 13	.45

Discussion

We investigated the CI effect on the acquisition of anticipation skills in a dynamic, temporally constrained environment. Furthermore, we reported a novel attempt to examine whether the structure of practice during video simulation training affects the transfer of these skills to the field. Specifically, we investigated the effects of a random and blocked schedule of practice on the acquisition, retention, and transfer of anticipation skills in tennis acquired through video simulation training. The main hypothesis of the CI effect was that in the laboratory-based retention test the random group would demonstrate significantly greater improvements in accuracy compared to the blocked group. Our data provides evidence for the CI effect as the random group demonstrated significantly more accurate responses in the 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 (Del Rey, 1989; Del Rey et al., 1982; Helsdingen et al., 2011a, 2011b; Shea & Morgan, 1979). However, these findings contradict those of Memmert et al. (2009), 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 anticipation skills during video simulation training in sport.

It was hypothesised that in a field-based transfer test the random group would demonstrate more accurate and faster anticipation skills when compared to the blocked group. In the 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 differences in RA in the transfer tests may be because scores were relatively high across all field-based 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 anticipations in the field-based protocol. Data provide novel evidence that the CI effect transfers from video simulation training to field-based setting. However, this finding will most likely only occur for intermediate or skilled participants, and not novices, due to the nature of field-based transfer tests requiring a level of motor expertise. Our findings provide support for previous literature (Hall et al., 1994) and extend current understanding by showing that principles from the motor skills literature regarding the CI effect apply to video simulation training to improve anticipation skills (Causer et al., 2012).

In line with the CI effect, we hypothesised that during the practice phase the blocked group would have more accurate anticipation skills compared to the random group. However, contrary to this hypothesis, RA was not significantly different between the two groups during the three practice sessions. These data contradict the majority of previous researchers who have investigated the CI effect (Magill & Hall, 1990; Merbah & Meulemans, 2011). However, some researchers have reported a lack of difference between blocked and random practice groups during practice, but have still found the hypothesised differences in the retention and transfer phase (i.e. Helsdingen et al., 2011b), somewhat contradicting the “typical” CI effect (Lee, 2012). A possible explanation for this finding is that the three invariant tennis skills contained variable parameters, such as shot location. The variable nature of both practice structures makes them less extreme forms in comparison to previous work from the motor skills literature (e.g. Shea & Morgan, 1979). Other researchers in both applied (Hall et al., 1994) and laboratory-based settings (Lee et al., 1992) 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.

The two main theories forwarded to explain the CI effect are the elaborative processing hypothesis (Shea & Morgan, 1979) and the action plan reconstruction hypothesis (Lee & Magill, 1983; Lee, Magill, & Weeks, 1985). 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 (Cross et al., 2007; Kantak et al., 2010; Lin, Fisher, Winstein, Wu, & Gordon, 2008). Anticipation skills are a perceptual-cognitive process that 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 elaborative processing hypothesis. Alternatively, the mere knowledge of an upcoming movement is suggested to generate an action plan in the motor system through a resonant mechanism, enabling people to anticipate, rather than react to others actions (Aglioti, Cesari, Romani, & Urgesi, 2008; Kilner, Vargas, Duval, Blakemore, & Sirigu, 2004). This suggests that random practice during anticipation training could have greater cognitive effort due to reconstructing actions plans when compared to blocked practice. Further research is required to reveal the underlying cognitive mechanisms that lead to the CI effect in anticipation training.

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 video simulation training and to the transfer of these skills to a field-based setting. A random practice schedule during video simulation training resulted in improved accuracy on a retention test in the laboratory when compared to a blocked schedule of practice. Furthermore, the positive changes in anticipation skills transferred to a field-based condition where the random schedule of practice resulted in faster DT compared to a blocked schedule of practice. Overall, the findings support previous researchers (Shea & Morgan, 1979) 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 anticipation skills through a video simulation technique.

Chapter 3:

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

Abstract

The CI effect shows that multiple skills practiced in a random order lead to superior learning compared to when practiced in a blocked order. There remains debate as to the mechanisms underlying this phenomenon. The aim of this study was to examine the CI effect during video simulation training for perceptual-cognitive skills and to investigate the underlying role of cognitive effort and error processing. In two experiments, novice participants anticipated three different tennis skills shown as life-sized video in either a random or blocked practice order group. Anticipation performance and the effect of errors were recorded across a pre-test, three practice sessions, retention test, and a laboratory-based transfer test using a novel structure of practice. In Experiment 1, cognitive effort was examined using a secondary choice reaction time task involving responses to high, but not low tones, separately across the preparation and feedback phase of a trial. In Experiment 2, cognitive effort was manipulated for two groups by inserting the Stroop test into the inter-trial interval. The CI effect was found in both experiments as the blocked groups made more accurate anticipation responses during practice, whereas the random groups were superior in the laboratory-based transfer test. Cognitive effort during practice was greater in random compared to blocked practice groups in Experiment 1. In Experiment 2, the additional cognitive effort between trials promoted learning for a blocked schedule of practice, but reduced learning for a random schedule of practice. Following an error, the random practice order groups exhibited greater cognitive effort in the preparation phase (Experiment 1) and inter-trial interval (Experiment 2) compared to a errorless trial, whereas the blocked group showed no difference between an error and errorless trials. The CI effect appears to be facilitated by increased cognitive effort due to error processing during task switching.

Introduction

The CI effect is a robust finding in the motor skills literature (for reviews, see Brady, 1998, 2008; Lee, 2012; Magill & Hall, 1990; Merbah & Meulemans, 2011). In Chapter 2 the CI effect was shown to extend to the acquisition of perceptual-cognitive skills through video simulation techniques (Broadbent, Causer, Ford, & Williams, 2014). However, the mechanisms underpinning this phenomenon were not examined. Researchers have shown that greater cognitive effort occurs during a random compared to a blocked schedule of practice, leading to the observed performance differences during practice and retention (Magill & Hall, 1990). Cognitive effort is the mental work involved in selecting and executing decisions and actions (Lee et al., 1994). In the CI effect, the cognitive effort during random practice is thought to be a result of task switching (Merbah & Meulemans, 2011). However, cognitive effort has been linked to error processing (Koehn, Dickinson, & Goodman, 2008), but not in conjunction with the CI effect. The current paper examines error processing as an additional explanation for the CI effect during the practice of anticipation skills in tennis.

As discussed in Chapter 1, two theories have been forwarded to explain the underlying mechanisms of the CI effect. These theories are the *elaborative processing* hypothesis and the *action plan reconstruction* hypothesis. Both theories detail how greater cognitive effort occurs during random compared to blocked ordered practice. According to the elaborative processing hypothesis, a random practice order leads to greater cognitive effort through comparative and contrastive analyses of the actions being executed because they differ from trial to trial (Shea & Morgan, 1979; Shea & Titzer, 1993). In comparison, during blocked practice the opportunity for comparing and contrasting the different actions is minimised due to the repetitive nature of the practice order. Support for this hypothesis was provided by Shea & Zimny (1983, 1988) who demonstrated the classic CI effect in a simple motor task and collected concurrent verbal reports and post-experiment interviews. In the random condition, there were more between-task comparisons resulting in a more refined and in-depth coding of the action representations compared to blocked practice where each movement was executed without much thought, almost "automatically" (see also, Del Rey & Shewokis, 1993; Wright, 1991; Wright, Li, & Whitacre, 1992). More recently, Lin and colleagues (Lin et al., 2008; Lin et al., 2009; Lin, Winstein, Fisher, & Wu, 2010) had novice participants practice three arm movement tasks in either a blocked or random practice structure. Single transcranial magnetic stimulation (TMS) pulses were synchronised to each inter-trial interval to reduce information processing during the two conditions. The typical CI effect was found for groups without TMS. However, the random practice advantage was eliminated when TMS was applied between random practice trials, as it was suggested to prevent them from conducting elaborative processing.

According to the *action plan reconstruction* hypothesis, random practice requires more effortful processing because the action plan of the motor program for the next trial has been forgotten and must be recalled. It has been forgotten due to the interference of executing a different preceding action and must, therefore, be retrieved from working memory. In comparison, blocked practice involves the same action plan on each trial so no forgetting or retrieval/reconstruction processes occur. Evidence for action plan reconstruction has been provided in a number of empirical studies (Lee & Magill, 1983, 1985; Lee et al., 1985). One method has been to prevent the forgetting that is predicted to occur between trials in a random practice condition by having participants observe a computer-generated demonstration of the movement pattern to be performed (Lee et al., 1997). Observing a congruent demonstration in the inter-trial period leads to random practice groups becoming more similar to blocked practice groups in both practice and retention tests, because it prevents forgetting and action plan reconstruction processes. More recently, Cross et al. (2007) used a key-press task to examine the neural substrates of the CI effect with functional magnetic resonance imaging. Consistent with the action plan reconstruction hypothesis, the random group imaging showed greater activity in the planning regions of the brain, when compared to the blocked practice group.

The explanation that cognitive effort underpins the CI effect in the motor skills literature has not been extended to perceptual-cognitive skills. The perceptual-cognitive skill concentrated on in this thesis is anticipation. In Chapter 2 it was suggested that the advantage of random practice might be explained by the elaborative processing hypothesis as anticipation of a skill may not involve constructing an action plan (Broadbent, Causer, Ford, et al., 2014). Alternatively, it was suggested that the knowledge of an upcoming movement excites the motor system through a resonant mechanism which activates an action plan, enabling people to anticipate, rather than react to others actions (Aglioti et al., 2008; Kilner et al., 2004). If this is the case, then random practice would be hypothesised to lead to greater cognitive effort through reconstructing actions plans when compared to blocked practice. The elaborative processing and action plan reconstruction theories are both underpinned by the greater cognitive effort and increased neural activity that occurs during a random compared to a blocked schedule of practice (Kantak et al., 2010). However, further research is required to reveal the underlying cognitive mechanisms that lead to the CI effect in anticipation skills.

Cognitive effort has been associated with error processing and the demands associated with success and failure on a task. When errors occur, performers identify discrepancies between the actual outcome and the desired goal (Rabbitt, 1966, 1967). They generate rules, hypotheses and knowledge about future task requirements so as to improve subsequent performance (Maxwell, Masters, Kerr, & Weedon, 2001). Therefore, errors appear to lead to greater cognitive effort when compared to errorless trials. While cognitive effort has been previously examined with reference to the CI effect (Li & Wright, 2000), the role of error processing in the CI effect has not previously been examined and may provide insight into the underlying mechanisms of this phenomenon. The increased cognitive effort from errors during a random schedule of practice can be hypothesised to occur in two different ways. First, blocked and random schedules of practice may contain similar error processing on each trial, but because a random schedule of practice leads to a greater number of errors compared to a blocked group (Magill & Hall, 1990), it may result in greater overall cognitive effort. Second, directly following an error on a trial the cognitive effort involved in error processing may be greater during a random schedule of practice compared to a blocked schedule. In this case, error processing heightens to the cognitive effort involved in task switching during random practice, showing that the number of error trials is not associated with the increased cognitive effort during random practice. The cognitive effort following errors during blocked and random schedules of practice needs to be investigated as an additional theory for the CI effect.

The aim of this chapter is to examine the underlying mechanisms of the CI effect to see if the cognitive effort explanations for it extend to the acquisition of anticipation skills through video simulation, and whether they are linked to performance errors. Cognitive effort will be investigated across two experiments in which novice tennis players anticipate three different tennis skills shown on life-sized video in either random or blocked practice order groups. Anticipation performance will be recorded during a pre-test, three practice sessions, retention test, and a laboratory-based transfer test to a novel structure of practice. It is predicted that the CI effect will occur in both experiments with the blocked group outperforming the random group during practice, but in the retention and laboratory-based transfer tests the random group will show superior learning compared to the blocked group. The role of cognitive effort in the CI effect will also be examined. It is predicted that the random group will exhibit greater amounts of cognitive effort across practice compared to the blocked schedule of practice, either supporting one or both of the action plan reconstruction hypothesis and the elaborative processing hypothesis from the CI literature. Furthermore, cognitive effort following errors and errorless trials during practice will be examined with the expectation that cognitive effort will be greater following an error compared to an errorless trial. Finally, both experiments will investigate the error processing associated with a blocked and random schedule of practice as an alternative explanation for the CI effect, with errors predicted to lead to greater cognitive effort when compared to errorless trials.

Experiment 1

Introduction

Research suggests that attention influences cognitive processing and the functional difficulty of the task as it is seen as having a finite capacity, of which a proportion is utilised when performing a task (Styles, 2000). The general capacity theory of attention (Kahneman, 1973) describes how this flexible capacity can be subdivided among tasks, so long as the sum of attentional demands does not exceed the available capacity (Abernethy, 1988, 2001). When a task demands a high level of cognitive effort, a large amount of attention is required and, therefore, there is a smaller amount of "residual" capacity available to perform subsequent tasks (Abernethy, Maxwell, Masters, van der Kamp, & Jackson, 2007).

Therefore, cognitive effort is often examined in both the CI and error literature using the dual- or secondary-task paradigm, which involves performance of two tasks simultaneously (Abernethy et al., 2007). Discrete secondary-tasks are often used, such as a probe reaction time task (PRT), in which participants respond to an auditory tone (Abernethy et al., 2007). With this method, the greater the cognitive demands of the primary task at any given moment, the slower the reaction time on the secondary task (Goh, Gordon, Sullivan, & Winstein, 2014). PRT tasks have been used to examine the underlying mechanisms of the CI effect in motor skill tasks (Li & Wright, 2000; Rendell et al., 2011), providing support for both the action plan reconstruction and elaborative processing hypothesis. However, researchers are yet to extend these findings to the acquisition of perceptual-cognitive skills through video simulation techniques. PRT tasks have also been used to examine the effect of errors on cognitive effort (Lam, Masters, & Maxwell, 2010), showing that it was greater on trials involving an error when compared to errorless trials. No researchers, to our knowledge, have examined the effects of errors on cognitive effort as a function of the CI effect.

The aim of this study is to examine the acquisition of anticipation skills under random or blocked practice conditions and to investigate the role of cognitive effort and errors in the CI effect. Novice participants anticipated three different tennis skills shown as life-sized video in either a random or blocked practice order with learning assessed across a pre-, retention, and laboratory-based transfer test to a novel structure of practice. In accordance with CI effect, it is expected that the blocked group will demonstrate superior RA compared to the random group across practice, but in the retention and laboratory-based transfer test the random group will demonstrate superior RA compared to the blocked group (Shea & Morgan, 1979). During practice, cognitive effort is examined using PRT in two phases of a trial. First, it is used during the preparation phase of a trial when action plan reconstructive processes is predicted to occur as this is when the participant is told the requirements of the upcoming task (Li & Wright, 2000). Second, it is used during the feedback phase of a trial in which elaborative processing process is predicted to occur as they gain feedback on performance which they can compare to previous successful and unsuccessful trials (Li & Wright, 2000). The random practice group is predicted to demonstrate greater cognitive effort compared to the blocked practice group, as shown through an increase in RT on the secondary task (Li & Wright, 2000). Moreover, the cognitive effort following an error will be analysed to determine whether the greater cognitive effort found during a random schedule of practice is due to a greater number of errors overall or greater error processing on a trial when compared to a blocked schedule of practice.

Method

Participants

Participants were 24 undergraduate students who were novice tennis players with no competition experience in the sport. They were randomly divided into either a blocked practice group (*n* = 12; *M* age = 23.3 years, *SD* = 4.5) or a random practice group (*n* = 12; *M* age = 23.5 years, *SD* = 3.2). Informed consent was obtained from the participants prior to participation. The research was conducted in accordance with the ethical guidelines of Liverpool John Moores University.

Test and practice film construction

Test and practice films developed for the experiment were the same as used in Chapter 2. Films were made for a pre-test, three practice sessions, a retention test, and a laboratory-based transfer test to a novel structure of practice. Each phase contained 36 trials and lasted between 5-10 minutes. Pilot work ensured the clips were of similar difficulty and no clips were repeated across the different phases. The 36 trials comprised of 12 forehand groundstrokes, 12 forehand volleys, and 12 forehand smashes. Each set of 12 shot trials comprised three trials to each of four locations: left short; left deep; right short; and right deep of the court. The pre-test trials were structured in a blocked order so that the three shots were in three separate blocks each containing either the forehand groundstrokes together, the smashes together, or the volleys together. The retention test contained a schedule of trials/shots that was the same as the groups experienced in their practice sessions (i.e., random group had a random schedule of practice in retention). The laboratory-based transfer test was structured in the opposite schedule of practice to the practice sessions (i.e., random group had a blocked schedule of practice in the transfer test).

For the practice phase, three different films were constructed corresponding to each of the three practice sessions. For the blocked group, the clips were arranged so that all the forehand groundstrokes were together, all volleys were together, and all smashes were together. The order of the blocks was counterbalanced across participants. For the random group, the clips were placed in a quasi-random order where no shot-type was repeated more than twice in a row. Participants received two presentations of the same shot during each trial in the practice phase. The first video contained clips that were temporally occluded at ball-racket contact and that occurred before the participant response. The second video occurred after their response and was not occluded, so that participants viewed the full clip and received feedback against which they could compare their response.

