Cognitive Effort in Contextual Interference and Implicit Motor Learning

by

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ABSTRACT

The broad aim of this dissertation was to explore the paradoxical accounts of contextual interference and implicit motor learning from the perspective of cognitive effort. Three key outcomes have emerged. First, from a theoretical perspective, the thesis offers a previously unexplored account for the contextual interference effect – one that potentially explains the paradoxical findings between contextual interference and implicit learning – the implicit learning hypothesis. The hypothesis states that random practice might share characteristics with implicit learning. High levels of cognitive effort due to task switching might prevent random learners from consciously focusing on their movements leading to a more passive mode of learning. Second, from a practical perspective, the thesis provides support for the application of implicit motor learning to performers who already possess explicit knowledge. Expert netball players practised shooting to an adapted ring while responding to a secondary task. Following the intervention, players were unaware of the knowledge underlying their technique adaptation, thus providing preliminary evidence for the use of implicit motor learning in high performance sport. Finally, from a methodological perspective, the thesis laid the foundation for the future development of measurement techniques for both cognitive effort and implicit/explicit processing. A battery of measures typically applied to implicit learning was used in a study of contextual interference. In addition, a behavioural measure of cognitive effort (time taken to prepare and execute movements) was explored in blocked and random practice. Furthermore, two experiments explored the use of a modified Stroop task as a potential measure of implicit/explicit processing. Overall, the thesis contributes to both the contextual interference and implicit motor learning research domains through advances in the areas of theory, practice, and methodology.

STUDENT DECLARATION

I, Megan Rendell, declare that the PhD thesis entitled ‘Cognitive Effort in Contextual Interference and Implicit Motor Learning’ is no more than 100,000 words in length, exclusive of tables, figures, appendices, references, and footnotes. This thesis contains no material that has been submitted previously, in whole or in part, for the award of any other academic degree or diploma. Except where otherwise indicated, this thesis is my own work.

Signature: [redacted] Date: 17 July 2011

ACKNOWLEDGEMENTS

I recall two critical moments prior to enrolling in my PhD candidature that led me to study motor learning. The first was in 2004 when I spent a day at the Australian Institute of Sport (AIS) in Canberra with Damian Farrow. He managed to tell lots of interesting stories about skill acquisition and from that day I was hooked. The second occurred in mid-2005 when Rich Masters presented some of his work at a conference I attended at the AIS. He opened my eyes to the amazing world of implicit learning and made quite a theoretical topic sound intriguing. Both Rich and Damo have provided the perfect mix of fatherly advice and straight up PhD-supervisor feedback. Thank-you for your endless support and patience.

In the past five years, I have lived in three different states, moved house seven times, got married, and am now expecting my first baby. I also saw Niagara Falls (albeit through a hotel window), stayed up all night in Las Vegas, had cocktails in New York City, and rode a camel in Morocco during a couple of fantastic conference trips. I managed to experience the amazing city of Hong Kong during my stints with Rich and his colleagues. Thanks to Rob Jackson, Jamie Poolton, Bruce Abernethy, Robyn Mellecker, Tiffany Zachry and Rich's family (Nancy, Tess, Jake, Noah, and Rei) for making me so welcome during my visits. On a sad note, I have been frequently reminded of the passing of Jon Maxwell as I read and cited his work in my thesis. I had the privilege of meeting Jon during my first trip to Hong Kong.

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LIST OF PUBLICATIONS

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Rendell, M. A., Masters, R. S. W., Farrow, D., & Morris, T. (in press). An implicit basis for the retention benefits of random practice. *Journal of Motor Behavior, 43.*[3]

Rendell, M. A., Masters, R. S. W., Farrow, D., & Morris, T. (under review). Implicit Processes in Contextual Interference. *Manuscript submitted for publication.*[4]

[1] The study in Chapter 3 of the current thesis
[2] Relates to the information presented in Chapters 1 and 2
[3] The study in Chapter 4
[4] The study in Chapter 5

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CHAPTER 1

INTRODUCTION

Motor learning has been described as a problem-solving process in which the goal of an action represents a problem and the development of an appropriate movement pattern represents the solution (Bernstein, 1996; Guadagnoli & Lee, 2004). Skill acquisition researchers are interested in understanding which practice variables serve to optimise this process and consequently to understand the mechanisms that subserve these variables. One concern for researchers and practitioners is to consider practice conditions in terms of the cognitive effort evoked. Cognitive effort refers to the “attention-demanding” characteristics of mental processes that are utilised when performing a task (Tyler, Hertel, McCallum, & Ellis, 1979). This thesis examines the notion of cognitive effort, specifically as it relates to two practice approaches that have conflicting implications for the demand on attention during motor skill learning: the scheduling of practice conditions (blocked and random practice) and the accrual of task-relevant knowledge during practice (implicit and explicit motor learning). Research evidence from studies of blocked and random practice typically suggests that cognitive effort is a functional characteristic of learning, but research evidence from implicit and explicit motor learning implies that minimising cognitive effort during learning can be beneficial.

At a practical level, coaches can be forgiven for questioning how they should apply both the blocked/random practice and implicit motor learning research to their training environments when contradictory conclusions exist. Interestingly, the premise of this thesis came from a conversation with an astute coach who remarked, “... but you told me mental effort is good for learning and now you are telling me that athletes benefit from implicit practice?” This observation highlights the need to bridge the gap between the two research domains to enable effective application. It also highlights the coach-science connection that will become apparent in the nature of the studies presented in this thesis. A broad overview of the two research areas will now be presented followed by the aims of the dissertation.

In random practice, learners rehearse a number of different tasks in a haphazard sequence, such that no two skills are repeated on consecutive trials. Researchers have consistently demonstrated that random practice promotes better learning than the alternative “blocked practice” in which a learner rehearses the same task repeatedly for a block of repetitions. Research has previously shown that when learners undertake random practice, their performance is less successful during acquisition, but superior to blocked learners in tests of retention (see Brady, 1998; Lee & Simon, 2004; Magill & Hall, 1990 for reviews). This phenomenon has been termed the “contextual interference effect” (Battig, 1966).

Two main hypotheses have been suggested to account for the contextual interference effect. The first suggests that random practice is more effective because learners make more elaborate comparisons among the tasks they are practicing. According to this hypothesis, the more effortful mental processing engendered by random practice leads learners to appreciate the distinctiveness of the different tasks and results in more unique representations in long-term memory, (this is referred to as the *“elaboration hypothesis”*; Shea & Zimny, 1983). The second hypothesis suggests that random practice evokes superior outcomes because learners encounter a partial forgetting of one skill during the period that they are practicing other skills. When they return to the “forgotten” skill, they are required to construct the plan for that task all over again (referred to as the *“reconstruction hypothesis”*; Lee & Magill, 1985). The common denominator in the two theories is more effortful mental processing (or “cognitive effort”) provoked by random practice and diminished processing resulting from a blocked schedule.

Implicit motor learning is based on the alternative premise that motor skill learning can occur, and can be effective, without an early dependence on effortful processing (Masters & Maxwell, 2004). Implicit motor learning involves practice in which the environment is structured to minimise the amount of conscious, rule-based information that is processed by the learner. In implicit motor learning, the performer does not acquire conscious mechanical rules for the skill that is practised. The key benefit of this type of practice is that it minimises the likelihood that performers will consciously focus on the mechanical rules when they experience anxiety or performance pressure (and it has therefore been proposed as a method for minimising the occurrence of the colloquially termed problem “paralysis-by-analysis”).

One consideration in drawing together the contextual interference and implicit motor learning research areas is how these concepts can be incorporated into the daily training environment. If implicit motor learning is of benefit to expert performers who have previously accumulated a large amount of explicit instruction, then the recommendation from a practical perspective might be to incorporate aspects of both random practice and implicit motor learning into training. This recommendation, however, requires resolution of the paradoxical implications of the contextual interference and implicit motor learning research in terms of the cognitive effort utilised during learning.

Aims of the Dissertation

General Aims

The thesis aims to extend the existing motor learning research by investigating the paradox between the cognitive effort accounts of contextual interference and implicit motor learning. Furthermore, the thesis aims to provide recommendations for practitioners in the field, informed by the findings presented in this dissertation and existing motor learning research.

Specific Aims

1. To investigate whether implicit motor learning is beneficial to performers who have previously accumulated a large amount of explicit knowledge.
2. To apply a number of measures typically employed in studies of implicit motor learning as a means of assessing cognitive effort during low and high contextual interference practice.
3. To test whether the addition of a concurrent cognitively demanding secondary task to random practice results in learning outcomes that are similar to those experienced by random learners who do not perform a secondary task.
4. To investigate alternative measures of cognitive effort and implicit/explicit processing.

Chapter Organisation

Chapter 1 has introduced a broad overview of the research. In addition, the general and specific aims of the thesis have been detailed. Chapter 2 provides a comprehensive review of the relevant literature. This chapter critically reviews the issues that arise as a consequence of defining practice conditions in terms of cognitive effort. The scheduling of practice conditions (contextual interference) and the accrual of task-relevant knowledge during practice (implicit and explicit motor learning) are considered from the perspective of cognitive effort.

Chapters 3-7 provide the details of five independent, but interrelated, studies that were designed to address the general and specific aims outlined earlier in the thesis. In Chapter 3, an investigation is presented into the use of implicit learning to adapt technique in expert performers who have previously accumulated a large amount of explicit knowledge. Implicit motor learning has been widely investigated within cohorts of novice performers (e.g., Masters, 1992; Maxwell, Masters, & Eves, 2003; Liao & Masters, 2001), but researchers have yet to investigate the application of implicit learning to highly skilled performers. This chapter details a study aimed at addressing this limitation and also highlights the challenges concerned with applying implicit motor learning to an elite training environment. The suggestion is made that it is prudent to consider what other methods of implicit learning might bring about beneficial learning outcomes in skilled athletes.

In Chapter 4, the details of a study are provided which aimed to investigate the paradox at the centre of the thesis, by measuring cognitive effort and working memory dependence during low and high contextual interference practice. The proposition that random practice might offer a potential method of imposing implicit learning is explored. The study investigates the possibility that the working memory resources of random learners might be so overwhelmed by the information required to generate multiple motor solutions (i.e., task switching) that they are unable to test hypotheses and store rules or knowledge about the movement solutions that they generate. The data presented suggests that random practice might share some characteristics with implicit learning, and therefore offers a potential method of imposing implicit learning in a high performance sport setting (thus overcoming the applied challenges highlighted in Chapter 3). A number of limitations regarding the study are outlined, which imply a need to further investigate whether random practice shares characteristics with implicit learning.

The study presented in Chapter 5 aimed to address the limitations of the Chapter 4 study and further investigate the proposition that the benefits of random practice are subserved by similar processes to those which underlie implicit motor learning. Specifically, in Chapter 5, the details of a study are provided which tested whether preventing elaboration and reconstruction during random practice (by performing a concurrent cognitively demanding secondary task) would result in learning outcomes that were similar to those experienced by random learners who did not perform a secondary task. In this chapter, limitations with reference to the measurement techniques are also discussed.

In Chapter 6, a post hoc analysis of a set of data collected in the Chapter 4 study is provided as a means of generating a new measure of cognitive effort. The analysis measures the time taken to execute skill trials in blocked and random learners. The premise of the investigation is that higher levels of cognitive effort are likely to be associated with slower movement preparation times due to the increased amount of processing that accompanies high cognitive effort. Conversely, lower levels of cognitive effort are likely to be associated with faster movement preparation times due to relatively fewer processing requirements. The data presented does not differentiate between blocked and random learners, highlighting the need to further investigate potential measurement techniques.

Chapter 7 presents a study investigating an alternative measure of implicit/explicit processing. The chapter reports on two experiments which explored the use of a modified Stroop task to measure implicit/explicit processing in different cohorts of participants. The first experiment explored the use of a modified Stroop task as a measure of implicit/explicit processing during errorless and errorful learning. The experiment investigated whether words related to the task being practised (golf putting) would cause interference, and hence slower response times, in errorful learners compared to errorless learners. In the second experiment, the modified Stroop task was explored as a measure of implicit/explicit processing in highly skilled swimmers. It was hypothesised that swimming-related stimuli would produce slower response times than control stimuli due to the cognitive expertise developed by the highly skilled swimmers over the course of many years of skill acquisition. The data presented in the two experiments did not differentiate between implicit and explicit processing using the modified Stroop task. The chapter discusses a number of limitations and suggests that it might be worthwhile to implement the modified Stroop test in a different cohort of participants such as sufferers of the “yips” or people who have a tendency to perform poorly under pressure.

Chapter 8 provides a summary and general discussion of the interrelated studies. The theoretical implications are considered and the practical implications of the findings are discussed. Finally, future research directions are outlined in light of the findings presented in the thesis.

CHAPTER 2

REVIEW OF THE LITERATURE

This literature review is divided into three sections. The first section discusses the concept of cognitive effort and provides a definition of cognitive effort that will form the basis for the thesis. The second section reviews literature concerning the contextual interference effect and relates the contextual interference effect to cognitive effort. The third section outlines research investigating implicit motor learning and highlights the theoretical underpinnings of implicit motor learning in terms of cognitive effort, the benefits to learners, the various models which create an implicit learning environment, and measurement considerations.

Cognitive Effort

During learning, we are required to hold information in our mind for varied periods of time so that it is available for immediate use. Information held in this way is considered to be stored in “short-term memory” or “working memory”. When a large amount of information needs to be used, this process can be quite effortful or attention-demanding (Gathercole, 1999). If a large amount of information is required to perform a task, then attention load is high and working memory must work hard to process the information. In this situation, a performer would experience a high amount of cognitive effort. If less information is required to perform a task, then attention load is low, less information is processed by working memory, and the performer experiences low levels of cognitive effort. The amount of information that must be processed to perform a task (and therefore the amount of cognitive effort that is required) depends on a range of factors such as: the difficulty of the task being practised; the arousal, motivation, and skill level of the performer; the availability of intrinsic feedback; the amount of instruction and extrinsic feedback provided by a coach; and the complexity of the practice environment.

One relevant definition of cognitive effort is provided by Tyler et al. (1979, p. 608) who suggest that cognitive effort refers to, “the amount of the available processing capacity of the limited-capacity central processor utilised in performing an information-processing task”. This definition of cognitive effort highlights the limited capacity nature of attention as well as the reliance on the central component of working memory in tasks that are cognitively demanding.

An alternative definition of cognitive effort is provided by Lee, Swinnen, and Serrien, (1994, p. 329), in which cognitive effort is described as, “the mental work in making decisions”. In terms of motor learning, “making decisions” refers to a process that occurs when a performer focuses on errors after completing a movement attempt and decides how to correct the movement in future performances (Sherwood & Lee, 2003).[5] For example, if a learner attempts to putt a golf ball and notes that the ball falls slightly short and to the left of the hole, he or she might decide to adjust the grip or stance so that the next practice attempt will, hopefully, reach the hole. This definition of cognitive effort highlights the decision-making processes that underlie motor learning and as such is relevant to the current thesis.

Given that cognitive effort is a function of levels of attention demand and reliance on working memory resources, it is important to consider these concepts in detail. In the following paragraphs, the terms attention and working memory will be discussed and their importance in cognitive effort will be highlighted. This section will conclude with a definition of cognitive effort that will form the basis for the thesis.

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[5] In the implicit motor learning literature, the process of interpreting movement-related feedback and making changes in future practice attempts is referred to as “hypothesis-testing behaviour” (Masters & Maxwell, 2004).

Theories of Attention

The term attention is used widely in everyday language; however it is also a concept for which scientific literature has not yet given a clear definition. The key reason is that attention is not unitary. Instead, it refers to at least three broad concepts. First, the term is used to explain the selectivity of attention, that is, the process by which some information is processed whilst other information is ignored. Second, it relates to our state of alertness or readiness for action. Third, attention is seen as an "amount of something" or as being the limited amount of information that can be processed at a given time (Styles, 2000; Williams, Davids, & Williams, 1999). This final aspect of attention is most closely related to cognitive effort because it suggests that attention is something that has a finite capacity, of which a proportion is utilised when performing a task. The limited capacity nature of attention is described by the general capacity theory of attention (largely attributed to Kahneman, 1973).

The general capacity theory considers attention to have a general, flexible capacity that can be subdivided among tasks so long as the sum of attentional demand does not exceed the available capacity (Abernethy, 1988, 1993). The amount of total attention capacity available for a given task will depend on the task requirements and the skill level, motivation, and arousal of the performer. Consequently, differences in a particular individual's performance over time may be explained by fluctuations in their total attention capacity due to changes in arousal and motivation (Kahneman, 1973). This model further suggests that 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, 1988). In this case, there will be a drop in performance in one or both tasks. Conversely, when a task is not excessively demanding, a performer will have more residual capacity available to allocate to other tasks and performance on each task may be effective (see Figure 2.1).

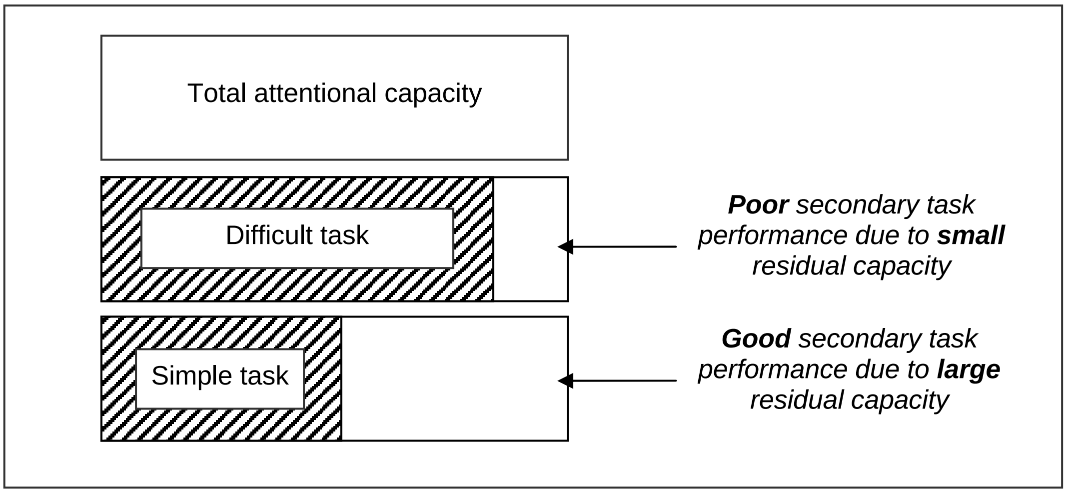

Figure 2.1. Schematic representation of the general capacity theory of attention (adapted from Abernethy, 1988, 1993). *Note.* While this diagram provides a useful overview of the general capacity theory of attention, skill level, arousal, and motivation of the performer are not accounted for.

The general capacity theory of attention highlights the limited capacity nature of attention. Cognitive effort arises from the level of dependence on this limited capacity system during skill execution. In considering reliance on attention during learning it is important to address the related concept of “working memory”. Working memory is a hypothetical system which supports attention control by temporary storage and online manipulation of information (Baddeley, 2000; Baddeley & Hitch, 1974).

Working Memory

Working memory is a multi-component model which is made up of a central executive (which controls attention) and three subsidiary systems: the phonological loop (for holding speech-based information), a visuospatial sketchpad (for holding visual information), and an episodic buffer, which is capable of integrating information from a variety of sources (Baddeley, 2000). The phonological loop is purported to be responsible for temporarily holding verbal and acoustic information (Gathercole, 1999). Specifically, the phonological loop is thought to control the following processes: acoustic storage (storage of the most recent auditory speech item in sensory form); phonological analysis and storage (analysis of the phonological structure of the to-be-remembered material); temporal order (coding of the temporal context of information); rehearsal (covert rehearsal of phonological material to be maintained for longer periods of time); retrieval (rapid, serial scanning of information to retrieve stored information); and reintegration (reconstruction of incomplete phonological traces from stored knowledge). The visuospatial sketchpad, by contrast, is purported to hold visuospatial information, possibly by fractioning visual, spatial, and kinaesthetic information into separate components. The episodic buffer is assumed to be responsible for providing a temporary interface between the two subsidiary systems (the phonological loop and the visuospatial sketchpad) and long term memory. The central executive is assumed to control the episodic buffer and is considered to be responsible for ensuring that previously fractured information is bound into coherent chunks of usable information.

It is clear that working memory provides a complex model for how information is manipulated at any given moment. This discussion of working memory highlights the numerous cognitive processes that, if employed during a particular task, produce demands on the limited capacity system. A comprehensive definition of cognitive effort needs to consider the concepts of attention and working memory as well as highlight the decision-making aspect of motor learning. Drawing heavily on the definitions by Tyler et al. (1979) and Lee et al. (1994) outlined previously in this chapter, the following definition incorporates the core concepts of attention and working memory as well as including the term “making decisions”, which refers to the error detection and correction processes that occur during motor learning. This definition will be used as the basis for the current thesis:

> Cognitive effort refers to the amount of attention load imposed on working memory when making decisions.

In Chapter 1, the paradoxical role of cognitive effort in contextual interference and implicit motor learning was introduced. The case for cognitive effort as a functional component of skill learning is based on the argument that learning is promoted by practice variables that result in an intense use of the limited-capacity resources of working memory (Lee et al., 1994). This argument is central to current theories that propose beneficial effects of contextual interference, but contradicts theories of implicit motor learning, which suggest beneficial outcomes from learning without the intense use of working memory resources. Research on contextual interference will now be examined and the implications of its theoretical explanations discussed from the viewpoint of cognitive effort.

Contextual Interference

As detailed in Chapter 1, the contextual interference effect refers to the relatively consistent finding that practicing motor tasks under a random practice schedule (in which practice trials are randomly sequenced throughout the practice session) results in impaired performance during learning, but superior performance on tests of retention and transfer (see Brady, 1998; Lee & Simon, 2004; Magill & Hall, 1990 for reviews). Essentially random practice refers to skill switching in which a performer practices two or more skills in a random or serial order, not repeating the same skill for more than one consecutive practice repetition. Blocked practice, in contrast, refers to repeating the same skill over and over again for a block of practice repetitions before switching to a different skill. For learners who practice motor tasks under a blocked practice schedule, according to the contextual interference effect, performance during learning is elevated, while retention and transfer performance are impaired.

The contextual interference effect was first considered in the verbal learning domain (Battig, 1966, 1972, 1979). As Lee and Magill (1985) noted, Battig originally described the beneficial effects of high interference learning in 1966, and only later (in 1979) coined the term “contextual interference”. Battig (1966) originally referred to contextual interference as “intratask interference”:

> Intertask facilitation is produced by intratask interference. That is to say, if learning of a first task is carried out under conditions of high intratask interference, this is likely to result in maximal facilitation of the subsequent learning of a partially similar or related second task (p. 227, cited in Lee & Magill, 1985).

In the past thirty years, researchers have become interested in the contextual interference effect in the motor learning domain. The contextual interference effect was first explored in motor skill learning by Shea and Morgan (1979). Incidentally, both Shea and Morgan, and Battig, found independent support for the contextual interference effects in two different domains (verbal and motor learning) while they were working at the same institution – the University of Colorado (Lee & Magill, 1985). Since Shea and Morgan's study of contextual interference, which bridged the gap between the verbal and motor learning domains, there has been much interest in the research topic with studies largely focusing on the theoretical underpinning of the effect and the scope of its application (Brady, 1998, 2004).

Researchers have focused mainly on two explanations for the contextual interference effect: the elaboration hypothesis (which was first suggested by Shea & Morgan, 1979) and the reconstruction hypothesis (first outlined by Lee & Magill, 1985). These two theories will now be discussed in detail together with a summary of alternative theories for the contextual interference effect, which have also received interest in the theoretical literature.

Theories of Contextual Interference

Elaboration hypothesis. Some researchers (e.g., Shea & Morgan, 1979; Shea & Zimny, 1983, 1988) proposed that higher levels of cognitive effort occur for random learners during practice because they engage in better relational and or distinctive processing of their actions (i.e., they tend to compare and contrast the tasks that they are learning). According to this hypothesis, also referred to as the "elaboration and distinctiveness hypothesis" (Brady, 1998), learning under blocked conditions occurs primarily via intra-task (within-task) processing. Since only one task is practised for a set of trials, the factors associated with only that one task are held in working memory, and the learner is able to rely on one plan to execute the movement. Conversely, in random practice conditions, the learner engages in more elaborate and distinctive cognitive activity by way of both intra-task and inter-task (between-task) processing. Demands on working memory are low in blocked practice and high in random practice. As a result of the comparative processing that occurs during random practice, it is thought that random learners acquire more elaborate memory representations of the tasks that they have practised. According to this account, the diminished performance of random learners during acquisition is caused by the need to actively differentiate the movement solutions of each task.

Shea and Morgan (1979) conducted a seminal study of contextual interference in the motor learning domain. In their study, Shea and Morgan asked participants to practice three versions of a barrier knocking task in which they were required to hit a series of lights with a tennis ball. The three versions of the task differed in which barriers they were required to knock down. The total time, in seconds, between the onset of the stimulus light and the completion of the response was considered to be the overall index of performance. The blocked group practised all repetitions of one version of the task before switching to another, whereas the random group practised the three versions in a less systematic order (with the restriction of no more than two trials of a given task version to be repeated in a row). Retention performance was measured after a 10 min or 10 day delay under blocked and random sequences. Transfer performance was also measured on either a task of the same or greater complexity than the originally learned task. The results showed that both retention and transfer performance were superior for random learners compared to blocked learners. With reference to transfer, the effect was most apparent when transfer was tested on the more complex task. Figure 2.2 shows performance during acquisition and retention. Shea and Morgan tentatively suggested that random learners were forced to use multiple processing strategies to optimise their performance during acquisition, whereas blocked learners were not required to use multiple processing strategies. This suggestion is in line with the elaboration hypothesis because it suggests that random learners are engaging in more elaborate processing during acquisition.

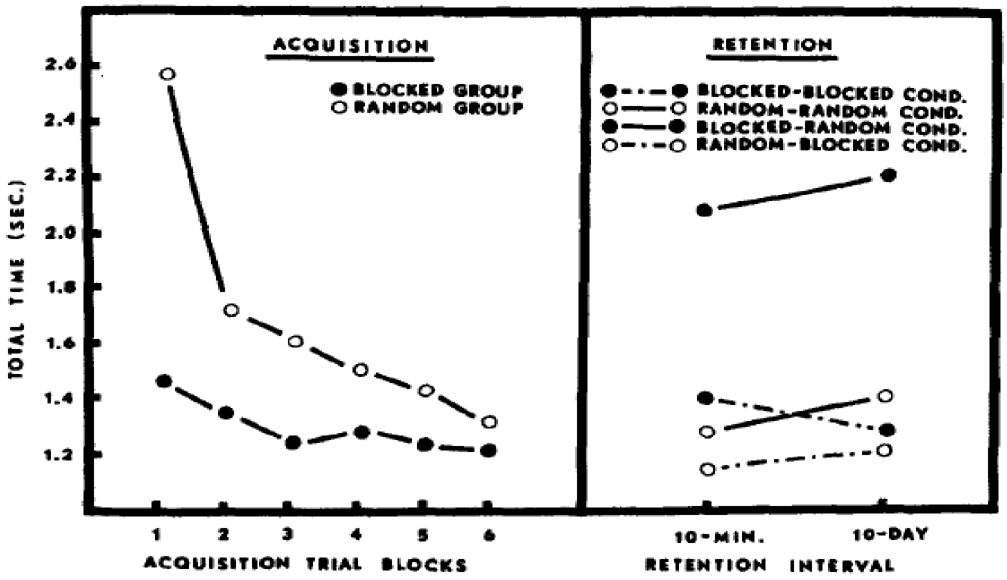

Figure 2.2. In this figure from Shea and Morgan (1979, p. 183), total time in seconds is presented during acquisition and retention collapsed over sex and tasks.

Note. At acquisition, data for three trial blocks is computed and presented as separate acquisition trial blocks. At retention, the conditions represent the following: (1) “blocked-blocked” refers to blocked practice during acquisition and blocked test conditions at retention; (2) “random-random” refers to random practice during acquisition and random test conditions at retention; (3) “blocked-random” refers to blocked practice during acquisition and random test conditions at retention; and (4) “random-blocked” refers to random practice during acquisition and blocked test conditions at retention.

Further evidence for the elaboration hypothesis has been provided by studies which have recorded participants' verbal reports following learning in either blocked or random schedules. The first studies to utilise this method in their investigations of contextual interference were by Zimny (1981) and Shea and Zimny (1988), who found support for the elaboration hypothesis. Specifically, participants who were engaged in random practice reported that they made more comparisons among tasks and used a number of different learning strategies that resulted in enhanced retention.

Wright (1991) adopted a different methodology and also found empirical support for the elaboration hypothesis in a study in which he manipulated the type of processing utilised by blocked learners during practice. Wright provided either *intertask* processing or *intratask* processing to assess whether the provision of additional information supported learning outcomes. The additional processing was established through verbalisations of task information during the intertrial interval. Participants were presented with diagrams which were used as the basis for them to describe commonalities with either the task that had just been performed (intertask processing) or commonalities with the other tasks they had performed in the acquisition phase (intratask processing). The results revealed that additional intertask processing facilitated retention benefits for blocked learners (thus supporting the elaboration hypothesis) while additional intratask processing did not facilitate retention performance (inconsistent with an alternative theory – reconstruction hypothesis – which will be discussed later in this chapter).

Wright, Li, and Whitacre (1992) replicated and extended the work of Wright (1991) by supplementing blocked *and* random practice with additional intertask processing, additional intratask processing, or no additional processing. The results replicated those of Wright by demonstrating beneficial outcomes from engaging blocked learners in additional intertask processing. A finding of added interest from this study was that supplementing random practice with intertask elaborations did not enhance learning, suggesting that there is a limit on the magnitude of interference that can produce beneficial outcomes.

In a recent study, Lin, Fisher, Winstein, Wu, and Gordon (2008) found further support for the elaboration hypothesis using single transcranial magnetic stimulation (TMS) pulses. TMS is a non-invasive method of studying the human brain in which a pulsed magnetic field is used to create targeted current flow in the brain. The stimulation can temporarily excite or inhibit specific areas of the brain (Hallett, 2000). Lin et al. synchronised a TMS pulse to the intertrial interval of blocked and random practice of a motor task. In accord with the contextual interference effect, when there was no stimulation during the intertrial interval for the random group, the learning outcomes were enhanced. When stimulation was included during the intertrial interval, the learning benefits diminished. The authors interpreted this finding as supporting the elaboration hypothesis since the perturbation of information processing between random practice trials presumably prevented elaboration and diminished learning outcomes. On the contrary, perturbation between blocked practice trials did not result in enhanced learning outcomes (a finding which the authors interpreted as going against the reconstruction hypothesis – which will now be discussed in detail).

Reconstruction hypothesis. The reconstruction hypothesis provides an alternative to the elaboration hypothesis as an account for the contextual interference effect (Lee & Magill, 1985). This hypothesis is also referred to as the “action plan reconstruction hypothesis” (e.g., Brady, 1998) and the “forgetting-reconstruction hypothesis” (e.g., Lin et al., 2008). According to the reconstruction hypothesis, random learners forget the movement solution of each task as they process the task requirements of the other. On switching back to the initial task, they are forced to undergo a demanding reconstructive process to re-plan the way in which they will perform the task. The learner must re-plan both the relevant movement information as well as task-related information from the environment. In contrast, blocked practice does not encourage the learner to engage in reconstructive processing because the action-plan is held in working memory and remembered for each consecutive movement trial. The need for random learners to repeatedly plan the movement solution results in poorer performance during acquisition, but ultimately promotes the retention of tasks because the learner is well-practised at reconstructing the motor solution (a factor that is helpful in tests of retention).

Lee and Magill (1985) noted similarities between the contextual interference effect and the variability of practice hypothesis derived from schema theory (Schmidt, 1975). Schema theory suggests that actions involve four movement components: the pre-response conditions of the motor system, the movement parameters of the action plan, the sensory feedback, and the outcome of the response (knowledge of results). The idea behind schema theory is that with practice, the relationship between those four components of the movement is represented as a schema. The variability of practice hypothesis suggests that the effective development of schemas is dependent on the learner experiencing variations of the different components of the movement. Although schema theory does not make specific predictions about the scheduling of practice trials, it is relevant to the current discussion of the reconstruction hypothesis because it provides detail regarding which aspects of a movement solution need to be forgotten and retrieved during the reconstruction process. Specifically, according to the reconstruction hypothesis, during random practice, learners must re-plan the pre-response conditions of the motor system as well as determine the desired parameters before each movement.