A PRT secondary task was added to the practice films. High (2500 Hz) and low (300 Hz) tones that were 240 ms in duration were overlaid on the two videos using editing software (Adobe Premier CS5, San Jose, USA). Probes were presented in a way that their onset could not be predicted through randomising inter-stimulus intervals (Wulf, McNevin, & Shea, 2001) and inserting catch trials in which a probe did not occur (Salmoni, Sullivan, & Starkes, 1976). Additionally, a tone was added to the films two seconds after the trial number appeared on screen that was used as a reference point for analysing the decision times (DT) of the verbal responses of the participants.

Procedure

The experimental apparatus and setup is the same as the laboratory-based setup from the previous chapter (Figure 2.2a). The only difference from Chapter 1 is the response used by the participants. Previously a physical response was used but with the constraints of the current task procedures due to the secondary task a verbal response was used. Participants were informed of the response requirements prior to testing and wore a lapel microphone (Seinheisser EW 100 ENG G2 RF, Germany). They were required to respond quickly and accurately to the onscreen shot by verbally stating a number between one and four that corresponded to an area of the court where the ball could bounce (1 = left short, 2 = right short, 3 = left deep, 4 = right deep). Participants did not perform a movement response, but stood still with a tennis racket in hand.

Participants were required to react to the PRT task on high but not low tones by pressing a push-to-make switch that was ergonomically attached to their tennis racket. For each participant, the three practice sessions were split into one practice block with no tones, one block with tones in the first video (preparation phase), and one block with tones in the second video (feedback phase). These practice blocks were counterbalanced across participants. Participants also completed a PRT task alone prior to the experiment with no primary task so as to measure their base reaction time. RT in this tone only condition was not different between the blocked (M = 257 ms, SD = 61) and random groups (M = 272 ms, SD = 57), p >.05. The microphone and the button press were synchronised and analysed using a developed algorithm through the computing environment MATLAB (Mathworks R2007, UK). This procedure allowed the verbal response by the participant, the onset of the high tones, and the moment the participants pressed the button to be recorded.

Dependent measures and statistical analysis

The dependent variables for the primary anticipation task were RA and DT. RA was expressed as the number of successful trials in which the response was the same as the location of the ball's bounce on the court. DT (ms) was calculated as the difference between the time of the verbal response on each trial and the time of ball-racket contact or temporal occlusion. Responses initiated prior to ball-racket contact or occlusion received a negative value. RA and DT in the primary task were analysed using a 2 Group x 6 Session mixed-design ANOVA, with repeated measures on the last factor. Partial-eta squared was calculated for effect size. For *post hoc* analysis, Bonferroni pairwise comparisons were used for any significant main effects or interactions. In order to limit the potential inflation of type-1 errors through multiple comparisons, each alpha level was adjusted using the Bonferroni correction method. Updated alpha values are reported throughout.

The dependent variable for the secondary task was reaction time (RT), which was calculated using the difference between the onset of the high tone on each trial and the button press by the participant. Secondary task RT was analysed using a 2 Group x 2 Phase (preparation phase, feedback phase) ANOVA, with repeated measures on the last factor. To check that the secondary task did not disrupt performance on the primary task, RA and DT data from the primary task was analysed using a 2 Group x 3 Condition (no tone, preparation video, feedback video) ANOVA, with repeated measures on the last factor. For *post hoc* analysis, Bonferroni pairwise comparisons were used for any significant main effects or interactions. Updated alpha values are reported throughout.

The role of errors on cognitive effort as a function of blocked and random schedule of practice was examined in two stages. First, it was expected that the number of errors would be greater in random compared to a blocked practice order. Moreover, greater cognitive effort was expected in random compared to a blocked practice order either due to a greater frequency of errors or greater error processing per trial. To determine the amount of error processing per trial following an error, mean RT and DT were calculated on a trial following error for the two practice conditions. Separate independent t-tests were conducted for mean RT and DT on a practice trial following an error between the two practice groups. In the event that these t-tests produced no significant differences between practice orders, then because there are more errors in random compared to blocked practice schedules, any differences in cognitive effort between the conditions would be due to a greater number of errors overall. Second, mean RT on a trial following error was analysed using a 2 Group x 2 Phase (preparation, feedback) x 2 Error (errorless, error) ANOVA. Mean DT on a trial following error was analysed using a 2 Group x 3 Session x 2 Error (errorless, error) ANOVA. For *post hoc* analysis, Bonferroni pairwise comparisons were used for any significant main effects or interactions. Updated alpha values are reported throughout. The alpha level for significance was set at $p < .05$ for all other tests.

Results

Primary anticipation task

Response accuracy. Figure 3.1 shows mean RA for the two groups on the pre-test, practice sessions, retention test, and laboratory-based transfer test. A 2 Group x 6 Session ANOVA on RA revealed no group main effect, F (1, 22) = 2.10, p =.16, η_p^2 = .09. There was a significant main effect for session, F (5, 110) = 7.06, p < .01, η_p^2 = .24. RA in the pre-test (M = 50%, SD = 7) was significantly lower than in the retention (M = 59%, SD = 8) and laboratory-based transfer test (M = 59%, SD = 8), all p < .05. There was a Group x Session interaction, F (5, 110) = 7.93, p < .01, η_p^2 = .27. Bonferroni pairwise comparisons revealed no between-group differences at the pre-test or in the first or second practice session. In the third practice session, the blocked group (M = 59%, SD = 7) made a greater frequency of accurate responses compared to the random practice group (M = 50%, SD = 7), p < .01. RA was not different between groups in the retention test, but in the laboratory-based transfer test the random group (M = 62%, SD = 7) demonstrated significantly greater RA compared to the blocked group (M = 54%, SD = 6), p < .01.

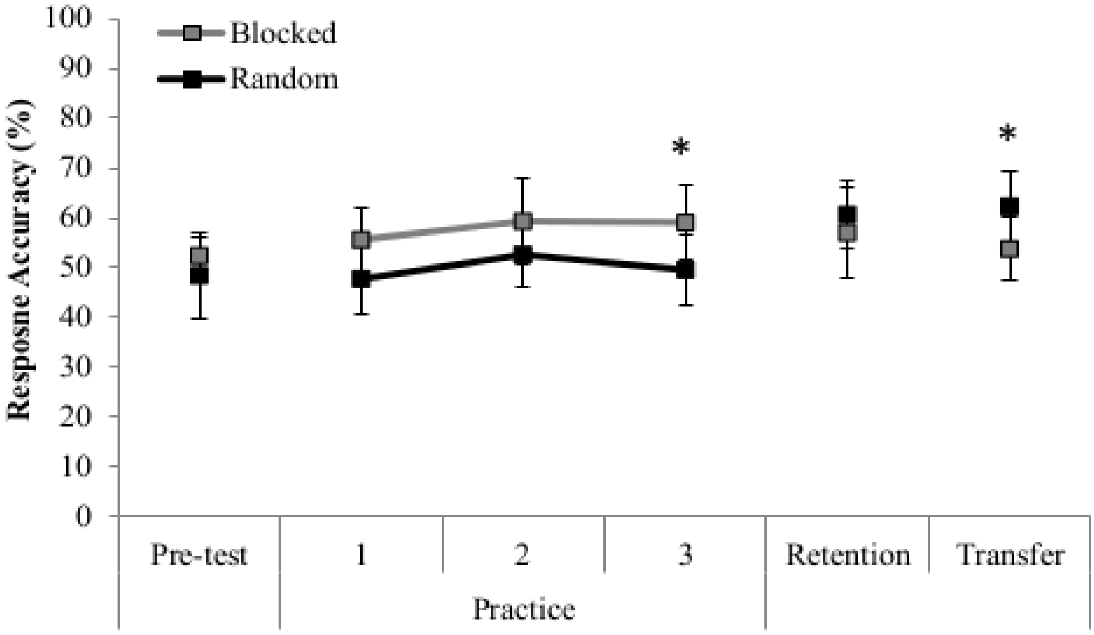

Figure 3.1: Mean (and SD) response accuracy (RA; %) in the pre- test, practice 1-3, retention test, and the laboratory-based transfer test for the blocked and random group. *$p < .05$

Decision time. Table 3.2 shows the mean DT in the primary task for the two groups across the pre-test, practice sessions, retention test, and laboratory-based transfer test. A 2 Group x 6 Session ANOVA on DT revealed no group main effect, F (1, 22) = .06, p = .81, η_p^2 = .01, phase main effect, F (5, 110) = .59, p = .71, η_p^2 = .03, or interaction, F (5, 110) = 1.28, p = .28, η_p^2 = .06.

Secondary task

Reaction time. Figure 3.3 shows mean RT for the two groups on the PRT task across the preparation and feedback phases. A 2 Group x 2 Phase ANOVA revealed a significant group main effect for RT, F (1, 22) = 5.68, p = .03, η_p^2 = .21. The blocked group (M = 394 ms, SD = 101) had a significantly faster RT compared to the random group (M = 496 ms, SD = 127). There was no main effect for phase, F (1, 22) = .74, p = .40, η_p^2 = .03, and no interaction, F (1, 22) = .02, p = .89, η_p^2 = .01, indicating that the random group had a significantly slower RT across the preparation and feedback phase when compared to the blocked group.

Table 3.2: Mean (and SD) decision time (DT; ms) in the primary task for the blocked and random groups across the pre-test, three practice sessions, retention test, and laboratory-based transfer test

	Decision Time (ms)					
	Pre-Test	Practice 1	Practice 2	Practice 3	Retention Test	Transfer Test
Blocked (SD)	910 (446)	892 (248)	821 (275)	869 (220)	927 (273)	933 (277)
Random (SD)	952 (591)	903 (193)	881 (172)	895 (260)	766 (172)	815 (148)

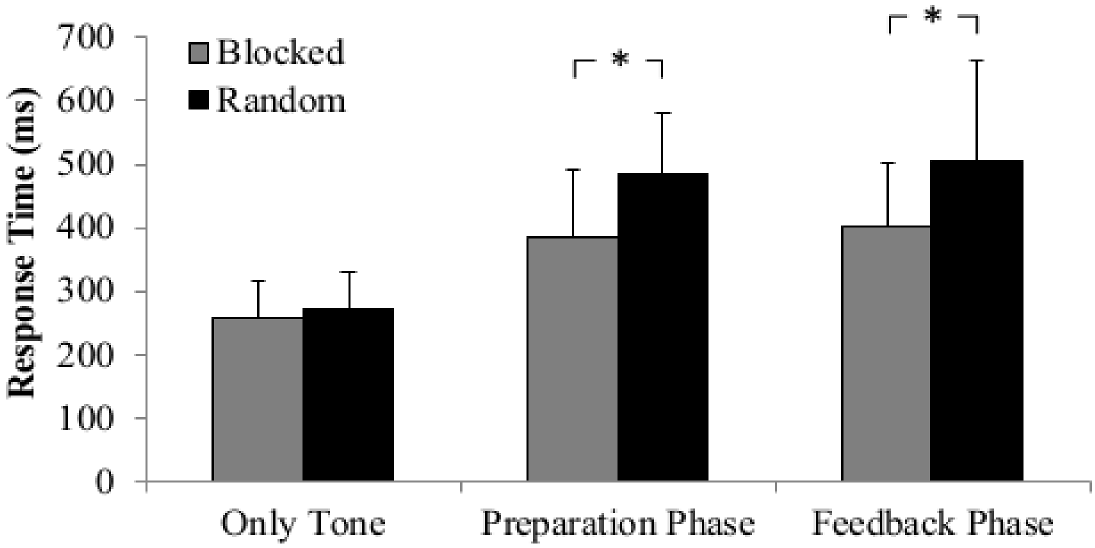

Figure 3.3: Mean (SD) response time (RT; ms) in the PRT for the blocked and random group in only tone, preparation phase, and feedback phase. *$p < .05$

Interference with primary task. A 2 Group x 3 Condition ANOVA on RA in the primary task revealed a group main effect, F (1, 22) = 12.40, $p < .01$, $\eta_p^2 = .36$. There was no condition main effect, F (2, 44) = .49, $p = .62$, $\eta_p^2 = .02$, as RA was not different in the tone only condition (M = 54%, SD = 10), preparation condition (M =

53%, *SD* = 9), and the feedback phase (*M* = 55%, *SD* = 6). There was no Group x Condition interaction, *F* (2, 44) = 1.41, p = .25, η_p^2 = .06, suggesting that the secondary task had not affected RA in the primary task for the two groups. A 2 Group x 3 Condition ANOVA on DT in the primary task revealed no Group x Condition interaction, *F* (2, 44) = .83, p = .44, η_p^2 = .04, no group main effect, *F* (1, 22) = .12, p =.73, η_p^2 = .01, and no condition main effect, *F* (2, 44) = .17, p = .85, η_p^2 = .01. DT was not different in the tone only condition (*M* = 885 ms, *SD* = 215), the preparation condition (*M* = 877 ms, *SD* = 219), and the feedback phase (*M* = 864 ms, *SD* = 250), suggesting that the secondary task had not disrupted DT in the primary task.

Error analysis

There was a significant difference in RT between a blocked (*M* = 401 ms, *SD* = 86) and random (*M* = 513 ms, *SD* = 157) schedule of practice following an error, *t*(46) = -3.15, p < .01. This suggests that cognitive effort was greater for the random compared to blocked group on each separate trial, rather than the same as blocked on each trial and due to a greater frequency of errors across the whole practice. The significant values meant an analysis of the accumulated cognitive effort of the two groups was not required. However, for DT, while the random (*M* = 910 ms, *SD* = 186) group were descriptively slower than the blocked (*M* = 858 ms, *SD* = 228) schedule of practice this did not reach significance, *t*(22) = -.61, p = .55.

Primary anticipation task. Table 3.4 shows the mean DT of the two groups following error and errorless trials. A 2 Group x 3 Session x 2 Error ANOVA on DT revealed no group main effect, *F* (1, 22) = .14, p = .71, η_p^2 = .01, session main effect, *F* (2, 44) = .75, p = .48, η_p^2 = .03, error main effect, *F* (1, 22) = .58, p = .46, η_p^2 = .03, or any interactions, all p > .05. The Group x Error interaction approached significance, *F* (1, 22) = 3.10, p = .09, η_p^2 = .12. Further analysis revealed a trend in the data as DT for the blocked group was not significantly different following an errorless (*M* = 869 ms, *SD* = 220) and error (*M* = 858 ms, *SD* = 228) response in the previous trial, $t(11) = .65$, $p = .53$. However, DT for the random group following an error trial (*M* = 910 ms, *SD* = 186) was slower compared to following an errorless trial (*M* = 880 ms, *SD* = 197), with this difference approaching significance, $t(11) = -2.00$, $p = .07$.

PRT. Table 3.4 shows the mean RT of the blocked and random groups as a function of performance (errorless, error) in the previous trial. A 2 Group x 2 Phase x 2 Error ANOVA on RT revealed a significant group main effect, $F\ (1, 22) = 5.63$, $p = .03$, $\eta_p^2 = .21$. There was no main effect for phase, $F\ (1, 22) = 1.31$, $p = .26$, $\eta_p^2 = .06$, or error, $F\ (1, 22) = .10$, $p = .75$, $\eta_p^2 = .01$. ANOVA revealed a significant Phase x Error interaction, $F\ (1, 22) = 5.28$, $p = .03$, $\eta_p^2 = .19$. RT following an error was not different between the two phases, whereas RT following an errorless trial in the feedback phase was significantly slower (*M* = 476 ms, *SD* = 154) compared to the preparation phase (*M* = 425 ms, *SD* = 126), $p = .04$. No other interactions were significant, all $p > .05$. Further inspection of the data indicated a trend in the data showing that an error trial, the random group had a significantly slower RT in the preparation phase (*M* = 520 ms, *SD* = 147) compared to the blocked practice group (*M* = 399 ms, *SD* = 85), $F\ (1, 22) = 6.18$,

Table 3.4: Mean (and SD) decision time (DT; ms) in the primary task, and mean (and SD) reaction time (RT; ms) in the secondary task, for the blocked and random groups on successful and error responses in the previous trial.

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

p = .02, but not following an errorless trial, F (1, 22) = 3.45, p = .08, or in the feedback phase following an errorless, F (1, 22) = 3.70, p = .07, or error trial F (1, 22) = 3.73, p = .07.

Discussion

As predicted, in the primary anticipation task the traditional CI effect was found with the random practice group displaying superior learning compared to the blocked practice group (Broadbent, Causer, Ford, et al., 2014; Shea & Morgan, 1979). Moreover, the blocked practice group displayed superior performance during practice compared to the random group. Furthermore, the random schedule of practice exhibited greater cognitive effort as shown by slower PRT compared to a blocked practice schedule. Greater cognitive effort was found in both the preparation and feedback phase of a trial for the random when compared to the blocked schedule of practice. Data contradicts the two separate hypothesis put forward in the CI literature, which state that either reconstructive processes prior to the task or elaborative comparisons following the task account for the CI effect. However, it supports previous research by Li and Wright (2000) who showed greater cognitive effort across the whole of a trial for a motor skill practiced in a random compared to blocked schedule, suggesting the two theories combined may explain the CI effect.