Evidence supporting the reconstruction hypothesis has been provided by a range of studies. For example, Lee and Weeks (1987) investigated the influence of forgetting on short-term retention of movement information. In the study, participants were required to engage in a linear positioning task in which they were asked to move a perpendicular handle to a criterion position. They were then instructed to estimate the criterion position by returning the handle to the criterion position either immediately after movement execution or following a 20 s period of attention-demanding activity. The results revealed that when participants were asked to respond following the delay, there was considerably less variable error than when their responses were recorded immediately. These findings suggest that forgetting has potential benefits for the process of movement representation and provide potential support for the reconstruction hypothesis.

Further support for the reconstruction hypothesis was provided by Gabriele, Hall, and Lee (1989) in a study investigating the effects of mental imagery on random practice. In the second experiment presented in the study, the experience of undertaking random imagery or irrelevant imagery was compared to equivalent amounts of either physically practicing the movement patterns in a random sequence or physically practicing the movement patterns in a random sequence with a rest interval between patterns. A blocked physical practice control group also was included. The results showed that the inclusion of random imagery (relevant or irrelevant) produced equal interference during acquisition and as much retention benefit as physical random practice. The finding that irrelevant imagery group produced similar results to the random imagery and physical random groups highlights the importance of cognitive processes in the contextual interference effect and argues against the position that the contextual interference effect is promoted by the processing of similar items in working memory (the elaboration hypothesis).

Cognitive effort and contextual interference. Both the elaboration and reconstruction accounts of the contextual interference effect suggest that effortful reliance on cognitive processes results in an embellished representation within working memory of the tasks being practised and hence better learning outcomes. The elaboration hypothesis suggests that task switching during random practice places a high level of demand on working memory resources due to the inclination to compare and contrast more than one task in memory at a given moment. The reconstruction hypothesis suggests that task switching forces learners to repeatedly “dump” and then re-plan each movement solution in working memory as they alternate the allocation of their attentional resources between the different skills that they are learning (Lee & Simon, 2004). In a practical sense, the best advice on the basis of this research is to schedule practice trials so that learners are afforded many opportunities to engage in cognitively demanding processes. In a sporting context, this could be implemented by a coach directing the player to practice two (or more) distinct skills in a random order, rather than practicing one skill over and over again (e.g., players could be asked to switch between practicing a forehand and backhand in tennis, or switch between a set and a spike in volleyball).

Young, Cohen, and Husak (1993) examined how elaboration and reconstruction influence the acquisition and retention of a simple aiming task, by engaging learners in a range of interpolated activities during the inter-trial interval (post knowledge of results) of blocked and random learners. In two experiments, Young et al. found that engaging in tasks related to either elaborative or reconstructive processes could support retention. In the first experiment, the researchers provided computer-generated movement representations depicting a successful movement on a monitor following each trial. Four separate random practice conditions were included together with a blocked practice control condition. Three of the random conditions included movement representations while the fourth condition served as a control. The movement representations presented to each of the three experimental random conditions differed. Participants were shown movement representations about either the same-trial, the next trial, or other (a randomly determined trial). The results indicated that there were detrimental and slight beneficial effects for retention when these types of representations were provided, relative to the random control condition. The second experiment additionally examined the influence of providing movement representations during blocked practice. The findings from the second experiment indicated that different types of interpolated activities presented in the inter-trial interval facilitated retention for blocked practice conditions highlighting the importance of these processing opportunities for retention.

The findings of the Young et al. (1993) study suggest that the elaboration and reconstruction hypotheses might be considered as complementary rather than contradictory. Specifically, Young et al. propose that the elaboration and reconstruction hypotheses share two common characteristics. Firstly, both suggest active or effortful processing as an essential requirement for retention. The elaboration hypothesis emphasises the process of making comparisons within and between movement variations and the reconstruction hypothesis emphasises the requirement of regenerating a movement solution. Second, both facilitate the retrieval of movement information either by the development of alternative paths (elaboration) or by the regeneration of a response solution (reconstruction). These processes are not necessitated in blocked practice. The conclusion drawn from this research is that the elaboration and reconstruction hypotheses share common characteristics that are essential for retention.

A recent study by Li and Wright (2000) provided empirical evidence for the contention that cognitive effort is associated with contextual interference effect. Poorer performance (during learning) of participants undertaking random practice was associated with higher cognitive demand compared to that of blocked learners. Li and Wright used a secondary task paradigm in which participants practised key-press sequences. The secondary task (a choice reaction-time task) was presented to participants at one of two time-points in the inter-trial interval. Overall, the results showed that random learners performed slower on the secondary task, presumably because the need to elaborate or reconstruct their key-press movements meant that they had less working memory resources to draw on for the secondary task. This research finding provides direct evidence that the beneficial effects of random practice are related to a higher degree of cognitive effort.

Further evidence for increased cognitive effort during random practice is presented by a study employing functional magnetic resonance imaging (fMRI) methods. Cross, Schmitt, and Grafton (2007) found the typical effects associated with contextual interference. Interestingly, the results showed that during the pre-response period, the random group displayed greater cognitive activity in the sensorimotor and pre-motor regions of the brain. The authors reported that these regions are associated with preparation, sequencing, and response selection of motor performance.

Alternative theories. Additional theories that have been proposed to explain the contextual interference effect are worth noting (although they will not form the basis for the thesis). The “retroactive-inhibition” or “retroactive-interference” hypothesis relies on the idea that later learned patterns affect memory for earlier learned experiences (Poto, 1988; Meeuwsen, 1987). According to the retroactive-inhibition account, newly acquired and practised information impedes the retrieval and performance of previously learnt information. In contextual interference, this means that the retention performance of blocked learners might be impeded by the activity interpolated between the original learning and the retention test (i.e., the second task learned interferes with the retention performance of the first task learned) (Del Rey, Liu, & Simpson, 1994).

An alternative view is presented by Schöllhorn, Michelbrink, Beckmann, Trockel, Sechelmann, and Davids (2006), who proposed stochastic resonance as a potential mechanism for the contextual interference effect. Schöllhorn et al. argued that high contextual interference can be described as learning with many different levels and types of noise, which can amplify the learning signal via a mechanism known in physics as “stochastic resonance”[6]. In a practical sense, Schöllhorn et al. suggested that one noisy signal may be a fundamental target skill, such as passing or shooting in soccer, and the other noisy signal could be an additional random sequence of exercises that is intentionally added to the target skill during practice to create noise. They referred to this approach as differential training and emphasised the role of adaptive behaviours, rather than the process of repeating movements. In terms of both differential training and random practice, the athlete can rely on a broader spectrum of individual movement solutions than in traditional drill-based practice.

[6] According to this approach, noise is not seen as a negative variable as it is viewed in the cognitive literature.

Finally, researchers have suggested that the contextual interference effect could be related to task interest over time. Specifically, random learners might find practice more interesting than blocked learners, resulting in heightened levels of motivation and in turn beneficial learning outcomes (Lee & Simon, 2004). One study that explored this proposition (Jackson, 2006) found that, task interest did indeed have a positive effect on participants' level of performance; however this influence was not dependant on the level of contextual interference under which a participant practised. These results therefore do not support motivational basis for the contextual interference effect. Interestingly, the suggestion that random practice is more motivational than blocked practice contradicts studies of "active learning" which propose that participants tend to prefer repeating movements (i.e., blocked practice) (Cohn, Ghahramani, & Jordan, 1996; Huang, Shadmehr, & Diedrichsen, 2008). Participants have been shown to prefer to repeat movement sequences following a skill trial in which they produced a large error and tend to avoid repeating movements following a skill trial in which they produced a movement perfectly (Huang, Shadmehr, & Diedrichsen, 2008).

Implicit Motor Learning

So far, we have seen how practice variables that engage working memory and are cognitively demanding might be considered to be the most effective for learning. In the following section, research evidence from implicit motor learning studies is discussed within the context of the cognitive effort account. Implicit motor learning is based on the alternative premise that motor skill learning can occur, and can be effective, without an early dependence on working memory (Masters & Maxwell, 2004). The processes underlying implicit learning are also known as procedural, unconscious, unselective, U-mode, and tacit knowledge. The processes underlying explicit learning are also known as declarative, conscious, and selective or S-mode (Hayes & Broadbent; 1988; Magill, 1998).

Theory of Implicit Motor Learning

Highly skilled athletes have an acquired ability to perform complex motor skills using automatic control mechanisms (e.g., Leavitt, 1979; Rose & Christina, 1990). Beginning with the work of Fitts and Posner (1973), motor learning theory asserts that performers progress through relatively distinct stages as they acquire a skill. At first, the task is very demanding as each individual component of the skill requires attention (referred to as the “cognitive stage”). With some practice, a learner may reach the “associative stage”, which is characterised by proceduralisation of the skill. That is, the learner is now able to chunk individual components of the task together in order to control multiple parts concurrently. Finally, with significant practice, an “autonomous stage” may be achieved where the skill can be performed automatically – with minimal attention demand.

A variety of characteristics differentiate automatic processing from non-automatic processing. Automatic processing has been described as capacity-free (Pashler, 1994; Shiffrin & Schneider, 1977); fast (Posner & Snyder, 1975); effortless (Logan, 1988; Shiffrin & Schneider, 1977); and autonomous; or, as occurring without intention (Kahneman & Treisman, 1984; Logan, 1988; Pashler, 1994). As skills become automated, various adjustments may also occur to the way information is processed. These include, a change from declarative knowledge to procedural knowledge, as knowledge may be directly applied without the mediation of other interpretative procedures (Anderson, 1982); a restructuring of the task components into coordinated, integrated, or reorganised units (Cheng, 1985); and a move towards retrieval of past solutions from memory in a direct, single-step fashion (Logan, 1988). All of these characteristics highlight the benefits of automated movement control.

While the ultimate intention of motor learning is automated movement control, traditional approaches have historically focused on the first stage of Fitts and Posner's (1973) model by augmenting explicit knowledge of the skill with rules and instructions, of which learners are consciously aware (Masters, 1992). The logic behind these methods (which are especially popular with coaches), is that information can be provided to learners in a time-efficient manner that facilitates rapid improvements in motor learning and movement control. Implicit motor learning is based on the alternative premise that positive learning outcomes can be achieved by minimising provision of explicit information early in the learning process and hence minimising the need to effortfully hold information in working memory. Implicit learning is generally regarded as, "… the process whereby a complex, rule-governed knowledge base is acquired largely independently of awareness of both the process and the product of the acquisition" (Reber, Walkenfeld, & Hernstadt, 1991, p. 888). Furthermore, implicit learning is also characterised by an absence of an intention to learn and by the resulting knowledge being difficult to express (Berry & Dienes, 1993).

Implicit motor learning, as first envisaged by Masters (1992), involves structuring the practice environment to encourage reliance on procedural knowledge and reduce the amount of explicit control allocated to the components of the motor skill being learned. Implicit motor learning occurs as the result of a reduction in "hypothesis-testing" behaviour. In typical motor learning situations, learners generate movement strategies and appraise their effectiveness based on outcome feedback.

Explicit knowledge accrues as a consequence of this hypothesis testing behaviour. Specifically, during hypothesis testing, learners produce verbal rules or knowledge of how they achieve the task, which is stored for future performance if found to be useful. If the hypothesis is not found to be useful, it is usually discarded (Allen & Reber, 1980; Hayes & Broadbent, 1988). This process is equivalent to the process of "making decisions" outlined in the definition of cognitive effort that was provided earlier in this literature review. In summary, implicit motor learning involves a reduction in hypothesis testing behaviour during motor skill acquisition, which results in a person being unaware of the knowledge structures that they are acquiring (Masters & Maxwell, 2004).

Benefits of Implicit Learning over Explicit Learning

Implicit motor learning has been shown to produce a number of beneficial outcomes over the more traditional explicit approach to skill acquisition. Compared to explicitly learned skills, implicitly learned skills have been shown to: (1) be less susceptible to skill breakdown under pressure (e.g., Lam, Maxwell, & Masters, 2009; Masters, 1992; Hardy, Mullen, & Jones, 1996; Maxwell, Masters, & Eves, 2000); (2) require less attentional control (e.g., Masters, 1992; Maxwell, Masters, & Eves, 2003); (3) be robust under aerobic and anaerobic fatigue (e.g., Poolton, Masters, & Maxwell, 2007b; Masters, Poolton, & Maxwell, 2008); and (4) be less prone to forgetting over time (e.g., Allen & Reber, 1980; Poolton et al., 2007b). Evidence for the benefits of implicit learning have been illustrated using a number of motor skills including: golf putting (Masters, 1992; Maxwell et al., 2000), topspin forehand in table tennis (Liao & Masters, 2001), balancing (Shea, Wulf, Whitacre, & Park, 2001;

Orrell, Eves, & Masters, 2006), and rugby passing (Poolton et al., 2007b). The beneficial characteristics of implicit learning will now be discussed in detail.

Less susceptible to skill breakdown under pressure. From a theoretical standpoint, implicit learning is proposed as a method by which to avoid reinvestment (Masters, Polman, & Hammond, 1993). The concept of reinvestment is derived from "self-focus theories", which propose that individuals have different predispositions to direct conscious attention to step-by-step control of normally automatic movements. When this occurs, under pressure for example, interference or disruption of the movements can occur (Baumeister & Showers, 1986; Beilock & Carr, 2001; Langer & Imber, 1979; Masters, 1992). When performers possess a large pool of explicit knowledge, they are more prone to the effects of reinvestment and therefore may be more likely to suffer from "choking", which is a term used to describe suboptimal performance under pressure (Baumeister & Showers). Masters (1992) hypothesised that if explicit knowledge can be minimised through implicit learning approaches, then the performer will be less likely to consciously focus on the knowledge underlying the skill.

Reinvestment refers specifically to a trait tendency to introduce conscious control of a movement by focusing on particular components of it (Masters, 1992; Masters et al., 1993). Recently, Masters and Maxwell (2008) further developed the theory of reinvestment proposing that reinvestment can occur as a consequence of a variety of contingencies, such as fatigue, boredom, a changing environment, equipment, or even injury. More generally, the disruption of automatic functioning as a result of competition pressure has been described as the "Bliss-Boder hypothesis" (Bliss, 1893; Boder, 1935), "deautomatization" (Deikman, 1969), and the "constrained action hypothesis" (Wulf, McNevin, & Shea, 2001). A comprehensive definition of reinvestment was provided by Masters and Maxwell (2004, p. 204) in which they described reinvestment as, “the propensity for manipulation of conscious, explicit, rules based knowledge, by working memory, to control the mechanics of one’s movements during motor output”.

Masters et al. (1993) developed a 20-item questionnaire that measures individual predispositions for reinvestment. Scores on the scale ranged from 0 to 20 and included questions such as, “I remember things that upset me or make me angry for a long time afterwards”. In one study reported by Masters et al., participants who scored highly on the Reinvestment Scale exhibited a greater tendency for motor disruption under stressful (evaluative) conditions during a golf-putting task. In a second study, high reinvestment was associated with a perceived likelihood to choke under competition pressure in squash and tennis as rated by officials who were familiar with the participants. Two further studies were conducted that also provided support for the proposition that the Reinvestment Scale does indeed assess a personality trait characterised by a propensity towards reinvestment of controlled processing. The Scale was shown to have both internal reliability (coefficient alpha = .80) and test-retest reliability (r = 0.74). Further support for the Reinvestment Scale was also reported by Jackson, Ashford, and Norswothy (2006); Jackson and Beilock (2007); Maxwell, Masters, and Poolton (2006); Wong, Masters, Maxwell, and Abernethy (2008).

Support for the Reinvestment Scale was also found by Chell, Graydon, Crowley, and Child (2003) in an investigation of performance under stress during a wall-volley task. Participants who scored highly on the Reinvestment Scale reported an increase in somatic anxiety and a reduction in self-confidence when under conditions of high stress. These participants also exhibited deterioration in performance under high stress compared to participants who scored low on the Reinvestment Scale. The researchers interpreted these results as supporting the predicative ability of the Reinvestment Scale.

Masters, Eves, and Maxwell (2005) highlighted some limitations of the scale. The major concern raised was that the original scale does not directly examine movement, which draws into question its face validity. As a result, Masters et al. developed the Movement Specific Reinvestment Scale (MSRS) which included items such as, “I’m concerned about my style of moving”. The MSRS includes two factors. Factor 1 (Conscious Motor Processing) relates to self-awareness when moving and a high score on this factor describes individuals who worry about their style of moving and are interested in making a good impression in social situations. Factor 2 (Mechanical Reinvestment) relates to conscious monitoring of movement kinematics and individuals who score highly on this factor are likely to monitor the mechanics of their movements. The MSRS has also been used to assess the propensity for conscious monitoring in people with Parkinson’s disease (Masters, Pall, MacMahon, & Eves, 2006), in stroke patients (Orrell et al., 2006), and in elderly fallers (Wong et al., 2008).

Less attention control. Skills learned implicitly have been shown to require less on-line attention control than explicitly learned skills. Therefore, when a performer acquires and subsequently performs a skill using implicit processes, then he or she is availed with a portion of “spare” cognitive resource with which to process additional environmental demands (e.g., Masters, 1992; Maxwell et al., 2003). Earlier in this chapter, it was stated that automatic control emerges as a function of skill during the motor learning process. Using implicit learning, it appears to be possible to perform skills using minimal attention control even during the early stages of the motor learning process. The amount of attention control required to perform a particular task can be measured using dual-task methodology which will be discussed in greater detail later in this literature review (see “Dual-Task Learning” under “Implicit Learning Models”).

Robust under fatigue and durable over time. Poolton et al. (2007b) and Masters, Poolton, and Maxwell (2008) have reported that implicit motor performance is robust when the performer is physically fatigued. This work was based on the premise that implicit processes are evolutionarily older than explicit processes, which affords them more stability and resilience (Reber, 1992). Poolton et al. showed that the performance of implicit learners was not affected by the imposition of an anaerobic test (the double Wingate Anaerobic test protocol), whereas under the same test conditions, performance of explicit learners deteriorated. Furthermore, in part two of the study, a sample of the participants was recalled after a one-year retention period. The performance of both the implicit and explicit learners showed resilience to fatigue after this one-year hiatus. The authors interpreted the resilience of the explicit learners as being a result of forgetting (i.e., over the one-year break there was deterioration in explicit knowledge, but not motor performance, indicative of implicit control).

Masters et al. (2008) also found evidence of the robust performance of implicit learners under fatigue – this time under aerobic fatigue. In the study, participants learned a throwing task via either an implicit or explicit learning protocol. A VO_{2max} running test was conducted following learning. The results showed that implicitly learned processes remained stable under the aerobic fatigue conditions, whereas there was deterioration in explicitly learned processes. Masters et al. argued that implicit motor learning may result in greater efficiency of movement or movement control, allowing better use of resources depleted by fatigue. These findings together with the findings of the Poolton et al. (2007b) study have obvious applied benefits for sports performance. They suggest that implicit learning might be beneficial for sports in which skills are required to be performed under either aerobic or anaerobic fatigue.

Implicit Motor Learning Models

Researchers have developed a range of methods that promote implicit processing during acquisition of a cognitive task. In a seminal study of implicit learning by Reber (1967), participants acquired a simple set of rules underlying an artificial grammar by memorising meaningless letter strings. After participants had memorised the letter strings, they were informed that the strings followed the rules of a grammar. They were then asked to classify novel strings as either being grammatically correct (following the underlying rules) or not. The results showed that participants were able to classify the letter strings at greater than chance levels; however they were unable to explicate the rules underlying the grammar. This study showed implicit learning in the cognitive domain, and more recently implicit learning has been applied to the learning of motor skills.

It is interesting to note that the implicit learning literature approximately parallels the historical timeline of the contextual interference literature with respect to its translation from the verbal to the motor learning domain. Early work in the contextual interference area was conducted in verbal learning studies by Battig (1966). This occurred at a time when interest in implicit learning was also focused on the verbal learning domain, with Reber (1967) conducting work in implicit grammar learning. Both research domains received interest from motor learning scientists in the

1970s. Shea and Morgan (1979) applied contextual interference to the motor learning domain and Pew (1974) applied implicit learning to the motor learning domain.

In the early work of Pew (1974), participants were asked to complete a waveform tracking task on an oscilloscope using a joystick. The waveform contained an underlying rule-based structure in which the middle third of the waveform did not vary from trial to trial, while the first and last third of the pattern was variable. Following learning, participants were able to complete the middle section with fewer movement errors than the first and last phase. Importantly, participants were unable to verbally report any knowledge regarding the invariant characteristics of the middle section of the waveform. This model showed that participants were able to effectively learn a movement pattern without concurrent acquisition of the knowledge underlying that movement. Recent work, however, has called these findings into question (Chambaron, Ginhac, Ferrel-Chapus, & Perruchet, 2006).

In the intervening years, a number of additional models of implicit motor learning have been developed. These include: (1) reducing the number of instructions traditionally given during learning (Green & Flowers, 1991); (2) loading working memory with a cognitively demanding secondary task (dual-task learning: Masters, 1992; Hardy et al., 1996; Bright & Freedman, 1998; Maxwell et al., 2000); (3) minimising task demands resulting in minimisation of performance errors and hence conscious processing (errorless learning: Maxwell, Masters, Kerr, & Weedon, 2001; Poolton, Masters, & Maxwell, 2005); (4) withholding visual and auditory information from the learner (reduced feedback learning: Masters, 2000; Maxwell et al., 2000); (5) explaining the skill requirements by analogy or metaphor (analogy learning: Lam et al., 2009; Law, Masters, Bray, Eves, & Bardswell, 2003; Liao & Masters, 2001; Masters, Poolton, Maxwell, & Raab, 2008); and (6) providing outcome feedback at marginally perceptible thresholds of awareness (subliminal learning: Masters, Maxwell, & Eves, 2009).

Reducing the amount of traditional instruction. Green and Flowers (1991) investigated the result of either providing or not providing participants with direct instructions for how to perform a computer-based catching skill. Participants who were provided with traditional instructions made significantly more errors than the uninstructed group. Green and Flowers interpreted these findings being as the result of additional cognitive load experienced by the instructed group. Specifically, the instructions imposed on the explicit learning group required them to rehearse and remember the rules. This interfered with the motor control of the task.

Dual-task learning. Masters (1992) was the first to apply implicit motor learning to a sport skill. The model adopted in this study was dual-task learning. Dual-task learning involves loading working memory with a demanding secondary task to minimise the opportunity for learners to process information relating to skill execution. There are a number of studies which provide evidence of implicit learning under conditions of secondary task load (Bright & Freedman, 1998; Hardy et al., 1996; MacMahon & Masters, 2002; Masters, 1992; Maxwell et al., 2000).

Masters (1992) asked a group of participants to practice golf putting while constantly generating random letters at a specific rate in order to direct attention away from the movements (thus causing learning *without* knowledge of the rules underlying the movements). He asked a second group of participants to practice golf putting using a written set of explicit instructions about how to putt (thus causing learning *with* knowledge of rules). The findings confirmed that dual-task learning was accompanied by the accrual of fewer explicit, verbalisable rules relative to explicit learning. Furthermore, when tested under conditions of stress, evidence was found to support the prediction that the group who learned with the concurrent secondary task were less likely to suffer movement failure under pressure.

The findings of this study were later replicated by Hardy et al. (1996) who additionally investigated whether the improvements in the stress conditions observed by Masters (1992) were due to a release from the secondary task load. Hardy et al. replicated and extended Masters' study by including an additional implicit learning group which was asked to carry out the secondary task (articulatory suppression) during both the learning and the stress trials. The study by Hardy et al. revealed that both of the implicit learning groups continued to improve their performance under stress, whereas the explicit learning group did not. This study provided evidence discounting the contention that improvements in the implicit learning group in the stress conditions in Masters' study were due to release from the secondary task load, providing further evidence for the implicit learning outcomes of dual-task practice.

One study that challenged the implicit benefits of dual-task learning was conducted by Bright and Freedman (1998). Bright and Freedman investigated the same issue highlighted by Hardy et al. (1996), but incorporated two different levels of task difficulty within their design: easy and hard. They claimed to show that when released from a hard secondary task load in a stress condition, participants exhibited larger increases in performance than participants released from an easy secondary task. Subsequent research papers have suggested that the discrepancy in findings is due to flaws in the design of the study by Bright and Freedman. Maxwell et al. (2000) proposed that participants used in the study were not true novices and therefore the findings could have been influenced by explicit knowledge that the participants had previously accumulated. Mullen, Hardy, and Oldham (2007) also highlighted issues with the Bright and Freedman study, reiterating the concerns noted by Maxwell et al.

regarding participants' level of previous experience, noting that "any comparison between experiments in which novices acquire a motor skill in implicit practice conditions and those in which non-novices are used is confounded" (Mullen et al., p. 144). Mullen et al. also noted that the methodology Bright and Freedman used to assess the verbal reports failed to include two blind independent raters, as was the case in the Masters (1992) and Hardy et al. studies.

A key issue with the dual-task methodology is that secondary task loading during learning has been shown to produce a decrement in performance as a result of the attention demand required to perform two concurrent tasks. Maxwell et al. (2000) explored whether the performances of explicit learners and dual-task loaded implicit learners would converge over an extended period of practice. After 3,000 practice trials, the implicit learning group still showed significantly poorer performance than the explicit learning group. There was, however, no difference between the groups at retention suggesting a moderate convergence between the groups as a result of practice. Koedijker, Oudejans, and Beek (2008) however, found that over 10,000 trials of learning a table tennis task, implicit learners were at least as good, if not better than explicit learners.

MacMahon and Masters (2002) investigated whether a less demanding secondary task could be used to resolve the issue of poorer performance under secondary task load. Specifically, MacMahon and Masters investigated whether secondary tasks that only load on the phonological loop component of working memory (and not the central executive) create an implicit mode of learning without a disruption of motor performance. Only the central executive tasks (random letter generation and counting backwards) resulted in suppression of explicit rule accrual, with the phonological loop tasks (articulatory suppression and unattended speech) failing to reduce verbal rule accrual. These results suggest that dual-task learning might have limited real-world applications and as a result, researchers have investigated various other implicit motor learning models. The results are also interesting in light of our current investigation of cognitive effort because they provide insight into the specific aspect of cognitive effort that needs to be by-passed in order to support implicit learning. Specifically, the study suggests that by-passing the central executive, which controls attention, is essential in producing the benefits of implicit learning.

Errorless learning. Errorless learning is another model that has previously been shown to exhibit implicit characteristics (Masters, MacMahon, & Pall, 2004; Masters et al., 2008; Maxwell et al., 2001; Orrell et al., 2006; Poolton et al., 2005). In errorless learning, the environment is modified to minimise the number of mistakes the learner makes and hence minimise the amount of attention devoted to explicitly processing rules and hypotheses underlying performance. Errorless learning results from a lack of dependence on conscious processing to identify and eliminate errors. Relative to errorful practice (in which participants experience a large number of errors), errorless learning has been shown to enhance performance during retention and reduce performance decrements during execution of a concurrent cognitive task (Capio, Poolton, Sit, Holmstrom, & Masters, 2010; Maxwell et al., 2001; Poolton et al., 2005). In a number of errorless learning studies, participants have practised a skill at first from a distance close to the target and incrementally repeated the skill from increasingly challenging distances (Masters et al., 2008; Maxwell et al., 2001; Poolton et al., 2005). For example, novice golfers learned a putting task implicitly by beginning putting at a distance of 10 cm from the target and subsequently completed blocks from gradually increasing distances from the target (Maxwell et al., 2001).

Poolton et al. (2005) showed that a brief period of errorless learning can promote processing in the procedural pathway even when explicit rules are introduced later in learning. Poolton et al. asked participants to practice a golf putting task over eight blocks of 50 practice trials (400 trials in total). One group was given six explicit instructions for how to perform the task prior to the fourth block of learning (implicit-explicit group). A second group was given the same six instructions prior to the learning phase (explicit group). In a secondary task transfer test, the implicit-explicit group were able to maintain performance on the putting task showing a reliance on procedural processing. The performance of the explicit group, in contrast, deteriorated under secondary task transfer load.

Reduced-feedback learning. Reduced-feedback learning is based on a similar premise to errorless learning. Specifically, implicit learning is the result of a reduction in working memory reliance because the learner does not formulate hypothetical rules about performance outcomes (Maxwell et al., 2003). In both errorless learning and reduced-feedback learning, a learner has little or no information about outcome errors, either because no errors have occurred (errorless learning) or because there has been minimal sensory access to errors (reduced-feedback learning). The learner then adopts an implicit mode of control which negates the need for working memory to formulate hypotheses about how to improve performance.

Maxwell et al. (2003) explored reduced-feedback learning in a series of three experiments. All three experiments required participants to putt golf balls either with full or reduced feedback about the outcome of their putts. The availability of feedback was expected to encourage learners to engage in hypothesis-testing behaviour (and hence produce explicit learning). A reduction in feedback was expected to minimise hypothesis-testing behaviour (and hence produce implicit learning). In the first experiment, the results did not differentiate between the treatment conditions, suggesting that the reduced feedback group may have engaged in some explicit processing during learning. In the second experiment, all participants were asked to perform a visual search task between trials during the learning phase to prevent learners in the reduced feedback group from using working memory to process proprioceptive and tactile sensory feedback between putting attempts. The results demonstrated that the visual search task prevented the build up of explicit knowledge in the reduced feedback group supporting the premise detailed by the reduced feedback model. The final experiment extended the first two studies in two ways: (1) an additional control group that performed an irrelevant motor task during the learning phase (rather than the putting task) was included, and (2) an additional dependent measure was included which assessed the acceleration profile of the golf club during the putting movement with an accelerometer. The purpose of the additional control group was to confirm that the reduced feedback groups who performed the putting task had successfully acquired some aspects of the putting skill during the learning trials. The purpose of the additional dependent measure was to assess whether the groups differed in their acceleration profile (as an indicator of learning). The results confirmed that learning took place under reduced feedback conditions. Overall, the second and third experiments provided support for the reduced-feedback model as a means of reducing explicit hypothesis-testing during learning.

Analogy learning. Analogy learning has received notable interest because of its potential use within an applied setting. As such, it is perhaps less stringent in its evasion of working memory reliance. Analogy learning works on the principle that summarising or “chunking” task-relevant knowledge into a single metaphor or analogy reduces the amount of information that is consciously processed in working memory (Koedijker et al., 2008; Masters, 2000; Orrell et al., 2006; Poolton, Masters, & Maxwell, 2007a). Despite analogy learning being a means of reducing the processing load of working memory, rather than wholly circumventing its contribution, research findings have shown that implicit-type motor learning still takes place. For example, in a study by Liao and Masters (2001) table tennis novices were able to learn to hit a forehand topspin implicitly by being given the analogy of a right angle triangle. Participants were instructed to, "Pretend to draw a right-angled triangle with the bat" (p. 310). They were further instructed that to impart topspin to the ball, they should strike the ball while bringing the bat up the hypotenuse of the triangle. Skills learned by analogy have been shown to be less prone to the effects of both secondary task loading and psychological stress than explicitly learned skills (e.g., Law et al., 2003; Liao & Masters; Poolton et al.; Koedijker et al.).

Subliminal learning. Masters et al. (2009) showed that it is possible to promote implicit learning by presenting outcome feedback at a subliminal level (below the level of conscious awareness). Masters et al*.* asked participants to practice hitting golf balls to a target that was concealed to prevent participants receiving visual feedback about the outcome of their performance trials. Feedback about the resultant location of the ball was then provided for either: (1) a duration that was available to conscious awareness (supraliminal threshold), (2) a duration that was only available subliminally (subjective threshold), or (3) a duration that was not at all perceptible (objective threshold). The data showed that the absence of feedback (objective threshold) resulted in no beneficial learning outcomes, whereas learning was observed in the other two conditions. Following the learning phase, participants were asked to perform a transfer condition in which the target was unconcealed. In this condition, there was an increase in performance in both the subjective and objective conditions, but there was a decrease in performance for participants who could consciously see the outcome during learning. The researchers concluded that providing feedback at sub-optimal levels produced an implicit mode of learning.