As predicted, cognitive effort was greater following errors in random compared to blocked order practice. Two hypotheses were proposed to explain the increased cognitive effort following errors in a random compared to blocked schedule of practice. Firstly, the greater cognitive effort may occur as the sum of trials because random practice has more errors during practice compared to blocked practice. Secondly, the greater cognitive effort may occur directly following an error trial. The data supported the second hypothesis that random practice elicits greater cognitive effort directly following an error trial when compared to blocked practice. Trends in the data were found concerning error processing for the two groups. Following an error trial, the random group exhibited slower RT in the preparation phase of the next trial when compared to an errorless trial, but the blocked group showed no difference between successful and unsuccessful trials. Moreover, DT in the execution phase for the random group tended to be slower following an error trial compared to an errorless trial, whereas there were no differences in DT for the blocked group between trial types. Data provides an indication that error processing may provide an alternative explanation for the CI effect. The combination of switching tasks during a random schedule of practice and error processing may result in greater cognitive effort compared to a blocked schedule of practice.

Experiment 2

Introduction

Researchers investigating the elaborative processing and the action plan reconstruction hypotheses have often referred to the *inter-trial interval* as a critical timed period for the increased cognitive effort (Magill & Hall, 1990). The elaborative processing hypothesis predicts that disrupting cognitive processes during the inter-trial interval will disrupt the comparative and elaborative processes taking place for a random schedule of practice and therefore will diminish the superior learning of random practice (Lin et al., 2008; Lin et al., 2010). In contrast, the action plan reconstruction hypothesis predicts that a cognitively demanding task during the inter-trial interval will promote forgetting in a blocked schedule of practice and thus increase the reconstructive processes occurring resulting in increased learning for the blocked schedule of practice (Lee & Magill, 1983, 1985). In Experiment 1, greater cognitive effort was found *during* acquisition of a perceptual-cognitive skill in a random compared to blocked schedule of practice (Li & Wright, 2000). However, while cognitive effort has been examined in the inter-trial interval during the acquisition of motor skills, researchers are yet to investigate it during the acquisition of perceptual-cognitive skills. Moreover, for the CI effect cognitive effort in the inter-trial interval has not previously been examined as a function of errors.

The aim of Experiment 2 was to examine cognitive effort in the inter-trial interval using a cognitively demanding task (Stroop test; Macleod, 1991) between practice trials in a blocked and random schedule, and as a function of errors. Novice participants were divided into blocked, random, blocked-Stroop (BStroop), and random-Stroop (RStroop) groups. It was expected that the CI effect would occur in the primary anticipation task for the two groups without the Stroop test. For the two Stroop groups, the Stroop test in the inter-trial interval might interfere with the elaborative comparisons made during a random schedule of practice, restricting the learning benefits of this schedule (Lin et al., 2008; Lin et al., 2010). Alternatively, the Stroop test in the interval may cause short-term forgetting in the blocked practice group, promoting reconstructive activity and superior learning (Lee & Magill, 1983, 1985, 1987). Errors will elicit more cognitive effort compared to errorless trials, although greater cognitive effort is expected following errors during a random, compared to a blocked, schedule of practice.

Method

Participants

Participants were 56 undergraduate students who were novice tennis players with no competition experience in the sport. They were randomly divided into either a blocked group (*n* = 14; *M* age = 20.7 years, *SD* = 1.6), random group (*n* = 14; *M* age = 20.9 years, *SD* = 1.1), BStroop group (*n* = 14; *M* age = 20.9 years, *SD* = 1.4), or a RStroop group (*n* = 14; *M* age = 21.1 years, *SD* = 1.1). Participants were mainly male, but there were three females in each group. Informed consent was obtained from the participants prior to participation. The research was conducted in accordance with the ethical guidelines of Liverpool John Moores University.

Test and practice film construction

The film clips used and the protocol were the same as in Experiment 1. For the BStroop and RStroop groups, a Stroop test was inserted in the inter-trial interval of practice trials using computer video editing software (Adobe Premier CS5 software, San Jose, USA). The Stroop test was selected due to the high cognitive demands it places on working memory (Kane & Engle, 2003). The Stroop test presents three colour words, such as red, green, and blue, with a font colour of text different to that of the word. A black screen appeared prior to the Stroop test on each trial that had either "colour" or "word" in a large white font to inform the participants of their verbal response type. Participants were required to respond quickly and accurately by verbally stating either the word that was printed or the colour that the word was printed in, as directed. Each word was presented on screen for 90 ms as pilot work demonstrated that this time allowed the task to be completed successfully, but was challenging enough to cause interference. The order of presentation was randomised so that participants were unaware of the response they had to provide prior to each trial. The randomised presentation requires a new action plan to be implemented into working memory on the subsequent trial, potentially causing more interference to the primary task (for a review of Stroop effect theory, see Macleod, 1991). Performance on the Stroop test was filmed and later analysed using hand notation following the testing period.

Procedure

The experimental apparatus and set up was the same as in Experiment 1, although there was no PRT task, and the pre-test contained a blocked and random structure of practice. For the two additional groups, the Stroop test occurred after every trial in all three practice sessions. The lapel microphone was synchronised and analysed using a developed algorithm through the numerical computing environment MATLAB (Mathworks R2007, UK). It allowed the verbal response by the participant on both the primary anticipation task and the Stroop test to be recorded and later analysed.

Dependent Measure and Statistical Analysis

For the primary anticipation task, the dependent variables were the same as in Experiment 1. RA and DT were analysed separately using a 4 Group x 6 session mixed design ANOVA, with repeated measures on the last factor. For the Stroop test, the dependent variables were RA and DT. RA refers to the number of successful responses out of 108 trials and is defined as whether the colour or word verbalised by the participant matches the trial requirements for the colour or word displayed. DT (ms) was calculated as the difference between the verbal response on each Stroop trial and the moment the slide appeared on the screen. All responses were initiated after the slide appeared and received a positive value that was analysed through MATLAB with the software extrapolating all the data points for the verbal responses. Separate 2 Group x 3 Session mixed design ANOVAs with repeated measures on the last factor were used to analyse RA and DT on the Stroop test. For *post hoc* analysis, Bonferroni pairwise comparisons were used for any significant main effects or interactions. Updated alpha values are reported throughout. The alpha level for significance was set at $p < .05$ for all other tests.

Analysis of DT as a measure of cognitive effort following errors was conducted for both the primary anticipation task and the Stroop test. For both tasks, DT was analysed following an errorless and error response in the previous trial for the blocked and random groups. A 4 Group x 2 Error mixed design ANOVA with repeated measure on the last factor was used to analyse DT in the primary anticipation task. A 2 Group x 2 Error mixed design ANOVA with repeated measure on the last factor was used to analyse DT in the Stroop test. For *post hoc* analysis, Bonferroni pairwise comparisons were used for any significant main effects or interactions. Updated alpha values are reported throughout. The alpha level for significance was set at $p < .05$.

Results

Primary anticipation task

Response Accuracy. Figure 3.5 shows mean RA for the four groups on the pre-test, three practice sessions, retention test, and laboratory-based transfer test. A 4 Group x 6 Session ANOVA revealed no group main effect, F (1, 52) = .72, p =.55, η_p^2 = .04. There was a significant main effect for phase, F (5, 260) = 3.59, p < .01, η_p^2 = .07. Pairwise comparisons indicated that RA in the retention (M = 56%, SD = 8) and laboratory-based transfer test (M = 55%, SD = 8) was significantly greater than in the pre-test (M = 52%, SD = 8), all p < .05. There was a Group x Session interaction, F (15, 260) = 2.67, p < .01, η_p^2 = .13. Pairwise comparisons revealed no between-group differences at the pre-test, first practice session, and in the retention test. In the second

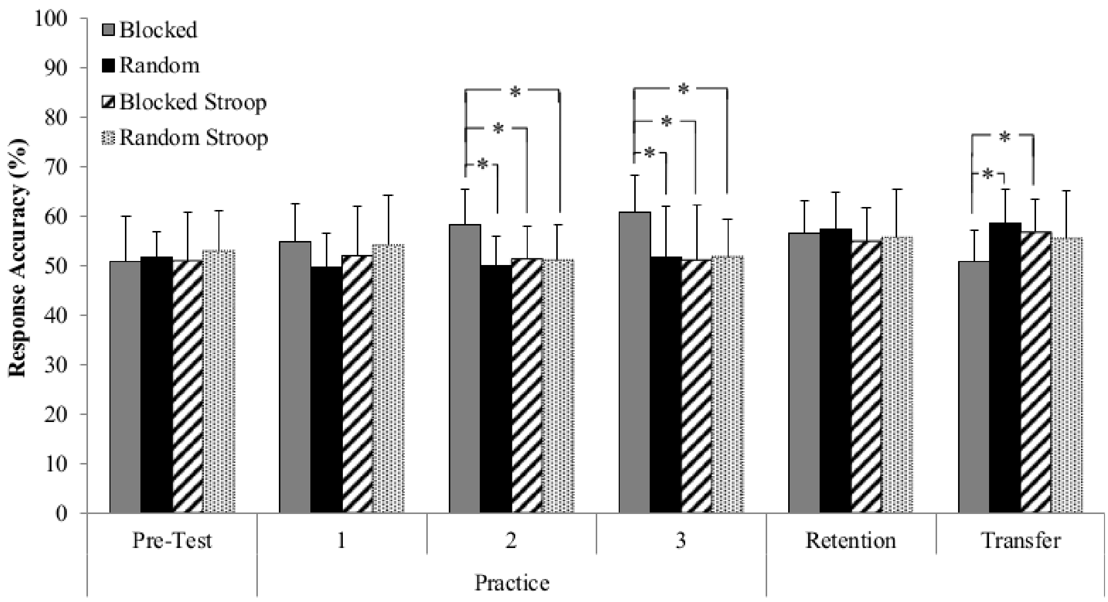

Figure 3.5: Mean (and SD) response accuracy (RA; %) in the pre- test, practice 1-3, retention test, and laboratory-based transfer test for the blocked, random, BStroop, and RStroop groups. *p < .05

and third practice session, the blocked group were significantly more accurate compared to the other three groups, $p < .01$. In the laboratory-based transfer test, the random group (M = 59%, SD = 7) and the BStroop group (M = 57%, SD = 7) had a significantly greater RA compared to the blocked group (M = 51%, SD = 6), $p < .01$ and $p = .05$, respectively, as well as compared to the RStroop group (M = 56%, SD = 9), although this alpha value approached significance ($p = .11$).

Decision Time. A 4 Group x 6 Session ANOVA revealed no group main effect, F (3, 52) = .49, $p = .69$, $\eta_p^2 = .03$. There was a phase main effect, F (5, 26) = 3.44, $p < .01$, $\eta_p^2 = .06$. Pairwise comparisons indicated that DT in the pre-test (M = 790 ms, SD = 205) was significantly faster than in practice 1 (M = 887 ms, SD = 212) and in the retention test (M = 870 ms, SD = 253), both $p < .05$. DT in the pre-test was not different to practice 2 (M = 862 ms, SD = 215), practice 3 (M = 871 ms, SD = 262), and the laboratory-based transfer test (M = 833 ms, SD = 241). There was no Group x Session interaction, F (15, 260) = .39, $p = .98$, $\eta_p^2 = .02$.

Stroop Test

Response Accuracy. Table 3.6 shows the mean RA in the Stroop test for the blocked and random groups across the three practice sessions. A 2 Group x 3 Session ANOVA revealed no group main effect, F (1, 26) = 1.23, $p = .28$, $\eta_p^2 = .05$. There was a

Table 3.6: Mean (and SD) response accuracy (RA; %) and decision time (DT; ms) in the Stroop test for the BStroop and RStroop groups across the three training sessions

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

phase main effect, F (2, 52) = 4.48, p = .02, η_p^2 = .15. Pairwise comparisons indicated that RA in practice 3 (M = 98%, SD = 3) was significantly greater than in practice 1 (M = 96%, SD = 3), p < .05. No interaction occurred, F (2, 52) = .60, p = .55, η_p^2 = .02.

Decision Time. Table 3.6 shows the mean DT in the Stroop test for the blocked and random groups across the three practice sessions. A 2 Group x 3 Session ANOVA revealed no group main effect, F (1, 26) = .014, p = .91, η_p^2 < .01, no main effect for session, F (2, 52) = 1.30, p = .28, η_p^2 = .05, and no interaction, F (2, 52) = .01, p = .99, η_p^2 < .01.

Error Analysis

Primary anticipation task. Figure 3.7 shows the mean DT in the primary task following an errorless or error response for the four groups. A 4 Group x 2 Error ANOVA revealed no group main effect, F (3, 52) =.27, p = .86, η_p^2 = .02, and no error main effect, F (1, 52) =.01, p = .92, η_p^2 < .01. However, there was a significant Group x Error interaction, F (3, 52) = 6.12, p < .01, η_p^2 = .26. Pairwise comparisons indicated

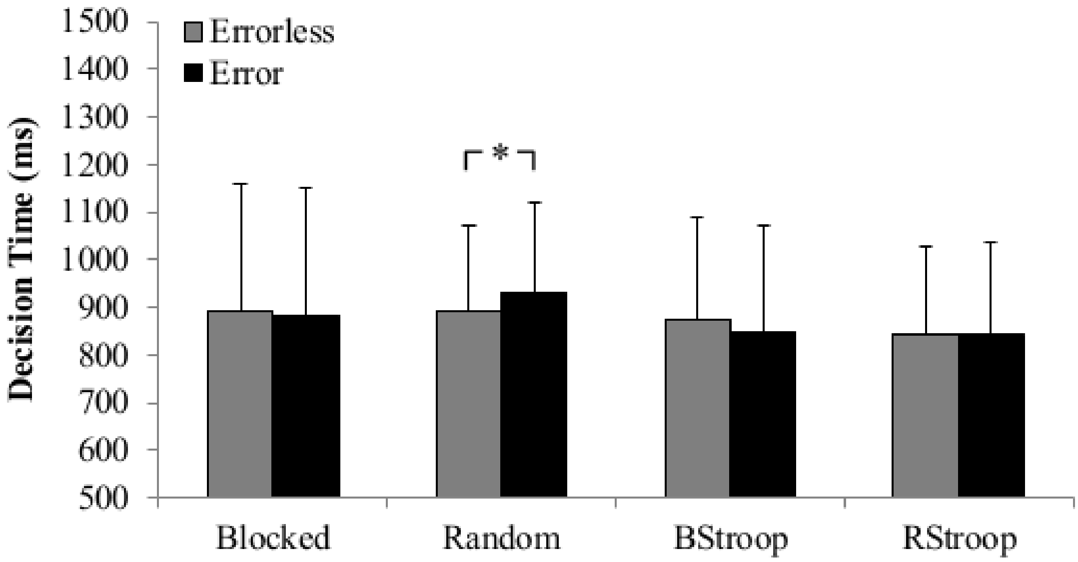

Figure 3.7: Mean (and SD) decision time (DT; ms) in the primary anticipation task following successful and error trials for the blocked, BStroop, random group and RStroop groups. *p < .05

that the random practice group had significantly slower responses following an error (*M* = 930 ms, *SD* = 225), compared to following an errorless trial (*M* = 893 ms, *SD* = 217), $p < .01$. In contrast, DT for the other three groups was not significantly different between successful and unsuccessful trials.

Stroop test. Figure 3.8 shows the mean DT on the Stroop test for the BStroop and RStroop groups based on performance in the previous trial. A 2 Group x 2 Error ANOVA revealed no group main effect, F (1, 26) = .01, p = .91, $\eta_p^2 < .01$. There was a significant error main effect, F (1, 26) = 12.16, $p < .01$, $\eta_p^2 = .32$. Pairwise comparisons indicated that DT was significantly slower following an error (*M* = 681 ms, *SD* = 87), compared to following an errorless trial (*M* = 664 ms, *SD* = 85), $p < .01$. There was also a significant Group x Error interaction, F (1, 26) = 4.25, p = .05, $\eta_p^2 = .14$. Pairwise comparisons indicated that DT for the RStroop was significantly slower following an error (*M* = 687 ms, *SD* = 85), compared to an errorless trial (*M* = 661 ms, *SD* = 81), $p < .01$. In comparison, DT for the BStroop group was not different following successful (*M* = 667 ms, *SD* = 91) and unsuccessful trials (*M* = 674 ms, *SD* = 91).

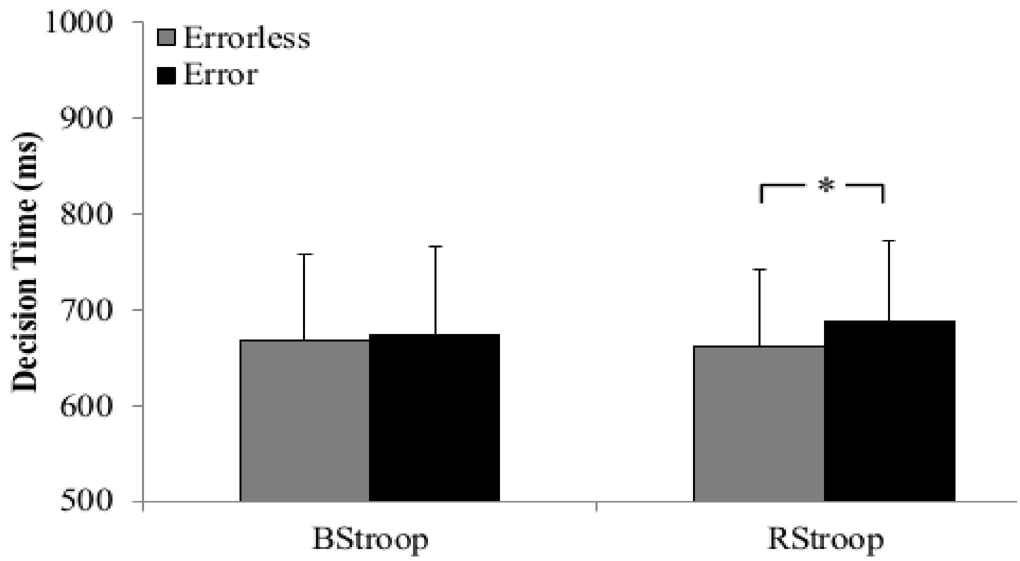

Figure 3.8: Mean (and SD) decision time (DT; ms) in the Stroop test following successful and error trials for the BStroop and RStroop groups. *$p < .05$

Discussion

As expected, for the two practice structure groups without the additional cognitive effort caused by the Stroop test, the traditional CI effect was found (Broadbent, Causer, Ford, et al., 2014). The random group had significantly more errors across practice compared to the blocked group, but in the laboratory-based transfer test the random group demonstrated superior learning compared to the blocked group. The CI effect was not found for the two Stroop groups. Across practice, the RStroop group was not significantly different to any of the other groups, whereas the BStroop group had significantly more errors than the blocked group. In the laboratory-based transfer test, the RStroop group were less accurate than the random group, and the BStroop group were significantly more accurate than the blocked group. Data concerning the RStroop group shows support for the elaborative processing hypothesis as the cognitively demanding Stroop task likely disrupted the between-task comparisons made during the inter-trial interval, restricting the learning benefits of a random schedule of practice (Lin et al., 2008; Lin et al., 2010). On the other hand, findings surrounding the BStroop group provide support for the action plan reconstruction hypothesis as the cognitively demanding Stroop task likely caused short-term forgetting, promoting reconstructive activity and superior learning (Lee & Magill, 1983, 1985, 1987; Simon & Bjork, 2002). It appears that both reconstructive and elaborative processes may lead to the superior learning of a random compared to blocked schedule of practice.

Errors were expected to elicit greater cognitive effort compared to errorless trials. As predicted, DT on the Stroop test in the inter-trial interval was slower following an error in the primary task, compared to following an errorless response. Data supports the previous literature on error processing that suggests cognitive effort is greater following an error. Performers display greater cognitive effort following an error as they are identifying discrepancies between the actual outcome and the desired goal, as well as generating rules, hypotheses, and knowledge for future task requirements (Koehn et al., 2008; Maxwell et al., 2001; Rabbitt, 1966, 1967). Less cognitive effort is required in the execution phase as it simply involves monitoring and controlling the action, which may explains why DT on the primary anticipation task was not different following an errorless and error trial (Holroyd, Yeung, Coles, & Cohen, 2005; Lam et al., 2010).

Concerning the CI effect, greater cognitive effort was expected following errors during a random, compared to a blocked schedule of practice. As predicted, DT on the primary anticipation task in the execution phase was slower for the random group, showing greater cognitive effort following an error compared to an errorless response, but not for the other three groups. These findings suggest that following an error, a random schedule of practice requires greater cognitive effort for the monitoring and controlling of the response compared to a blocked schedule of practice (Lam et al., 2010). However, cognitive effort in the execution phase was not different between errorless and error responses for the RStroop group. The Stroop test seems to have interrupted these cognitive processes, which may be the reason that RA for the RStroop group was not different to the blocked group in the laboratory-based transfer test. However, in the Stroop test, the RStroop group had a slower RT following an error compared to following an errorless trial. In comparison, RT for the BStroop group was not different following both errorless and error trials. Data suggest that following an error, a random schedule of practice likely requires greater cognitive effort to update the rules from the previous task and store these (Koehn et al., 2008). In comparison, a blocked schedule does not need the rules to be stored due to the repetitive nature of the task. Moreover, in the random schedule of practice when the previous trial is errorless, then the rules do not need to be updated, so the same rules are stored as before requiring less cognitive effort. Therefore, it may be the combination of switching tasks and error processing that results in the greater cognitive effort during a random compared to blocked schedule of practice.

General Discussion

Cognitive effort due to switching between tasks has previously been examined with reference to the CI effect (Li & Wright, 2000), but the effort associated with error processing in the CI effect has not previously been investigated. Therefore, the aim of the two experiments presented in this chapter was to investigate the cognitive processes underpinning the CI effect, specifically examining the alternative explanation for the role of error processing. Experiment 1 used a PRT task to measure cognitive effort in the preparation and feedback phase of a task during a blocked and random schedule of practice. Cognitive effort was examined following errorless and error trials for a blocked and random schedule of practice. Experiment 2 investigated the effects of inserting the cognitively demanding Stroop task into the inter-trial interval of a blocked and random schedule of practice, while again looking at the effects of errors on performance of the primary and secondary task.

In agreement with Chapter 2, during practice in both experiments the blocked group made more accurate anticipations compared to the random practice group, whereas in the laboratory-based transfer condition the random practice group were more accurate compared to the blocked practice group. Data support previous research on the CI effect in the motor skills literature (Magill & Hall, 1990) and provides confirmation that the effect extends to perceptual-cognitive skills training using video simulation techniques (Broadbent, Causer, Ford, et al., 2014). These data demonstrate the generalizability of the CI effect to perceptual-cognitive skills training, as the phenomenon has now been found to extend to skilled (Broadbent, Causer, Ford, et al., 2014) and novice participants using both complex movement responses (Broadbent, Causer, Ford, et al., 2014) and no movement responses. These findings indicate that movement execution may be less important for the CI effect to occur and that it is the cognitive processes that are key (Blandin, Proteau, & Alain, 1994).

The primary focus of the two experiments was examining the underpinning cognitive mechanisms of the CI effect. Different protocols in the two experiments verified the importance of cognitive effort in the CI effect and superior learning (Kantak et al., 2010). However, findings contradict the idea of two competing hypotheses (elaborative processing and action plan reconstruction) put forward in previous literature for the CI effect (Magill & Hall, 1990). In contrast, the data from the two current experiments suggest that elaborative processing and action plan reconstruction combined may underpin the CI effect. Experiment 1 demonstrated that cognitive effort was greater for a random schedule of practice in both the preparation and feedback phase, which have previously been linked to both the action plan reconstruction and elaborative processing hypotheses, respectively (Li & Wright, 2000). Experiment 2 showed that increasing cognitive effort using the Stroop test during a blocked schedule of practice caused forgetting and promoted reconstructive activities, leading to superior learning (Lee & Magill, 1983, 1985, 1987; Simon & Bjork, 2002). Moreover, inserting the Stroop task in the inter-trial interval of a random schedule of practice disrupted the elaborative processes taking place and reduced the learning benefits (Lin et al., 2008; Lin et al., 2010). Therefore, the elaborative processing and action plan reconstruction hypotheses might not be viewed as separate hypotheses, but rather as an integrated hypothesis involving greater cognitive effort across the whole of a trial.

The two experiments investigated cognitive effort following errors in performance as an additional explanation for the CI effect. Cognitive effort following errors was expected to be greater in a random compared to blocked schedule of practice, because error processing was believed to add cognitive load to task switching processing. The data showed some support for this hypothesis as at certain time points in a trial the random group demonstrated significantly greater cognitive effort following errors compared to an errorless response, while the blocked did not. Greater cognitive effort may occur following an error in random compared to blocked practice because performers engage in error processing in addition to the frequent task switching occurring in this practice structure. Error processing is thought to involve identifying discrepancies between the actual outcome and the desired goal (Rabbitt, 1966, 1967), as well as generating rules, hypotheses and knowledge about future task requirements (Maxwell et al., 2001).

Data from Experiment 1 provided insight into the role of error processing on cognitive effort in the CI effect. Following an error, the random practice structure group exhibited greater cognitive effort in the preparation phase when compared to an errorless trial, but not during the feedback phase, whereas the blocked group showed no difference between errorless and error trials in either phase. In Experiment 2, the random group displayed greater cognitive effort during the inter-trial interval following an error compared to an errorless trial. However, cognitive effort was not different for the blocked group following errors and errorless trials. The greater cognitive effort following an error for a random schedule of practice may be due to participants having to both update the current rules for the previous task and store these (error processing), as well as retrieving the rules for the upcoming task that have been previously stored (action plan reconstruction hypothesis). The updating of rules would occur through inter-task comparisons (elaborative processing hypothesis) made to identify discrepancies between the actual outcome and the desired goal (error processing). In contrast, following an error, a blocked structure of practice would not require the retrieval of rules (action plan reconstruction hypothesis) due to the repetitive nature of the task, so would merely require the rules for the task to be updated (error processing) and this would not involve inter-task comparisons (elaborative processing hypothesis), hence less cognitive effort would be required.

In summary, the two experiments provide corroborative evidence of the CI effect and the role of cognitive effort as an underlying mechanism. Moreover, the experiments suggest a novel explanation for the CI effect in which cognitive effort from elaborative processing and action plan reconstruction processes occurs across the preparation phase and inter-trial interval, in addition to error processing. The suggestion is that it is not solely the switching of the tasks during a random schedule of practice that increases cognitive effort and causes the CI effect, but also error processing in conjunction with the task switching that result in greater cognitive effort. Support for this extension to the CI theory was indicated in Experiment 1 by increased cognitive effort in the preparation phase following an error for the random, but not blocked, practice group. In Experiment 2, inserting the Stroop task in the inter-trial interval elicited greater cognitive effort following an error in a random schedule of practice, but not following an errorless trial, compared to the blocked practice group. In future researchers should look to examine error processing as an additional mechanism underpinning the CI effect. The CI effect has been shown to extend to a range of domains and conditions from simple motor skill tasks with novice participants (Shea & Morgan, 1979) to complex sporting tasks with expert athletes (Hall et al., 1994). Using similar methodologies to the current paper, further research is required to assess the role of error processing in conjunction with task switching in a variety of domains and conditions to determine the generalizability of this alternative theory.

Chapter 4:

The role of contextual information during perceptual-cognitive skill simulation training in sport

Abstract

Researchers investigating perceptual-cognitive skills training have predominantly concentrated on improving the use of advanced postural cues emanating from opponent movements. However, researchers are yet to examine the importance of contextual information for the retention and transfer of perceptual-cognitive skills from simulation training to the field. In this study a novel attempt is made to examine the role of contextual information during video-simulation training of anticipation skills in tennis and the transfer of these skills to the field. Participant response accuracy to a sequence of strokes played by an opponent was collected in a pre-test, across practice, in a laboratory retention test, and in a field-based transfer test. During practice, participants were placed into groups that viewed the sequence of shots in either a context-rich smart-random structure or a traditional random structure. Both groups improved response accuracy in the retention test compared to the pre-test, but the smart-random structure was significantly more accurate than the random schedule of practice. Furthermore, in the field-based transfer test, decision time on the final shot of each rally improved significantly for both groups. However, for all the shots in the rally decision time significantly improved for the smart-random group, while the random structure group showed no such improvements. The data demonstrates the benefits of perceptual-cognitive skills training in random practice structures to improve anticipation skills. The findings show, for the first time, the extended performance advantage gained from incorporating contextual information into simulated practice for the retention and transfer of perceptual-cognitive skills. The data have implications for designing appropriate practice schedules that replicate the processes used in the applied setting.

Introduction

Expert athletes adapt to changing contextual conditions during and across competitive events. In order to perform in these variable conditions, they require perceptual-cognitive and motor skills (Williams & Ericsson, 2005). Chapters 2 and 3 focused on using video-simulation techniques to train perceptual-cognitive skill. Findings demonstrated the benefit of a random, compared to a blocked, structure of practice for the acquisition of anticipation skill in tennis. However, these studies, and the majority of research in this area, did not attempt to recreate practice structures that replicate those experienced when physically playing the sport (Williams & Ward, 2007). Such practice structures increase the amount of available contextual information and researchers are yet to address the role of such information during video-simulation training for the transfer of learning from practice to the field (Broadbent, Causer, Williams, et al., 2014). The aim of the current study is to examine the role of contextual information during practice for the transfer of perceptual-cognitive skills from simulation to a field-based setting, specifically focusing upon anticipation in tennis.

Researchers have created systematic training interventions to improve the ability of less-skilled players to recognise advanced postural cues and anticipate opponent actions (Williams & Burwitz, 1993; Williams et al., 2002). As with the previous chapters, findings have demonstrated that perceptual-cognitive skills, specifically the use of advanced postural cues, can be trained using video-simulation techniques and transfers to field-based tasks (Broadbent, Causer, Williams, et al., 2014; Smeeton et al., 2005; Williams et al., 2002). However, researchers have failed to acknowledge the role of contextual information in sport-specific situations (Vicente & Wang, 1998), preferring instead to maintain experimental control by removing this information. Contextual variables include athlete characteristics, tactics, and tendencies; opponent characteristics, tactics and tendencies; as well as variables such as the score and time in the game (McPherson & Kernodle, 2003). Researchers investigating the role of contextual information during sport (Crognier & Féry, 2005; MacMahon & Starkes, 2008; MacMahon et al., 2009; McPherson & Kernodle, 2007; McRobert et al., 2011; Paull & Glencross, 1997) and medical performance (McRobert et al., 2013; Verkoeijen et al., 2004) have demonstrated that this information facilitates more efficient and accurate responses when compared to conditions with less or no contextual information.

Expert performers appear to store domain-specific contextual information and associated responses in memory. McPherson and colleagues (McPherson, 1999a, 1999b, 2000; McPherson & Thomas, 1989) examined the higher-order processing taking place in skilled and less-skilled players during simulated and actual tennis competition using a verbal report methodology. From their research and related studies (French & McPherson, 2004; McPherson & Kernodle, 2003; Tenenbaum, 2003) it was proposed that the superior decision making skills of expert performers are due to two adaptations in long-term memory, termed action plan and current event profiles. As discussed in Chapter 1, a*ction plan profiles* are rule-governed prototypes that contain cognitive skills for monitoring current conditions, such as player positions or ball placement, so as to make accurate response selections. In comparison, *current event profiles* are tactical scripts that guide the continuous building and modifying of concepts to monitor during the task. These profiles are built from previous performances and the current task as it progresses. They are used to keep relevant contextual information active with potential past, current, and possible future events (McPherson, 2008). These profiles allow expert players easy access to, and retrieval of, key information to select and execute decisions during a task.

Expert performers use these memory adaptions to plan and perform actions based on the current environmental situation (e.g. player positions, ball location), together with current and past contextual events, such as known opponent characteristics (e.g. strengths, tendencies, prior shot) (McPherson, 1999a, 1999b, 2000; McPherson & Thomas, 1989). In contrast, less-skilled participants generate few plans based on current and past events, and their weak problem representations consist of goals related to their executions, failed actions, or reactions to game events (McPherson, 1999a, 1999b, 2000; McPherson & Thomas, 1989). Advanced beginners access rudimentary action plan profiles by generating some pertinent conditions about current context, but lack current event profiles and rarely generate thoughts beyond the current game events (McPherson & Kernodle, 2007). Findings show that action plan and current event profiles develop as performers become more skilled (McPherson & Kernodle, 2007). However, the conditions of practice required to acquire and expedite the acquisition of these memory adaptions is yet to be investigated.

Researchers have investigated various conditions of practice, particularly contextual interference, revealing the benefits of a random practice structure over a blocked structure, for the acquisition of anticipation using advanced postural cues (Broadbent, Causer, Ford, et al., 2014). They have shown that cognitive effort underpins the learning benefits of a random schedule of practice (Broadbent, Causer, Williams, & Ford, in prep). However, random and blocked practice conditions do not simulates the pattern of skill executions that players encounter during an actual match. In traditional random practice conditions, the different skills practiced are arranged in a quasi-random order, whereby the same skill is not completed more than twice in a row (Shea & Morgan, 1979). In contrast, *smart-random practice conditions* occur when separate skills are combined in a tactically relevant way to simulate the conditions found in a competitive setting (Vickers, 2007). Smart-random conditions should simulate the cognitive processes players encounter during match play. These conditions contain contextual information from the execution and outcome of the previous skills by the player and, when an opponent performs these skills, they provide their tactics and tendencies. While the significance of contextual information for expert performance is apparent, the importance of such information during the training of perceptual-cognitive skills, as well as the cognitive effort it elicits, has rarely been investigated (for exception see, McPherson & Kernodle, 2007). Moreover, researchers have not considered the role of contextual information on the optimum transfer of perceptual-cognitive skills from video simulation protocols to the field.