Measurement Issues

A number of measures have previously been used to disassociate implicit and explicit processing. These include: (1) verbal reports, (2) probe reaction time, (3) secondary task transfer, (4) kinematic changes during learning, and (5) Electroencephalogram (EEG) coherence. Other measures that do not directly assess implicit processing, but which measure characteristics of implicit learning, include: (1) performance under stress (which assesses whether the skill is robust to anxiety), (2) transfer and retention tests (which assess whether performance on a skill is transferable to novel conditions and/or robust over time), and (3) physical stress tests (which assess whether skills are robust to physiological fatigue). The measures that purport to directly measure implicit processes will now be discussed in detail.

Verbal reports. Perhaps the simplest way to measure implicit processes is to ask participants to report the verbalisable knowledge they possess following a period of learning. This is typically done through verbal reports where participants are asked to describe all of the information they have used to control the learned movement. Participants are asked to report information, such as, “any rules, knowledge, methods, or techniques that they were aware of using to complete the task successfully” (Maxwell et al., 2000, p. 115), or to report “any rules or knowledge you have used or had become aware of using” (Liao & Masters, 2001, p. 311).

Although this measure provides a relatively straight-forward way of assessing implicit knowledge, there are limitations that are worth considering. Firstly, according to Shanks and St. John (1994) any measure of explicit knowledge must meet two criteria. The first criterion, the information criterion, states that in order to conclude that a participant has not accrued explicit knowledge, it must first be established that the information provided on the measure of awareness is in fact the information responsible for performance. The second criterion, the sensitivity criterion, states that in order to conclude that a measure is an adequate test of explicit knowledge, it must first be established that the test is sensitive to all of the relevant conscious knowledge. Shanks and St. John suggest that the verbal reports test is not an adequate measure of participants' awareness because: (1) different retrieval contexts exist between the performance setting and the test of verbal reports, and (2) there is no evidence to suggest that verbal reports provide an exhaustive index of conscious information (other tests such as recognition tests have been shown to detect information that is not reported in verbal protocol tests).

Shanks and St. John (1994) highlight a further issue with verbal reports suggesting that, in certain experiments, participants might misinterpret the instructions of the test to mean that they should only report rules (i.e., they might neglect to report important fragmentary information). Researchers have attempted to avoid this problem, however, by posing specific questions to participants that direct them to include all relevant information. For example, the two examples provided at the beginning of this section address this concern when they direct participants to report any "rules *or* knowledge" that they were aware of using. The examples provided address the issue of sensitivity and might also address the information criterion because they specifically direct participants to report knowledge that they "used" to perform the tasks.

Another issue with the verbal reports measure is that it can be difficult to differentiate between episodic knowledge and generic (retrospective) knowledge. Generic knowledge captures the prescriptive information about how a skill is typically performed. Episodic knowledge, by contrast, refers to a specific memory – an autobiographical record of a particular performance instance (Beilock & Carr, 2001). Researchers have shown that generic knowledge increases as a function of expertise – as skill improves, more highly expert performers are able to report more general knowledge about the domain in which they are skilled. Episodic knowledge, on the other hand, represents access to declarative memory about a particular movement instance (Beilock & Carr, 2004; Beilock, Wierenga, & Carr, 2002). As skill acquisition progresses, there is typically a reduction in episodic knowledge as greater reliance is placed on automatic control mechanisms. The verbal reports used in implicit learning typically tap into episodic memories. Implicit learning is associated with a reduction in episodic recollections (as consequently generic knowledge) whereas explicit learning is associated with more highly declarative episodic memories.

The issues detailed here highlight the limitations of verbal reports as a means of differentiating between implicit and explicit knowledge. The best research designs are likely to consider these limitations and include verbal reports within a battery of measures that rather than relying on a single measure to establish the state of a participant's awareness following a learning intervention.

Probe reaction time. A second measurement technique that aims to quantify the demands on attention resources used during motor performance is probe reaction time (PRT). This method has recently been used in both the contextual interference and implicit learning research domains (Lam et al., 2009; Li & Wright, 2000). The PRT methodology involves the addition of a discrete secondary task during the inter-trial interval of the primary task of interest. The secondary task typically takes the form of an auditory tone to which participants are required to respond. The latency of the reaction time to the tone is taken as an indication of the amount of attention capacity that is being occupied at that moment in time to control performance of the primary task (Abernethy, 1988). The greater the attention requirements of the primary task at that moment in time, the slower the reaction time to the secondary task.

Secondary task transfer. A similar, though distinct, measure that has been used in implicit motor learning research is performance during secondary task transfer. This measure differs from PRT in that it employs a continuous secondary task to measure attention control over a number of practice repetitions and is implemented following the learning phase. In this measure, participants perform the primary and secondary tasks under two conditions (independently and concurrently). Participants are typically instructed to give attention priority to the primary task. Changes in performance on the primary or secondary task from single- to dual-task conditions are taken as an indication of how much attention the performer requires to conduct the primary task (Abernethy, 1988). It is thought that when processing demands exceed the available capacity, there will be a reduction in performance on either the primary or secondary task (depending on the instructions given to participants regarding where they should allocate their attentional priority).

A methodological consideration in dual-task studies is the selection of the most appropriate secondary task. Abernethy (1988) suggested that there are two important considerations; structural interference and continuity. Structural interference refers to overlapping demands in a particular modality in terms of sensory input, cognitive processing, or motor output. For instance, Smith and Chamberlin (1992) employed an experimental design in which a player was required to run as quickly as possible through a slalom course (primary task) while dribbling a soccer ball (secondary task), where the same limbs were required for both tasks. In this example, there may be structural interference between the two tasks. Abernethy asserted that structural interference is of benefit to studies investigating “real world” problems of interference. An example is Davids’ (1982) investigation of peripheral vision, which comprised a primary task of catching a ball and a secondary task of responding to peripheral lights (with the common modality being vision). In this situation the interference between the two tasks matches the real-world interference. Conversely, for studies where the interest lies in investigating total attention demand, or the time course of attention demand, it is more appropriate to design secondary tasks which do not cause structural interference.

The second consideration in secondary task selection, continuity, refers to whether the secondary tasks should be more discrete or continuous. Cognitive tasks that are used as secondary tasks can be thought of on a continuum from discrete to continuous. It is generally agreed that tasks that are more continuous should be chosen, with the advantage being that this ensures a constant level of attention demand. In contrast, a secondary task that is inserted at discrete time points may allow participants to switch their attention between the two tasks, thus making the logical interpretation of data very difficult (Abernethy, 1988). It is notable that this is one of the main problems with Bright and Freedman’s (1998) study of dual-task learning detailed earlier in this chapter. Some examples of continuous tasks include verbally responding to three frequency levels of auditory stimuli by differentiating between low, moderate, and high tones (Landers, Qi, & Cortet, 1985); pressing a button or verbally responding as fast as possible to an auditory tone (Prezuhy & Etnier, 2001); and identifying geometric shapes that are projected onto a wall (Leavitt, 1979).

A third methodological consideration relates to the control of temporal uncertainty in the presentation of the secondary task (Abernethy, 1988, 1993). Importantly, the probability of the probe stimulus occurring must remain consistent throughout the primary task. Under normal conditions, the temporal uncertainty regarding the onset of the secondary task probe reduces as the primary task proceeds. That is, the longer the primary task continues without the presence of a secondary task probe, the more likely one is to occur. This can cause a reduction in reaction time as a participant becomes more expectant that a probe will occur. One way of overcoming this problem is to include “catch trials” within the design. A catch trial is one in which the primary task is performed without the secondary task (Abernethy, 1988).

The final methodological consideration is fundamental to dual-task research. The problem is that of attention switching between primary and secondary tasks. In dual-task studies, instructional sets are used to alter the priorities that participants are required to allocate to each of the two tasks (Abernethy, 1993). In most studies of sporting performance, participants are instructed to give attentional priority to the primary task. This allows researchers to assume that primary task performance is constant in both single- and dual-task conditions. Thus, changes in secondary task performance can be directly linked to attentional fluctuations in the demands of the primary task. A problem occurs when primary task performance drops in the dual-task condition. Instead of allocating priority to the primary task, the participant may be switching their resources between the two tasks. This makes a meaningful interpretation of results difficult. In order to overcome the problems of controlling primary task performance, researchers must ensure that they include clear instructions that explain to participants the importance of maintaining primary task performance at all times. Similarly, primary task performance should be closely monitored in both single- and dual-task conditions to ensure that performance is consistent.

Kinematic changes during learning. Poolton et al. (2005) used a four camera motion capture system to conduct a kinematic analysis of the head of a putter during a golf task. Specifically, measures of velocity, acceleration, jerk, trial-to-trial velocity variability, movement time, and distance travelled were collected. Although the results did not reveal any differences between an explicit group and a group who initially learned implicitly, the measures have potential applications for future research. Specifically, a similar protocol could be used to assess hypothesis testing behaviour with the logic being that greater amounts of hypothesis testing behaviour would be associated with greater trial to trial variability.

EEG coherence. Recently, researchers have investigated the use of EEG co-activation (coherence) as a measure of implicit motor learning. The EEG procedure provides researchers with a method of studying brain activity by means of electrodes attached to the scalp. EEG coherence relies on the use of computer analysis to derive a measure of the relationship between two areas of EEG recording. When measuring EEG from a number of sites, a high coherence between two locations suggests that they are functionally and/or structurally connected (Andreassi, 2000). In two recent studies, Zhu, Poolton, Wilson, Maxwell, and Masters (under revision) examined EEG coherence between the verbal-analytical (T3) and motor planning (Fz) regions, and between the visuospatial (T4) and the motor planning region (Fz) during a golf putting task. The first study aimed to compare coherence in high and low reinvestors. Participants who reported high scores on the “Conscious Motor Processing Factor” of the Movement Specific Reinvestment Scale displayed higher coherence between the T3-Fz regions than participants with low scores, suggesting greater verbal-analytical processing of movements for that group. The second study aimed to specifically compare coherence in implicit (errorless) and explicit (errorful) learning. Implicit learners displayed less coherence between T3-Fz than explicit learners. Furthermore, under conditions of pressure, explicit learners displayed more T3-Fz coherence than implicit learners, implying more verbal-analytical processing of movements under pressure. These studies demonstrate potential in the use of EEG T3-Fz coherence as a measure of the involvement of verbal-analytical processes in motor output.

Summary. Given the nature of implicit processes, there are obvious measurement limitations. Overall, the measures outlined here have been shown to successfully dissociate implicit and explicit processes, however future research would benefit from the development of either additional measures to compliment a battery of implicit learning measures or more sensitive measures that can be relied upon in isolation (advances in neuroimaging techniques may provide promise in this regard).

The Current Thesis

It is clear that the cognitive effort explanations of the contextual interference effect and the findings from implicit motor learning research represent a paradox (see Rendell, Masters, & Farrow, 2009). One line of research suggests advantages of practice that involve working memory dependent processes (i.e., the elaboration and reconstruction hypotheses for the contextual interference effect), whereas another line of research suggests advantages of practice that minimises or circumvents the role of working memory (i.e., the implicit motor learning effect). This thesis seeks to explore this paradox through a series of interrelated studies.

CHAPTER 3

STUDY ONE: IMPLICIT PRACTICE FOR TECHNIQUE ADAPTATION IN EXPERT PERFORMERS

Introduction

Considering the numerous benefits of automatic or procedural processing outlined in Chapter 2 (it is capacity-free, effortless, and autonomous), it is perhaps surprising that traditional coaching approaches are typically based on the provision of explicit or declarative instruction. Proponents of explicit coaching methods cite the key advantageous characteristic as being that learners are given guidelines for how to perform a skill which leads them to produce effective movements (rather than having to discover the most effective movement solution themselves). Explicit coaching methods typically result in rapid improvements in performance. Perhaps the most obvious problem with the explicit coaching approach (as outlined in Chapter 2), is that it can encourage the athlete to control movements in a conscious way, a process which can be detrimental in certain situations, such as under competition pressure. Implicit motor learning has been suggested as a method of overcoming the issues involved in the breakdown of explicitly learned skills under pressure (Masters, 1992).

Past research has tended to focus heavily on implicit motor learning in novice performers who have not previously acquired explicit rules governing the skill. Coaches working with skilled athletes are faced with the challenge of how to adapt skills that are well-learned and that normally operate best without conscious control. Using explicit coaching methods, athletes are encouraged to increase the attentional control directed to their movements to enable them to make the desired changes to their technique (thus reverting to a more conscious mode of control). The use of implicit learning techniques offers a potential method of changing well-learned technique without the need to revert to step-by-step control procedures that characterise novice sensorimotor skill execution.

The aim of the current study was to investigate implicit motor learning in performers who had previously accumulated a large amount of explicit knowledge. Significant challenges accompany the investigation of practice methods in expert performers (Sands, McNeal, & Stone, 2005). By definition, elite athletes are rare. Expert athletes are often unwilling to submit to research, so testing groups of experts that are large and homogenous (for statistical purposes) is difficult. Finding an appropriate control group becomes equally difficult or in some cases impossible. Researchers are typically left to rely on convenience sampling which makes lack of randomisation another issue. Furthermore, the generalisability of results may not apply because the research findings are only applicable to similar elite athletes, of which there are few in number (Sands et al.). Despite these challenges, much can be gained from studying populations of elite athletes because their experience in high-level training involves unique physical, emotional, and mental stressors (Sands et al.). In the current study, with the support of the head coach of the Australian Netball Team, a rare opportunity was given to influence the shooting practice sessions of two expert netball players over a six-week period. Given that these players are amongst the very best in their chosen sport, it is interesting to include them in an investigation of practice methods, despite the exclusion of traditional statistical approaches.

Prior to the practice intervention, the coach was asked to highlight the performance limitations of these two players when shooting, in order to gain an understanding of their shooting skills and to target the practice methods to suit them. For one player, issues of confidence and over-thinking were recognised. The coach suggested that a recent injury had a major influence on this particular player. Specifically, at the time of the study, the coach noted that the player sometimes seemed to feel slightly inadequate due to the challenges involved in returning to top form following the injury. The coach also observed that the player had developed a tendency to over-think her shooting.[7] The coach remarked that the player possessed a great skill capacity to read the game, and that she was clever at working the space and getting the ball without thinking, however, since the recent injury, shooting had become an issue due to a lack of confidence. For the other player, the coach highlighted an issue regarding the "flatness" of her shot. The coach commented that, "I think her shot is fairly flat, but she knows where the hoop is. She's able to pop it through, but I'm a bit concerned that on bigger height (playing against taller defence) the release of the ball will be too low and she could find herself in trouble in international matches with the way she shoots".

Based on these observations from the coach, a six-week training intervention was conducted to assess whether practice in an implicit learning environment would (1) address the issue of a flat ball trajectory, (2) increase players' levels of confidence, and (3) minimise "over-thinking" or conscious control of the shooting action. Specifically, this study investigated whether an advantageous increase in the shooting trajectory of expert netball shooters could be brought about, without increasing the amount of explicit processing, by asking the two expert netball shooters to shoot towards an adapted ring while responding to a concurrent secondary task (high and low pitched tones).

The adapted ring consisted of an additional 30 cm metal barrier which was attached to the standard ring through which participants were asked to shoot (see

[7] The theory of reinvestment (see for a review, Masters & Maxwell, 2008) signals that injury is one of many contingencies that can cause performers to over-think their skills.

Figure 3.1). The adapted ring may be considered a manipulation of a task constraint in order to bring about a change in skill.[8] In this study, the introduction of a task constraint has been coupled with an implicit intervention (using the dual-task methodology) with the aim of adapting shooting trajectory in an implicit manner.

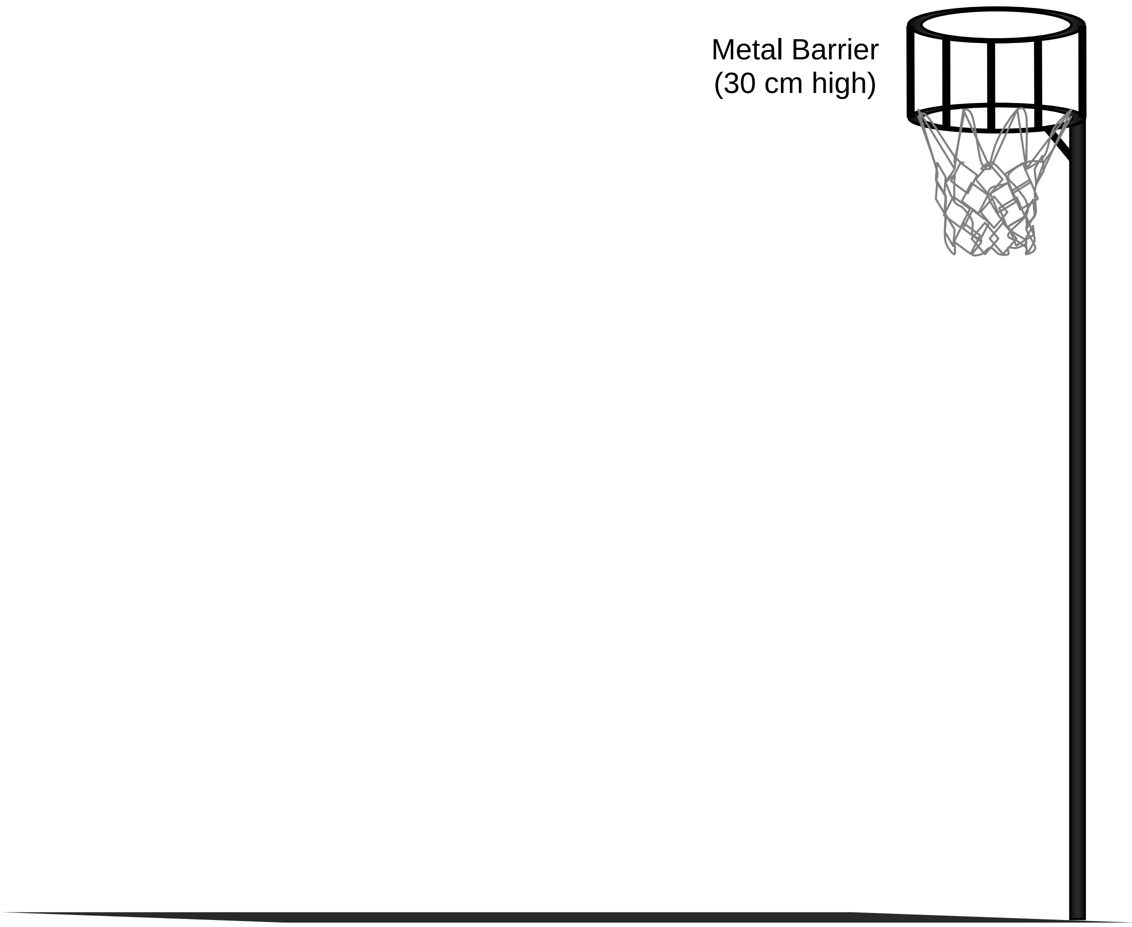

Figure 3.1. Schematic representation of the metal barrier attached to the netball ring.

[8] According to the constraints-led approach to skill acquisition, manipulating key organismic, environmental, and task constraints can influence emergent coordination patterns during goal directed behaviour (Davids, Button, & Bennett, 2008; Newell, 1986).

With regards to the shooting trajectory, previous research involving shooting tasks that require high degrees of accuracy (such as basketball and netball shooting) has identified two main advantages of a steep shooting trajectory: (1) a steeper shooting trajectory is more likely to result in the ball passing over the hands of the defender than a ball that has a shallower (or “flatter”) trajectory, and (2) a steeper trajectory produces a larger margin for error because the basketball or netball ring has a greater elliptical area through which the ball can travel (Bartlett & Robins, 2008; McLester & St Pierre, 2008) (see Figure 3.2).

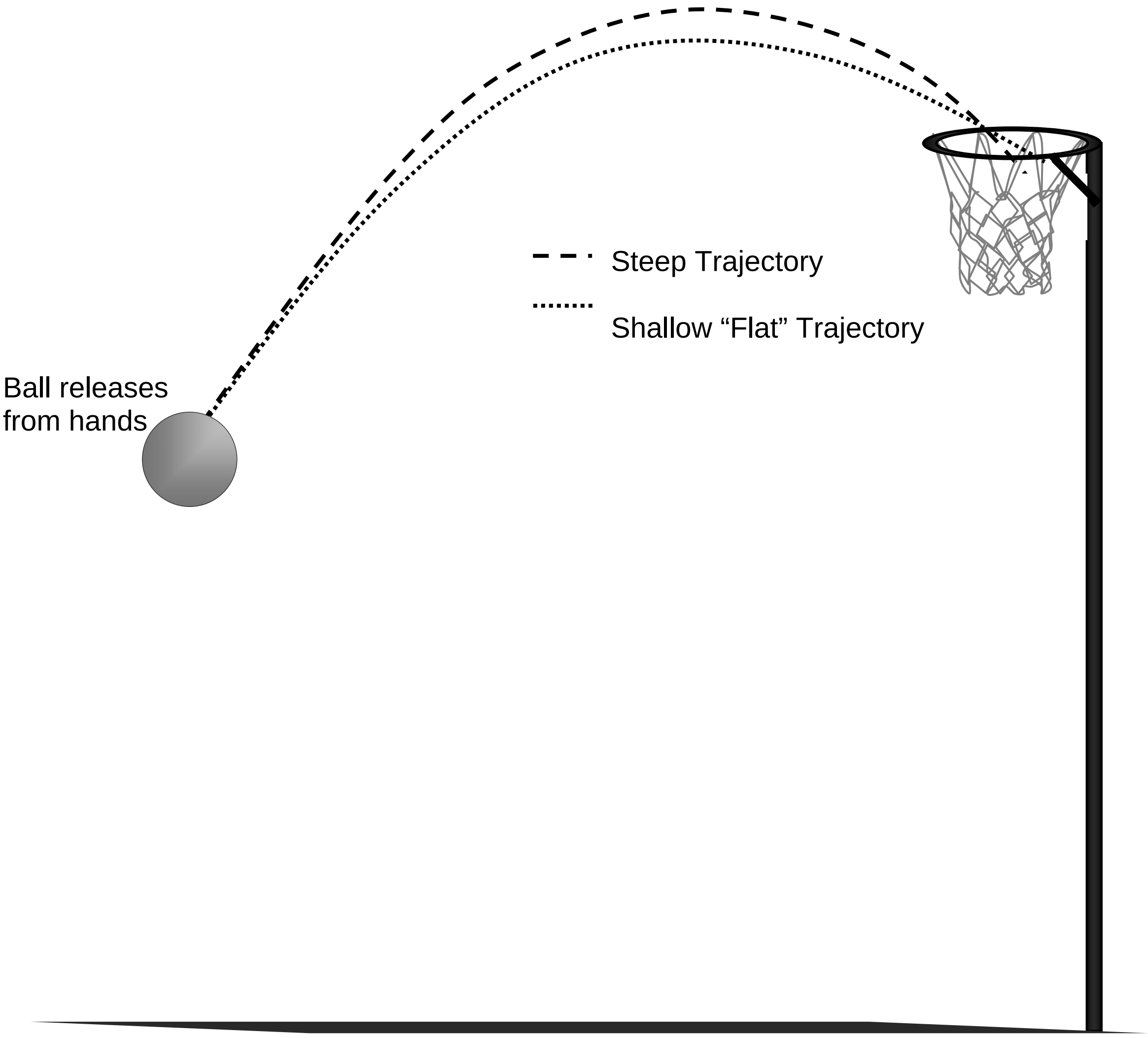

Figure 3.2. Schematic representation of steep and shallow shooting trajectories.

This study also investigated whether the practice intervention would have a supplementary beneficial influence on players' level of confidence (a variable that has an obvious influence on performance in real match scenarios). It was predicted that improving the players shooting skills through the implicit intervention would improve their confidence as a result of more successful shooting skills. A final element of the study design was to maintain high levels of interference in the practice environment in the way that would be observed in a typical training environment. This study adopts an applied approach that aims to draw on the experiential knowledge of the coach and is also grounded in the experimental outcomes of existing literature.[9]

Method

Participants

The participants were two expert female netball goal shooters who were squad members of the Australian National Team. 'Player A' was 31 years old and had been a member of the Australian squad for 10 years. For the past six years, she had been recognised as one of the top five players in her position at Open National level. She had played the sport for 24 years at the time of the study. 'Player B' was 22 years old, had been a member of the Australian squad for one year. For the past two years, she had been recognised as one of the top five players in her position at Open National level. At the time of the study, she had played the sport for a total of 12 years.

Design and Procedures

The study was a single-case design which consisted of three phases: (1) pre-test, (2) training intervention, and (3) post-test.

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[9] The study reported here details one aspect of a larger project aimed at improving the shooting skills of six members of the Australian Netball Squad.

Pre-Test

Participants provided informed consent (Appendixes A and B), demographic information, and details about their netball playing experience (Appendix C). The pre-test phase included the following battery of tests: single-task shooting performance, dual-task performance, verbal reports, and self-report ratings of confidence.

Single-task performance. Shooting performance was measured from two locations: 1 m and 3 m from the goal post along the backline (side-on to the goal post). Participants took 15 shots from each of the shooting locations in a randomised order (total = 30 shots). A research assistant was positioned near the goal post to retrieve the ball and return it to the participant for the next trial. Two standard digital video cameras filmed the participants to allow for post-processing of performance and to assess ball flight characteristics. One camera was focused on shooting performance from 1 m and the other was focused on shooting performance from 3 m. Both cameras were set up on the transverse line (10.17 m away from participants) and were perpendicular to the line of the participant and goal post. The location of the cameras was identified by first placing a marker half way between the participant and the goal post (1 m shooting location = 0.5 m from goal post; 3 m shooting location = 1.5 m from the goal post). A line was then taken at a 90º angle from that marker to the transverse line. The intersection of that line and the transverse line was then marked and the camera placed on top such that the centre of the tripod was directly over the marker.

The footage was analysed using Dartfish ProSuite software (Version 4.5) to obtain quantitative measures of two characteristics of ball flight: (1) maximum ball height and (2) release angle. The video was calibrated using the known height of the goal post. The distance tool was used to calculate the distance from the ground to the centre of the ball at its maximum ball height during ball flight. To calculate the release angle, the centre of the ball was digitised at release and five video frames after release. The angle tool was then used to calculate the release angle (in degrees). Shooting accuracy was scored by allocating a score of ‘1’ to any ball that travelled through the ring and a score of ‘0’ to any ball that missed.

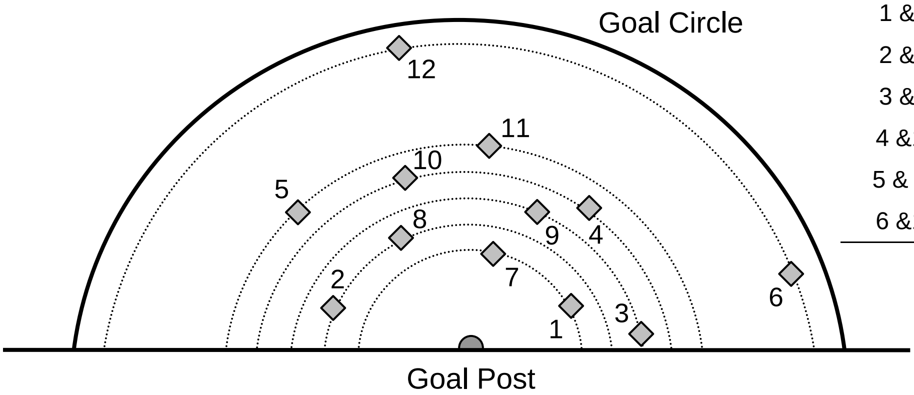
Dual-task performance. The automaticity of participants’ shooting skills was measured by a dual-task test. Participants completed two tasks concurrently. The primary task was identical to the test of shooting performance outlined above (however only 3 m shooting was tested due to restrictions of the time availability of players) and the secondary task required participants to respond with the word “tone” to high pitched tones presented in a series of high and low pitched tones. Participants were instructed that their first priority was to shoot as accurately as possible. During the dual-task test, participants wore a lapel mounted microphone that was used to record reaction time (in ms). The microphone wirelessly transmitted to a lap-top computer, where custom designed software (AIS React) automatically generated reaction time scores for each response. Prior to completing the dual-task test, a baseline measure of participants’ vocal reaction time was recorded. A series of 15 tones were played through a laptop computer and participants were asked to respond by saying the word “tone” as quickly as possible after they became aware of the sound.

Verbal reports. Participants were instructed to take three shots in their own time. Immediately following the shots, they were asked to describe their episodic recollection about the last shot that they took (Beilock & Carr, 2001). They were instructed to: “Pretend another goal shooter just walked into the room. Please describe any details you remember about the last shot that would enable them to replicate it exactly." Participants were then asked to recall their generic understanding of a netball shot. They were instructed that, "Certain steps are involved in executing a netball shot. Please list as many steps as you can, in the right order, that are involved in a typical netball shot." Verbal reports were scored by two independent raters, who compared scores until a consensus was reached. The number of rules reported (e.g., "I bent my knees") were then summed. Any statements that were irrelevant to the technical demands of the task (e.g., "I enjoyed the session") or that indicated a lack of conscious processing (e.g., "I just did it") were not considered rules.

Confidence. Twelve markers were placed within the goal circle so that two markers were placed at each of the following distances from the goal post: 1 m, 1.5 m, 2 m, 2.5 m, 3 m, and 4.9 m (see Figure 3.3). These distances were included to assess shooting confidence from typical distances in netball (up to 3 m) and also from a spot that was close to the edge of the circle (4.9 m). Each marker was placed at a different angle so that a wide range of angles around the goal post was represented. Participants were asked to stand with a ball in their hands on each of the markers. For each shooting position, participants were asked, "How confident are you that you will make this shot" on a scale from 1 (not at all confident) to 5 (extremely confident). Participants then took five shots from each of the 12 shooting locations (total = 60 shots). The order of the 60 shots was randomised among the 12 shooting locations. Participants' mean ratings of confidence and shooting accuracy were summed for each distance from the goal post.

Training Intervention

The training intervention took place over six weeks. There were two sessions per week in which participants practised between 125 and 195 shots (m = 160 shots per session, total = 1,925 shots during the intervention). For the duration of the training intervention, players also participated in normal training activities which involved all aspects of netball performance including shooting. This is a natural characteristic of investigating skilled players in their normal environment.



Markers	Distance from Goal Post
1 & 7	1.0 m
2 & 8	1.5 m
3 & 9	2.0 m
4 &10	2.5 m
5 & 11	3.0 m
6 &12	4.9 m

Figure 3.3. Schematic representation of the position of markers for the confidence test.

During the specialised shooting training sessions that were implemented, participants practised approximately half of the shots to an adapted ring. The remaining shots were to a standard ring. The rationale for including half of the shots to the standard ring was to maximise the likelihood that participants would be able to transfer their adapted shooting trajectory to the actual performance constraints. The adapted ring was made up of a 30 cm metal barrier that was welded onto a normal netball ring (see Figure 3.1). Players were instructed that, when using the adapted ring, they should attempt to “swish” the ball through the net (i.e., get the ball in without touching the sides of the barrier or net).

During all shots that were taken to the adapted ring, the two goal shooters were also asked to respond to a concurrent secondary task that was presented through a MP3 player. The secondary task consisted of high and low pitched tones which were digitally overlayed onto music (using Apple Final Cut Studio, Soundtrack Pro 2 editing software). Participants were asked to count the number of low pitched tones within each song that they were listening to. These were then reported to the experimenter and participants were given feedback about whether they were correct in their counting. This ensured that participants were attempting to perform the task correctly. The music consisted of a selection of songs identified by the participants as being enjoyable. The secondary task used during the acquisition phase differed from the dual-task test on two characteristics: (1) the tones were overlayed onto music to make the task enjoyable and sustainable over the six-weeks of practice, and (2) participants were asked to count the tones rather than simply responding with the work “tone” when they identified a target tone.

Immediately following the last acquisition session, footage for a self-recognition test was collected (see “Post-test” for more information).

Post-Test

The battery of tests included in the pre-test phase were re-administered in the post-test phase, with the inclusion of one additional test (self-recognition). The purpose of the self-recognition test was to ascertain whether participants were aware of any changes that occurred to their shooting trajectory as a result of the training intervention. The measure was based on the idea that explicit changes in technique would be accompanied by a capacity to consciously recognise changes in ones own performance from video footage taken pre- and post- intervention.