The aim of the current study was to compare the effect of a smart-random practice structure compared to a normal random practice structure during video simulation training for the retention and transfer of anticipation skill in tennis. Tennis rallies filmed from a first person perspective were displayed on a life sized screen and the final shot in the rally was occluded. The preceding shots in the rally were presented to groups in either a smart-random or fully random structure during practice. The smart-random structure of practice contained more contextual information, such as opponent tactics and tendencies, because the shots were organised in a tactically relevant manner, when compared to a random structure of practice. Both conditions contained postural cue information, but participants in the random practice group may rely more so on it as the preceding shots in that condition were not organised in a tactically relevant manner. Anticipation performance was measured in a pre-test, laboratory retention test, and field-based transfer test. Both groups were expected to improve their anticipation as a result of the training intervention, but due to the extra available contextual information, the smart-random structure group will demonstrate superior retention when compared to the random structure (Crognier & Féry, 2005; McRobert et al., 2011). Moreover, in the field-based transfer test, both groups were expected to improve anticipation performance from the pre-test, but the smart-random group is predicted to have additional benefits to learning compared to the random structure due to the available contextual information. Finally, cognitive effort was assessed across practice to provide an insight in to the underlying mechanisms of the two structures of practice, particularly the smart-random structure which has not previously been examined. It is predicted that a smart-random practice will require less cognitive effort compared to a random structure of practice as the information available to the participant is structured in a more interpretable manner (Guadagnoli & Lee, 2004)

Method

Participants

Participants were 21 intermediate level tennis players who were divided into either a smart-random practice group (n = 11; M age = 20.7 years, SD = 1.6) or a random practice group (n = 10; M age = 20.9 years, SD = 1.1). Participants in the two groups were matched by ensuring there were no between-group differences in average start age playing tennis (smart-random group: M age = 12 years, SD = 6; random group: M age = 11 years, SD = 6), the average numbers of hours a week they currently played tennis (smart-random group: M hrs/wk = 4 hrs, SD = 3; random group: M hrs/wk = 4 hrs, SD = 2), and their average current LTA rating (smart-random group: M rating = 7.6, SD = 0.6; random group: M rating = 8.1, SD = 0.8). Separate independent t-tests on each of these variables showed no between-group differences (all $t < 1$). Informed consent was obtained from the participants prior to participation. The research was conducted in accordance with the ethical guidelines of Liverpool John Moores University.

Task and apparatus

Figure 4.1 shows the experimental set up for the video and field-based protocols.

Video-based task. Test films were constructed for the video-based task. Films were constructed in, both, a smart-random and random structure for a pre-test, three practice sessions, and a retention test. In each film, 50% of the final shots were groundstrokes, 33% volleys, and 17% smash shots, which is representative of the distribution of final shots in tennis matches (O'Donoghue & Ingram, 2001). Films were shown on a large portable projection screen (2.74 x 3.66 m; Cinefold Projection Sheet, Draper Inc., Spiceland, IN, USA) positioned on a tennis court 4 m from the baseline where the participants stood. The size of the image approximated the proportions normally experienced in game situations when participants are positioned on the baseline of the court.

The films were created by filming intermediate level tennis players from a first person perspective executing tennis rallies. The opponent was located at the far end of the tennis court and the other player was situated slightly behind the baseline. A camera (Canon XM-2, Tokyo, Japan) was positioned on the baseline of the court. Tennis shots were played from behind the camera so that only the opponent appeared in the video footage. Each rally started with a serve from the opponent and then the rally commenced, with a minimum of two other strokes played including the final shot. The two tennis players were informed of the rally sequence to play. Because the importance and prevalence of anticipation in tennis is increased in defensive situations (Triolet et al., 2013), the final shot in each rally was played by the opponent from an offensive situation. The player behind the camera always returned the ball high over the net to the centre of the opponent court, simulating a defensive type of shot. In contrast, the opponent played attacking shots to different areas of the court seeking to win the rally.

The footage was edited using video editing software (Adobe Premier CS5, San Jose, USA). Each trial consisted of video clips of all of the shots from a rally. The start of each trial began with a black screen and the trial number, which appeared for 3 seconds, followed by the initiation of the first video clip. For both groups, the final shot of the rally was the same, and each trial was the same, but the order of the preceding shots was manipulated depending on the group. For the smart-random group, the shots preceding the final shot were structured in a tactically relevant manner. Each rally started with the serve and the subsequent shots were in the same order as the rally occurred during filming. For the random structure group, the preceding shots were randomised so that no rally began with a serve and the penultimate shot was never the same as in the actual rally, making the order of shots different to the actual filmed rally.

In both practice conditions, the shots/clips preceding the final shot contained all ball flight information from the participant side and from the opponent. When the ball flight from the opponent reached the baseline and disappeared off screen behind the camera, the screen went black. In this task, participants held a racket and were instructed that they could move as in a normal tennis match. When the screen went black, the participant was required to respond by simulating a return stroke. These return strokes were used to increase the fidelity of the experiment, rather than as a dependent measure. Following the return stroke, the video started again as the ball flight of the next shot/clip reappeared on screen.

The final shot in the rally was occluded 80 ms before ball-racket contact point and the screen went black. The 80 ms occlusion point was selected based on previous research, which shows shots anticipated at this time point use both postural cue information and contextual information to guide performance (Triolet et al., 2013). At occlusion of the final stroke, the participant simulated a return stroke that indicated their anticipated direction (left/right) and they verbalised the depth of the opponent shot (short/deep). Response accuracy was analysed on the final shot of the rally. Accuracy on the previous shots in the rally were assumed to be correct, as they had returned the ball.

Field-based task. Participants were required to respond to shots played by an opposing intermediate level tennis player on a standard indoor tennis court. The opponent was one of the tennis players used for the video footage in the video-based tests and training films. The lead experimenter briefed the opponent that he was to try and win every point, using different final shot strokes (groundstroke, volley, smash) and to only count a successful rally as one where he won the point from an offensive position. The participant always received the serve and then the rally commenced. A rally was deemed suitable for use when the opponent was in an offensive situation on the final shot, the final shot was in the court, and the number of shots in the rally was equal to or greater than three strokes. The participant was told to complete rallies against the opponent with the rally ending once the point was won.

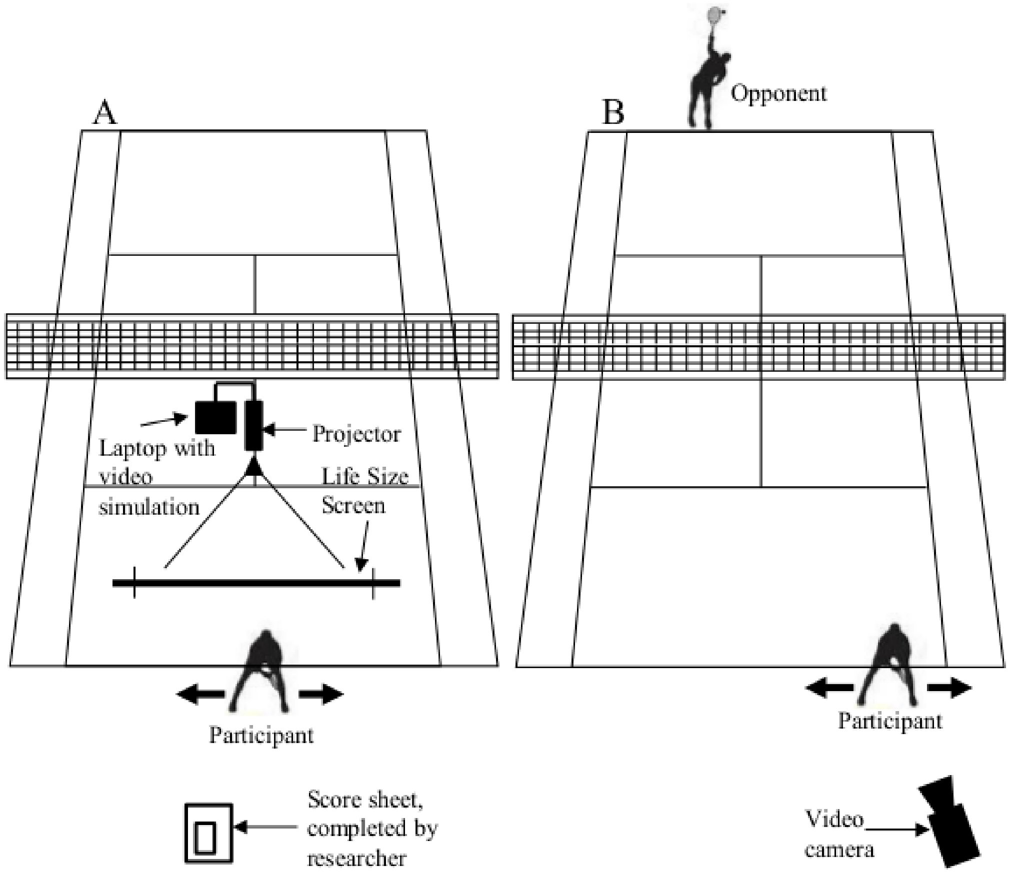

Figure 4.1: The experimental setup used in (A) laboratory-based protocol and (B) field-based protocol

Procedure

The experiment consisted of pre-tests in the laboratory and field, three video-simulation practice sessions, a video-based retention test, and a field-based transfer test. The pre-test and practice sessions were completed on the first day and the laboratory retention test and field-based transfer test was completed seven days later.

Laboratory pre-test and retention test. Participants completed the video-based task in the laboratory pre-test and retention test. The films made for the pre-test and retention test contained 36 trials. The pre-test and retention test were split into two blocks of 18 trials, with one structured in a smart-random order and one in a random order, so as not to favour either group. Both tests took approximately 15 minutes each to complete.

Field pre-test and transfer test. Participants completed the field-based task during the field-based pre- and retention test. For each participant, 18 rallies were selected from those that occurred and were deemed suitable. Participant responses were filmed using a video camera (Canon XM-2, Tokyo, Japan) with wide angled lens and a sampling frequency of 50 Hz. The camera was located behind and to the right of the participant. It recorded the moment of opponent racket/ball contact and the movements of the participant. The pre-test and the field-based transfer test took approximately 30 minutes each.

Practice phase. Three video-simulation practice sessions occurred directly after the laboratory and field pre-tests. Participants completed the video-based task as per the laboratory pre- and retention test, but they received feedback following their response. No verbal instructions were given regarding the information on screen or participant movements or responses. Each training session consisted of 24 trials and took approximately 15 minutes to complete. Across practice, the Rating Scale of Mental Effort (RSME) was used to assess the amount of cognitive effort participants perceived they had invested in the anticipation task (Zijlstra, 1993).

Dependent Measure and Statistical Analysis. For the video-based protocols, RA was the primary dependent variable. RA was recorded on only the final shot of the rally/trial. There were three different types of RA; direction, depth, direction + depth. Accurate direction is when the participant movement responses were to the same side (left, right) as where the ball bounced. Accurate depth was when participant verbal responses (short, deep) matched where the ball bounced. Accurate direction + depth involves a combination of both the previous definitions, making four possible responses (left short, left deep, right short, right deep). In the field-based tests, RA and DT were the primary dependent variables. As with the video-based protocol, RA was recorded on only the final shot of the rally. However, in the field-based protocol, only shot direction was analysed, as incorporating depth was not possible because the ball usually travelled through to the participant no matter if it bounced short or deep. DT was defined as the time period from ball-racket contact by the opponent to the initiation of movement by the participant (ms). 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' (Triolet et al., 2013, pp. 822). A response initiated prior to ball contact received a negative value. Footage of the field tests were analysed using video editing software (Adobe Premier CS5). Inter- and intra-observer reliability measures were obtained for DT by using intraclass correlation techniques (Atkinson & Nevill, 1998) on all of the data from two participants, one from each group. The obtained correlation coefficients for the inter- (.961) and intra-observer (.909) measures demonstrated the data analysis was reliable.

RA in the video-based pre-test and retention test were analysed separately to the practice session data. Separate analysis was conducted for RA in the video-based tests and practice sessions for direction, depth, and direction + depth. RA across practice was analysed using a 2 Group (smart-random, random) x 3 Practice Session (practice 1, practice 2, practice 3) mixed design ANOVA with repeated measures on the last factor. To analyse RA in the video-based pre- and retention test a 2 Group (smart-random, random) x 2 Test (pre, retention) x 2 Practice Condition (smart-random, random) mixed design ANOVA with repeated measures on the last factor was used. To analyse RA and DT in the field pre- and retention test, a 2 Group (smart-random, random) x 2 Test (pre, retention) mixed design ANOVA with repeated measures on the last factor was used. Analysis for DT was not only conducted on the final shot of the rally, but also on the average DT of all the shots in the rally to provide a more global representation for the overall improvements in anticipation.

RSME data across practice were analysed using a 2 Group (smart-random, random) x 3 Practice Session (practice 1, practice 2, practice 3) mixed design ANOVA with repeated measures on the last factor. RSME data were converted into a percentage score for descriptive statistics. The Bonferroni *post hoc* procedure was used for any significant within-participant main effects. The Fisher Least Significant Difference (LSD) *post hoc* procedure was used for any significant interactions. The alpha level for significance was set at $p < .05$ for all tests.

Results

Figure 4.2 shows mean RA (a) direction (b) depth (c) depth + direction, for the two groups on the pre-test (smart-random, random), three practice sessions, and the retention test (smart-random, random).

Laboratory Pre- and Retention Test

Direction. The 2 Group x 2 Test x 2 Condition ANOVA revealed a significant main effect for test, F (1, 19) = 13.93, $p < .01$, $\eta_p^2 = .42$. Pairwise comparisons indicated that directional RA in the retention test (M = 64%, SD = 8) was significantly higher than in the pre-test (M = 55%, SD = 9), $p < .01$. There was a Test x Condition interaction, F (1, 19) = 22.02, $p < .01$, $\eta_p^2 = .54$, and a three-way Group x Test x Practice Condition interaction, F (1, 19) = 14.35, $p < .01$, $\eta_p^2 = .43$. *Post hoc* analysis indicated no difference between the groups at pre-test in the smart-random (smart-random: M = 49%, SD = 15, random: M = 55%, SD = 16) and random condition (smart-random: M = 59%

SD = 12, random: *M* = 56%, *SD* = 7). However, in the smart-random condition in the retention test, the smart-random group (*M* = 79%, *SD* = 8) were significantly more accurate than the random group (*M* = 65%, *SD* = 13). In the random condition on the retention test, the random group (*M* = 62%, *SD* = 8) were significantly more accurate than the smart-random group (*M* = 50%, *SD* = 12). There were no other significant main effects or interactions ($p > .05$).

Depth. The 2 Group x 2 Test x 2 Condition ANOVA revealed a significant main effect for practice condition, F (1, 19) = 17.31, p <.01, η_p^2 = .48. Pairwise comparisons indicated that depth RA in the random condition (*M* = 63%, *SD* = 10) was significantly higher than in the smart-random condition (*M* = 51%, *SD* = 10), $p < .01$. There was also a Group x Test interaction, F (1, 19) = 6.72, p =.02, η_p^2 = .26. *Post hoc* analysis indicated that the random group significantly improved in RA from the pre- (*M* = 51%, *SD* = 9) to retention test (*M* = 60%, *SD* = 8), whereas the smart-random group showed no difference between the pre- (*M* = 60%, *SD* = 5) and retention tests (*M* = 57%, *SD* = 4). There were no other significant main effects or interactions ($p > .05$).

Depth + Direction. 2 Group x 2 Test x 2 Condition ANOVA revealed a significant main effect for test, F (1, 19) = 7.98, p =.01, η_p^2 = .30. Pairwise comparisons indicated that RA in the retention test (*M* = 37%, *SD* = 8) was significantly higher than in the pre-test (*M* = 31%, *SD* = 8), $p < .01$. There was also a Test x Condition interaction, F (1, 19) = 7.31, p =.01, η_p^2 = .28. *Post hoc* analysis indicated that the smart-random condition in the pre-test (*M* = 26% *SD* = 9) was significantly lower than the smart-random condition in the retention test (*M* = 37% *SD* = 10), whereas the random condition in the pre- (*M* = 35% *SD* = 13) and retention test (*M* = 37% *SD* = 11) were not significantly different. There were no other significant main effects or interactions ($p > .05$).