Self-recognition test. Footage of the participants shooting at 1 m and 3 m away from the goal post (along the backline) was collected during the pre-test session and the last training session (a total of 50 shots were captured). The footage was captured from a camera that was perpendicular to the participant and goal post. The experimenters ensured that the camera was in an identical position in the pre-test and final training sessions. The camera position was measured by placing a marker 2 m from the goal post along the backline, and then measuring 8 m from that marker towards the transverse line at a 90º angle. The camera was fully extended on the tripod and zoomed out to the widest angle. Participants were asked to wear identical clothing for both the pre-test and final training session. Footage from the two sessions was then randomised and digitally altered (using Adobe Premiere Pro 2.0 software) to appear in "grayscale" (black and white) to help disguise the superficial features of the video. The footage was played to participants during the post-test session. They were asked to respond to each clip by reporting whether they thought it was from the pre-test session or the final training session.

Results

Single-Task Performance

From the distance of 1 m, there were no changes in shooting performance from pre-test to post-test for either player (Player A: Pre = 14/15, Post = 15/15; Player B: Pre = 15/15, Post: 15/15). In contrast, from 3 m, Participant A showed an improvement from pre-test to post-test (Player A: Pre = 6/15, Post = 11/15) while Player B's shooting performance did not change from pre-test to post-test (Pre = 6/15, Post: 7/15).

Dual-Task Performance

In terms of shooting performance, during the pre-test Player A performed better under secondary task load but in the post-test she performed better under single-task load. Player B also performed better under secondary task load in the pre-test, but her shooting performance was similar between single- and dual-task conditions in the post-test. Figure 3.4 shows the players' shooting accuracy under single- and dual-task conditions in the pre- and post-tests.

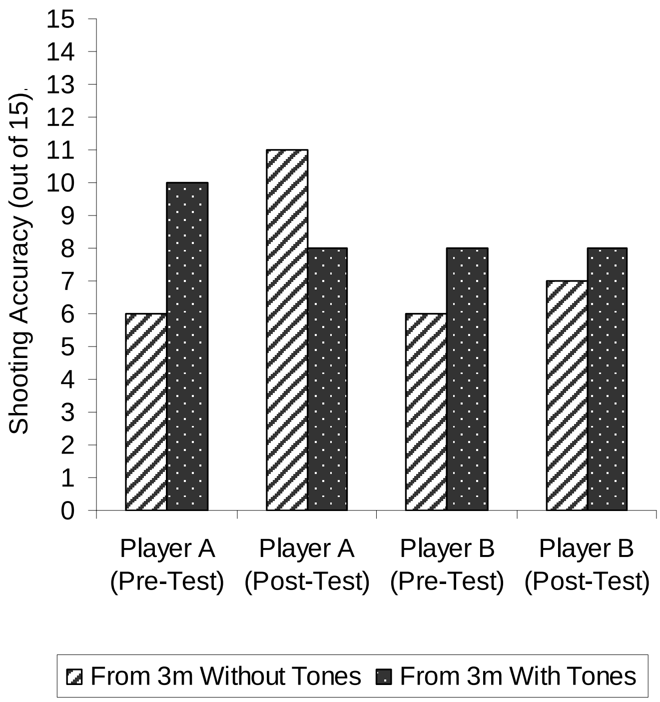


Figure 3.4. Shooting accuracy from 3 m under single-task (without tones) and dual-task (with tones) conditions.

With reference to secondary task performance, both Player A and Player B displayed slower vocal reaction time responses in the dual-task condition than the single-task condition during both the pre-test and the post-test. Figure 3.5 displays the players' reaction times to the tones under single- and dual-task conditions in the pre- and post-tests.

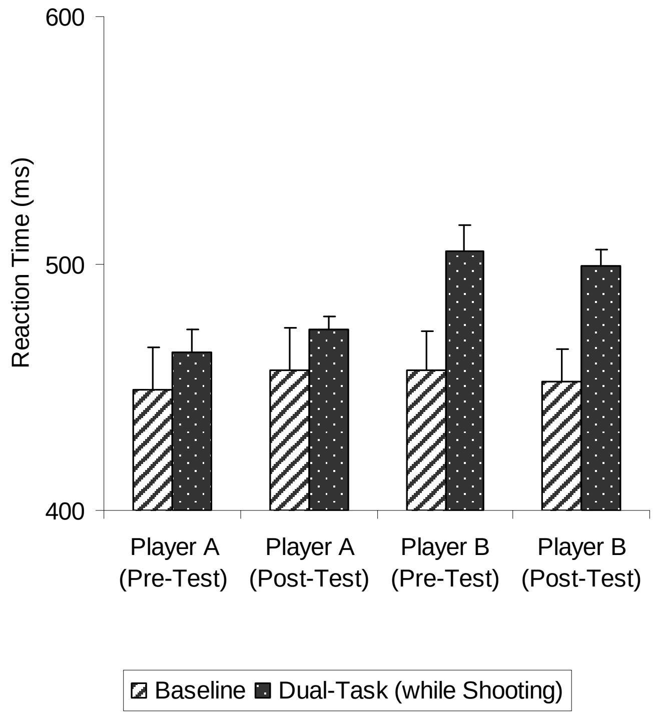


Figure 3.5. Reaction time to tones under single-task (without shooting) and dual-task (with shooting) conditions, with standard error bars.

Self-Recognition Test

Both players were close to chance levels in the self-recognition test. Player A was able to correctly identify 24/50 images as being from the pre-test or from the last acquisition session. Player B was able to correctly identify 23/50 images.

Verbal Reports

There was no change in the number of generic rules reported by Player A from pre-test to post-test (Pre = 8 rules, Post = 8 rules). Player B reported one additional generic rule in the post-test condition compared to the pre-test condition (Pre = 6 rules, Post = 7 rules). Neither player mentioned the shooting trajectory as part of their pre- or post-test generic reports. Both Player A and Player B reported no episodic rules in either the pre-test or post-test conditions. (See Tables 3.1 and 3.2 for a full list of the generic and episodic rules reported.)

Table 3.1

Players' Generic Verbal Reports from the Pre- and Post-Tests

	Pre-Test	Post-Test
Player A	1. I would have my feet as balanced as I can 2. Toes pointing towards the post 3. Both arms straight up 4. Elbow up near ear 5. The ball should be resting just on the finger tips not on the palm of the hand 6. Then with a fairly smooth movement 7. Elbows and knees bend down together 8. Then flick straight up	1. Balanced feet 2. Shoulder width apart 3. Pointing towards the post 4. The ball should start on a straight arm 5. Quite high above your head. 6. A one handed shot 7. Then, bend elbows and knees slightly 8. And flick up
Player B	1. A balanced stance first of all 2. You would also have a relative degree of knee bend 3. The knee bend would be at the same time as the shot 4. The focus of your eyes on the post 5. As well as bending the elbow 6. And a flick of the wrist to finish	1. First of all you have to be balanced 2. Shoulders facing towards the target 3. Hold the ball mainly in one hand. 4. With the second hand to guide the shot 5. Elbows bend and knee bend are almost simultaneous 6. The extension of the elbow towards the ring 7. And a flick of the wrist at the end of the shot

Table 3.2

Players' Episodic Verbal Reports from the Pre- and Post-Tests

	Pre-Test	Post-Test
Player A	• In terms of my actions I wasn't really thinking about them	• I can't remember
Player B	• I wouldn't say that there was much going through my head	• I wasn't thinking about much at all

Confidence

Table 3.3 presents the results for the confidence ratings for Player A and Player B. The results show essentially no change in pre-test to post-test confidence. Player A showed a very slight decrease in confidence from 2 m. Player B showed a small increase in confidence from 2.5 m and 3 m and a small decrease from 4.5 m.

Table 3.3

Players' Ratings of Confidence (Out of a Score of Five)

	Distance from Goal Post					
	1 m	1.5 m	2 m	2.5 m	3 m	4.5 m
Payer A (Pre)	5	5	5	5	4	2
Player A (Post)	5	5	4.5	5	4	2
Player B (Pre)	5	5	4.5	4	3.5	3
Player B (Post)	5	5	4.5	4.5	4	2

Note. Circled values indicate a change from pre-test to post-test.

Table 3.4 presents the results for the shooting accuracy in the confidence test for Player A and Player B. Player A showed a slight improvement in accuracy from 1.5 m, a slight decrease in accuracy from 2 m, and a larger decrease in accuracy from 3 m. Player B showed a decrease in accuracy from 2 m and slight decrease from 2.5 m.

Table 3.4

Shooting Accuracy in the Confidence Test (Out of 10 shots)

	Distance from Goal Post					
	1 m	1.5 m	2 m	2.5 m	3 m	4.5 m
Player A (Pre)	10	7	10	9	9	2
Player A (Post)	10	10	9	9	6	2
Player B (Pre)	10	10	10	9	8	2
Player B (Post)	10	10	6	7	8	2

Note. Circled values indicate a change from pre-test to post-test.

Ball Flight Characteristics

The mean maximum ball height for Player A was 12 cm lower following the intervention (Pre: M = 3.93 m, SD = 0.07 m; Post: M = 3.81 m, SD = 0.06 m). For Player B, the mean maximum ball height was 13 cm lower following the intervention (Pre: M = 3.88 m, SD = 0.06 m; Post: M = 3.75 m, SD = 0.05 m). The release angle for Player A was just over 1° smaller following the intervention (Pre: M = 55.67°, SD = 1.76°; Post: M = 54.30°, SD = 1.03°). For Player B, the release angle was just over 2° smaller following the intervention (Pre: M = 53.72°, SD = 1.40°; Post: M = 51.49°, SD = 1.40°).

Discussion

This study investigated whether implicit motor learning can be used to adapt technique in skilled athletes. The study adopted a single-case design involving two expert netball players. The participants undertook a six-week training intervention in which they practised shooting to an adapted ring (hypothesised to cause an advantageous increase in the steepness of the shooting trajectory) while responding to a concurrent secondary task (high and low pitched tones overlayed onto music). A number of pre- and post-test measures were used to assess: (1) whether there were any changes to the players' shooting action following the intervention and (2) whether any changes that occurred were subserved by implicit processes.

The results of the study showed that there was indeed a change in the trajectory of the players' shots following the intervention, but that this change was contrary to the intended aim (i.e., both players demonstrated a *decrease* in the maximum height of ball flight following the intervention). Importantly, for the purpose of this study players were unaware of the change (suggesting an implicit adaptation) and accuracy remained unchanged or improved in the post-test (except for Player A in the 3 m dual-task condition).

Two possible reasons emerge for the reduction in shooting height observed in this study. The first explanation is based on the manipulation of the task constraint (the adapted ring). According to the constraints-led approach, organismic, environmental, and task constraints interact in the emergence of co-ordination in goal-directed behaviours. The application of the constraints-led approach considers the effect of identifying and manipulating key constraints under which skilled behaviour emerges. The use of equipment and artificial aids during practice to constrain learners' movement patterns is one method of influencing skill acquisition (Davids et al., 2008); however a key factor in this model is that the manipulation of constraints must be carefully designed to ensure that movement transfer into subsequent performance is optimal. Specifically, the representativeness of particular task constraints is critical to the application of the constraints-led approach, with successful manipulations helping performers achieve their goals by acting to find optimal information to guide action (Gibson, 1979). It is possible that in the current study an artificial aid was introduced that did not guide the players towards optimal information for co-ordination of their shooting action. This finding highlights the importance of carefully designed constraint manipulations to optimise transfer into subsequent performance.

A second possible explanation relies on the concept of ironic processes of mental control in which people (including athletes) occasionally perform in a way that is precisely opposite to that which they intend (De La Peña, Murray, Janelle, 2008; Wegner, 1994). For example, the result of a golfer telling himself or herself not to leave a putt short may be that he or she fails to strike the ball hard enough to reach the hole. This unintended result can be considered as “ironic” because it corresponds to exactly the behaviour which the performer aspires to avoid (De La Peña et al.). In the current study, players underwent a six-week intervention including practice to the adapted ring. Players were aware of the objective of the task constraint. The addition of the secondary task during the intervention ensured that players were not explicitly controlling their movement solutions, but there is no evidence to suggest that players did not utilise self-instruction in their movement solution. That is, it is possible that players told themselves not to shoot the ball with a flat trajectory but that their movement solution was controlled implicitly.

According to ironic process theory (Wegner, 1994), performance is achieved through the interaction of: (1) the “operating process” which promotes the intended change by searching for information that is consistent with the goal, and (2) the “monitoring process” which searches for information that is inconsistent with the intended goal. The operating process typically functions at an explicit level whereas the monitoring process typically functions at an implicit level. Under certain situations, attention resources are diverted away from the operating process, resulting in the monitoring process being prioritised. The result is that the monitoring process therefore activates the exact thoughts that the performer is trying to avoid. Previous research has shown that the result can be either ironic effects (exactly that which the performer attempts to avoid: Wegner, Ansfield, & Pilloff, 1998) or over-compensation (exactly the opposite to that which the performer attempts: Binsch, Oudejans, Bakker, & Savelsbergh, 2009; Beilock, Afremow, Rabe, & Carr, 2001).

It is possible that the results of the current study are a manifestation of the ironic process theory. Specifically, players might have explicitly told themselves to not to shoot with a flat trajectory, but the result was that the monitoring processes (which occur at an implicit level) interfered with their performance, materialising in errors in the exact direction of self-instruction. In this case, players' attempts to self-regulate produced an ineffective motor action which was the result of implicit monitoring processes (i.e., they explicitly told themselves not to shoot flat which ironically result in them shooting even flatter).

Despite the contrary change in shooting trajectory (the aim was to increase the arc of the ball), there did appear to be changes in performance that were supported by implicit knowledge. A number of measures confirm that the players were unaware of the knowledge underlying the adaptations of their technique. Firstly, players showed essentially no increase in the number of generic or episodic rules that they reported following the intervention. Both players did not report a single episodic rule during the pre- or post-test sessions. This finding suggests that players were not consciously processing their shooting action. Secondly, both players remained robust under secondary task load following the intervention as indicated by the consistency in single- to dual-task reaction time from pre-test to post-test. Finally, players were unable to differentiate their shooting action in the self-recognition test, despite the fact that there was a change in the maximum ball heights of their shots. This was demonstrated by their performance at close to chance levels on the self-recognition test.

With reference to the confidence measure, the intervention did not have an effect on players' beliefs in their shooting ability. This was highlighted by the finding that there was no real change in the levels of confidence reported in the pre-test and the post-test conditions. Interestingly, participants' level of confidence from the six distances corresponded closely to their actual shooting performance from those locations. The results suggest that, up until a distance of 3 m from the goal post, the players were very confident in their shooting ability and this was reflected in high shooting accuracy. From a distance of 4.5 m, both players reported lower levels of confidence and this corresponded with a lower shooting accuracy. Based on the current design, the causality of the relationship between shooting accuracy and confidence is not clear. That is, the poor shooting accuracy from 4.5 m may be due to low levels of confidence, or on the contrary, the players may have reported low levels of confidence because they were aware of the fact that their shooting accuracy was poor from the distance. Furthermore, it is not possible to conclude whether there was a gradual decrease in confidence and shooting accuracy between the distances of 3 m and 4.5 m, or whether there was a specific threshold at which sudden decreases in confidence and shooting accuracy occurred.

The feedback from the Head Coach of Australian Netball, based on the players' reported experiences of the intervention, provide insight and valuable feedback for future training programs. Firstly, Player A commented that she liked the dual-tasking and felt that it was beneficial to her shooting. She felt that it was a strategy that she could take into a game context. She was less favourable about the adjusted ring. She commented that she didn't like practicing with the high ring and felt that it was not beneficial for altering her shooting trajectory (a comment that parallels the findings in the study).

Player B was also positive about the dual-task intervention. She suggested that the, "multi-skill tasking activities provided a good distracter that was similar to a noisy crowd". On a less positive note, she suggested that the intervention might have made her more aware of her shooting style because of the emphasis placed on the skill (although the results of the study do not support this suggestion). She felt that it would have been better to conduct the intervention very early in the pre-season rather than immediately before the beginning of the season as was the case here. She felt that the adjusted ring was good in theory, but was not realistic, especially over a long period of time. These comments highlight the fact that there were positive outcomes from the study, but also suggest that more comprehensive trialling of the task constraint would have been beneficial. The comments of the players were used to make adjustments to the practice recommendations which were then implemented over a longer period of time (the course of the season).

The Head Coach suggested that overall the project had some beneficial outcomes and it resulted in significant gains throughout the season. However, a challenging issue is that she felt that there was no longer term uptake of the program in the following season and shooting performance suffered as a consequence. The coach also recommended that a more developmental level group of athletes (for example Under 21 players) might be the perfect cohort in which to implement these training initiatives.

This study was conducted on a very limited sample of participants due to the difficulties involved in controlling the training protocols of elite athletes. The results do, however, offer interesting insights insofar as they provide the first tentative evidence that implicit practice might have a potential application in adapting well-learned skills. The practical advantages of being able to adapt an aspect of expert performance using implicit methods are substantial. As outlined in the introduction to this chapter, implicit practice ensures that performers do not have access to explicit, conscious knowledge about how they move. Thus, they are unlikely to revert to consciously control of their movements, as predicted by theory of reinvestment (Masters & Maxwell, 2008), when faced with situations that involve psychological stress (e.g., anxiety created by a game situation) or when they return from injury or lose confidence, for example. Implicitly controlled skills also tend to be less attention-demanding than explicitly learned skills which enable experts to have spare attention capacity to devote to other aspects of performance (e.g., Masters, 1992; Maxwell et al., 2003). Finally, research evidence suggests that implicitly controlled skills have a resistance to physiological stress, suggesting that skills learned through implicit methods will hold up under competition fatigue (Masters et al., 2008; Poolton et al., 2007b). While this study did not specifically measure whether the skills that were practised were associated with these beneficial outcomes, the mechanisms involved (namely conscious, explicit processing of movements) appear to be by-passed, offering support for the notion that the training protocols used in the current design are likely to result in such benefits.

Future research should consider whether the dual-task approach to implicit practice is the most amenable protocol to use in an applied learning environment or whether other approaches, such as errorless learning are more appropriate. One consideration in this regard is whether the rate of learning using dual-task approaches would be too slow for the constraints imposed by elite level sport. (This suggestion is based on previous research which has highlighted the issue of slow learning using dual-task approaches: e.g., Maxwell et al., 2000). Researchers should consider exploring other existing models of implicit learning within a sample of skilled performers, and/or investigate new models of implicit learning which are amenable to the elite practice environment.

In conclusion, implicitly controlled skills have many advantages over explicitly controlled skills. Practice conditions that encourage implicit processing in expert performers are likely to result in beneficial outcomes (for example, due to low interference from conscious control during high pressure scenarios). The current study demonstrated the possibility of adapting well-learned skills using implicit practice techniques. Future research, incorporating larger sample sizes, is required to verify the findings outlined in the current study.

CHAPTER 4

STUDY TWO: AN IMPLICIT BASIS FOR THE RETENTION BENEFITS OF RANDOM PRACTICE

Introduction

In the previous chapter, a study was reported which investigated whether skilled performers (national level netball representatives), who have previously accrued a substantial amount of task-relevant explicit knowledge, could adapt the movement patterns underlying their well-learned skills using implicit motor learning. A key challenge was highlighted with this approach – specifically, the rate of learning might bring about alterations in technique that are too slow for an elite training environment. It is therefore prudent to consider what other methods of implicit learning might bring about beneficial learning outcomes in skilled athletes. In this chapter, the proposition that random practice might offer potential in this regard is explored.

In Chapter 2, previous research was outlined that empirically established that random practice is associated with higher levels of cognitive activity than blocked practice (Li & Wright, 2000). Research evidence to date, however, has not substantiated that the increase in cognitive activity during random practice is necessarily task related. This study explores the possibility that the working memory resources of random learners might be so overwhelmed by the information required to generate multiple motor solutions (i.e., task switching) that they are unable to test hypotheses and store rules or knowledge about the movement solutions that they generate. If this proposition is true, then it would suggest that random practice might mimic the learning of those who engage in implicit practice. This concept goes against the traditional explanations of contextual interference, but might explain the paradoxical findings that exist between contextual interference and implicit learning studies.

The aim of this study was to measure cognitive effort and level of implicit/explicit learning in blocked and random practice of a complex motor task. In line with previous research showing that random learners experience high levels of *cognitive effort*, it is hypothesised that, relative to blocked practice, random practice will result in: (1) poor task performance during acquisition, (2) superior performance on tests of retention, (3) poor performance on a probe reaction time test during acquisition, and (4) high levels of cognitive demand during acquisition as measured by a self-report questionnaire. Based on the suggestion that the cognitive effort experienced by random learners results in an *implicit mode of learning*, it is further hypothesised that random practice will result in: (5) robust performance under secondary task load on a transfer test, and (6) the accrual of minimal verbal rules and the testing of few hypotheses.

Method

Participants

Nineteen participants (8 women, 11 men) with limited experience in playing Australian Rules Football (ARF) took part in the study. Participants (mean age = 28.5 years, *SD* = 7.09 years) possessed no more than two years experience in ARF over their lifetime, had not participated at a level higher than club, and none were involved in organised ARF activities in the period immediately preceding or during the study. Three participants in each group had previously played the game for an average of two years, while the remaining participants had no previous playing experience.

Participants agreed not to practice the tasks or any skills related to ARF other than during the prescribed training sessions throughout the duration of the study. All participants provided informed consent prior to commencing the experiment.

Apparatus and Tasks

Two tasks, the drop punt kick and handball, were learned. The drop punt is a kicking technique which is the primary method of passing the ball between team-mates in ARF. It is preferred by players over other methods of kicking because it is accurate and has a high speed of execution which is important in the time-stressed game environment. The drop punt kick requires the player to hold the ball vertically and drop and kick it before it hits the ground, resulting in the ball spinning backwards end over end (Australian Football League, 2004). The handball task is an alternative method of passing the ball between team-mates over relatively short distances. The handball requires the player to grip the ball with one hand and then hit it with a clenched fist using the other arm (referred to as the “punching arm”). A side-on stance is preferred to allow the punching arm to swing through freely (Australian Football League, 2004).

Researchers (e.g., Barreiros, Figueiredo, & Godinho, 2007) have previously suggested that there is a need to bridge the gap between laboratory and applied research. Specifically, the use of unusual laboratory tasks and single session acquisition phases incorporating massed practice conditions and short retention intervals have been highlighted as being of concern. Researchers have traditionally included deliberately exotic and novel tasks in studies of contextual interference (Barreiros et al.). The rationale behind the inclusion of the kicking and handball tasks in the current study was to incorporate real-world tasks to ensure that any findings could be generalised to real-life situations (while still maintaining the novelty of the tasks). Both of the tasks were modified to minimise the chance that the participant had previously encountered the particular movement actions that were required (i.e., to ensure that the tasks were novel to the participants). Although the kick roughly represented a drop punt kick, participants were constrained by a 4.5 m high roof which forced them to adopt more of a “stabbing” motion and use less follow through than they would in a regular drop punt kick. For the handball task, participants were required to use their non-preferred arm as their punching arm.

The target for the kicking task (Figure 4.1) comprised a grid of 49 squares with sides of 50 cm in length (overall size = 3.5 m^2). The centre of the target was 1.75 m from the ground. The target was painted onto fabric, attached to a net, and positioned with the bottom edge level with the ground. The design of the kicking target reflected the nature of the task (i.e., a large target was required due to the level of outcome variability expected from the task and a square target was used because of the logistical ability to construct a target which measured 3.5 m in height and width). Participants were instructed to aim for the central square of the target. Participants kicked from a distance of 15 m. This distance was chosen because it is the minimum distance that the ball must travel for the receiving player to claim a “mark” in the game of ARF (meaning that if the receiving player catches a ball that has been kicked more than 15 m, then the game stops while he prepares to kick).

50 cm

1	2.36	3.29	3.63	3.29	2.36	1
2.36	4.01	5.25	5.75	5.25	4.01	2.36
3.29	5.25	6.99	7.88	6.99	5.25	3.29
3.63	5.75	7.88	10	7.88	5.75	3.63
3.29	5.25	6.99	7.88	6.99	5.25	3.29
2.36	4.01	5.25	5.75	5.25	4.01	2.36
1	2.36	3.29	3.63	3.29	2.36	1

3.5 m

Figure 4.1. Target and scoring values for the kicking task.

The target for the handball task (Figure 4.2) consisted of six concentric rings painted onto fabric. The diameter of the centre circle measured 30 cm and each additional ring increased by increments of 30 cm. The design of the handball target reflected the traditional shape of targets used in training scenarios in Australian Rules Football. The target was attached to a net and positioned with the centre at a height of 1.2 m (the lowest point of the outside ring was therefore 30 cm above the ground). Participants were instructed to aim for the central circle of the target. Participants handballed from a distance of 5 m.

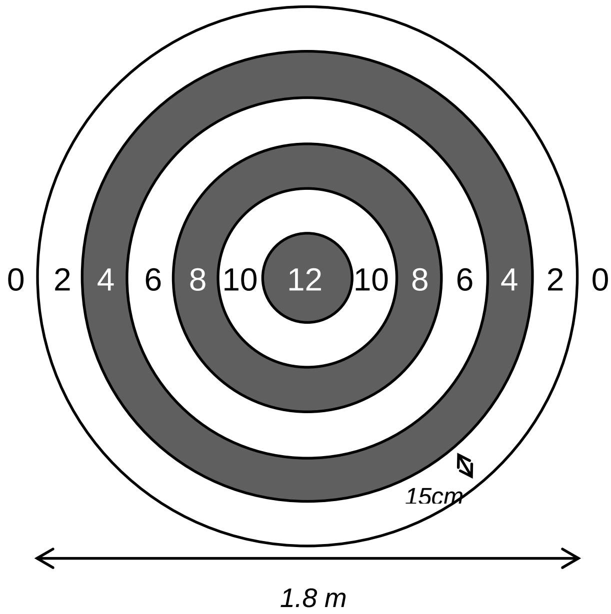


Figure 4.2. Target and scoring values for the handball task.

Measures

Performance outcome (accuracy). Performance on the kicking and handball tasks was recorded by assigning scores to the target grids (Figures 4.1 & 4.2) and recording the outcome location of the ball as it hit the target. The experimenter recorded the scores in real time. Recordings from two video cameras that were focused on the targets were used to confirm reliability of the in situ scoring (100 trials were sampled to compare the in situ and video-based scoring methods: concurrence = 97%).

Probe reaction time (PRT). A PRT measure was used to assess the level of cognitive effort imposed by the kicking and handball tasks. Simple verbal reaction time to an auditory tone was recorded during inter-trial intervals in the acquisition phase (see Procedure for more detail). Participants were instructed to respond by saying “tone” as quickly as possible upon presentation of the auditory tone. Probes were presented and recorded (in ms) with custom designed software (AIS React) and a wireless lapel-mounted microphone that transmitted to a laptop computer.

The National Aeronautics and Space Administration-Task Load Index (NASA-TLX). Four of the six dimensions of the NASA-TLX questionnaire (Hart & Staveland, 1988) were used as a subjective measure of each participant's cognitive effort (Appendix G). The four dimensions were: mental demand, performance, effort, and frustration. In reference to mental demand, participants were asked, "How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?" For the performance dimension, participants were asked, "How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?". The question relating to effort was, "How hard did you have to work (mentally and physically) to accomplish your level of performance?". Finally, in terms of frustration, participants were asked: "How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?". The end-points for scales for mental demand, effort, and frustration were "low" and "high", and for performance the end-points were "good" and "poor".

Secondary task transfer test. Participants were asked to perform a secondary task while concurrently performing the kicking and handball tasks. High pitched (660 Hz) and low pitched (440 Hz) tones were played to participants through computer speakers. Participants were required to indicate detection of the high tones as rapidly as possible by saying "tone". The high tones occurred randomly only 25% of the time. Tones were 500 ms in length and occurred once within every 2 s. This test has been shown to differentiate implicit learning from explicit learning, with implicit learners showing less disrupted motor performance when carrying out the secondary task (e.g., Poolton et al., 2005). Participants were instructed to give equal priority to the primary and secondary tasks. Changes to primary task performance were assessed as an indication of attentional load.

Verbal reports. Participants were asked to describe any “movements, methods or techniques” that they had used consciously while performing the tasks. For each task (kicking/handball) the reports were collected following the pre-test and the final acquisition session.

Design and Procedures

The study consisted of a pre-test, acquisition period, transfer test, and retention test. All sessions occurred in a large indoor laboratory. Participants signed an informed consent form (Appendixes D and E) and provided information about demographics and previous experience (Appendix F).

Pre-test. Participants were shown two instructional videos (each of approximately 5 min duration) that demonstrated the technique required to perform a drop punt kick and a handball. The videos were edited samples from a DVD entitled “Great Skills, Great Players” (Australian Football League, 2002). The sound was muted during the videos to prevent the participants from receiving verbal instructions about the tasks. Participants were instructed to duplicate the technique shown in the videos, but to adapt the technique to meet the demands imposed by the low roof height (in the kicking task) and the use of their non-preferred hand (in the handball task). After viewing the videos, the participants performed a blocked schedule pre-test of the kicking and handball tasks (trials = 20; 10 kicks, 10 handballs). Immediately following completion of the pre-test, participants provided verbal reports and completed the NASA-TLX.

Acquisition phase. Prior to the first acquisition session, participants were assigned to one of two groups, which differed in the practice schedule used: blocked (n = 9) and random (n = 10). The number of females and males were approximately equal in each group (blocked: females = 4, males = 5; random: females = 4, males = 6). The groups were matched for previous ARF experience. A t-test of the pre-test accuracy scores confirmed that there were no significant performance differences between the groups for the handball task ($t(17) = -.05$, $p = .962$) or the kicking task ($t(17) = .13$, $p = .895$).

The acquisition phase consisted of 320 practice trials of both the kicking task and the handball task (640 trials per participant in total). The acquisition phase lasted four weeks, with two sessions per week for the first three weeks and one session in the final week. The first six training sessions included 50 practice trials of each task (100 trials total) and the final training session included 20 practice trials for each task (40 trials total). Fewer trials occurred in the final acquisition session because the participants were asked to also complete the transfer test within the same session. To include 100 practice trials within the session may have introduced issues of fatigue and boredom during the transfer test.

Within each session, the blocked learners practised all trials for one task and then completed all trials for the other task. The order of tasks was counterbalanced across participants and alternated in each practice session. For the random group, participants practised each task in a random order during each session. The random schedule was different for each practice session, but the same for each participant.

The same task was not repeated for more than three consecutive trials in the random schedule.

Reaction time probes were manually initiated by the experimenter to enable the probes to be presented during the inter-trial interval (prior to movement initiation). Since the execution and inter-trial interval was individual to each participant, it was not possible to initiate the probes at regular intervals. At the beginning of the first acquisition session, a baseline measure of participants' verbal reaction time was obtained from responses to 20 probe tones. The purpose of this baseline measure was to assess each individual participant's raw verbal reaction time (without the imposition of a concurrent task). For each consecutive block of 50 trials during the acquisition period, a different 10-trial segment was probed (see Figure 4.3). In the random condition, the kicking and handball trials were scheduled such that an equal number of kicking and handball trials occurred within the block of 10 trials that were probed with the auditory tone. No probes occurred in the final acquisition session due to the small number of trials completed. Participants completed the NASA-TLX immediately upon completion of the acquisition trials in each session.