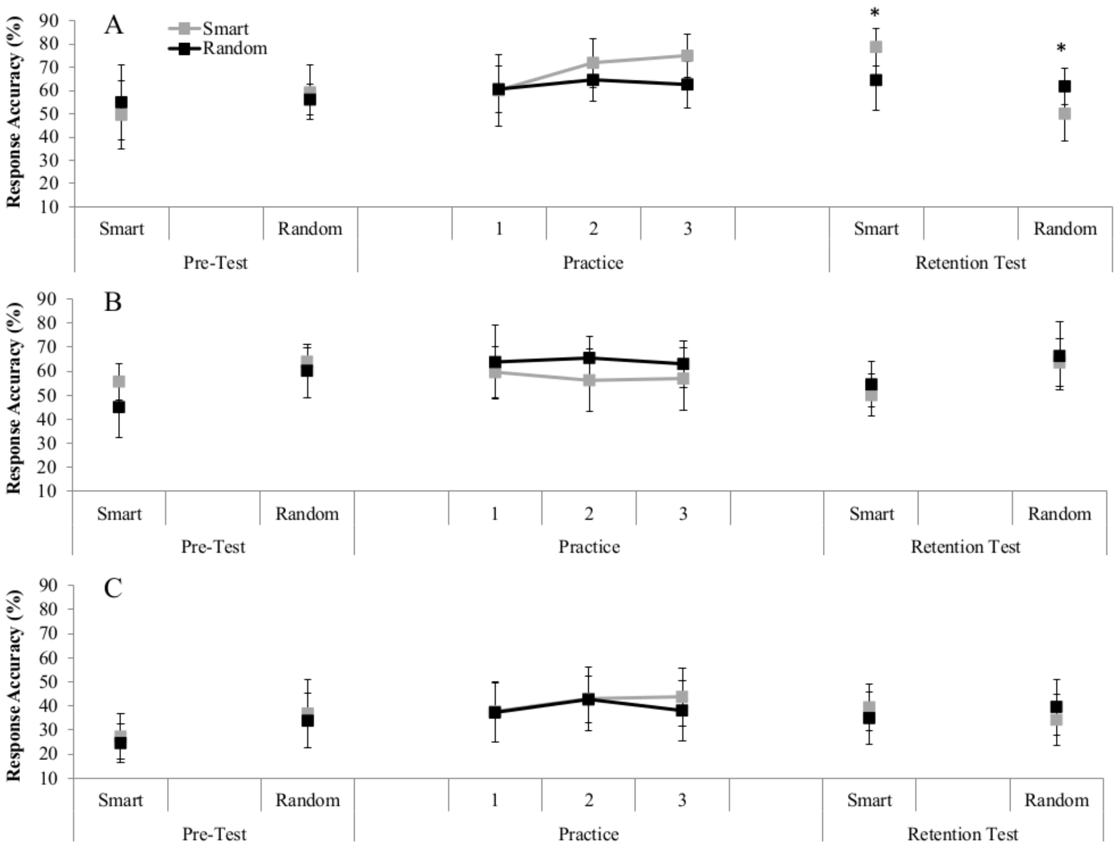

Figure 4.2: Mean (and SD) response accuracy (RA; %) in (A) direction (B) depth (C) depth + direction, for the two groups on the pre-test (smart-random, random), practice 1-3, and the retention test (smart-random, random). *$p < .05$

Field Pre- and Transfer Test

Figure 4.3 shows mean DT in (a) all the shots and (b) the final shot, for the two groups (smart-random, random) on the pre-test and the retention test.

Response accuracy. The 2 Group x 2 Test ANOVA revealed a significant group main effect, F (1, 19) = 10.16, p = .01, η_p^2 = .35. Pairwise comparisons indicated that RA for random group (M = 97%, SD = 4) was significantly higher compared to the smart-random group (M = 93%, SD = 6), albeit that this is only a one trial difference. There were no other significant main effects or interactions (p > .05).

Decision time. For all shots, the 2 Group x 2 Test ANOVA revealed no significant group main effect, F (1, 19) = .78, p = .39, η_p^2 = .04. However, there was a significant main effect for test, F (1, 19) = 19.40, p < .01, η_p^2 = .51. Pairwise comparisons indicated that DT in the retention test (*M* = 290ms, *SD* = 41) was significantly faster than in the pre-test (*M* = 324ms, *SD* = 39). There was also a Group x Test interaction, *F* (1, 19) = 4.27, *p* = .05, η_p^2 = .18. *Post hoc* analysis indicated that the smart-random group significantly reduced their DT from pre- (*M* = 325ms, *SD* = 29) to retention test (*M* = 275ms, *SD* = 31), whereas the random group showed no significant improvements from pre- (*M* = 323ms, *SD* = 50) to retention (*M* = 305ms, *SD* = 46).

For the final shot, the 2 Group x 2 Test ANOVA revealed no significant group main effect, *F* (1, 19) < .01, *p* = .98, η_p^2 < .01. However, there was a significant main effect for test, *F* (1, 19) = 19.92, *p* < .01, η_p^2 = .51. Pairwise comparisons indicated that DT in the retention test (*M* = 164ms, *SD* = 93) was significantly faster than in the pre-test (*M* = 253ms, *SD* = 70). There were no other significant main effects or interactions (*p* > .05).

Practice

Direction. The 2 Group x 3 Practice Session ANOVA revealed a group main effect, *F* (1, 19) = 7.77, *p* = .01, η_p^2 = .29. Pairwise comparisons indicated that RA in the smart-random group (*M* = 69%, *SD* = 13) was significantly higher than in the random group (*M* = 63%, *SD* = 10). There was also a significant session main effect, *F* (2, 38) = 3.35, *p* =.05, η_p^2 = .15. *Post hoc* analysis indicated that RA in the first practice session (*M* = 60%, *SD* = 13) was significantly lower than in the second (*M* = 68%, *SD* = 11) and third practice session (*M* = 69%, *SD* = 11). There was no interaction between Group and Session (*p* > .05).

Depth. The 2 Group x 3 Practice Session ANOVA revealed a group main effect, *F* (1, 19) = 6.50, *p* =.02, η_p^2 = .26. Pairwise comparisons indicated that RA in the random group (*M* = 64%, *SD* = 11) was significantly higher than in the smart-random group (*M* = 58%, *SD* = 12). There was no significant main effect for session or interaction (*p* > .05).

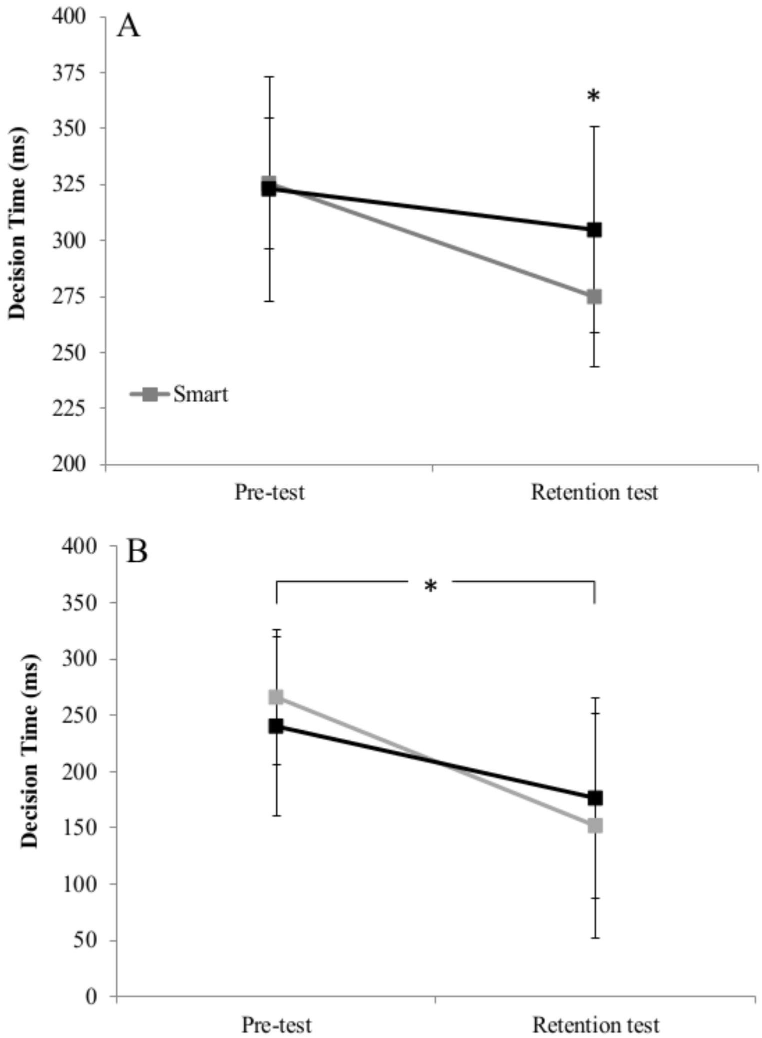

Figure 4.3: Mean (and SD) decision time (DT; ms) in (A) all shots (B) and final shot, for the two groups (smart-random, random) on the pre-test and the retention

Direction + depth. 2 Group x 3 Practice Session ANOVA revealed no group main effect, F (1, 19) = .76, p =.39, η_p^2 = .04, no main effect for phase, F (2, 38) = .90, p =.42, η_p^2 = .05, and no Group x Phase interaction, F (2, 38) = .29, p =.75, η_p^2 = .02.

Rating scale of mental effort

Practice. The 2 Group x 3 Practice ANOVA revealed a significant group main effect, F (1, 19) = 6.66, p = .02, η_p^2 = .26. Pairwise comparisons indicated that cognitive effort was significantly higher for the random group (M = 85, SD = 15) compared to the smart-random group ($M = 69$, $SD = 15$). There was no significant main effect for session or interaction ($p > .05$).

Discussion

In the current study, simulated tennis rallies were used to examine the role of contextual information during an anticipation task. Participants viewed the rallies in either a smart-random or random practice structure. Anticipation performance was measured over a pre-test, three practice sessions, a laboratory retention test, and a field-based transfer test. In the laboratory retention test, both groups were expected to improve performance compared to the pre-test. However, it was predicted that the smart-random structure group would have additional benefits to learning and, therefore, demonstrate superior RA in the retention test when compared to the random group. Similarly, in the field-based transfer test it was predicted that both groups would reduce DT following practice, but the smart-random group would demonstrate faster DT compared to the random group. Using the RSME we examined cognitive effort across practice and it was predicted that the smart-random group would require less cognitive effort as the information available is in a more interpretable manner compared to a random structure of practice.

Retention of learning

Analysis of RA in the laboratory-based setting was separated into direction, depth, and depth + direction. The RA direction results supported the hypotheses as both groups improved RA from the pre- to retention test. Furthermore, the smart-random group, who trained with the addition of contextual information, were superior to the random group under the smart-random retention condition, demonstrating the extended benefits of training with context-specific information (McRobert et al., 2013). However, the smart-random structure group reverted back to their pre-test RA level under the random retention condition, suggesting an overreliance on contextual information and demonstrating that the training adaptations are constrained to context-specific situations. In comparison, there were no significant differences for the random group in the two retention conditions. It may be the random group used advanced postural cues to select their responses as their practice condition contained low amounts of contextual information. Therefore performance would not be different under the two retention conditions, regardless of tactical information available, as postural cue information was available in both. These data provide some support for previous research demonstrating the benefits of advanced postural cue training (Williams et al., 2002; Smeeton et al., 2005; Broadbent, Causer, Ford, et al., 2014). The findings highlight the importance of contextual information during training and the significance it has on achieving optimal performance in context-specific conditions (McRobert et al., 2013). They have direct implications to the applied world as they demonstrate the role of information available and task constraints simulating court match play for performance (Pinder et al., 2011).

In contrast, RA for depth and depth + direction contradicted the hypotheses. For depth, the random group improved accuracy from pre- to retention, whereas the smart-random group showed no significant improvements. For depth + direction, both groups improved performance from pre- to retention test, but no between-group differences were found. Previously in studies investigating anticipation skills in tennis, depth and direction have been investigated as dependent variables and have not had an effect on performance due to the conditions of practice (e.g. Broadbent, Causer, Ford, et al., 2014). However, in an actual tennis match, a player will rarely have to predict the precise bounce location and typically players will attempt to predict the ball-racket contact point near, or on, the baseline (Triolet et al., 2013). For direction, the prediction of bounce location will be the same as predicting this interception point. In contrast, when predicting depth the bounce location could be “short” but the interception point could be “deep” due to the force and angle of the opponents shot causing the ball too often travel deeper. Therefore, in previous studies where the structure of practice has not represented an actual match then the prediction of depth has not affected performance. However, in the current study a smart-random structure of practice replicated more closely the processes that occur naturally during tennis, thus causing the prediction of depth for bounce location more difficult compared to if the shots were separate as in random practice. The findings highlight the importance of capturing the true task demands when designing a representative task for perceptual-cognitive skill training (Dicks et al., 2009; Pinder et al., 2011b).

Transfer to the field

The current study also examined the transfer benefits of the two practice conditions to a field-based task. In the field-based protocol, RA on the final shot of each rally did not improve from pre- to retention test. As in previous studies, with field-based transfer tests, RA was over 90% correct for both groups in the pre- and retention test, suggesting a ceiling effect (e.g. Broadbent, Causer, Ford, et al., 2014). In field-based tasks, RA is often very high compared to laboratory-based protocols, as athletes have full, rather than occluded, vision. Full vision allows athletes to have access to a richer and more detailed visual display, as well as other key environmental information, such as sounds and proprioceptive feedback. Therefore, in field-based protocols DT is normally examined. In the current experiment, DT was analysed for all the shots in the rally collapsed and the final shot separately.

Data from all the shots collapsed revealed that both groups improved from pre- to retention test. However, the smart-random group had significantly reduced DT in the retention test compared to the random group. This finding demonstrates the importance of contextual information during video simulation training for improving the transfer benefits of anticipation to the field. The suggestion is that simulation protocols that include contextual information allow for the development of action plan profiles and current event profiles (McPherson & Kernodle, 2007). These profiles reduce the time required to encode and retrieve information from long-term memory and, thus, reduces the time to make decisions during simulated match play (Ericsson et al., 1993). Further analysis for DT on the final shot showed that both groups reduced DT from pre- to retention test, but there were no between-group differences. This finding suggests that training in which participants mainly use advanced postural cues has the same transfer benefits than training with contextual information for the final shot in the rally. This supports previous work that shows the transfer benefits of perceptual-cognitive skill simulation training for individual shots (Broadbent, Causer, Ford, et al., 2014; Williams et al., 2002; Smeeton et al., 2005).

Practice

Across practice, analysis of RA was separated into direction, depth, and direction + depth. For direction, RA increased across practice for both groups, however, the smart-random structure group were significantly more accurate than the random group, supporting previous research showing that a random schedule of practice results in a greater amount of errors across practice (Broadbent, Causer, Ford, et al., 2014; Broadbent et al., in prep). The depth analysis showed no significant improvement across practice; however, the random group were significantly more accurate compared to the smart-random structure group. This finding supports the previous explanation that predicting the depth of bounce location was more difficult for the smart-random structure group as it is not a process that is usually required during actual competition (Triolet et al., 2013). Analysis on direction + depth revealed no significant improvement across practice. This latter finding suggests that the task may have been too difficult for the participants, possibly due to the unnatural processes of predicting direction + depth during tennis. This finding has important implications for future research using video-based simulation techniques as benefits of learning can be found for a smart-random structure of practice, but only if the appropriate response is selected based on the natural processes that occur in an actual match scenario.

Across practice, data from the RSME indicated that cognitive effort was significantly higher for the random group compared to the smart-random group. This finding supports previous research on the CI effect that shows a random schedule of practice results in increased cognitive effort (Broadbent, Causer, Ford, et al., 2014; Broadbent et al., in prep). Furthermore, it supports hypotheses stating that less cognitive effort is required when the information available is structured in a more interpretable manner (Guadagnoli & Lee, 2004). The suggestion is that due to the context-specific nature of a smart-random schedule of practice, and its more interpretable information, some of the cognitive processes involved for these skilled participants may have been completed relatively automatically and, therefore, with less cognitive effort (Logan, 1988; Shiffrin & Schneider, 1977). In comparison, a random schedule of practice has increased interference, and less context, so the participants will have to use a greater amount of cognitive effort to process the available information (Lee, 2012). While a random schedule of practice promotes long-term learning, through increased cognitive effort, a smart-random structure of practice appears to require less cognitive effort but that have additional learning benefits (McPherson, 1999a, 1999b, 2000, 2008; McPherson & Thomas, 1989).

Conclusion

In summary, novel data are reported showing that video-simulation training containing contextual information increases the retention and transfer of perceptual-cognitive skill in sport. A smart-random structure of practice resulted in superior anticipation on the video-based retention test compared to a random schedule of practice. Furthermore, in a transfer test to a field-based protocol, while both groups demonstrated reduced DT on the final shot of the rally, a smart-random structure of practice resulted in reduced DT across the whole of the rally. In addition, the findings contradict previous research advocating the use of increased cognitive effort across practice to promote learning (Lee et al., 1994), whereas they support the idea that information should be structured in an interpretable manner and at an appropriate level of challenge for the performer (Guadagnoli & Lee, 2004). The findings suggest that context-specific information during practice, some of which may be processed automatically, allows for the development of more efficient memory structures that benefit performance in the applied setting (McPherson & Kernodle, 2007).