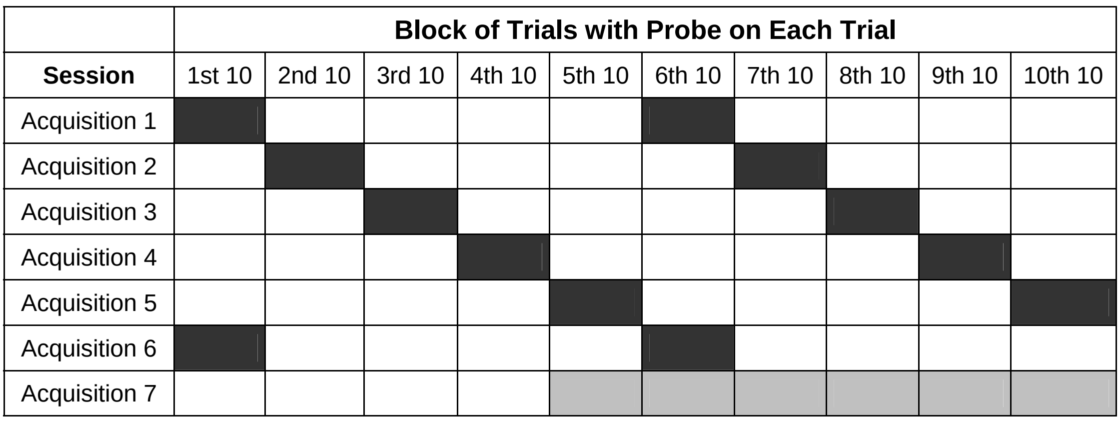


Figure 4.3. Scheduling of acquisition trials with probes for the PRT measure.

Secondary task transfer test. The secondary task transfer test was conducted after a 10 min break following the final acquisition trial. The test incorporated a blocked schedule of 20 trials (10 kicks, 10 handballs) and required the participants to attempt to perform both the primary and the secondary tasks to the best of their ability (see Measures section for more details).

Retention test. The retention test was conducted five weeks after the last acquisition session. Participants performed the kicking and handball tasks in a blocked schedule (trials = 20; 10 kicks, 10 handballs).

Analysis

Accuracy. Kicking accuracy was calculated using the scoring system outlined in Figure 4.1. A score of 10 was awarded for a ball that hit the central square of the target (the intended goal) and a score of 1 was awarded for a ball that hit the outermost corners of the target. A score of 0 was given if the ball missed the target area all together. Handball accuracy score was calculated using the scoring system outlined in Figure 4.2. A score of 12 was awarded if the ball hit the central circle of the target and a score of 2 was given if the ball hit the outermost ring on the target. A score of 0 was awarded for a ball that missed the target area. Acquisition trials during which there was a reaction time probe were excluded from analysis.

PRT. Mean verbal reaction time to the probes (in ms) was calculated separately for the kicking task and the handball task. Reaction times that were greater than two standard deviations above or below the mean were removed as outliers.

NASA-TLX. Each of the four dimensions was recorded on a 20-point bipolar scale. A score from 0 to 100 on each dimension was obtained by assigning a score of 5 to each scale point.

Verbal reports. Verbal reports were scored by two independent raters, who then compared scores until a consensus was reached. The raters were blind to the experimental conditions under which each participant performed. The raters determined whether statements were related to movement (mechanical rule) or the testing of a hypothesis (hypotheses). The number of mechanical rules reported (e.g., handball: "I gripped the ball lightly with the platform hand", or kick: "I made contact with the ball on the bottom point") and the number of hypotheses tested (e.g., handball: "I adjusted the point of contact on the ball", or kick: "I tried to adjust my follow through") were then summed. Any statements that were irrelevant to the technical demands of the task (e.g., "I enjoyed the session") were not included in the analysis because the study only focused on the rules and hypotheses that were specifically related to the tasks that participants were learning. A minimal number of hypotheses were reported by each group for both the kicking and handball tasks at pre-test and after the last acquisition session (all means < 0.7), so mechanical rules and hypotheses were combined and an analysis was performed on the total amount of task relevant knowledge reported following the pre-test and the last acquisition session.

Results

Performance during the acquisition period

It was hypothesised that relative to blocked practice, random practice would result in poor skill performance during the acquisition period. To test this hypothesis, kicking and handball performance during the acquisition period were evaluated with separate Learning Group x Acquisition Session (2 x 7) analyses of variance (ANOVAs) with repeated measures on the acquisition session factor. There was a significant improvement in performance across the acquisition sessions for both the handball task (F(6, 102) = 7.76, $p < .05$, *partial* $\eta^2 = .313$) and the kicking task (F(6, 102) = 3.58, $p < .05$, *partial* $\eta^2 = .174$). However, there was no significant main effect for learning group in either task (handball, F(1, 17) = 0.19, $p = .669$, *partial* $\eta^2 = .011$; kicking (F(1, 17) = 0.03, $p = .856$, *partial* $\eta^2 = .002$). There were also no significant learning group by acquisition session interaction effects for the handball task (F(6, 102) = 0.37, $p = .897$, *partial* $\eta^2 = .021$) or the kicking task (F(6, 102) = 1.27, $p = .279$, *partial* $\eta^2 = .069$). Figure 4.4 shows performance on the handball task and Figure 4.5 shows performance on the kicking task.

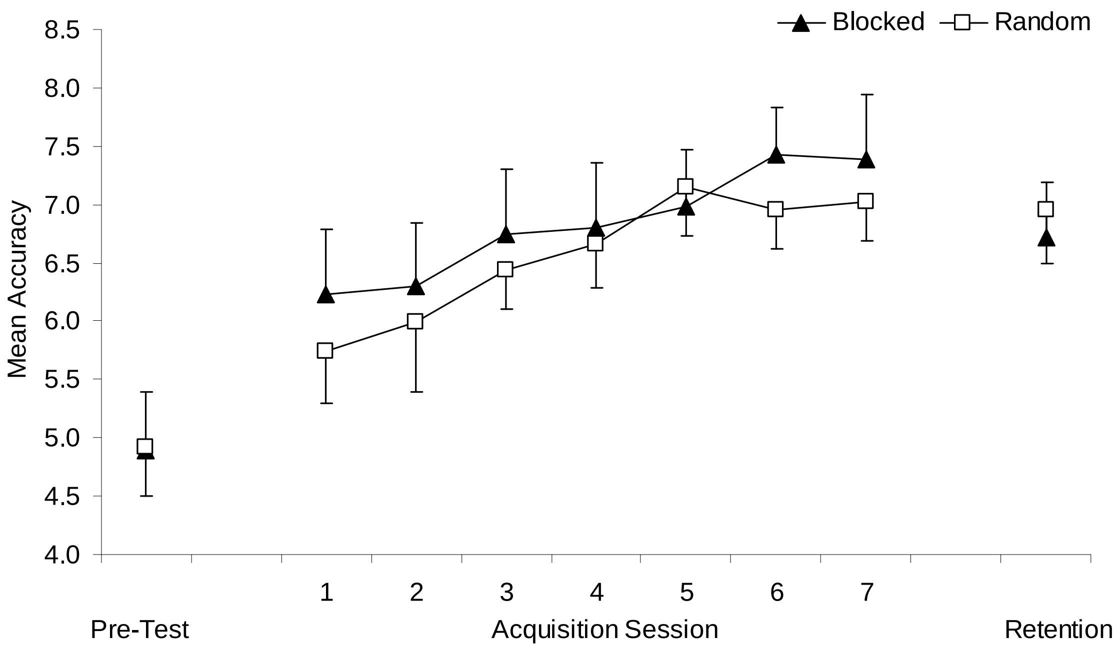


Figure 4.4. Mean accuracy scores for the blocked and random groups on the handball task during pre-test, acquisition, and retention, with standard error bars. *Note.* Scoring is out of a possible 12 points.

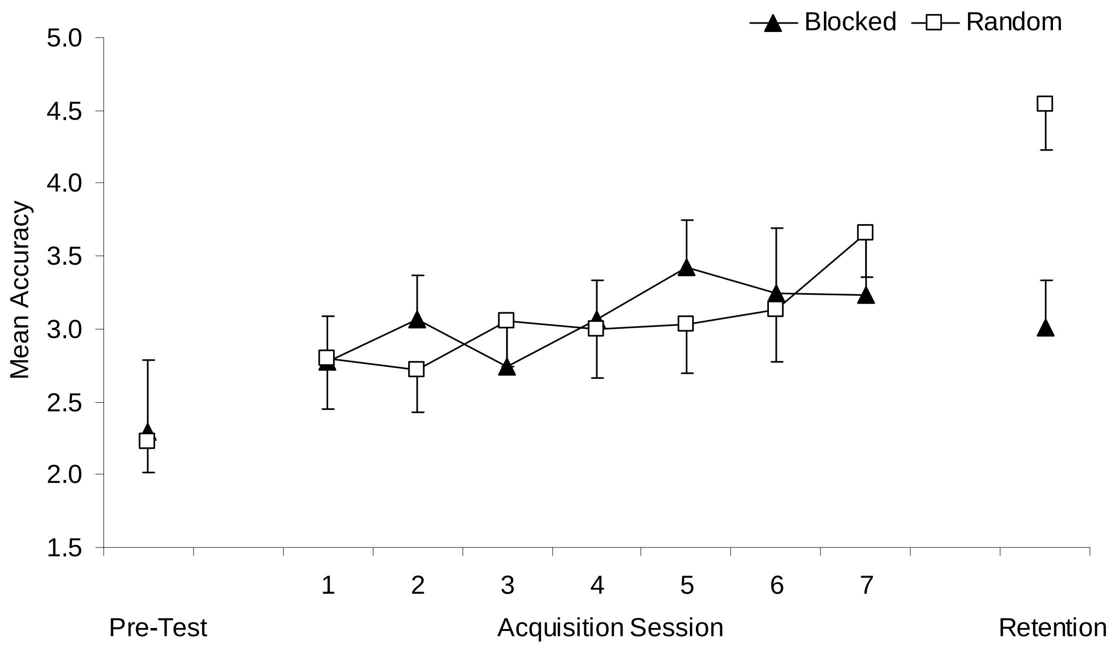


Figure 4.5. Mean accuracy scores for the blocked and random groups on the kicking task during pre-test, acquisition, and retention, with standard error bars. *Note.* Scoring is out of a possible 10 points.

Performance during the retention test

It was hypothesised that relative to blocked practice, random practice would result in superior retention performance. To test this hypothesis, kicking and handball performance during the pre-test and the retention test were analysed with two separate Learning Group x Test Occasion (2 x 2) ANOVAs with repeated measures on the test occasion factor. For the handball task, there was a significant main effect for test occasion ($F(1, 17) = 33.69$, $p < .001$, *partial* $\eta^2 = .665$), such that the level of performance for both groups improved from the pre-test to the retention test (see Figure 4.4). There was neither a significant main effect for learning group ($F(1, 17) = .06$, $p = .813$, *partial* $\eta^2 = .003$), nor a significant interaction effect ($F(1, 17) = .11$, $p = .747$, *partial* $\eta^2 = .006$).

For the kicking task, there was a significant main effect for test occasion (F(1, 17) = 22.56, $p < .05$, *partial* $\eta^2 = .570$); however there was no significant main effect for learning group (F(1, 17) = 3.64, $p = .073$, *partial* $\eta^2 = .176$). There was a significant learning group by test occasion interaction (F(1, 17) = 6.31, $p < .05$, *partial* $\eta^2 = .271$). Paired sample *t*-tests confirmed the impression given in Figure 4.5 that there were no significant differences from pre-test to retention for the blocked group (t(8) = -1.25, $p = .248$), while the random group showed a significant improvement in performance from the pre-test to the retention test in the kicking task (t(9) = -7.28, $p < .001$).

PRT

There were no significant differences between the blocked (M = 474 ms, SD = 63 ms) and random (M = 466 ms, SD = 59 ms) learners on the baseline measure of verbal reaction time (t(17) = .267, $p = .792$). It was hypothesised that relative to blocked practice, random practice would result in high levels of working memory demand during acquisition as shown by poor PRT performance. To test this hypothesis, PRT during the acquisition phase was analysed using two separate Learning Group x Acquisition Session (2 x 6) ANOVAs with repeated measures on the acquisition session factor, and reaction time to the probe (handball or kicking) as the dependent variable.

For the handball task, the analysis revealed that there was a significant decrease in PRT across the acquisition sessions (F(5, 85) = 4.97, $p < .001$, *partial* η^2 = .226), in the absence of a significant learning group effect (F(1,17) = 4. 14, $p = .058$, *partial* $\eta^2 = .196$), or an interaction effect (F(6, 85) = .28, $p = .921$, *partial* $\eta^2 = .016$). For the kicking task, the analysis revealed that the random learners were significantly slower than the blocked learners ($F(1, 17) = 4.94$, $p < .05$, *partial* $\eta^2 = .276$), in the absence of a significant effect for acquisition session ($F(5, 85) = 1.92$, $p = .097$, *partial* $\eta^2 = .102$), or an interaction effect ($F(5, 85) = .85$, $p = .517$, *partial* $\eta^2 = .048$). Figure 4.6 shows the mean PRT for blocked and random learners on trials preceding the handball task and Figure 4.7 shows the mean PRT for trials preceding the kicking task.

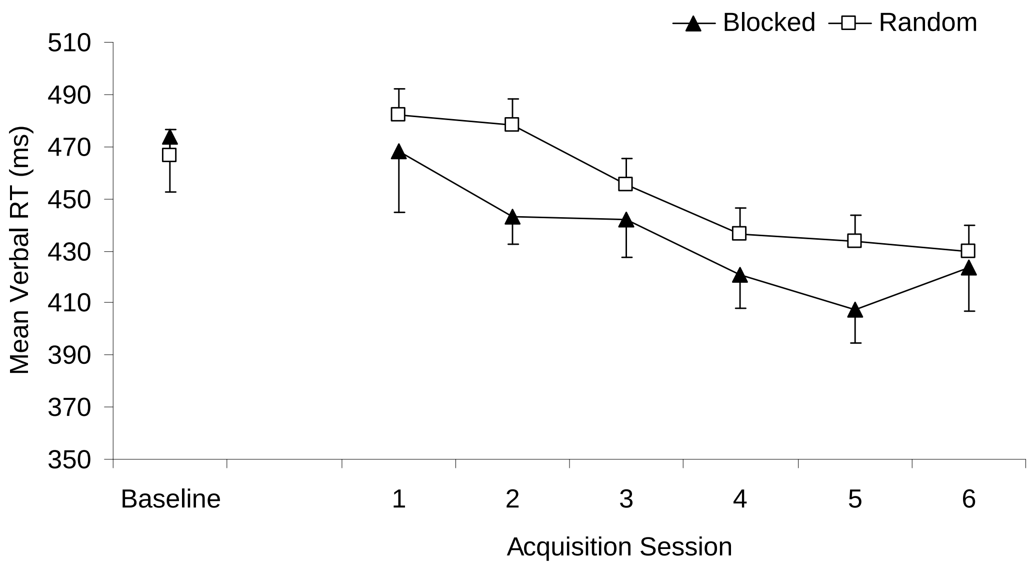


Figure 4.6. Mean verbal reaction time for the blocked and random groups to the PRT measure on trials preceding the handball task, with standard error bars.

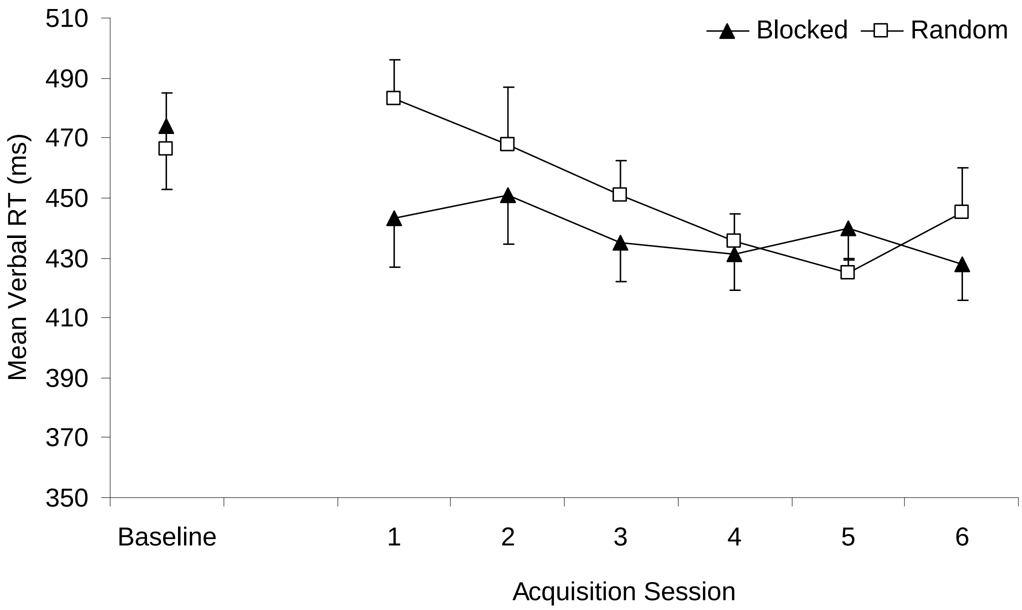


Figure 4.7. Mean verbal reaction time for the blocked and random groups to the PRT measure on trials preceding the kicking task, with standard error bars.

NASA-TLX.

The high levels of working memory demand hypothesised to occur during random practice were also expected to result in high self-report levels of cognitive effort (on the NASA-TLX). To test this hypothesis, four separate Learning Group x Test Occasion (2 x 7) ANOVAs were conducted with repeated measures on the test occasion factor; and the subjective ratings of mental demand, effort, frustration, and performance as the dependent variables. The NASA-TLX was administered during each of the seven acquisition sessions. Three participants (two from the blocked group and one from the random group) failed to respond to the questions on one of the seven testing occasions due to time constraints. All participants who had missing data were excluded from the NASA-TLX analysis. Given that these omissions were not on a systematic basis, they are unlikely to have an effect on the group data. Figure 4.8 shows the blocked and random groups' mean subjective ratings on the NASA-TLX scales (mental demand, effort, frustration, and performance).

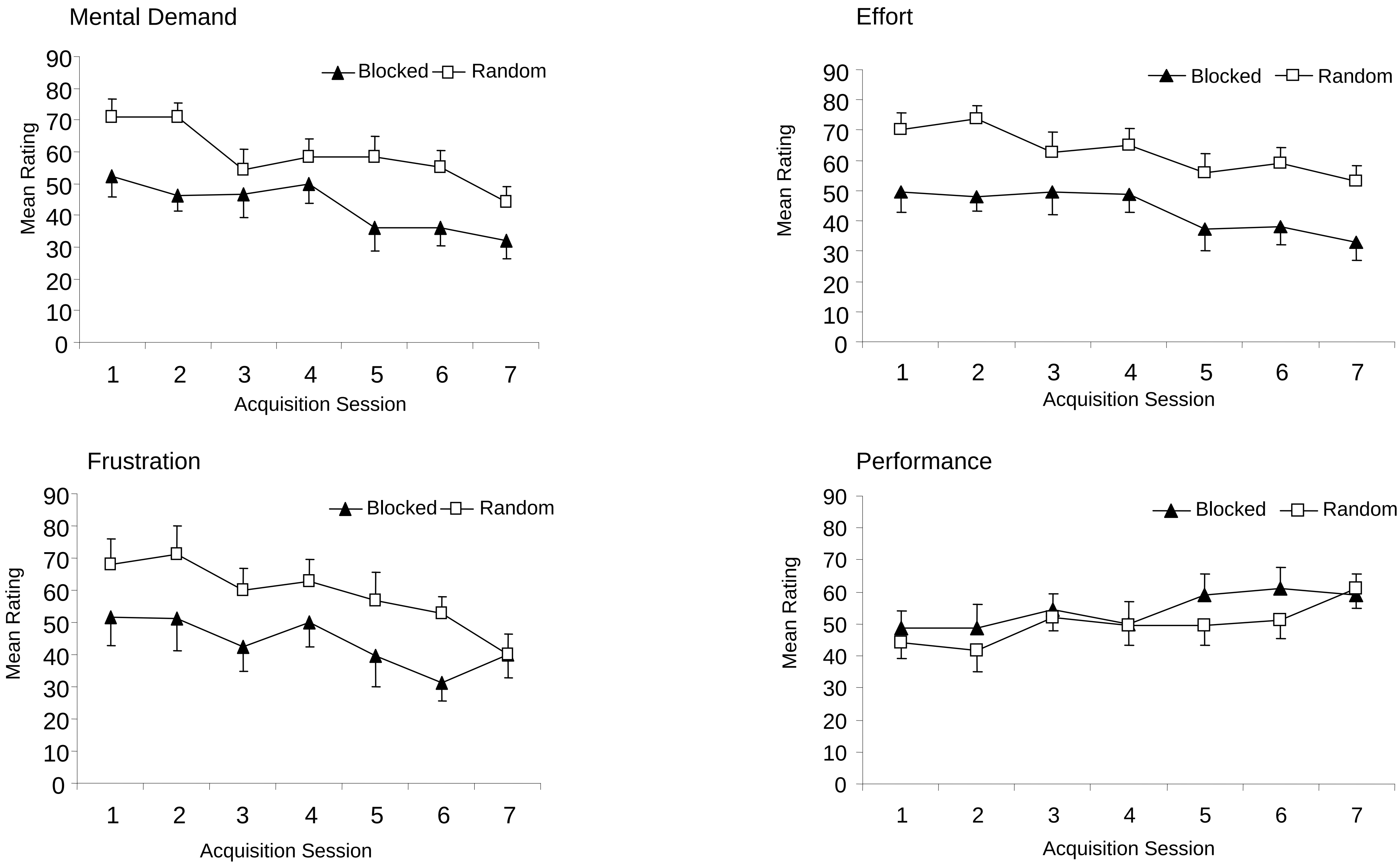


Figure 4.8. Mean subjective rating for the blocked and random groups on the mental demand, effort, frustration, and performance scales of the NASA-TLX, with standard error bars.

With reference to scores on the NASA-TLX, the random learners reported higher scores than the blocked learners on the measures of mental demand ($F(1, 14) = 5.94$, $p < .05$, *partial* $\eta^2 = .298$), effort ($F(1, 14) = 8.83$, $p < .05$, *partial* $\eta^2 = .387$), and frustration ($F(1, 14) = 4.62$, $p < .05$, *partial* $\eta^2 = .248$). Ratings also differed significantly across the test occasions for the measures of mental demand ($F(6, 84) = 9.28$, $p < .05$, *partial* $\eta^2 = .399$), effort ($F(6, 84) = 5.23$, $p < .05$, *partial* $\eta^2 = .272$), and frustration ($F(6, 84) = 4.62$, $p < .05$, *partial* $\eta^2 = .48$). However, there were no significant interaction effects between learning group and test occasion for the measures of mental demand, effort, or frustration (mental demand: $F(6, 84) = 2.01$, $p = .073$, *partial* $\eta^2 = .125$; effort: $F(6, 84) = .57$, $p = .752$, *partial* $\eta^2 = .039$; frustration: $F(6, 84) = 1.09$, $p = .374$, *partial* $\eta^2 = .072$). For the performance variable, there were no significant main effects for learning group ($F(1, 14) = 1.52$, $p = .238$, *partial* $\eta^2 = .098$) or test occasion ($F(6, 84) = 2.18$, $p = .053$, *partial* $\eta^2 = .135$), nor any significant interaction effects ($F(6, 84) = .45$, $p = .843$, *partial* $\eta^2 = .031$).

Performance during the transfer test

Based on the suggestion that the cognitive effort experienced by random learners results in an implicit mode of learning, it was hypothesised that random practice would result in robust performance under secondary task transfer. To test this hypothesis, paired sample *t*-tests were used to compare the single- and dual-task performance of the blocked and random learners[10]. For the handball task, there was no difference in performance (handball accuracy) from single- to dual-task conditions for either the blocked ($t(8) = .636$, $p = .542$) or random ($t(9) = .506$, $p = .625$) groups (see Figure 4.9). For the kicking task, there was no difference in performance (kicking

[10] Paired sample *t*-tests were used because a priori hypotheses were set. It was hypothesised that the random group would be more robust under secondary task load than the blocked group on both the handball and kicking task.

accuracy) from single- to dual-task conditions for the blocked group ($t(8) = -.048$, $p = .963$); however the random group showed a significant improvement from single- to dual-task conditions ($t(9) = -2.516$, $p < .05$) (see Figure 4.10).

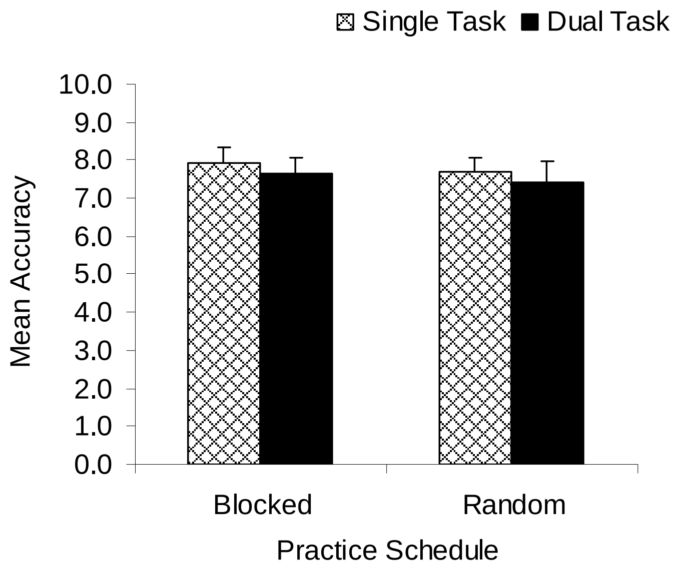


Figure 4.9. Mean accuracy scores for the blocked and random learners under single- and dual-task conditions on the handball task, with standard error bars.

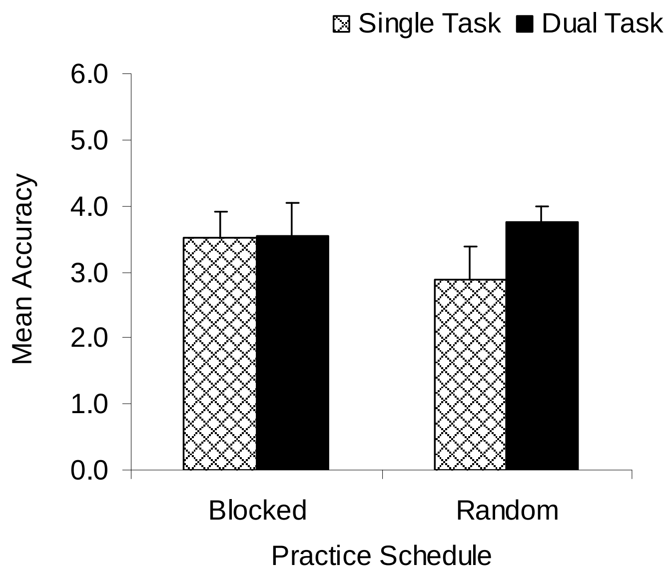


Figure 4.10. Mean accuracy scores for the blocked and random learners under single- and dual-task conditions on the kicking task, with standard error bars.

Verbal reports

The final hypothesis was that random learners would form minimal task relevant knowledge (reflected by sparse verbal reports) due to the implicit mode of learning for random learners. To test this hypothesis, paired sample *t*-tests were used to compare the amount of task relevant knowledge reported by the blocked and random learners after the pre-test session compared to the amount reported after the last acquisition session. For the handball task, there was no significant difference for either the blocked ($t(8) = 1.65$, $p = .137$) or the random learners ($t(9) = 1.07$, $p = .313$) (see Figure 4.11). For the kicking task, there was no difference for the blocked group ($t(8) = 1.05$, $p = .325$); however there was a trend indicating that the random group reported less task relevant knowledge following the acquisition period, although this finding did not reach statistical significance ($t(9) = 2.20$, $p = .055$) (see Figure 4.12).

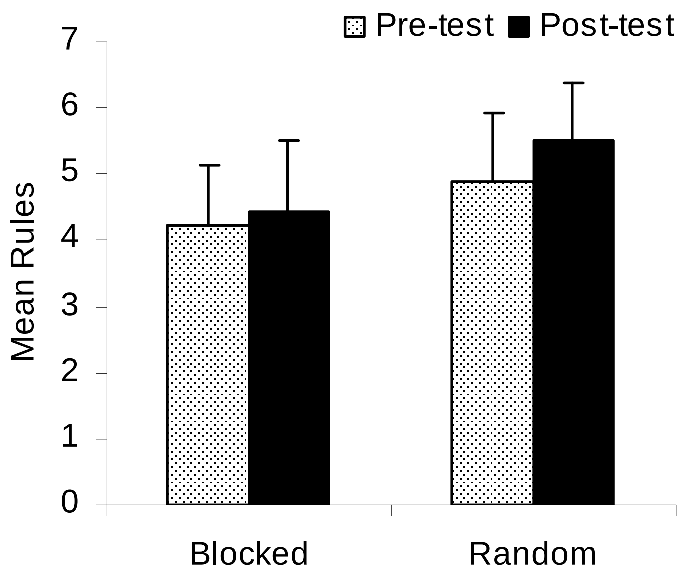


Figure 4.11. Mean number of verbal rules for the blocked and random groups on the handball task, with standard error bars.

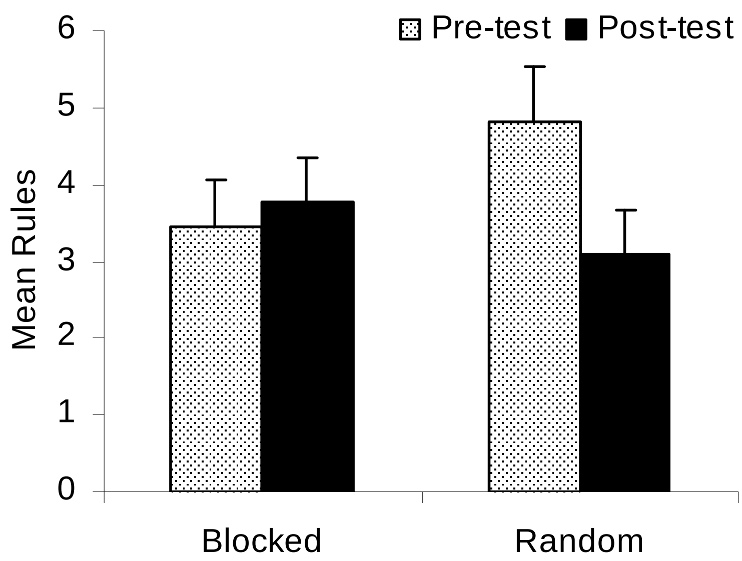


Figure 4.12. Mean number of verbal rules for the blocked and random groups on the kicking task, with standard error bars.

Discussion

The purpose of this study was to explore the hypothesis that the retention benefits of random practice are subserved by the mechanisms underlying implicit motor learning. This study explores whether random learners would be overwhelmed by high levels of cognitive effort due to interference from task switching that would prevent them from consciously interpreting their movement outcomes (and consequently accruing explicit task relevant knowledge). The results provide some support for this proposition; however the effect appears to be mediated by the task being learned.

In line with previous research showing that random learners experience high levels of cognitive effort (e.g., Brady, 1998; Lee et al., 1994; Li & Wright, 2000; Young et al. 1993), it was hypothesised that, relative to blocked practice, random practice would result in: poor performance during acquisition, superior retention, slower PRTs during acquisition, and high self-report levels of cognitive effort. The results delivered mixed findings regarding these hypotheses. First, contrary to expectations, there was no difference between the level of performance of the blocked and random learners during acquisition. This finding contradicts the traditional contextual interference effect, but supports research suggesting that high contextual interference schedules are less likely to adversely affect performance during acquisition of applied tasks than laboratory based tasks. For instance, Goode and Magill (1986) did not observe between-group differences during acquisition in their applied study of blocked, random, and serial practice of badminton serves (despite finding significant differences between the learning groups on both the retention and transfer tests). Similarly, in their comprehensive review of contextual interference studies in applied settings, Barreiros et al. (2007) found that the suppressed performance for random learners was not evident during the acquisition phase in the majority (61%) of studies that assessed acquisition performance.

With reference to retention, the findings were skill dependent. For the handball task, there were no retention benefits for the random practice schedule compared to the blocked schedule. In contrast, for the kicking task, there was a significant interaction between the groups, demonstrating that the processes subserving kick execution adapted differentially as a consequence of random compared to blocked learning. The random learners were remarkably successful on the retention test, indicating that the learning benefits of random practice were evident for the kicking task in the current study.

The degree of variation in the skills used in contextual interference studies has been highlighted in the existing literature (e.g., Porter & Magill, 2010). Magill and Hall (1990) suggested that including skills from different motor programs is likely to increase the amount of interference caused during the learning process (this is based on Schmidt's 1975, 1988 view of a motor program). Magill and Hall suggested that when tasks were consistent on aspects such as relative timing, sequence of events, and spatial configurations, then the tasks were unlikely to introduce a sufficient level of interference to produce the traditional interaction effect. This was the basis for the inclusion of two distinctly different skills (kicking and handball). Given that significantly disparate trends for the two tasks were observed in relation to retention, it might have been preferable (in terms of gaining clear results) to select skills which fulfilled the criteria of being from two different motor programs, but which were of the same classification of skills (such as two different badminton serves, as adopted by Goode and Magill, 1986; or driving, middle distance swing, pitching, and chipping in golf, as adopted by Brady, 1997). This suggestion is echoed by the "challenge point framework" advocated by Guadagnoli and Lee (2004) which will be considered in more detail later in this discussion.

The task being learned also appeared to differentiate probe reaction time responses in the different schedules. There was no difference between the blocked and random learners in PRT performance during the handball task; however the random learners displayed significantly slower PRTs than the blocked learners during the kicking task. This finding supports the contention that random learners experienced higher levels of cognitive effort during practice, but in the more demanding kicking task only. (This finding also highlights the importance of task differences that were discussed previously in relation to the retention findings.)

In light of the observation that performance at retention and on the PRT measure was differentially affected by task complexity, it is unfortunate that separate ratings for the kicking and handball tasks were not included in the self-report measure of cognitive effort. Overall, however, the results from this measure suggest that random learners experienced higher levels of mental demand, effort, and frustration during the acquisition phase of the study. These findings provide further support for the hypothesis that random learners experience higher levels of cognitive effort than blocked learners. The findings are also consistent with previous studies which highlighted the role of cognitive effort in contextual interference studies (Brady, 1998; Lee et al., 1994; Li & Wright, 2000; Young et al. 1993).

The weight of the evidence (from the retention data, the PRT measure, and self-report ratings) indicates that the level of cognitive effort was higher for the random learners than for the blocked learners (for the more difficult of the two tasks: the kicking task). The data relating to the second set of hypotheses also showed differential results for the kicking and handball tasks. Based on the suggestion that the cognitive effort experienced by random learners results in an implicit mode of learning, it was hypothesised that random practice would result in robust performance on a secondary task transfer test, and the accrual of minimal verbal rules and the testing of few hypotheses.

The introduction of cognitive load in the secondary task transfer test provides a measure of the working memory resources required to perform the primary task. With reference to the first primary task (handball), there were no significant differences in handball accuracy for the blocked and random learners between the single- and dual-task conditions. This finding demonstrates that both groups were able to cope with the demands of the secondary task. The results for the second primary task (kicking) were disparate to those of the handball task. For the blocked learners, there was no significant difference in performance on the kicking task between the single- and dual-task conditions. However, for the random learners, there was a significant *improvement* in performance on the kicking task under secondary task load.

One interpretation of the finding that the random learners were able to perform the kicking task exceptionally well under the demands of a secondary task is that they performed the kicking task with minimal demands on working memory. This finding is consistent with prior studies of implicit motor learning (e.g., Masters, 1992; Maxwell et al., 2003; Masters et al., 2008) and also with studies showing that the addition of a secondary task can be beneficial to primary task performance because it reduces online attentional control (Beilock, Carr, MacMahon, & Starkes, 2002). Implicit and explicit processes occur on a continuum rather than being two distinct categories of learning. This means that the level of performance achieved under secondary task load reflects the amount of processing capacity required to perform the primary task (and hence gives an indication of the level of implicit control). Superior performances under secondary task load can be interpreted as relying on a lesser amount attentional control (and hence are more implicit) whereas poorer performances under secondary task load can be interpreted as relying on a greater amount of attentional control (and hence are more explicit). It is possible that maintaining performance under secondary task load indicates some degree of implicit control (as was the case in the blocked condition for both skills and the random condition for the handball skill). However it is suggested that the random group’s exceptional performance on the kicking task under secondary task load indicated that the level of reliance on implicit processes was greater in this condition than in any other testing condition in the current study.

Successful performance on the secondary task used in the current study (verbally identifying high pitched tones from an array of high and low pitched tones) is dependent on a number of psychological processes, such as encoding, matching, and response processes. However, it is arguable that this secondary task is not as difficult as those used in previous implicit learning studies, such as random letter generation (Poolton et al., 2007a) and counting backwards (Liao & Masters, 2001), which call upon the short-term storage or rehearsal resources of memory. This is a possible reason why there were no decrements in performance under secondary task load for the blocked learners in either task or the random learners in the handball task.

An alternative interpretation of the secondary task transfer results is that the exceptional performance for the random group on the kicking task under secondary task load was due to a decrement in performance under single-task conditions rather than an improvement under dual-task conditions per se. If this interpretation is correct, then the reason is likely to be that the secondary task transfer testing was done under blocked conditions. The disruption in single-task performance for the random group would be due to the change in processing that occurred as they switched from a random schedule during acquisition to a blocked schedule on the single-task transfer test. Specifically, the nature of the blocked trials might have enabled the random learners to begin hypothesis-testing based on the immediate feedback from their previous trial and hence cause them to adopt a more explicit mode of control.

The final measure explored in this study was the amount of task relevant knowledge reported by participants. The amount of knowledge that was reported following a blocked schedule pre-test was compared to the amount reported immediately after both groups had completed their final acquisition session using the different practice schedules. This study investigated whether the random group reported fewer rules and hypotheses following learning because this would indicate that they had less task relevant knowledge available after random practice. It would also suggest that they had adopted a more implicit mode of control similar to the type of learning seen in other paradigms, such as loading working memory with a demanding secondary task (dual-task model: Hardy et al., 1996; MacMahon & Masters, 2002; Masters, 1992); explaining the skill requirements by analogy or metaphor (analogy learning: Law et al., 2003; Liao & Masters, 2001); withholding visual and auditory information from the learner (reduced feedback learning: Masters, 2000; Maxwell et al., 2000); giving task-related, but goal-irrelevant, instructions (Farrow & Abernethy, 2002); and simplifying task demands to prevent errors and hypothesis testing (errorless learning: Maxwell et al., 2001; Poolton et al., 2005). As was the case with the majority of measures in this study, the results were different for the kicking and handball tasks. For the handball tasks, both the blocked and random learners did not differ from pre-test to post-test in the amount of task relevant knowledge reported. However, for the kicking task, the random group tended to report a smaller amount of task relevant knowledge when they were assessed following the final acquisition. Although this finding did not reach statistical significance, it indicates that the random group possibly acquired the kicking task using similar implicit processes to those used in other implicit learning paradigms. (The blocked group showed no change in task knowledge following the intervention.)

The findings from the secondary task transfer test and the verbal reports point towards the possibility that the random learners adopted, or were forced to adopt, an implicit mode of control during acquisition (for the kicking task only). These findings again highlight the proposition that the task being learned is a critical factor in the interpretation of contextual interference results, a suggestion that complements the challenge point framework (Guadagnoli & Lee, 2004). In their model, Guadagnoli and Lee differentiated two types of task difficulty: “nominal task difficulty”, which reflects a constant amount of task difficulty regardless of task level or conditions, and “functional task difficulty”, which refers to how challenging the task is relative to skill level and the conditions experienced. The ideas presented within the challenge point framework are constructed as a series of predictions and empirical data is required to verify whether these predictions hold true. One prediction of the challenge point framework is that the advantage of random practice for learning will be largest for tasks of the lowest nominal task difficulty. Although the present study was not a direct test of the challenge point framework, the finding that the advantage of random practice was largest for the kicking task contradicts this prediction of the challenge point framework. It is arguable that the kicking task has a higher nominal task difficulty than the handball task because: (1) it requires a higher number of degrees of freedom; (2) it involves interception with a moving object (the ball was dropped before it was kicked, whereas in the handball, the platform hand supported the ball while the opposite arm swung through to contact it); and (3) because the release point of the ball was considerably further away from the target (kicking task: 15 m; handball task: 5 m).

This study represents a systematic attempt to quantify the type of cognitive processing associated with different practice schedules using a number of existing measures. The findings complement the suggestion that random practice might be subserved by the same mechanisms as those underlying implicit motor learning. Further research is required to verify these findings and future research should attempt to systematically manipulate the practice environment to help understand the contradiction between the two theories explored here. One possible methodological approach might be to observe the consequences of preventing elaboration or reconstruction in random practice (for example, by using a cognitively demanding secondary task). If the retention benefits of random practice are *dispelled* in a condition where cognitive effort is prevented, then perhaps there is further support for the existing theories of contextual interference. If, on the other hand, the retention benefits of random practice are *maintained*, alternative explanations of the contextual interference effect, such as an implicit motor learning explanation warrant further consideration. (This suggestion is pursued in the study presented in Chapter 5). This study also highlights task difficulty as an interesting topic that could provide the basis for further study.

In summary, this study has investigated the contextual interference effect using a number of measures that have typically been applied to implicit motor learning research. The aim was to highlight the discrepancy between research outcomes from those two research areas and to provide some empirical data that helps to gain insight to the cognitive effort paradox. Overall, the results lend support to the notion that the cognitive effort experienced by random learners results in an implicit mode of learning, perhaps due to the interference caused by task switching. However, these results were based on the outcomes of the more complex of the two learned tasks (the kicking task), which highlights the importance of task difficulty in the interpretation of the contextual interference effect. Further studies, involving systematic manipulations of cognitive effort in the contextual interference and implicit motor learning domains are needed to fully understand the mechanisms underlying the contextual interference effect.

CHAPTER 5

STUDY THREE: IMPLICIT PROCESSES IN CONTEXTUAL INTERFERENCE

Introduction

Chapter 4 presented evidence to suggest that the retention benefits of random practice may be driven by mechanisms which are also present during implicit motor learning. The study employed a number of measures to assess the level of cognitive effort and implicit/explicit processes that occurred during blocked and random practice of two motor skills (kicking and handball in Australian Rules Football). The results showed that relative to blocked practice, random practice resulted in higher levels of cognitive activity. However, the results also suggested that random practice shared characteristics with implicit learning (i.e., superior secondary task transfer performance and less access to verbally-based task knowledge). These results were evident for random practice of the more complex of the two motor skills studied – kicking. In the study outlined in Chapter 4, it was proposed that working memory resources of learners may be so overwhelmed by the information required to task switch during random practice, that they are unable to test hypotheses relating to the movement solutions that they generate, or rehearse and store verbal, task-related rules and information (the implicit learning hypothesis – Masters, 1992). Thus, random practice may involve high levels of cognitive activity that are not directly allocated to developing movement solutions.

The present study was designed to specifically investigate the proposition that the benefits of random practice are subserved by similar processes that underlie implicit motor learning. The rationale for the study was that preventing elaboration and reconstruction during random practice (by requiring learners to concurrently perform a cognitively demanding secondary task) would result in learning outcomes no different to random learners who did not perform a concurrent secondary task. In other words, it is likely that if random practice is based on implicit processes, then random learners who are prevented from engaging in task related processes during learning would behave in the same way as random learners who do not have the imposition of a secondary task. Based on the implicit learning hypothesis for random practice developed in Chapter 4, it was hypothesised that the participants who learned via random practice or random practice + concurrent secondary task would show: (1) poor performance during acquisition, (2) superior retention performance, (3) superior secondary task transfer performance, and (4) less task related knowledge by reporting fewer verbal rules and hypotheses than participants who learned via blocked practice.

Method

Participants

Twenty-seven novice table tennis players (17 females and 10 males; age: M = 30.44 years, SD = 9.28 years) participated in this study. Participants were selected from the staff population at the Australian Institute of Sport. Each participant was assigned randomly to one of three groups (blocked, random, and random + concurrent secondary task) with the restriction that gender within each group was approximately equal. The inclusion criteria included that participants had not previously participated in competitive table tennis. Participants agreed not to practice the tasks other than during the prescribed training sessions throughout the duration of the study. All participants provided informed consent prior to commencing the experiment (Appendixes H and I).

Tasks

The task was to learn two table tennis serves: a cross-court forehand serve and a cross-court backhand serve. All serves were practised and tested on a regulation table tennis table. The participants used a regulation bat and plastic balls which were supplied by the experimenter. The aim, for participants, was to hit a target that was located cross-court, on the receiver's side of the table. Participants used their preferred hand for serving throughout the study. For right handed players, the forehand serve was played from right-to-left and the backhand serve was played from left-to-right. Left handed players began the skills on the diagonally opposite side of the table (forehand: left-to right; backhand: right-to-left).

Participants began the action by tossing the ball into the air and were instructed that their task was to land the ball once on their side of the table before bouncing it over the net and landing it on the target cross court on the opposite side of the table. Each target comprised a grid that measured 62 cm long by 62 cm wide and was divided by grid lines at 2 cm intervals. The task goal for participants was to hit the "bulls-eye" (the central cells of the targets). The bulls-eye was coloured red, so that it was easy to identify. The two targets were positioned in the outer corners of the table, so that the outer edges were in line with the end and the side of the table (one in the left corner and one in the right corner).

Learning Conditions

The participants were randomly assigned to one of three treatment groups: blocked (n = 9), random (n = 9), or random + concurrent secondary task (n = 9).

Blocked. The blocked group practised the skills in a blocked order in which they performed 150 forehand serves, followed by 150 backhand serves during each of the three practice sessions. The practice schedule was the same among all participants in the blocked condition.

Random. The random group practised the same number of trials; however the schedule was adjusted so that the participants used a serial schedule in which they alternated between the forehand serve and backhand serve on each practice trial. An alternating or serial practice schedule, rather than a truly random schedule, was used in the current study for two reasons: (1) the serial schedule required participants to switch between skills on each consecutive trial which ensured that participants were never able to use the trial that occurred immediately previously as a means of adjusting their movement solution for the ensuing trial, and (2) serial practice schedules have previously been shown to result in the same beneficial learning outcomes as random practice (Lee & Magill, 1983).

Random + secondary task. The random + secondary task group was identical to the random group, with the exception that they were required to perform a concurrent secondary task. The secondary task required participants to count out loud backwards from a 3-digit number continuously while still performing the table tennis task. The instructions to participants were to focus on the secondary task intently as a first priority and that their table tennis tasks were of secondary importance. If the experimenter noticed participants counting slowly, a reminder was provided to keep concentrating on the secondary task.

The number from which participants were required to count backwards changed after every 10 trials (the experimenter called out the new number before each block of trials). On Day 1, participants in this group were always asked to count backwards in 3s. On Day 2, participants were randomly asked to count backwards in either 3s or 4s. On Day 3, participants were randomly asked to count backwards in either 3s, 4s, or 6s[11]. The reason for adding an extra magnitude in each session was to maintain task difficulty throughout the acquisition phase (previous researchers have highlighted the limitations in the use of a secondary task over a long period of time due to the potential learning that can occur – for a review see Abernethy, 1988).

Procedure

Acquisition phase. Prior to beginning the first acquisition session, participants were asked to report their name, gender, date of birth, and to provide information about their previous experience of playing table tennis (Appendix J). They were then shown a short instructional video that demonstrated the general movement actions of the forehand and backhand serves. The video consisted of a right-handed, recreational table tennis player (27 years experience) who performed six forehand serves and six backhand serves. The video did not contain any verbal instructions about how to perform the skills. The instructions to participants were that they should attempt to duplicate the technique shown in the video.

Participants attended one practice session on each of three consecutive days (three sessions in total). The sessions lasted for approximately 40 mins and included 150 forehand serves and 150 backhand serves (totalling 450 practice trials for each skill over the duration of the acquisition period). In each practice session, the blocked group performed all 150 forehand serves, followed by all 150 backhand serves, whereas the random group and the random + secondary task group alternated between a forehand serve and a backhand serve on each practice trial. Participants were not given any verbal feedback about the outcome location of the balls although it was possible for them to see where the ball landed from their side of the table.

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[11] The participants were not asked to count backwards in 5s because of the ease with which participants would have been able to respond to this task – counting backwards in 5s prescribes that the response will always end in either a “0” or a “5” making the task relatively simple.

Performance on the serving tasks was recorded by assigning scores to the target grids. Each row of the grid was assigned a number and each column was assigned a letter or symbol. The experimenter recorded the cell reference in which the ball landed after each trial. The balls were coated in talcum powder so that a small mark was left on the table where the ball landed. In the case of a "line ball", the cell in which the majority of the mark appeared was recorded. If the ball landed on a line and the mark was equally distributed between more than one cell, then the cell closest to the target was recorded.

Verbal reports. Participants' explicit recollections of verbal knowledge associated with executing the tasks were recorded by asking them to respond to the following statement, "Certain steps are involved in performing the table tennis skills that you learned this week. Imagine you were asked to explain how to perform these skills to someone else. Using dot points, please list as many steps as you can think of, in the right order, which you would use to explain how to perform these skills". Participants were asked to respond for the forehand and backhand skills separately by typing their responses on a laptop computer. The verbal reports were completed immediately after the final acquisition session.

Participants' responses were scored by two independent raters, who then compared scores until a consensus was reached. The raters were blind to the experimental conditions under which each participant performed. The raters determined whether statements were related to movement (mechanical rule) or the testing of a hypothesis (hypotheses). The number of mechanical rules reported (e.g., "I held the bat with a pistol grip") and the number of hypotheses tested (e.g., "I found that it helped to try and hit the ball more softly if it went beyond the target on the previous attempt") were then summed. Any statements that were irrelevant to the technical demands of the task (e.g., "I found the session fun") were not included in the analysis.

Retention phase. A retention test was administered after a one-day rest period. Participants completed 20 forehand serves and 20 backhand serves in each of a blocked and a random (alternating) schedule. The blocked and random schedules were counterbalanced across groups. The scores on the blocked and random schedules were combined to form an overall retention measure. There were two reasons for including both the blocked and random schedules as an overall retention test: (1) to eliminate the issue of one or two, but not all groups having previously experienced that particular practice schedule, and (2) because the inclusion of both blocked and random schedules more closely matches what would happen in a real game scenario and hence was a more ecologically valid test of retention.

Secondary task transfer phase. A transfer test was given in the same session as the retention test. The retention and transfer phases were counterbalanced across groups. The transfer tests followed the same procedures as in retention; however participants were asked to perform a secondary task while concurrently performing the forehand and backhand tasks. High pitched (660 Hz) and low pitched (440 Hz) tones were played to participants through computer speakers. Participants were required to indicate detection of the high tones as rapidly as possible by saying "tone". The high tones occurred randomly only 25% of the time. Participants were instructed to prioritise the primary forehand and backhand tasks (they were instructed that, "Your primary aim is to perform the forehand and backhand tasks, and if you are able to respond to the tones at the same time, then this is your secondary priority."). Tones were 500 ms in length and occurred once within every 2 s. Probes were recorded (in ms) with custom designed software (AIS React) and a wireless lapel-mounted microphone that transmitted to a laptop computer. The blocked and random schedules were combined into overall transfer measures for the forehand and backhand tasks separately (based on the same reasons as outlined in the retention test). It was not possible to differentiate between the reaction times that occurred during the forehand and backhand trials in the random schedule with the method employed; therefore the reaction times to both tasks were combined.

Results

Acquisition Phase

Performance during the acquisition period was evaluated with separate Learning Group x Acquisition Session (3 x 3) ANOVAs with repeated measures on the second factor for the forehand and backhand tasks. Figure 5.1 shows performance on the forehand task and Figure 5.2 shows performance on the backhand task.

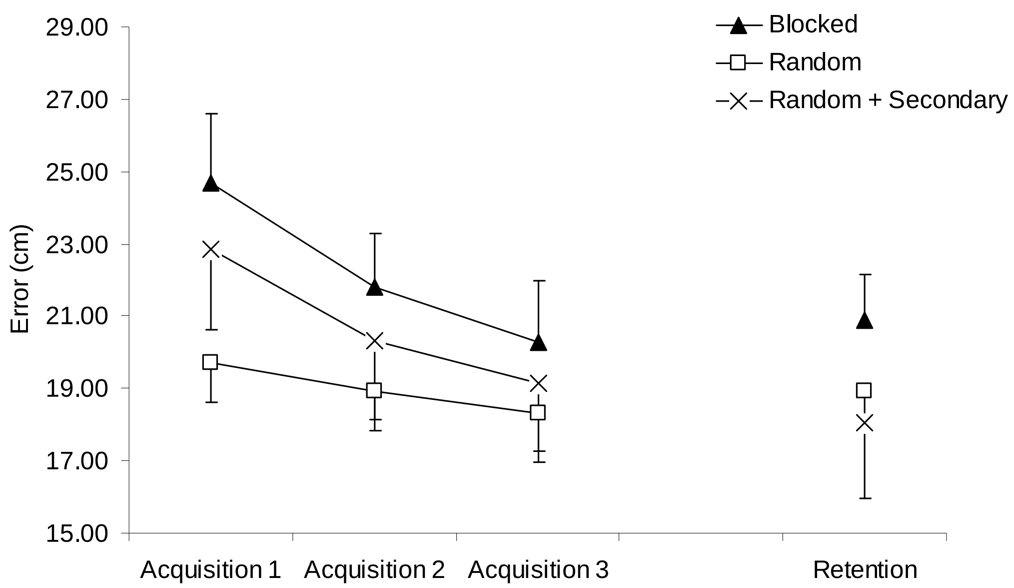

Figure 5.1. Mean accuracy scores for the blocked, random, and random + secondary task groups on the forehand task during acquisition and retention, with standard error bars.

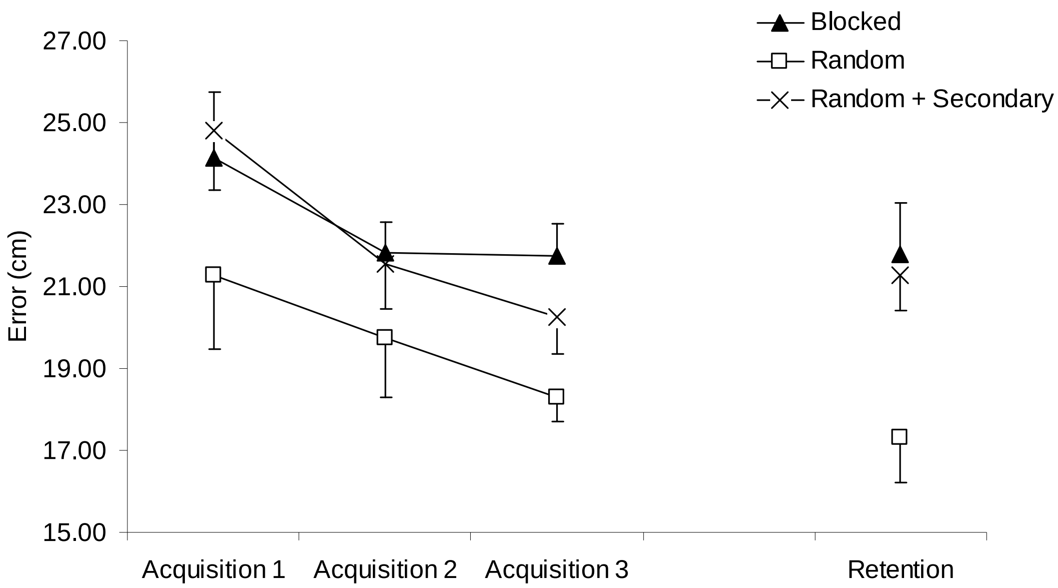

Figure 5.2. Mean accuracy scores for the blocked, random, and random + secondary task groups on the backhand task during acquisition and retention, with standard error bars.

There was a significant improvement in performance across the acquisition sessions for both the forehand task ($F(2, 48) = 29.69$, $p < .001$, *partial* $\eta^2 = .553$) and the backhand task ($F(2, 48) = 29.74$, $p < .001$, *partial* $\eta^2 = .553$). However, there was no significant main effect for learning group in either task (forehand, $F(2, 24) = 1.62$, $p = .219$, *partial* $\eta^2 = .119$; backhand ($F(2, 24) = 1.05$, $p = .365$, *partial* $\eta^2 = .081$). There were also no significant learning group by acquisition session interaction effects for the forehand task ($F(2, 48) = 2.52$, $p = .07$, *partial* $\eta^2 = .173$) or the backhand task ($F(2, 48) = 1.46$, $p = .230$, *partial* $\eta^2 = .083$).

Retention Phase

The performance differences of the three learning groups on the retention test were analysed with separate one-way ANOVAs for the forehand and backhand tasks. There were no significant differences between the groups on either task at retention (forehand: $F(2, 26) = 1.53$, $p = .236$, backhand: $F(2, 26) = 2.22$, $p = .130$; see Figures 5.1 and 5.2).

Transfer Phase

Accuracy. Performance on the primary table tennis tasks during single and dual-task conditions was compared using separate Learning Group x Test (3 x 2) ANOVAs for the forehand and backhand tasks with repeated measures on the test factor. There were no significant main effects for learning group (forehand, $F(2, 24) = .14$, $p = .825$, *partial* $\eta^2 = .124$; backhand, $F(2, 24) = 1.21$, $p = .315$, *partial* $\eta^2 = .092$) or test (forehand, $F(1, 24) = 1.22$, $p = .280$, *partial* $\eta^2 = .048$; backhand, $F(1, 24) = .19$, $p = .667$, *partial* $\eta^2 = .008$). There were also no significant interaction effects (forehand, $F(2, 24) = 1.69$, $p = .205$, *partial* $\eta^2 = .016$; backhand, $F(2, 24) = 1.15$, $p = .334$, *partial* $\eta^2 = .087$; see Figures 5.3 and 5.4).

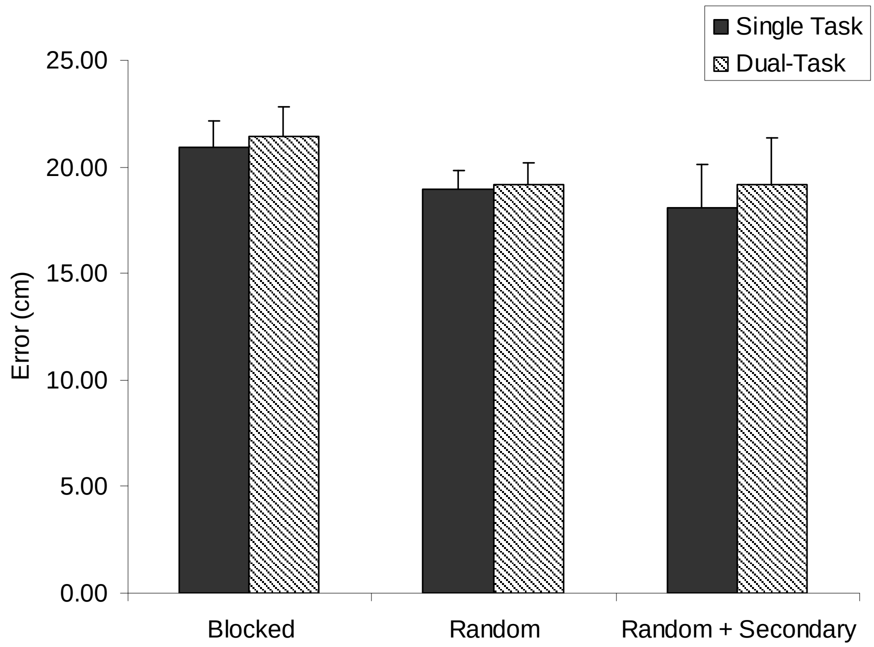

Figure 5.3. Mean accuracy scores for the blocked, random, and random + secondary task groups on the forehand task under single and dual-task conditions, with standard error bars.

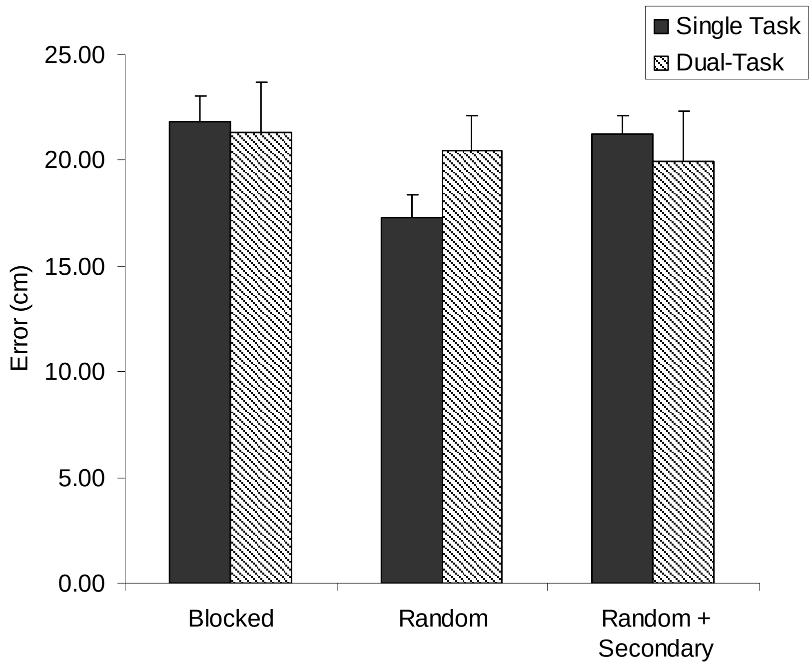

Figure 5.4. Mean accuracy scores for the blocked, random, and random + secondary task groups on the backhand task under single and dual-task conditions, with standard error bars.

Reaction times to the tones were analysed with a Learning Group x Test (3 x 2) ANOVA with repeated measures on the test factor (single-task and dual-task). There were an insufficient number of responses to analyse backhand and forehand separately so mean reaction times of forehand and backhand were combined and included in the analysis. There was a significant main effect for test ($F(2, 24) = 10.21$, $p < .01$, *partial* $\eta^2 = .460$) and learning group ($F(1, 24) = 83.31$, $p < .001$, *partial* $\eta^2 = .776$). There was also a significant learning group by test interaction effect ($F(2, 24) = 22.36$, $p < .001$, *partial* $\eta^2 = .640$). Follow-up tests revealed that there were no significant differences between the reaction times of the groups under single task conditions ($F(2, 26) = .273$, $p = .763$). However, there were differences between the groups under dual-task conditions ($F(2, 26) = 22.21$, $p < .001$), with faster response times in both the random group and the random + secondary task group compared to the blocked group (*p*s < .01), but no difference between the random group and the random + secondary task group (p = .445). Figure 5.5 shows reaction times to tones under single and dual-task conditions.

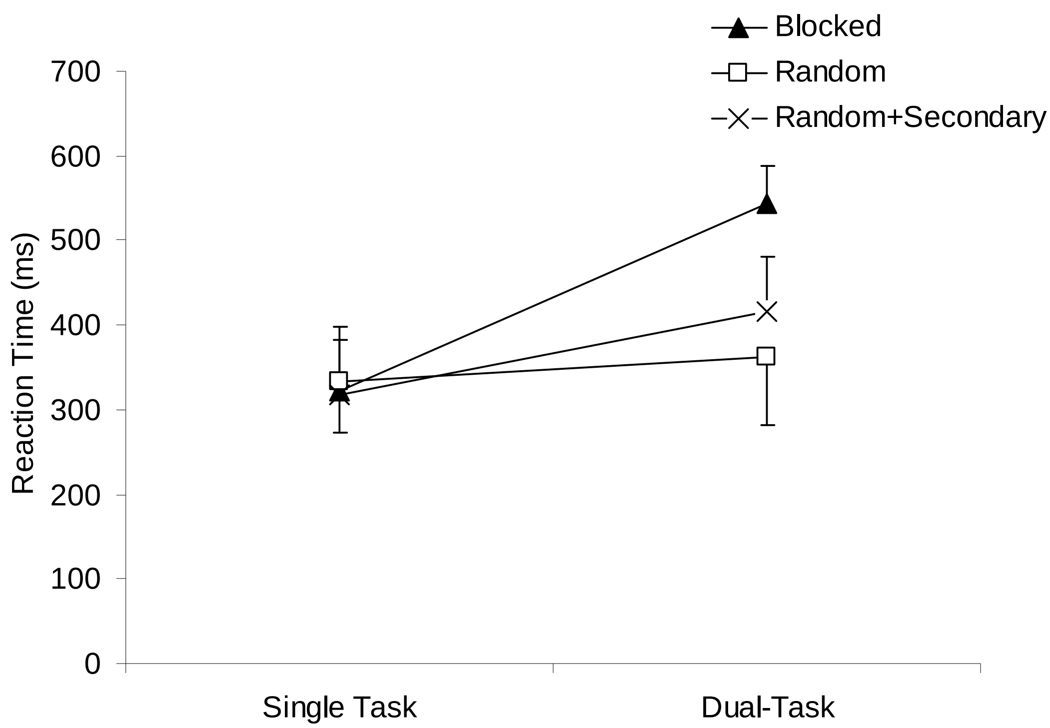

Figure 5.5. Mean reaction time to the secondary task for the blocked, random, and random + secondary task groups under single- and dual-task conditions on the combined forehand and backhand tasks, with standard error bars.