Chapter 5:

Epilogue

This chapter will synthesise the work presented in the thesis and discuss the theoretical and applied implications. An outline of potential limitations of the studies will be included throughout, as well as directions for future research.

Aims of the thesis

The aim of the current thesis was to investigate the effect of different practice conditions on the retention and transfer of perceptual-cognitive skill in sport, specifically anticipation in tennis. Previous research on perceptual-cognitive skill training has examined the effect of skill level (Hagemann et al., 2006), age (Caserta, Young, & Janelle, 2007), instructional approaches (Smeeton et al., 2005), and anxiety (Oudejans & Pijpers, 2009). However, researchers are yet to examine how practice should be structured during simulation training to facilitate skill acquisition, despite the widespread use of this method (Causer et al., 2012). In the current thesis two concepts concerning different structures of practice were investigated; the CI effect (Chapter 2 and 3) and contextual information (Chapter 4). The thesis examined these concepts from a theoretical and applied perspective by investigating the cognitive effort underlying the different conditions and the transfer benefits of the practice structures to a field-based setting, respectively.

Across the experiments, participants were required to anticipate shot location when viewing a life-sized video of opponents playing three distinct tennis skills occluded around ball-racket contact and filmed from a first person perspective. In each experiment, the task was administered in a pre-practice-retention-transfer test design, with the practice phase containing different practice orders for the three skills. In Chapter 2 and 4 the transfer test was to a field-based protocol, while in Chapter 3 the transfer test was to a novel structure of practice in the laboratory. In Chapter 2, the CI effect from the motor learning literature was investigated by comparing a blocked and random schedule of practice. Subsequently, Chapter 3 investigated the underlying mechanisms of the CI effect. In two experiments, cognitive effort was examined for blocked and random schedules of practice in accordance with the two main theories from the CI literature, the elaborative processing hypothesis and the action plan reconstruction hypothesis. Both theories detail how greater cognitive effort occurs during random practice compared to blocked ordered practice, leading to the observed performance and learning differences. In the CI effect, cognitive effort during random practice is thought to be a result of task switching (Magill & Hall, 1990), but cognitive effort has also been linked to error processing (Lam et al., 2010). Therefore, an additional explanation for the CI effect was forwarded by investigating the role of error processing as an underlying mechanism. Finally, Chapter 4 investigated, for the first time, the role of contextual information during perceptual-cognitive skill training. A smart-random practice order that contained greater contextual information was compared to a traditional random practice order, to determine its effects on the retention and transfer of anticipation skill in tennis. The final shot in each sequence was the same between conditions and was occluded prior to ball-racket contact point. However, the smart-random structure contained the order of shots found in a tennis 'rally', whereas the traditional random order did not resemble a 'normal' tennis rally structure and presented the preceding shots in a random order.

Summary of key findings

The CI effect shows that a blocked schedule of practice results in better performance during practice, whereas random practice leads to better retention and transfer of skill (Shea & Morgan, 1979). In Chapter 2 and 3, the CI effect was shown to extend to the retention and transfer of perceptual-cognitive skills training in sport. In Chapter 2, the CI effect was demonstrated as the random practice group had greater response accuracy scores on the laboratory retention test compared to the blocked group. Moreover, in Chapter 2, the decision times of the random practice group were faster compared to the blocked group in a field-based transfer test. In Chapter 3, the CI effect was found in two experiments as the blocked groups made more accurate anticipation judgments during practice, whereas the random groups were superior on the laboratory-based transfer test to a different structure of practice. However, in Chapter 4, smart-random practice orders that contained contextual information were shown to benefit skill acquisition above and beyond a random structure of practice. A smart-random practice structure led to more accurate anticipation judgements in a retention test and faster overall decision times in a transfer test when compared to a traditional random schedule of practice. These findings show, for the first time, the advantage of contextual information during video simulation training for the retention and transfer of anticipation skills to a real-life setting (McPherson & Kernodle, 2003, 2007).

In Chapter 3, the underlying mechanisms of the CI effect were examined in perceptual-cognitive skill training. In Experiment 1, cognitive effort was examined using a probe reaction time task, involving responses to tones across the preparation and feedback phase of a trial. In Experiment 2, cognitive effort was manipulated for two additional practice order groups by inserting the cognitively demanding Stroop test into the inter-trial interval. Experiment 1 showed that cognitive effort during practice was greater in random practice compared to blocked practice groups in both the preparation and feedback phase of a trial. In Experiment 2, the additional cognitive effort between trials promoted learning for a blocked practice order, but reduced learning for a random practice order. These findings support a combination of both the elaborative processing hypothesis and action plan reconstruction hypothesis (Lee, 2012). Furthermore, following an error, the random practice groups exhibited greater cognitive effort in the preparation phase (Experiment 1) and inter-trial interval (Experiment 2) compared to errorless trials, whereas the blocked groups showed no difference between errorless and error trials. In summary, these two experiments provide an alternative account of the underlying mechanisms associated with the CI effect by suggesting that the increased cognitive effort during random practice is not only associated with switching tasks, but is due to error processing in conjunction with task switching.

This section has provided a synthesis of the key findings from Chapters 2, 3 and 4. The subsequent sections will discuss the theoretical and applied implications of these findings, as well as the potential limitations of this research and future directions.

Theoretical implications

From a theoretical perspective this thesis investigated three concepts from the literature; the CI effect, contextual information, and the role of cognitive effort during practice.

Contextual Interference Effect

The CI effect refers to how a random structure of practice facilitates superior learning compared to a blocked structure of practice. The CI effect has been replicated in many studies across various contexts and domains as described in several review articles (Brady, 1998, 2008; Lee, 2012; Magill & Hall, 1990; Merbah & Meulemans, 2011). However, researchers have not examined how practice should be structured during video-based simulation so that learners acquire fast and dynamic perceptual and cognitive skills that transfer to more ecologically valid situations (Causer et al., 2012). Chapter 2 demonstrated that the CI effect extended to this new domain as a random schedule of practice led to superior retention of anticipation skill compared to a blocked schedule (Shea & Morgan, 1979). Furthermore, it was demonstrated for the first time that for intermediate tennis players the CI effect increases transfer of learning from video simulation training to a field-based task, highlighting the importance of using appropriate practice schedules during video simulation training (Causer et al., 2012). These findings contradict the study by Memmert et al. (2009) who found no group differences between a blocked and random schedule of practice for the training of anticipation skills in badminton. However, the experimental design of the Memmert et al. study was flawed as the task was only a single shot in badminton, the overhead stroke, and the landing location of the shuttlecock was manipulated. By definition, this task design bears greater resemblance to variable practice because CI is the scheduling of practice for a number of *different* skills, not a single skill (Magill & Hall, 1990). Therefore, the current thesis used three distinct tennis skills structured in a blocked or random schedule and verified for the first time that the CI extends to perceptual-cognitive skills training. Overall, the current thesis shows support for the generalizability of the CI effect and adds to the ever growing literature base surrounding the concept (Lee, 2012).

Underpinnings of the Contextual Interference Effect

The findings from Chapter 2 provided a rationale to investigate whether the underlying cognitive mechanisms found for the CI effect in motor learning extend to the perceptual-cognitive domain. While there is much previous work investigating the underlying mechanisms of the CI effect, researchers have still not yet agreed on the exact processes involved. The two main theories forwarded to explain the CI effect are the elaborative processing hypothesis (Shea & Zimny, 1983, 1988) and the action plan reconstruction hypothesis (Lee & Magill, 1983, 1985). Researchers have previously viewed the two theories as separate entities (for exception, see Li & Wright, 2000). While the two theories differ on the exact mechanisms involved, both agree that the superior learning of a random schedule of practice is due to increased cognitive effort compared to blocked practice (Lee et al., 1994). Chapter 3 investigated these hypotheses by examining and manipulating cognitive effort across two experiments. These two experiments indicate that the two theories may not be mutually exclusive and that the increased cognitive effort during a random schedule of practice, compared to blocked practice, may be due to both elaborative and reconstructive processes combined (Li &

Wright, 2000; Young, Cohen, & Husak, 1993). In Chapter 3 cognitive effort was greater in both the preparation and the feedback phase, which are linked to the action plan reconstruction and the elaborative processing hypothesis, respectively (Li & Wright, 2000). Furthermore, Chapter 3 showed that increasing cognitive effort in the inter-trial interval promoted reconstructive activity for the blocked group and benefited learning, but also disrupted elaborative processing for the random group and had detrimental effects on learning. This suggests that, prior to a trial, random practice promotes reconstructive activities due to 'forgetting' occurring as a function of task switching, but this process does not occur for a blocked practice group (Cross et al., 2007; Lee & Magill, 1983, 1985). Following a trial, a random schedule of practice allows for inter- and intra-task comparisons, which promotes elaborative processing compared to the repetitive nature of blocked practice (Lin et al., 2008; Lin et al., 2009; Lin et al., 2010).

Chapter 3 further investigated the underlying mechanisms of the CI effect by proposing a novel hypothesis involving error processing. Greater cognitive effort is found following an error, compared to an errorless trial, as the performer attempts to identify discrepancies between the actual outcome and the desired goal, generating rules for the task (Rabbitt, 1966, 1967). While the importance of cognitive effort for a random schedule of practice has been substantiated in the literature, the role of error processing in the CI effect has not been previously researched. The findings from Chapter 3 demonstrated that for a random schedule of practice, cognitive effort was greater following an error compared to following an errorless trial in the execution phase, the preparation phase and the inter-trial interval. However, for a blocked schedule of practice no difference in cognitive effort was found between error and errorless trials. The execution phase involves the monitoring and controlling of the response and the suggestion from the current thesis is that the more cognitive effort spent on these processes the greater the learning potential (Lam et al., 2010). However, Experiment 2 in Chapter 3 demonstrates that too much cognitive effort can interrupt the monitoring and controlling of the response during the execution phase and can have detrimental effects on overall learning.

The data concerning error processing in the preparation phase and the inter-trial interval can be explained by combining theories from the error processing and the CI literature to produce an additional account for the CI effect. Following an errorless trial during random practice, performers switch tasks and complete reconstructive processes in the preparation phase to retrieve the rules for the upcoming task (Lee & Magill, 1985). In comparison, a blocked schedule of practice does not require these reconstructive activities as there is no task switching. These processes for a random schedule of practice will elicit greater cognitive effort compared to a blocked schedule. However, following an error, additional processes occur in the preparation phase and inter-trial interval, which further differentiate the cognitive effort of the two groups. In the inter-trial interval following an error, both groups identify discrepancies between the actual outcome, previous trials and the desired goal in order to update the rules for the previous task and store them (Maxwell & Masters, 2004). For a blocked schedule of practice this process involves intra-task comparisons, whereas for a random schedule of practices intra- and inter-task comparisons would occur causing additional elaborative processes that increase the cognitive effort required (Shea & Zimny, 1988). Moreover, the inter-trial interval is relatively short, so for the random practice group the updating and storage of rules would most likely overlap with the preparation phase in which reconstructive activities occur (Lee et al., 1997). The alternative explanation forwarded in Chapter 3 for the CI effect suggests that it is not solely the switching of tasks during random practice that causes the additional cognitive effort. Instead, it is proposed that error processing in conjunction with reconstructive and elaborative processes caused by switching tasks results in the greater cognitive effort and superior learning for a random compared to a blocked schedule of practice.

Contextual Information

While the benefits of a random schedule of practice have been demonstrated comprehensively (Lee, 2012), researchers are yet to investigate the importance of contextual information on perceptual-cognitive skill simulation training. Previous research has shown that contextual information acts as a constraint on expertise (McRobert et al., 2011; Crognier & Fery, 2005), but no researchers have examined whether contextual information can improve skill acquisition. In Chapter 4, simulated tennis rallies were used to create a smart-random practice schedule that contained contextual information of previous shots and opponent tendencies. In contrast, a traditional random schedule of practice contained the preceding shots in a random order that contained less contextual information, with participants under that condition likely to only have access to postural cue information. Both groups improved performance in the laboratory-based retention test and this transferred to improved field-based performance. However, the smart-random structure of practice led to greater retention and transfer performance compared to the traditional random group. These findings suggest that while training anticipation skills in a random order promotes learning (Broadbent, Causer, Ford, et al., 2014), a smart-random structure of practice that contains contextual information has additional learning benefits (McRobert et al., 2011).

The data from Chapter 4 supports predictions surrounding memory adaptations for skilled performers (Ericsson & Kintsch, 1995). They have more advanced memory structures compared to novice performers that allow for a more efficient encoding and retrieval of information from LTM and more elaborate cognitive representations during tasks (McPherson, 1993). These memory adaptations have been termed action plan profiles and current event profiles (McPherson, 1999a, 2000). During a task, action plan profiles provide rule-governed prototypes that match the situation with appropriate visual and motor actions. Current event profiles are constantly evolving during the task to provide tactical scripts for context specific situations (McPherson, 1999b). The findings in Chapter 4 suggest that for intermediate tennis players simulated training with contextual information allowed for the development of action plan profiles and current event profiles, which the traditional random practice group could not acquire (McPherson & Kernodle, 2003). Therefore, following the simulation training, in the field-based protocol the smart-random group demonstrated reduced decision time compared to the random group, as the ability to encode and retrieve information from LTM had been improved (Ericsson et al., 1993).

Some key concepts surrounding the findings in Chapter 4 are specificity of practice or transfer appropriate processing (Barnett et al., 1973; Lee, 1988). These hypotheses hold that transfer of skill from one environment to another depends not on superficial similarities between tasks, but rather that the same processes take place in each (Eich, 1995). Therefore, information processing during practice should be the same as that in the retention and transfer test, which in sport is the competition activity. When the processing is the same between practice and retention or transfer tests, the effectiveness of practice may be maximised. The current thesis provides support for this idea as a smart-random structure of practice transferred more effectively than a random schedule of practice to a field-based protocol. While the notion of specificity is already fundamental to training in the biological sciences, with training replicating the demands placed on the body in a real match situation (Elliott & Mester, 1998; Reilly, 2005), the current thesis is one of the first to investigate this concept in perceptual-cognitive skill simulation training (see also, Williams, Ward, Ward, & Smeeton, 2008).

Cognitive Effort

During practice, information must be held in either STM or LTM so that it is available for use by working memory when required (Baddeley, 2000). Some tasks require more information to be held than others depending on many factors, such as the difficulty of the task or skill level of the participant. The more information that needs to be retrieved and processed, the more cognitive effort required for the task (Gathercole, 1999). The current thesis indicates that different structures of practice require varying amounts of cognitive demand for the learner (Lee et al., 1994). The skill being learnt in this thesis remained the same across each chapter, the only difference being the order in which the participants viewed the three different tennis strokes that they had to anticipate. A blocked structure of practice resulted in lower cognitive effort compared to the random schedule of practice for novice participants in Chapter 3. Previous research and the current thesis propose that a random schedule of practice increases cognitive effort compared to blocked practice due to the interference caused by task switching (Lee et al., 1994) and error processing (Chapter 3). The increased cognitive effort during a random schedule of practice is suggested to cause a detriment to performance during practice, but underpins the superior learning found in the CI effect (Lee, 2012). However, Chapter 4 indicated that for skilled participants a smart-random condition of practice results in superior learning compared to a random schedule of practice, but may require *less* cognitive effort. These findings from Chapter 4 suggest that it is not only how much information cognitive effort the condition promotes, but it is also important how interpretable the information is for the individual and how close the practice condition replicates the decision making processes that occur naturally in the real-life setting (Barnett et al., 1973; Lee, 1988).

Challenge point

The data from this thesis support the challenge point framework discussed in Chapter 1. The framework suggests that practice conditions vary in functional task difficulty and, therefore, provide different learning potentials (Guadagnoli & Lee, 2004). The current thesis provides an insight into the optimal challenge point for video simulation training for anticipation in tennis for intermediate and novice participants. The conditions of practice were manipulated in this thesis so that the nominal task difficulty remained relatively the same throughout, but the functional task difficulty differed between the practice conditions. In Figure 5.1, the five different practice conditions examined in this thesis are plotted onto the inverted-U line from the challenge point framework showing their functional task difficulty and learning potential (Guadagnoli & Lee, 2004).