Verbal reports. A minimal number of hypotheses were reported by each group for both the forehand and backhand tasks (all means < 0.6), so mechanical rules and hypotheses were combined and an analysis was performed on the total amount of task relevant knowledge reported. Differences in task relevant knowledge between the three learning groups were analysed with separate one-way ANOVAs for the forehand and backhand tasks. There were significant differences between the groups' task relevant knowledge on both the forehand and backhand tasks (forehand: $F(2, 25) = 9.54$, $p < .01$, backhand: $F(2, 25) = 7.97$, $p < .01$; see Figure 5.6).

Tukey's post hoc tests revealed that, for the both tasks, there was a significant difference between the blocked group and the random group (both *p*s < .01) and between the blocked group and the random + secondary task group (forehand: $p < .01$; backhand $p < .05$). There was no difference between the random group and the random + secondary task group for either the forehand or backhand tasks (both *p*s > .05).

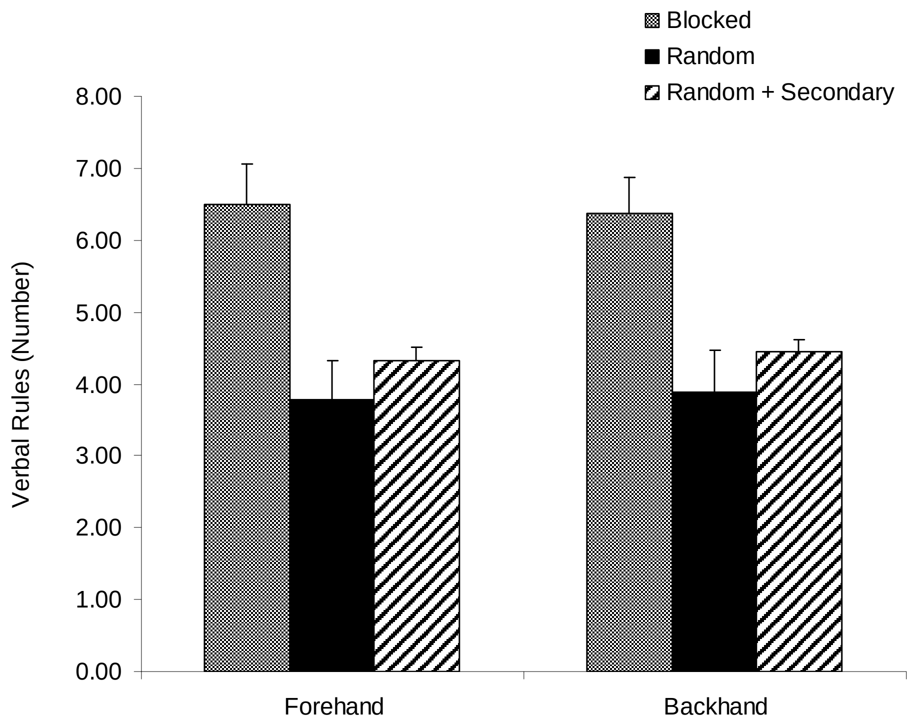

Figure 5.6. Mean number of verbal rules for the blocked, random, and random + secondary task groups on the forehand and backhand tasks, with standard error bars.

Discussion

The purpose of this study was to explore whether the benefits of random practice are subserved by the same or similar cognitive processes that subserve implicit motor learning. The study examined the effect of adding a cognitively demanding secondary task to a random practice schedule, hypothesising that the secondary task would not dispel the retention benefits of random practice. It was hypothesised that learners who practised in a random schedule *only* and those who practised in a random schedule *with* a concurrent secondary task would display poor performance during acquisition, but superior performance in retention and transfer, and would report fewer verbal rules and hypotheses than blocked learners. These hypotheses were based on the suggestion that the benefits of random practice might be due to a reduction in processing of task-related rules and testing of hypotheses because of the additional cognitive load imposed by task switching during random practice schedules. Hence, it was predicted that preventing learners from engaging in these cognitive activities (by way of a concurrent cognitively demanding task) would not influence the characteristics of random practice.

The results partially supported the hypotheses. Contrary to the traditional contextual interference effect, there were no significant performance differences between the groups during acquisition or at retention. There were, however, observable indications that participants in the random group that practised under single-task conditions and the random group that practised under a secondary task load learned in a more implicit way than participants in the blocked group. Specifically, both of the random groups reported a smaller amount of task relevant knowledge and displayed superior performance on a secondary task transfer test when compared to the blocked learners. These two characteristics are synonymous with implicit motor learning (Masters, 1992; Maxwell et al., 2000; Maxwell et al., 2003; Poolton et al., 2005) and suggest that the two random groups learned in a more implicit way than the blocked learners. The consequences of these results are limited, however, by the lack of significant between-group differences in the performance data.

In understanding the performance data during acquisition and at retention, it is worth considering the findings of a recent study by Lin et al. (2008). As discussed in Chapter 2, Lin et al. used single disruptive TMS pulses during the intertrial interval of blocked and random practice. The researchers were interested in what effect the TMS pulses would have on blocked and random practice. Lin et al. predicted that if the elaboration hypothesis is true, then perturbing elaboration using TMS would interfere with the learning outcomes of random but not blocked practice. In contrast, if the reconstruction hypothesis is true, then the addition of TMS should encourage reconstructive activities in blocked practice. Their results showed that perturbing information processing between random practice trials diminished the learning benefits of random practice, thus supporting the elaboration hypothesis. The addition of TMS to blocked practice did not result in learning benefits, going against the reconstruction hypothesis. These results are relevant to the current discussion insofar as they consider the effect of preventing cognitive processes by adding a perturbation during blocked and random learning. In the current study, the imposition of the concurrent secondary task to random practice resulted in learning outcomes that were similar to both the single-task random condition and the blocked condition. Based on this performance data, neither the elaboration hypothesis nor the reconstruction hypothesis is supported because there were no differences between the single-task blocked and random groups. Instead, the data might simply suggest that the contextual interference effect was not observed in the current data and that there might be other factors to account for the findings.

Previous researchers have highlighted a range of factors that influence the occurrence of the contextual interference effect (Brady, 1998; Guadagnoli & Lee, 2004; Magill & Hall, 1990). Two factors that are consistently cited are task characteristics and participant characteristics. With reference to task characteristics, considerations include the type of tasks (laboratory vs. non-laboratory) and the variation between the tasks being practised (tasks from the same vs. different motor programs). In a recent review, Barreiros et al. (2007) highlighted a lack of traditional contextual interference findings in research that incorporated non-laboratory tasks (such as badminton, baseball, golf, soccer, tennis, and volleyball skills). In almost three quarters of the studies (71%), the contextual effects typically associated with the acquisition phase were not evident in studies of non-laboratory tasks. Similarly, almost two thirds of non-laboratory studies (58%) did not show better retention performance for random learners. According to the observations by Barreiros et al., the present results resemble existing patterns of data from studies of non-laboratory tasks and might help to explain the lack of significant findings in the performance data in this study.

Furthermore, consideration of the difference between motor tasks in terms of the motor programs utilised might also help to explain the performance data in the current study. According to Schmidt's conceptualisation of a motor program (Schmidt, 1975, 1988), variations of a skill are considered to be controlled by different motor programs if the relative timing, event sequence *and/or* spatial configurations of the tasks differ (see Magill & Hall, 1990). According to this categorisation, the forehand and backhand table tennis skills are controlled by different motor programs. Specifically, the spatial configurations of the two service actions are different. In the backhand serve, the left and right hands cross over during the period between the ball toss and bat-ball contact. In the forehand serve however, the hand tossing the ball and the hand controlling the bat never cross. Similarly, in the forehand the arm holding the bat is extended away from the body during the upsweep towards the ball, whereas in the backhand, the hand arm holding the bat crosses the body during the upsweep motion. The event sequence, in contrast, is similar between the forehand and backhand skills. This view is backed up by the observation that, for each participant, the verbal reports for the forehand compared to the backhand skills were almost identical. The relative timing also appeared to be quite similar between the two skills with many participants in the random group seeming to produce a constant rhythm despite alternating between forehand and backhand (it should be noted that this was not specifically measured, but rather this suggestion is based on the observations of the experimenter). Overall, given that the tasks fulfilled the notion of possessing different spatial configurations, they can be considered as relying on two different motor programs.

Magill and Hall (1990) suggested that when skills in contextual interference studies use different motor programs, a difficult learning situation is established. They further suggested that this learning environment results in more effortful processing and facilitates learning. The tasks for the present study were selected based on this contention. However, when combined with the limited skill level of the participants, it is possible that the learning situation that was created might have been a substantial challenge to learners (challenging enough to prevent the traditional contextual interference effect). This notion corresponds to the suggestion (from Magill & Hall, 1990) that the difficulty of random practice may overwhelm novices in the early stages of learning. This idea is also echoed by Landin and Hebert (1997) who found that the optimal schedule along the contextual interference continuum may be determined by a learner's level of proficiency (also see Guadagnoli & Lee's, 2004 "challenge point framework").

In line with the influence of optimal practice difficulty, it is also possible that the serial schedule of switching between skills added to the level of complexity that was experienced. In the random schedule, participants were asked to switch between the forehand and backhand skills on every practice repetition, thereby preventing them from engaging in the same task on more than one consecutive trial. This may have increased the difficulty of the learning environment because they were not able to repeat the same motor program for two consecutive trials. Coupled with other factors such as the skill level of participants and the different motor programs underlying the skills, this might explain why the retention benefits of random practice were not evident. The suggestion that the practice environment was highly challenging for the participants is supported by the observation that participants exhibited a high degree of outcome variability during the acquisition and the test phases. In addition, participants' overall outcome scores could be considered relatively poor, with many balls not even reaching the target area.

Despite the lack of observable between-group differences in outcome performance, the other key measures in this study provide some support for the contention that random practice is subserved by more implicit processes than blocked practice. The participants who engaged in blocked practice reported significantly more task relevant knowledge than either of the two random practice groups. This finding suggests that the blocked learners had a larger pool of explicit knowledge following practice (a finding that has previously been linked to explicit learning; e.g., Maxwell et al., 2001). Similarly, it suggests that the single task random group acquired a smaller pool of explicit knowledge, which was essentially equal to the group in which random participants were loaded with the secondary task. This finding supports the results of the study reported in Chapter 4.

Further support for the implicit learning hypothesis is provided by the transfer test. There were no significant differences between the groups on primary task accuracy performance (in line with the instructions provided to participants to prioritise primary task performance). There were however, significant differences in the reaction times to the secondary task tones. Specifically, participants who practised under blocked conditions were significantly slower to respond than participants in either of the two random groups (which did not differ from each other). This occurred despite there being no differences in single task reaction times, suggesting that the random learners were able to perform the primary task with less attention control than the blocked learners. Robust performance under secondary task transfer has previously been interpreted as an indication of implicit learning (e.g., Poolton et al., 2005) and provides further support for the implicit learning hypothesis for random practice.

It is important to note that the arguments presented here regarding the challenging conditions created by: (1) the applied nature of the tasks, (2) the use of tasks from different motor programs, and (3) the serial scheduling of trials might have inadvertently been the very basis for the implicit behaviour exhibited on the measures of verbal protocols and secondary task transfer. Specifically, according to the implicit learning hypothesis discussed in Chapter 4, it is likely that when a learner is required to cope with a high degree of contextual complexity, then they are less likely to have spare attention available to process skill related information – they are potentially more likely to learn implicitly. If the proposition is true, then it has implications for the application of random practice based on the implicit learning hypothesis.

Specifically, according to the data presented here, coaches might be directed to consider whether the goal of practice is primarily one of learning (in which case lower levels of complexity might be most appropriate) or whether the benefits of implicit learning are sought (in which case higher levels of complexity might be required).

A final consideration in regards to the current study is that a blocked group with a concurrent secondary task was not included. The rationale behind the design was that the primary concern was to observe the effect of adding a secondary task to random practice. It was hypothesised that the traditional contextual interference effect would be observed between the single-task blocked and random groups and that the effect of the secondary task on random practice could be interpreted as a test of the implicit learning hypothesis. In the future, it would also be interesting to extend the current study by observing the effect of preventing cognitive processing during blocked practice.

In summary, it is evident that the indicators of implicit learning used in the current study were supported within both the single-task random group and the random + secondary task group. These groups responded differently to the blocked group on both a secondary task transfer test and in their reporting of verbal rules, but differences were not evident in the performance data in the current study, limiting the strength of conclusions. As it stands, the evidence from this study provides a platform for future research that was not previously identified. The suggestion that random practice might be subserved by implicit processes offers an alternative theoretical account to the established explanations of the contextual interference effect – principally elaboration or reconstruction. It is hoped that this contention lays the basis for theoretical advances in understanding of the contextual interference effect.

CHAPTER 6

STUDY FOUR: AN INVESTIGATION INTO MOVEMENT PREPARATION AND EXECUTION TIME AS AN INDICATOR OF COGNITIVE EFFORT DURING LEARNING

Introduction

The studies presented in the previous two chapters highlight the need to develop either: (1) additional measurement techniques to compliment a battery of measures of cognitive effort or (2) more sensitive measures that can be relied upon in isolation, such as new neuroimaging techniques. The aim of the study detailed in this chapter is to explore a behavioural measure that has the potential to be included within the existing battery of measures available to researchers examining cognitive effort. Specifically, this study investigates whether the time between movement trials is an index of cognitive effort.

Researchers have investigated the processes that take place during the inter-trial interval in studies of human perception and performance (Compton, Arnstein, Freedman, Dainer-Best, & Liss, in press). The inter-trial interval is the time between the end of a response and the onset of the next stimulus or movement trial. The inter-trial interval has been shown to be a time of active processing in certain experimental situations (such as when an error is made on the immediately previous trial or when a participant is required to switch between tasks). In these situations, the active processing involves cognitive control operations rather than being a mindless gap in which participants wait for the next trial (Compton et al.). In terms of the current discussion of contextual interference, the cognitive control operations explored in the existing literature include elaboration and reconstruction. In implicit motor learning, cognitive control operations are minimised during the intertrial interval due to a range of factors that differ depending on the method used (in errorless learning, for example, cognitive control operations, such as evaluation of performance responses and adjustments in strategy, are low because the previous trial is generally successful).

The mechanisms of cognitive control have been widely studied in experiments which utilise a task switching paradigm. Task switching experiments bear a close resemblance to random practice in the contextual interference literature. There are two main differences between the literature areas. Firstly, the focus of the task switching paradigm is to explore the mechanisms underlying cognitive control whereas the focus of the contextual interference literature is on understanding the mechanisms that support long term learning outcomes (retention of learned skills). Secondly, in task switching experiments, the tasks typically involve a response to a stimuli (such as a light or word appearing on a computer screen) whereas in the contextual interference literature in the motor learning domain, the tasks are often self-paced skills such as throwing a ball at a target or producing a movement with a computer joystick.

A range of paradigms have been employed within task switching experiments which differ in the scheduling of the task switch. Five basic paradigms of task switching are: (1) task switching involving mixed-task blocks (the task switches every trial)[12]; (2) predictable task switching (the tasks switch in a regular manner after a constant number of trials); (3) task cueing (includes an unpredictable sequence to which a participant receives an explicit cue preceding or accompanying the stimulus to convey the task requirements for the next trial) [13]; (4) intermittent instructions (participants perform a sequence of trials with the same tasks and are occasionally

[12] This paradigm corresponds to serial scheduling in studies of contextual interference and was implemented in the study presented in Chapter 5 of the current thesis.

[13] This paradigm corresponds to the random schedule typically used in studies of contextual interference and was implemented in the study presented in Chapter 4 of the current thesis.

interrupted by a cue that informs them what to do on the following trial sequence); and (5) voluntary task selection (participants decide themselves on each trial which of two tasks to perform) (Kiesel, Steinhauser, Wendt, Falkenstein, Jost, Philipp et al., 2010).

These paradigms have been widely used in experiments to examine the cognitive control mechanisms underlying task switching (see Kiesel et al. 2010; Vandierendonck, Liefooghe, & Verbruggen, 2010 for reviews). A consistent finding in these experiments is that switching from one task to another is slower and more error prone than repeating the same task (a finding that is consistent with studies of contextual interference). The increase in response time or error that accompanies a switch is referred to as the "switch cost" (the cost of task switching). Typically in these experiments, the timing of events is controlled (by controlling the intertrial interval duration, the response-stimulus interval, the response-cue interval, or the cue-stimulus interval). Differences in reaction times to stimuli in which a switch has occurred are compared to instances when a repetition occurs as a measure of the switch cost.

In the studies of contextual interference detailed in the preceding two chapters, there was limited time control in how the events unfolded. In the Chapter 4 study, participants in the random group were cued with the task requirements of the next trial after completion of the preceding trial. Random learners were then able to take as much time as they required before initiating the next movement response. In the Chapter 5 study, random learners knew that the task requirements of each trial alternated on consecutive repetitions and were able to take as much time as they required in between trials. Given the nature of the responses in these studies (both required self-paced motor tasks to be executed) and the uncontrolled timing of the trials, it was not possible to compare differences in reaction times to stimuli as a measure of cognitive control. An alternative method of measuring the switch cost is to calculate the difference in total performance time between conditions which require participants to switch and those which include only repetition of the same task (Vandierendonck et al., 2010). The application of this approach to the study of the contextual interference effect is unlikely to differentiate between implicit and explicit processes during learning; however it provides potential value insofar as it offers a possible measure of the level of cognitive control required for different task schedules.

The current study aims to compare the time taken to prepare and execute[14] skills in a blocked versus random schedule. The premise of this study is that the "switch cost" of random practice is likely to lead to an increase in the duration of preparation due to the increased amount of cognitive effort required to perform the task switch. Conversely, blocked practice is likely to be associated with relatively quicker preparation and execution times due to relatively less processing requirements. One of the aims of the study reported in Chapter 4 was to investigate the level of cognitive effort associated with blocked and random practice. According to a number of measures (task performance during acquisition and retention, PRT performance, and self-report levels of cognitive effort), random learners exhibited higher levels of cognitive effort than blocked learners. The study in Chapter 4 therefore, provides a suitable foundation for conducting the current investigation and as such the data collected in that study will be used in the current study. A post hoc analysis of the time taken to plan and execute trials in the Chapter 4 study was conducted to explore whether these measures can be used to assess cognitive effort

[14] See Method for more information regrading the inclusion of execution time as an indicator of cognitive effort in the current study.

during learning. This measure would be useful as an inclusion within the existing battery of measures available to researchers examining cognitive effort.

Method

Preparation and execution times were calculated for a sample of trials for each participant during the acquisition phase of the study detailed in Chapter 4. The analysis was conducted using video footage collected at the time of the study. Two video cameras were positioned such that the handball and kicking skills were captured from a side on view. For each participant, a sample of 10 trials was analysed (including the first five kicks and the first five handballs that were completed by a participant in each acquisition session). In total 2,090 trials were systematically analysed during the investigation.

Three time points were recorded and two time phases were calculated in the analysis (see Figure 6.1). The time points included: (1) Ball Pick Up (the first video frame after the ball had clearly left the ground when the participant collected it to begin the trial); (2) Movement Initiation (the first video frame at which the participant had clearly initiated their movement); and (3) Ball Release (the first video frame after the ball had clearly left the hands in the handball task or foot in the kicking task). The time phases that were then calculated included: (1) the Movement Preparation phase (from Ball Pick Up to Movement Initiation) and (2) the Movement Execution phase (from Movement Initiation to Ball Release). The rationale for including the Movement Execution phase in the current analysis was that, for both skills, there was an opportunity for participants to engage in cognitive processing once the movement had been initiated. In terms of the kicking task, most participants tended to take a substantial run-up as part of their skill. Experimenter observation suggested that some participants might have used this time to engage in task related cognitive processing for the more complex component of the skill which occurred later in the movement execution sequence. Similarly, in the handball task, during the phase when participants swung their arm backwards before swinging forwards to contact the ball, participants may have been making decisions about how they would strike the ball.

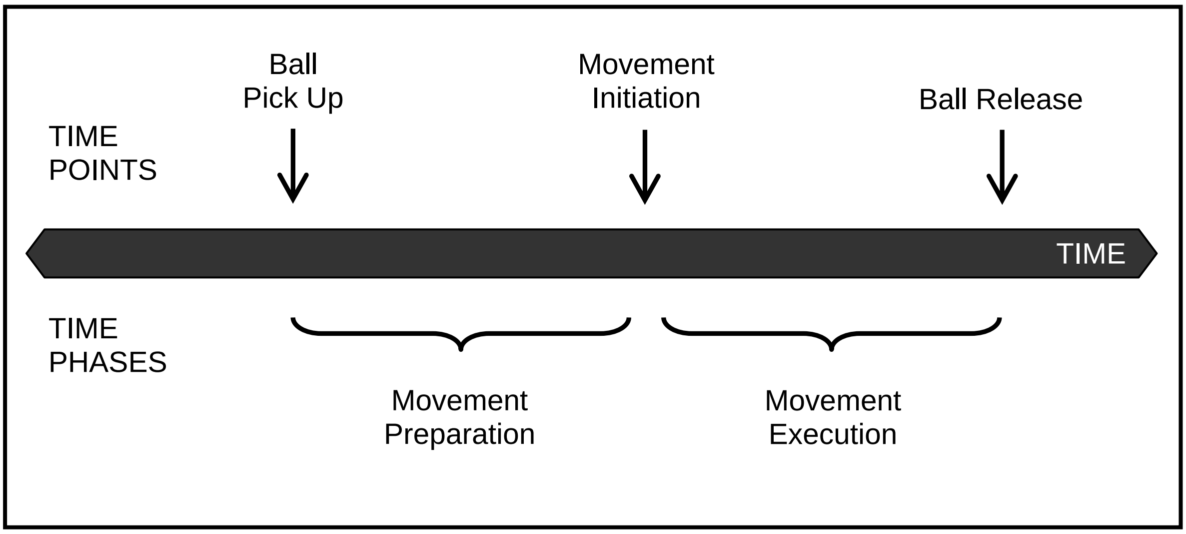

Figure 6.1. A schematic representation of the time points and time phases analysed.

In the movement preparation analysis for the kicking task, there were a number of participants who initiated their movement outside of the camera view. Participants were permitted to start their movement from any distance as long as they released the ball before reaching the required distance (that was marked on the ground with tape). These participants were excluded from the current analysis.

Results

Movement preparation (handball task). A 2 (group) x 7 (session) ANOVA was used to compare the movement preparation times of blocked and random learners on the handball task (see Figure 6.2). The results showed that there were no significant main effects for group (F(1, 12) = .52, p = .484, *partial* η^2 = .042) or session (F(6, 72) = .31, p = .932, *partial* η^2 = .025). There as also no significant interaction effect (F(6, 72) = 1.11, p = .366, *partial* η^2 = .085).

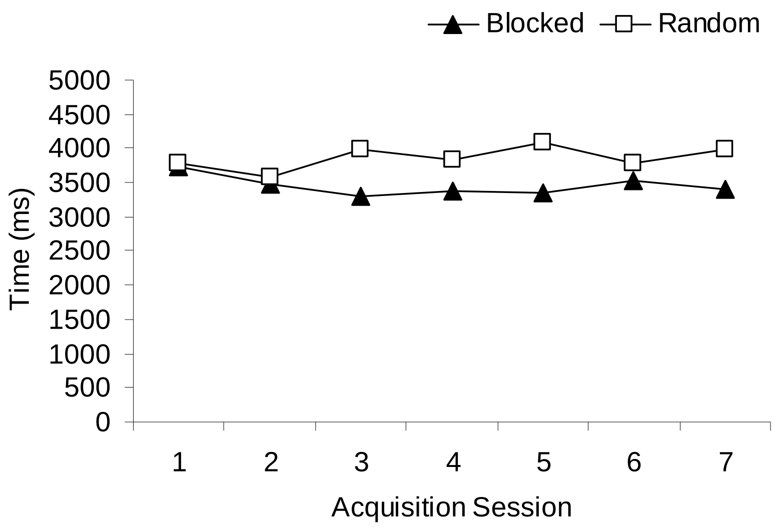

Figure 6.2. Movement preparation times of blocked and random learners on the handball task.

Movement execution (handball task). A 2 (group) x 7 (session) ANOVA was used to compare the movement execution times of blocked and random learners on the handball task (see Figure 6.3). The results showed that there were no significant main effects for group (F(1, 12) = .04, p = .848, *partial* η^2 = .003) or session (F(6, 72) = 1.63, p = .151, *partial* η^2 = .120). There was also no significant interaction effect (F(6, 72) = .18, p = .981, *partial* η^2 = .015).

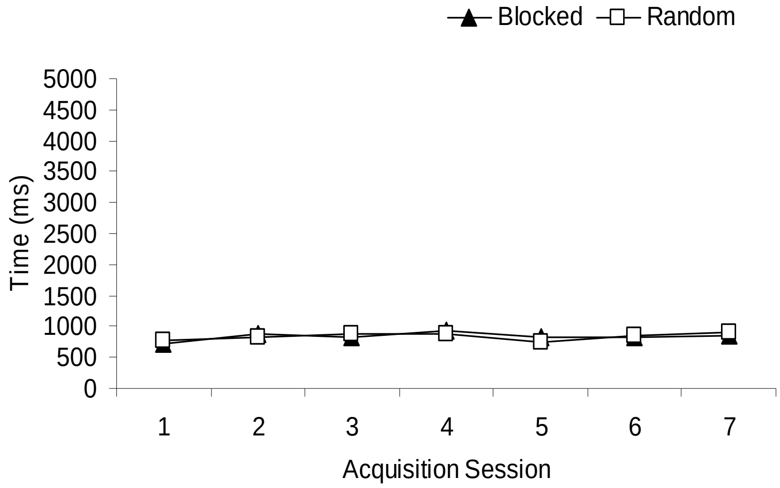

Figure 6.3. Movement execution times of blocked and random learners on the handball task.

Movement preparation (kicking task). A 2 (group) x 7 (session) ANOVA was used to compare the movement preparation times of blocked and random learners on the kicking task (see Figure 6.4). The results showed that there were no significant main effects for group (F(1, 10) = .16, p = .701, *partial* η^2 = .015) or session (F(6, 60) = 1.13, p = .358, *partial* η^2 = .101). There was also no significant interaction effect (F(6, 60) = 1.23, p = .302, *partial* η^2 = .110).

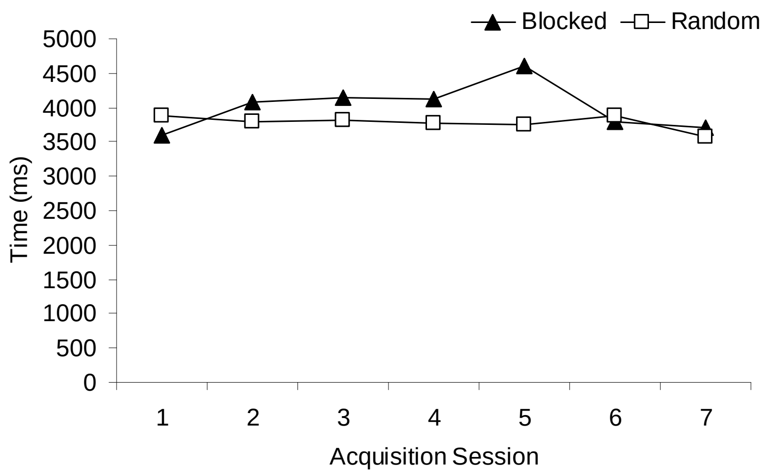

Figure 6.4. Movement preparation times of blocked and random learners on the kicking task.

Movement execution (kicking task). A 2 (group) x 7 (session) ANOVA was used to compare the movement execution times of blocked and random learners on the kicking task (see Figure 6.5). The results showed that there were no significant main effects for group ($F(1, 12) = .98$, $p = .342$, *partial* $\eta^2 = .075$) or session ($F(6, 72) = .15$, $p = .988$, *partial* $\eta^2 = .013$). There was also no significant interaction effect ($F(6, 72) = .08$, $p = .998$, *partial* $\eta^2 = .007$).

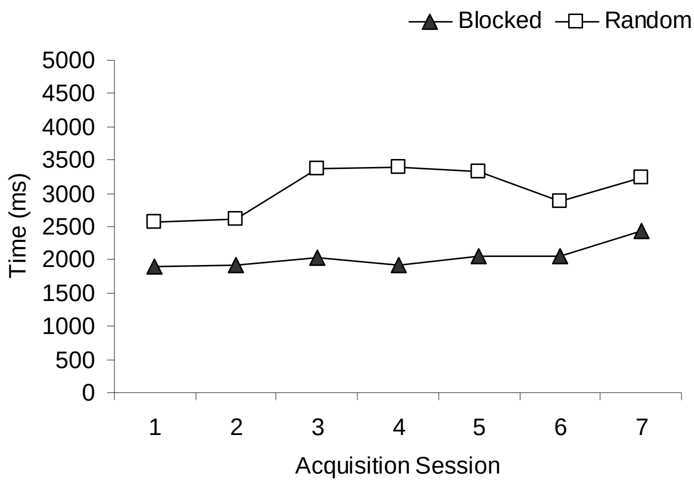

Figure 6.5. Movement execution times of blocked and random learners on the kicking task.

Discussion

The aim of the current study was to investigate whether the duration of movement preparation and movement execution can be assessed as a measure of cognitive effort. A post hoc analysis was conducted on a sample of trials from the study outlined in Chapter 4. It was hypothesised that random practice would be associated with slower preparation and execution times than blocked practice due to an increase in cognitive effort caused by task switching. The results showed that there were no significant differences in the preparation and execution times of blocked and random learners on the kicking and handball tasks. This was the case for both the time taken from Ball Pick Up to Movement Initiation and also from Movement Initiation to Ball Release.

There are three possible explanations for the non-significant findings. First, it is possible that recording of the time taken to plan and execute movements does not provide the sensitivity required to differentiate between the different practice schedules. Specifically, the results of the study in Chapter 4 suggested that random practice was associated with a higher level of cognitive effort than blocked practice. Simply measuring the duration of the time taken to plan and execute movement trials might not have captured the differences in the types of processing adopted by the different learning groups.

The second possible explanation is that the timing of the preparation and execution phases was not significantly different between the learning groups because there were other mediating variables that influenced the timing of participants' responses. This explanation is supported by the observation that participants tended to fall into a rhythm during the testing session, such that the time taken between trials was relatively consistent amongst different trials for a single participant in the random group regardless of whether a task switch had just occurred. In addition, participants might have felt that they wanted to complete the testing session in a rapid fashion due to the repetitive nature of the session (and possible feelings of boredom that they experienced). This would have negated any natural differences in their tendency to undertake slower or faster preparation and execution times due to the schedule of practice, while still allowing differences in the level of cognitive effort adopted.

A final explanation for the lack of significant differences in preparation and execution times of blocked and random learners is that the disparity in level of cognitive processing could have occurred before the movement preparation and execution phases examined in the current study. In the task switching literature, a two-stage model has been proposed to account for switch costs. The first phase (termed the *Endogenous Component*) starts as soon as participants complete their performance on the previous trial and are cued about the upcoming trial (either due to a known order or cueing from the experimenter). These endogenous processes entail "retrieval or reinstatement" of the relevant task-set (where the task-set refers to the cognitive processes and mental representations that enable a person to satisfy the requirements of a given task). In the motor learning literature the concept of a task-set is similar to concept of an action plan described by Schema Theory (see Chapter 2). The endogenous phase involves goal-shifting in which the current goal is inserted into working memory and the previous goal is deleted. The second phase is termed the *Exogenous Component* which occurs only after a stimulus has been presented. The exogenous phase includes a process of rule-activation in which the rules for the current task are loaded into working memory.