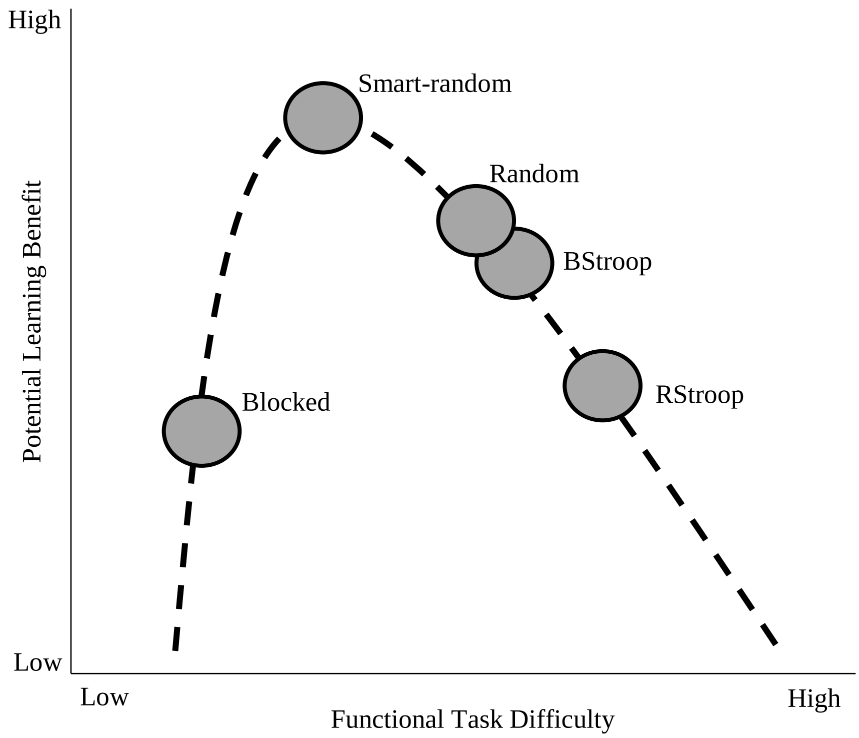

Figure 5.1: The five conditions of practice examined in this thesis (blocked, random, BStroop, RStroop, smart-random) plotted on to the inverted-U curve from the challenge point framework (Guadagnoli & Lee, 2004)

In terms of the challenge point framework and the classic CI effect, traditional random practice increases functional task difficulty when compared to blocked practice. The increase in functional task difficulty results in increased cognitive effort through reconstructive and elaborative processes, which ultimately leads to increased learning.

In Chapter 3, inserting a cognitively demanding task into a blocked and random schedule of practice increased the functional task difficulty for both novice groups. For the BStroop group, an increase in available information promoted reconstructive processes in the preparation phase, thus increasing cognitive effort and the learning potential. However, for the RStroop group, the increase in functional task difficulty meant that the elaborative processes taking place during feedback were disrupted and the information-processing system may have become overloaded, which was detrimental to learning. These findings support the inverted-U theory in the framework: when the task becomes too cognitively demanding not all of the information can be processed, resulting in reduced learning (Marteniuk, 1976).

However, in Chapter 4, based on RSME scores, intermediate participants cognitive effort was lower during a smart-random structure of practice, but skill acquisition was *greater* when compared to a traditional random practice order. The smart-random and traditional random structures of practice contained exactly the same clips, but the smart-random structure contained more context-specific information, such as opponent tendencies and the preceding shot, whereas the traditional random practice structure did not. On the one hand, more information would be expected to increase the functional task difficulty, perhaps to a point where learning is degraded. If so, then the finding that a practice condition with more information that required less cognitive effort led to greater skill acquisition could be interpreted as contradicting the challenge point framework (Guadagnoli & Lee, 2004). On the other hand, the context-specific information may have contained more easily *interpretable* information (requiring less cognitive effort) when compared to the interference caused by a random structure (requiring more cognitive effort) and, therefore, the learning benefit supports the challenge point framework (Guadagnoli & Lee, 2004).

Applied implications

Perceptual-cognitive simulation training for tennis

From an applied perspective, the thesis confirms the potential benefits for athletes of simulated perceptual-cognitive skills training in sport. Chapters 2 and 4 assessed transfer of learning from perceptual-cognitive skills training to a more ecologically valid setting. Perceptual-cognitive skills training led to transfer of learning to the field. Transfer was greater from a smart-random structure of practice compared to a random structure and from both random structures when compared to a blocked structure. Furthermore, participants in these experiments were tennis players from either a development squad aged approximately 13 years old (Chapter 2) or intermediate players aged approximately 21 years old with an LTA rating of around 8 (Chapter 4). These groups would be suitable athletes for perceptual-cognitive skills training as it is a method for improving specific skills to attempt to achieve expertise in that domain (Ericsson, 2008; Ericsson & Williams, 2007). There is a large amount of research on perceptual-cognitive skills training as demonstrated by numerous review papers (Broadbent, Causer, Williams, et al., 2014; Causer et al., 2012; Williams & Grant, 1999; Williams, Ward, & Smeeton, 2004). The data presented in Chapters 2 and 4 extends this research by showing the effects of practice structures on the transfer from perceptual-cognitive skills training to a field-based task (Causer et al., 2012; Williams & Grant, 1999).

The current thesis demonstrates the practical use of video simulation techniques using a large screen showing life-sized dynamic visual stimuli from a first person perspective. It shows support for the benefits of maintaining high task functionality for the retention and transfer of perceptual-cognitive skills in sport. Well-designed physical practice is likely to be superior in maintaining the coupling between perception, cognition and action and should take priority. However, the thesis did not show support for the need for high fidelity of a task as complex and simple movement showed improvements in performance. This demonstrates that athletes can engage in it when they are not able to physically practice; when injured, travelling to competition, resting at home, or recovering from training. In cases where athletes are unable to physically respond, then perceptual-cognitive skills training without a movement response may be superior to other activities, acting as a form of observational learning (Horn, Williams, & Scott, 2002), albeit with greater cognitive effort (Lee et al., 1994). Furthermore perceptual-cognitive simulation training can replicate instances or scenarios that do not occur often in the real-life setting, allowing for more efficient training programmes (Williams & Ford, 2013). Based on the data presented in the thesis, when designing a perceptual-cognitive training session for tennis, the simulation must allow the participant to replicate the cognitive processes that occur in a real-life setting. The suggestion is that video simulations should be structured in a tactically relevant way. If this is not possible, or the coaches have a specific aim for the session that constrains the training structure, then it is advised that the training condition increase the cognitive effort required by the participant to complete the task so as to promote learning of the skills.

Limitations and future research

The current thesis explored various conditions of practice for perceptual-cognitive skills training, extending research from the motor learning literature. As with all research, answers to specific hypotheses are established but will often have limitations, which leads to numerous other questions to be investigated by future research.

Contextual interference effect

Chapter 2 and 3 extended the research on the CI effect to perceptual-cognitive skill training using simulation techniques with intermediate and novice performers, which had not previously been established (Memmert et al., 2009). Moreover, the study demonstrated for the first time that a random schedule of practice during simulation training benefits transfer to a field-based setting for intermediate participants. However, a limitation of the current thesis is that it was only investigated in tennis and used novice and intermediate tennis performers, not highly skilled athletes. The suggestion may be that for highly skilled athletes a random schedule of practice has no additional benefits to blocked practice and in fact an alternative structure of practice would be more preferable (see Chapter 4). Therefore the generalizability of the CI effect to perceptual-cognitive simulation training has not been fully confirmed (Lee, 2012). Future research should seek to verify the CI effect in perceptual-cognitive simulation training for different sports, including open and closed skills, as well as different skill levels ranging from novice to experts. Similarly, Chapter 3 proposed an alternative explanation for the CI effect combining the elaboration and reconstructive hypotheses, along with error processing in novice performers. Future research is required to examine the role of error processing as an alternative account for the CI effect in terms of its validity and generalizability. Using similar methodologies to those used in Chapter 3, research is now required to assess the role of error processing in conjunction with task switching in a variety of domains and with other skill levels to determine the generalizability of this alternative theory (Lee, 2012). Moreover, other mediating variables may have affected the findings in this thesis, such as motivation and attention (Lee & White, 1990). As shown in this thesis, random practice promotes greater cognitive effort compared to blocked practice, so tasks that are tedious or lacking in intrinsic interest might become less so from contextual interference.

Future research could incorporate new techniques and protocols to investigate the role of errors in the CI effect. One such methodology taken from the error processing literature is to include an errorless and errorful condition during a blocked and random schedule of practice (Maxwell et al., 2001; Poolton, Masters, & Maxwell, 2005). In perceptual-cognitive skills training, errorless conditions may be achieved by manipulating occlusion points to increase or decrease the difficulty of the task (Jones & Miles, 1978). Based on the predictions and data in this thesis, a random schedule of practice with errorless learning conditions will not elicit an optimum learning effect because it lacks the key additional processes that occur following an error. In addition, a blocked schedule of practice with errorful learning conditions should still not improve retention and transfer performance due to the lack of task switching during practice.

Alternatively, neuroscience techniques have been used in previous research to investigate the CI effect (e.g. Cross et al., 2007; Lin et al., 2008; Lin et al., 2009; Lin et al., 2010) and error processing (e.g. Gehring, Goss, Coles, Meyer, & Donchin, 1993; Holroyd, Coles, & Nieuwenhuis, 2002; Rodriguez-Fornells, Kurzbuch, & Munte, 2002; Yeung, Botvinick, & Cohen, 2004). In the CI effect the use of transcranial magnetic stimulation (TMS) demonstrated the causal significance of the neural processing within the primary motor cortex in the inter-trial interval for the superior learning of a random schedule of practice (Lin et al., 2010). Furthermore, Cross et al. (2007) used functional magnetic resonance image (fMRI) to demonstrate that a random schedule of practice results in greater activity in sensorimotor and premotor regions compared to the blocked group. These areas are associated with motor preparation, sequencing, and response selection (Cross et al., 2007). In terms of error processing, studies that recorded event-related brain potentials (ERPs) as an index of attentional processing have revealed a neural response following errors in the anterior cingulate cortex, which is termed error-related negativity (ERN; Gehring et al., 1993). A commonly held view is that the ERN reflects a monitoring process that signals errors whenever it detects a mismatch between the response produced and the correct response (Yeung et al., 2004). The ERN appears to be related to aspects of error correction, as a larger ERN amplitude occurs when an error is corrected quickly than when error correction is slow (Rodriguez-Fornells et al., 2002). Future research should incorporate the neuroscience techniques used in the previous research on the CI effect and errors to examine the alternative theory proposed in Chapter 3 and to assess the underlying impact of errors on the CI effect.

Contextual information

While Chapter 4 demonstrates the benefits of a smart-random structure of practice for intermediate participants, there is a need to examine the effects of this practice condition on expert and novice performers. Moreover, to support the behavioural data in Chapter 4, an understanding of the underlying mechanisms needs to be demonstrated. It was theorised that training with contextual information, such as court position and the opponents' tendencies, developed more detailed action plan profiles and current event profiles, allowing more efficient retrieval mechanisms in working memory (McPherson & Kernodle, 2007). Future research should seek to investigate this prediction using various methods. One such example, is a process-tracing method used to measure underlying expert perceptual and cognitive mechanisms termed think-aloud *verbal reports* (Ericsson, 2006); Ericsson and Simon (1980) proposed that participants can verbalise their thoughts concurrently or retrospectively without changing the structure of the cognitive processes involved in the task. Verbal reports have been used in numerous studies across a range of domains to provide data about the underlying knowledge structures and cognitive thought processes that support decision-making (McRobert et al., 2010). The protocol involves training and then recording the thoughts of participants during or immediately after a task, which can then be transcribed and analysed (Ericsson & Simon, 1993). Fox, Ericsson, and Best (2011) completed a meta-analysis of 94 studies to compare performance while giving concurrent verbalisations to a matching condition without verbalisation. The authors concluded that verbal report procedures do have limitations, such as interference on performance, the use of methodological instructions and interactions between the participants and experimenter, but it is a legitimate and practical method which at present is the only nonreactive method for collecting thought processes during a task (Fox et al., 2011).

McPherson and Thomas (1989) developed verbal data techniques to investigate the information accessed and processed by tennis players during simulated tennis situations and between points in actual competition. The experimenters simply conducted between-point interviews consisting of two questions: “What were you thinking about while playing that point?” and “What are you thinking about now?” The different types of knowledge participants reported were categorised into five concepts; goal concepts, condition concepts, action concepts, do concepts, and regulatory concepts. A similar research methodology would be a simple, but insightful, addition to the protocol in Chapter 4. The different memory structures that are developed during a random and smart-random structure of practice could then be investigated as they are acquired and the mechanisms underlying the findings could be proposed.

An alternative technique to examine the mechanisms underlying a smart-random structure of practice would be through the use of eye movement registration software. Previously, McRobert et al. (2011) demonstrated systematic differences in visual search behaviours between conditions with varying context-specific information, and between skilled and less-skilled participants. Less-skilled participants focused primarily on the primary cue source, whereas skilled athletes supplemented the primary cue source with additional task-relevant areas. Moreover, the additional contextual information available resulted in the skilled athletes demonstrating reduced mean fixation duration. The additional context allowed skilled participants to extract the information from the relevant location more efficiently. Although expert-novice differences were found in McRobert et al. (2011), the benefits of contextual information during simulated training on the visual search behaviours of athletes has yet to be investigated.

Cognitive effort

A running theme throughout the thesis was examining the role of cognitive effort in the learning effects of the different conditions. As discussed in the previous sections, one limitation of the current thesis is that the *amount* of cognitive effort is measured and not the *nature* of the cognitive processes, with the latter processes being inferred based on previous research and the timing of the effort. In Chapter 3, the increased cognitive effort in the CI effect was suggested to be due to a combination of elaborative processes, reconstructive activity and error processing, based on the timing of effort occurring in the preparation, feedback and inter-trial phases of a trial, respectively. In Chapter 4 the role of cognitive effort was linked to different memory structures, current event and action plan profiles, which was based on previous research in the area rather than actual data collected in the study. Assumptions made across the thesis require future research to verify them and extend these explanations.

A possible methodology to achieve this, which was discussed in the previous section, is through the use of verbal reports (Ericsson & Simon, 1993). Research from the perceptual-cognitive skill literature (North, Ward, Ericsson, & Williams, 2011), CI literature (Shea & Zimny, 1988) and the contextual information literature (McPherson, 1999a, 1999b, 2000), have utilised verbal report protocols to investigate cognitive processes. Future research should seek to use this methodology to verify the theories put forward in the current thesis, such as the role of error processing in the CI effect and the different memory structures involved when viewing tactically relevant simulations.

Perceptual-cognitive skill training

While the current thesis assessed the transfer benefits of various conditions of practice, a limitation was that it only examined short-term improvements. Future research is required to investigate the long-term transfer benefits of a smart-random and random schedule of practice during simulation training to a real-life setting (Lee, 2012). The transfer conditions in this thesis were administered after a relatively short retention period. In Chapter 2, the transfer condition was to a representative task in the field in order to maintain experimental control, as per other previous research in this area (Smeeton et al., 2005; Williams et al., 2002), rather than to actual competition. In contrast, researchers investigating the benefits of quiet eye (QE) skills training have demonstrated retained transfer of learning to real competition (Causer et al., 2011; Vine, Moore, & Wilson, 2011). Perceptual-cognitive skills training transfer tests could be conducted in actual competition and after a retained period. However, in the current thesis a transfer test to actual competition would be more difficult due to the task being tennis, which involves open skills, as opposed to the closed skills used in QE research.

An aspect of perceptual-cognitive simulation training that future research could consider is 2D *vs.* 3D simulation. As discussed in Chapter 1, and throughout the thesis, the key to successful simulation training is high functionality and high action fidelity. While the use of 3D simulation is prevalent in the medical community for the fine-tuning of different surgical skills (e.g. Christopher, William, & Cohen-Gadol, 2013; Heath & Cohen-Gadol, 2012; Smith et al., 2012), the effectiveness of such displays for the training of perceptual-cognitive skill in sport is rarely considered. One of the only studies thus far to compare 2D and 3D simulation techniques for perceptual-cognitive skill in sport concentrated on the decision-making skills of assistant referees in football (Put et al., 2014). Qualified assistant referees were shown 40 offside situations displayed in both 2D and 3D formats. Under 3D conditions, participants made more accurate decisions compared to under 2D conditions. The authors suggest that in dynamic and complex situations, the visual system can benefit from the availability of 3D information. Future research is required to confirm the transfer benefits of 3D simulation techniques to actual competition, compared to 2D, and to examine how 3D simulation interacts with the various conditions of practice.

Concluding remarks

In conclusion, this thesis provides an in-depth assessment of the various conditions of practice for perceptual-cognitive skills training, specifically for anticipation skills in tennis. Research on perceptual-cognitive simulation training is an area that in the last 20 years has received a considerable amount of attention. The current thesis addresses some limitations in that literature, such as transfer of learning and structure of practice (Causer et al., 2012; Williams & Grant, 1999). The current thesis extends previous research from the motor learning literature concerning the CI effect to the domain of perceptual-cognitive skills training (Lee, 2012). Furthermore, the thesis proposes a novel hypothesis to explain the CI effect, which could have theoretical and applied implications for future researchers and practitioners. The hypothesis suggests that cognitive effort associated with error processing in conjunction with task switching underpins the superior learning found for a random schedule of practice compared to a blocked schedule. Finally, the thesis demonstrates the benefits of a structure of practice that contains contextual information. A smart-random structure of practice during simulation training resulted in improved anticipation in a video-based task and reduced decision time in the transfer test to a real-life setting compared to a traditional random structure of practice. Overall, the findings in this thesis have corroborated and extended the literature surrounding perceptual-cognitive simulation training and conditions of practice required for optimal learning. The thesis will act as a catalyst for future research in several different areas from both a theoretical and applied perspective.

Chapter 6:

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