In the current study, participants performed two self-paced skills which were not coupled to an external stimulus[15]. It is arguable, however, that the processes described by the endogenous and exogenous model of task switching are relevant to the current discussion. In the current study, two phases were analysed – Movement Preparation and Movement Execution. Prior to these phases, participants in the random condition were cued as to the requirements of the upcoming trial. The cognitive processes experienced by the blocked and random learners might have

[15] Although participants were "cued" (i.e. told which skill to perform on the next trial), the skills they performed were self-paced (participants could initiate the movement whenever they chose to) and involved an invariant task goal (the goal was a static target on the wall). The types of tasks typically implemented in the task switching literature are commonly coupled to an external stimulus (e.g., the task might involve a response to an external stimulus such as a light or picture on a computer screen).

differed during the period preceding the phases analysed in the current study (in particular in the period from Cueing to Ball Pick Up).

Figure 6.6 shows the timeline of events during one experimental trial and is an extension of Figure 6.1 (see Introduction in this chapter) which did not include the end point of the preceding trial or time point at which the random group was cued (informed of which skill to complete on the next trial). It is possible that the differences in cognitive processes associated with blocked and random practice occurred prior to ball pick up.

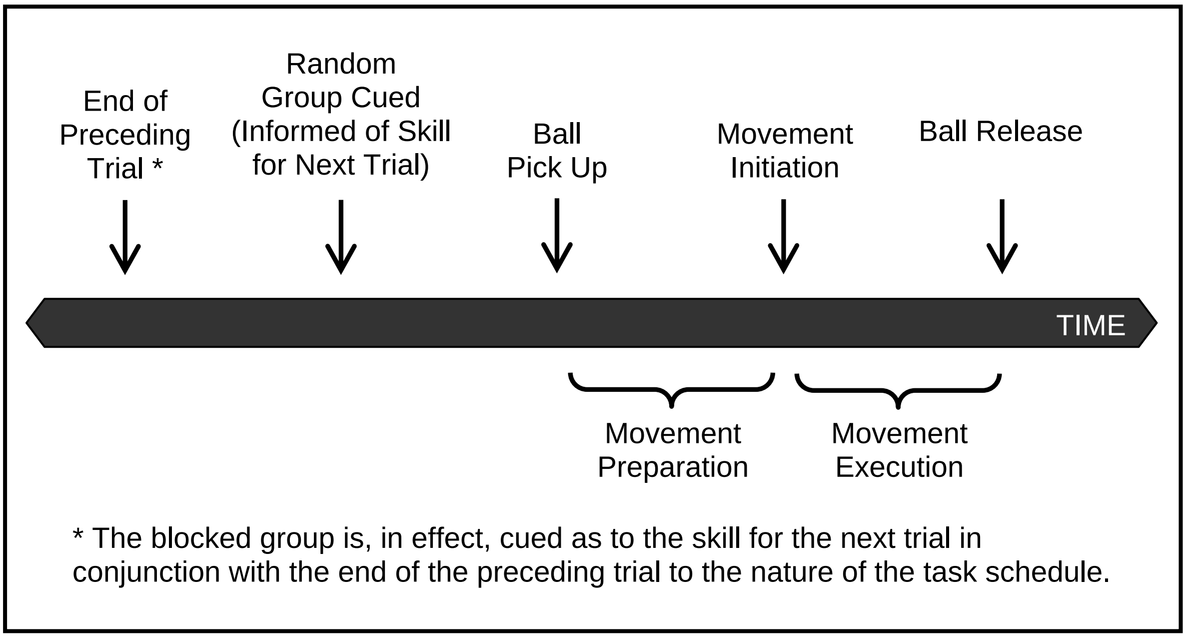

Figure 6.6. A schematic representation of the timeline of events during one experimental trial.

Figure 6.6 also shows that the relative time period for which participants are aware of the task requirements for the next trial is different for blocked and random learners. In blocked learning, the point at which participants become aware of the task requirements for the next trial coincides with the end of the preceding trial (because there is no task switching). In random practice, the participant does not become aware of the task requirements of the next trial until cued by the experimenter. The period of time available for planning and preparation for the upcoming trial is therefore shorter in the random group.

In addition to the difference in the time available for processing, there is likely to be a difference in the processing requirements that must occur during this phase in blocked and random learning. The predictions regarding exactly what type of processing occurs depends on which theoretical model is applied. According to the reconstruction view (see Chapter 2), it could be predicted that random learners must engage in both endogenous and exogenous processes. That is, following cueing, in line with the reconstruction hypothesis, it would be predicted that that random learners are required to retrieve or reinstate the task-set, shift their goal from the old to new task, and activate rules for the current task in working memory. In contrast, in blocked practice, learners are likely to only engage in exogenous processes because they do not need to retrieve a past task-set. Figure 6.7 shows the proposition that the processing requirements of random practice involve both endogenous and exogenous components, whereas the processing requirements of blocked practice are limited to the exogenous component.

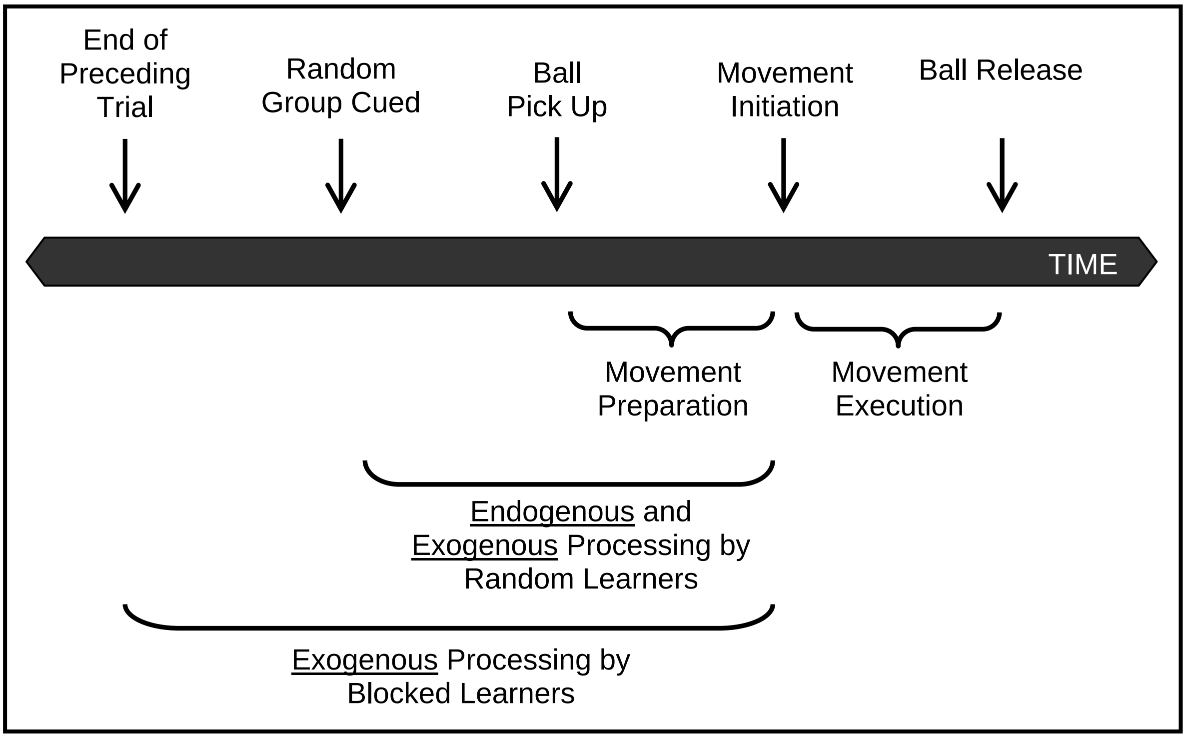

Figure 6.7. Processes for Blocked and Random Learners in One Experimental Trial based on the Reconstruction View of Random Practice.

Based on the implicit learning hypothesis for random practice detailed in Chapters 4 and 5, however, one would predict that random learners might be so overwhelmed by the requirements of task switching that they only engage in endogenous processes. That is, based on the implicit learning hypothesis, it would be predicted that random learners retrieve or reinstate the task-set and shift their goal (endogenous processes), but do not engage in activation of rules (exogenous processes). Blocked learners, on the other hand, are not required to retrieve or reinstate the task-set or shift their goal and have a substantial period of time to activate the rules regarding the upcoming trial in working memory. This suggestion compliments the contention of the implicit learning hypothesis that random practice is associated with higher levels of cognitive effort, but lower levels of explicit processing (they adopt a more implicit mode of learning than blocked learners). Figure 6.8 shows the proposition that the processing requirements of random practice involve only endogenous components, whereas the processing requirements of blocked practice involve only exogenous components.

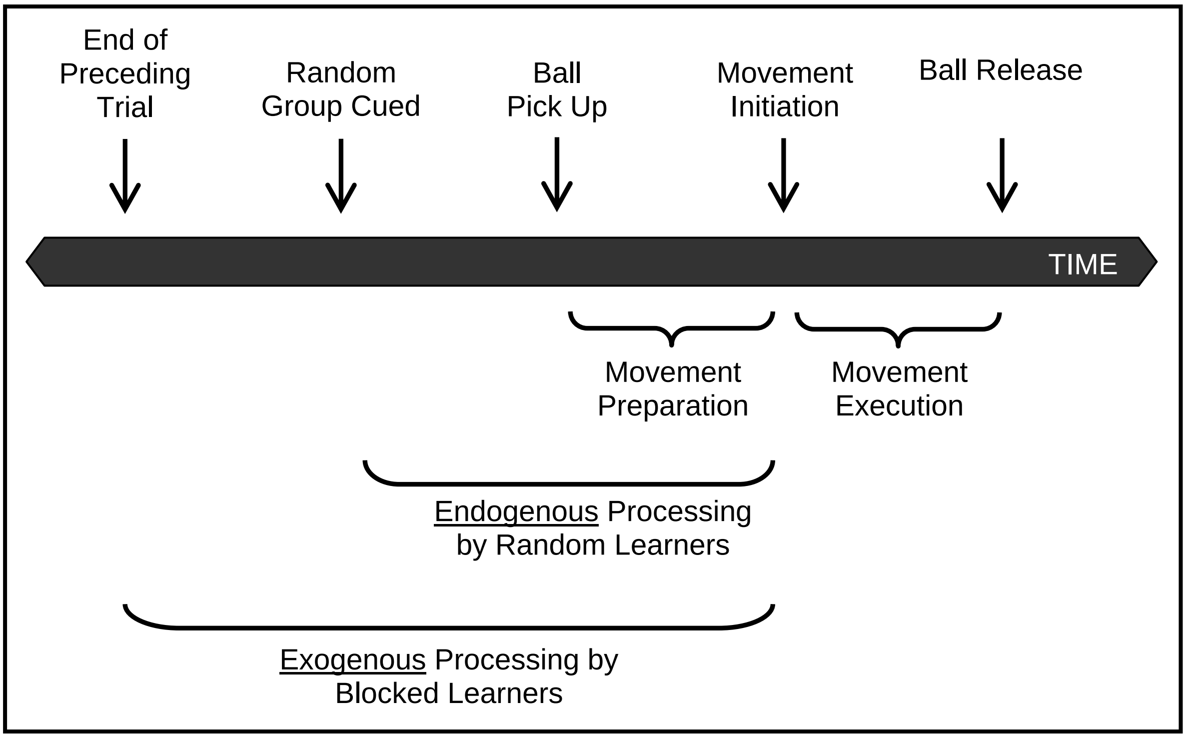

Figure 6.8. Processes for Blocked and Random Learners in one experimental trial based on the Implicit Learning Hypothesis for Random Practice.

This study has provided an investigation into the inter-trial interval during blocked and random practice. Two phases were analysed in the current study (Movement Preparation and Movement Execution), but no differences were observed between the learning groups in the duration of these periods. The investigation has, however, provided the basis for discussion regarding the time course of events that occurs during the inter-trial interval of blocked and random practice. The discussion has drawn on task-switching literature which is closely related to contextual interference research. The description of exogenous and endogenous processes adds to the implicit learning hypothesis outlined in Chapters 4 and 5 by detailing the difference in processes that might underlie blocked and random practice. It is hoped that the current discussion provides the foundation for further work that is required to substantiate the predictions made by the implicit learning hypothesis for blocked and random learning. Another theme highlighted by this chapter is the challenge for researchers to develop more sensitive measurement techniques to assess both cognitive effort and implicit/explicit processes which will be further explored in Chapter 7.

CHAPTER 7

STUDY FIVE: AN INVESTIGATION INTO THE USE OF A MODIFIED STROOP TASK AS A MEASURE OF IMPLICIT/EXPLICIT PROCESSING

INTRODUCTION

As highlighted in the previous chapter, one of the major challenges faced by researchers investigating implicit motor skill acquisition is to differentiate between implicit and explicit processes using definitive measurement techniques. A number of existing measures provide insight into the type of processing adopted by learners during implicit/explicit studies and have been previously utilised in the studies outlined in this thesis. These measures include: PRT (e.g., Lam et al., 2009), verbal reports (e.g., Maxwell et al., 2001), performance under secondary task load (e.g., Maxwell et al., 2001), and retention of learned skills over an extended period of time (Poolton et al., 2007b). Although these measures have been used as a means distinguishing implicit and explicit learning, additional measures would be beneficial in providing a comprehensive evaluation of the cognitive processing that accompanies different types of learning.

Chapter 6 detailed an investigation of movement preparation and movement execution time as an indicator of cognitive effort during learning (no differences were observed between blocked and random learners). It is also prudent to consider whether there are new methods of specifically differentiating between implicit and explicit processing (something that is not possible with the measure explored in Chapter 6). A measure that has potential in this regard is a variant of the Stroop task (Stroop, 1935). In a standard Stroop task, participants are presented with a series of words such as blue, green, red, and yellow. Participants are required to respond by naming the colour in which the word is printed (rather than saying the written word). For words with a congruent colour and meaning (e.g., “red” printed in “red”), response times are much faster than for words with an incongruent colour and meaning (e.g., “blue” printed in “red”). According to the “speed-of-processing account” of the Stroop effect, these findings are the result of faster processing times for the reading of colours than for the naming of colours. The difference in speed between the two processes causes interference as the participant works towards producing a response (Cohen, Dunbar, & McClelland, 1990). An alternative explanation is provided by the “automaticity account”, which suggests that the process of naming the ink draws more heavily on attention than reading the word (most likely because of the greater amount of exposure to reading words compared to naming ink colours). The result is slower response times for the naming of colours than for reading words (Cohen, Dunbar, & McClelland, 1990; Posner & Snyder, 1975). For comprehensive theoretical accounts of the Stroop effect see MacLeod (1991).

A modification to the standard Stroop task has previously been used to assess the salience of words to particular individuals. For example, Watts, McKenna, Sharrock, and Trezise (1986) used a modified Stroop test in which they presented emotionally-salient words to spider phobic participants. The emotionally salient stimuli included words such as “creepy”, “hairy”, and “crawl”. The stimuli were presented in different ink colours and participants were required to name the colour of the ink and ignore the written word. The performance of spider-phobic participants was severely inhibited on the modified Stroop task compared to their performance on the standard Stroop task and compared to non spider-phobic participants. Interference from salient words has also been found in other studies (e.g., Kindt & Brosschot, 1997; Lavy, Van Den Hout, & Arntz, 1993; Martin, Horder, & Gregory, 1992). Two explanations are provided to account for the inhibited performance of spider-phobic participants. First, spider words may arouse anxiety in spider-phobic participants, which inhibits performance. Second, phobic participants may possess more cognitive "expertise" or larger or more accessible knowledge structures for words relating to spiders, which prevents them from ignoring related words.

The purpose of the studies reported in this chapter is to investigate whether a modified Stroop task can be used as a measure of implicit/explicit processing. Two experiments are reported that explored the use of modified Stroop tasks as a measure of implicit/explicit processing in different cohorts of participants. In Experiment 1, the use of a modified Stroop task as a measure of processing during implicit and explicit learning was explored. Specifically, the experiment investigated whether words related to the task being practised (golf putting) would cause interference, and hence slower response times, in errorful learners compared to errorless learners. Experiment 2 explored whether the modified Stroop task could be used as a measure of implicit/explicit processing in highly skilled swimmers. It was hypothesised that swimming-related stimuli would produce slower response times than control stimuli due to the cognitive expertise developed by the highly skilled swimmers over the course of many years of skill acquisition. Two versions of the modified Stroop task were employed: (1) a word Stroop task, and (2) a pictorial Stroop task (a non-lexical version of the Stroop task).

Experiment 1

The purpose of this experiment was to investigate the use of a modified Stroop task as a measure of processing during implicit and explicit learning. It was hypothesised that errorful learners would respond more slowly to task-related words following learning because those particular words would become meaningful to them (more explicit). That is, errorful learners were likely to develop a higher level of cognitive expertise to task-related information than errorless learners as a result of their dependence on higher levels of explicit processing during learning. It was further hypothesised that the difference in processing modes during acquisition (implicit: errorless) versus (explicit: errorful) would be represented by differences in the amount of verbal reporting of rules and hypotheses – specifically that errorful learners would report a greater number of rules and test more hypotheses than errorless learners.

An additional aspect of this experiment was to include a manipulation of stress. The purpose of the manipulation was to see if stress would have an effect on response times in the modified Stroop task. As outlined earlier in this thesis (e.g., see Chapter 2), according to Masters and Maxwell's theory of reinvestment (Masters & Maxwell, 2008), psychological stress can influence attentional focus such that a performer consciously processes explicit information of how to perform movements. Research has shown that implicit motor learning (e.g., errorless learning) gives the learner immunity from reinvestment whereas explicit motor learning (e.g., errorful learning) promotes the accumulation of consciously accessible task-relevant knowledge, which can lead to reinvestment (see for a review, Masters & Maxwell, 2004). It was hypothesised that errorless learners would practice a golf putting task without accessing declarative knowledge of what they had learned and therefore under stress conditions, the words relating to golf putting would not cause interference in the modified Stroop task. In contrast, it was hypothesised that errorful learners of a golf putting task would have conscious access to knowledge relating to golf putting and that stress would increase the likelihood of reinvesting in this knowledge which would trigger slower response times to task-related stimuli in the modified Stroop task.

Method

Participants

Twenty-eight undergraduate students from the University of Hong Kong participated in the experiment. Participants were required to have no previous golfing experience. Ages ranged from 19 to 26 years (*m* = 21.25, *SD* = 1.55). Participants were randomly assigned to one of two conditions, with the restriction that gender was evenly distributed; errorless (n = 14) and errorful (n = 14). Participants were paid HK$100 (approximately AU$16) for their involvement in the experiment and provided informed consent prior to participation (Appendixes K and L).

Apparatus

All participants used a standard golf putter which was 89 cm long and used standard white golf balls. Putts were made to a hole that was 14 cm in diameter and 2 cm in depth from varying distances. The putting surface was as artificial grass mat, which was 4 m in length by 3 m in width. A standard PC equipped with E-Prime software (Psychology Software Tools, Pittsburgh, PA, USA) and a keyboard with four coloured keys (red, green, blue, and yellow) controlled both the presentation of stimuli and the recording of manual reaction time responses.

Tasks and Procedure

Figure 7.1 depicts an overview of the procedure. On arrival, a general explanation of the experiment was provided and informed consent was given.

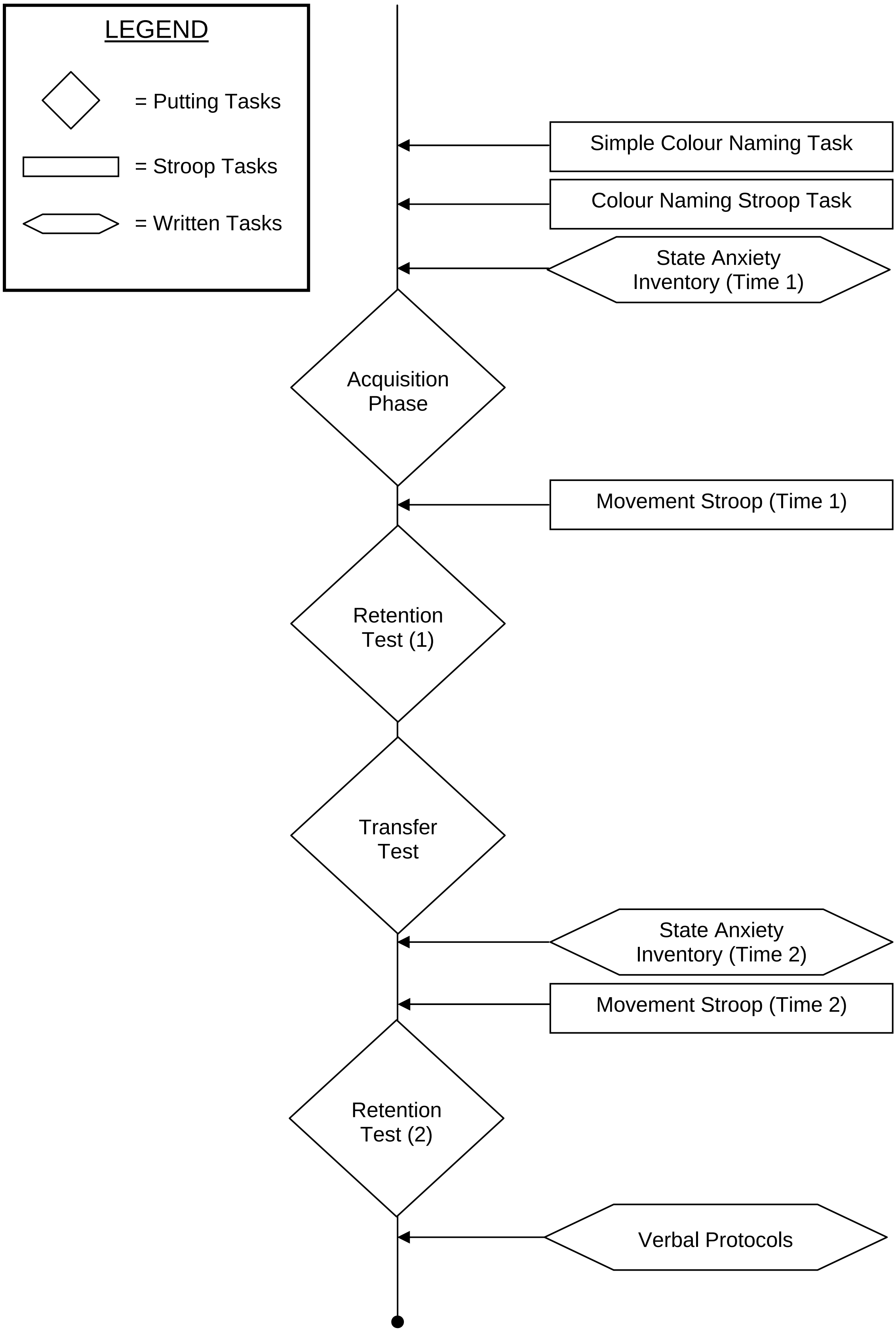

Figure 7.1. Flowchart displaying a summary of the procedure.

Simple colour naming task. All participants began by completing a simple colour naming task. The items in the task consisted of a series of five Os presented on a computer screen. Each series of Os was displayed in one of four colours (red, green, blue, or yellow). Participants were required to press a button corresponding to the colour of the Os as quickly as possible. The test included 20 items and the colours were rotated randomly through the items.

Colour naming Stroop task. Participants then completed a colour naming Stroop task. The items in this task were colour words (i.e., red, greed, blue, and yellow). Each colour word was printed in either a congruent colour (e.g., the word “red” in “red” text) or an incongruent colour (e.g., the word “red” in “blue” text). Participants were required to press the button corresponding to the colour in which the word was printed, rather than the meaning of the word. The test consisted of 20 items made up of four congruent and 16 incongruent words.

State-Trait Anxiety Inventory (Form Y; Spielberger, 1983). The STAI (State-Trait Anxiety Inventory) is a self-report measure of anxiety (Appendix M). The STAI assesses the separate dimensions of state and trait anxiety. The state anxiety dimension consists of 20 items rated on a 4-point Likert-type scale. Ten of the items are positively worded and 10 are negatively worded. The 20 items assess how a person feels right now (at this moment), and reflects the respondent’s perception of environmental stressors that may influence anxiety levels. Scores range from 20 to 80 and the higher the score the greater the level of anxiety. Internal consistency coefficients have ranged from .86 to .95; test-retest reliability coefficients have ranged from .65 to .75 over a 2-month interval (Spielberger et al., 1983). Extensive construct and content validity testing was conducted by the developers of the scale (Spielberger, 1983). Participants completed the scale on two occasions: (1) after the colour naming

Stroop task and (2) immediately following the transfer test (while under stress). The purpose of the anxiety measure was to assess whether the stress manipulation used in the transfer test was effective.

Acquisition phase. The acquisition phase consisted of three blocks of 50 putting trials performed from three distances (150 trials in total). The two learning groups (errorless and errorful) performed the trials from different distances. The errorless group performed the blocks from 25 cm, 50 cm, and 75 cm from the centre of the hole, while the errorful performed from 175 cm, 150 cm, and 125 cm. Putting accuracy was measured by a target grid which was drawn on the putting surface surrounding the hole. The target consisted of five concentric circles, with each radius increasing in a 15 cm increment from the edge of the hole. Scores ranged from '5' (in the hole) to '0' (outside the target grid).

Test phase. The test phase included three blocks of 10 putting trials (retention-transfer-retention) from a distance of 100 cm. During the retention tests, participants were simply instructed to putt as many balls as possible. During the transfer test, a stress manipulation was introduced by instructing participants as follows, "For the next part of the experiment, you will be expected to adhere to the following rules: (1) you must hole 10 putts in a row; (2) if you miss a putt, keep going until you do hole 10 in a row; and (3) once the test is complete, if you have missed any shots at all (i.e., you didn't get 10 in a row on the first attempt), then you will be asked to start the whole session again from the beginning." After each participant had completed 10 trials, regardless of how many balls they had successfully putted, they were asked to stop and complete the Movement Stroop task. Once they had completed the Stroop task, all participants were informed that they were not required to perform any more putts. Participants were debriefed at the end of the session. They were provided with a full explanation as to the rationale behind the stress condition and given the opportunity to ask questions.

As indicated in previous studies of errorless learning (e.g., Maxwell et al., 2000), it is usual within motor learning research to use a pre-test of ability to confirm that the experimental groups are matched. In errorless learning studies, it is not possible to use this procedure for three reasons: (1) the groups typically begin from different distances making their initial learning period non-comparable, (2) asking all participants to perform a pre-test from the distance at which the errorless group begins (in this case 25 cm from the hole) would result in a ceiling effect, and (3) asking all participants to perform a pre-test from the distance at which the errorful group begins (in this case from 175 cm) would introduce errors for the errorless participants, contradicting the aim of the experiment. Therefore, in line with previous studies, it was assumed that all groups were matched in ability due to the random allocation procedure.

Movement Stroop task. The movement Stroop task was administered on two occasions: (1) immediately following acquisition, and (2) immediately following the transfer test (while under stress). There were two versions of the movement Stroop task (see Tables 7.1 and 7.2). The test versions were counterbalanced across participants. Each test version consisted of 16 words. Eight words were related to golf putting (“movement words”) and eight were neutral (“control”) words.

Table 7.1

Stimulus Words Included in Version 1 of the Movement Stroop Task with Information about Word Length ("Length"), Frequency of Use in the English Language ("Frequency"), and Orthographic Neighbourhood Size ("Ortho. Size")

Movement Words				Matched Neutral Words			
Word	Length	Frequency	Ortho. Size	Word	Length	Frequency	Ortho. Size
Firm	4	34,530	4	town	4	51,299	4
Hips	4	6,726	7	cite	4	6,151	7
Bend	4	6,891	12	rats	4	7,486	12
hands	5	58,004	5	flame	5	34,637	5
swing	5	7,716	6	couch	5	4,971	6
wrists	6	2,255	0	orchid	6	2,383	0
stance	6	4,292	2	phones	6	4,292	2
alignment	9	4,132	0	buildings	9	6,984	0
Mean =	*5.4*	*15,568*	*4.5*	*Mean =*	*5.4*	*14,775*	*4.5*

Table 7.2

Stimulus Words Included in Version 2 of the Movement Stroop Task with Information about Word Length ("Length"), Frequency of Use in the English Language ("Frequency"), and Orthographic Neighbourhood Size ("Ortho. Size")

Movement Words				Matched Neutral Words			
Word	Length	Frequency	Ortho. Size	Word	Length	Frequency	Ortho. Size
Grip	4	7,900	6	soap	4	7,900	6
Feet	4	40,143	8	ship	4	51,299	8
Knees	5	9,040	1	juice	5	7, 653	1
Tense	5	2,805	4	waits	5	2,724	4
elbows	6	1,652	0	blouse	6	1,685	0
smooth	6	13,504	1	campus	6	13,903	1
posture	7	1,909	1	robbers	7	1,907	1
shoulders	9	7,751	0	migration	9	3,706	0
Mean =	*5.8*	*10,588*	*2.6*	*Mean =*	*5.8*	*11,876*	*2.6*

Each movement word was matched with its control word on three characteristics: (1) word length (number of letters), (2) frequency of use in the English language, and (3) orthographic neighbourhood size. It is important to match the word length characteristics of the movement and control words because if, for example, the movement words were longer than the control words, then any increase in reaction time to these words might be due to additional visual processing time caused by more complex words, rather than because of the meaningfulness of the words to participants. Likewise, frequency of use is an important feature to control because infrequently used words take longer to recognise than frequently used words (Larsen, Mercer, & Balota, 2006). The Hyperspace Analogue to Language (HAL) frequency norms provided by Lund and Burgess (1996) were used, which are based on approximately 131 million words gathered across 3,000 Usenet newsgroups in February 1995 (see Larsen et al., for more information). Finally, orthographic neighbourhood size is an important lexical feature to control because it also relates to word recognition speed (Larsen et al.). This feature refers to the number of words in the English language into which a single word can be transformed by changing one letter (while preserving the identity and position of the other letters). Previous research has shown that words that have larger orthographic neighbourhoods tend to be associated with faster processing speed [16] (see Forster & Shen, 1996; Huntsman & Lima, 2002; Sears, Lupker, & Hino, 1999).

An interference index was calculated by computing the movement word minus its matched control word. A positive index indicates that naming the colour of the

[16] This result is somewhat surprising – one might think that increased similarity to other words should slow reaction times. Several explanations for the source of the facilitation have been proposed, however, including: (1) the activation model (McClelland & Rumelhart, 1981), (2) the multiple read-out model (Grainger & Jacobs, 1996), and (3) the rime model (Ziegler & Perry, 1998). See Lavidor, Johnston, & Snowling (2006) for a review of these explanations.

movement word was slower than naming the colour of the neutral word. A negative index indicates that naming the colour of the movement word was faster than naming the colour of the neutral word.

Verbal reports. At the end of the experiment, all participants were asked to report the verbal rules used to perform the putting task, by answering the following question, "Please write down in as much detail as possible, any movements, methods or techniques you remembered using when practicing the golf putting task". Verbal reports were scored by two independent raters, who then compared scores until a consensus was reached. The raters were blind to the experimental conditions under which each participant performed. The raters determined whether statements in verbal reports were related to movement (mechanical rule) or the testing of a hypothesis (hypotheses). The number of mechanical rules reported (e.g., "I gripped the putter with my right hand on top") and the number of hypotheses tested (e.g., "I adjusted my stance when the ball went too far to the left") were then summed. Any statements that were irrelevant to the technical demands of the task (e.g., "I enjoyed the session") were classified as irrelevant. A minimal number of hypotheses were reported by each group (both means < 0.6). For that reason, the number of mechanical rules and hypotheses reported were combined and an analysis was performed on total amount of task relevant knowledge.

Results

Simple Colour Naming Task

An independent samples *t*-test confirmed that there was no difference in response latency between the errorless (*m* = 892.07 ms; *SD* = 145.65 ms) and errorful (*m* = 872.40 ms; *SD* = 207.90 ms) groups ($t(26) = -.29$, $p = .772$) on the simple colour naming task.

Colour Naming Stroop Task

Table 7.3 displays the response latency (in ms) for the errorless and errorful groups in the colour naming Stroop task. A 2 (Group) x 2 (Word Type: Congruent/Incongruent) ANOVA with repeated measures revealed no significant main effect for group ($F(1, 26) = 1.28$, $p = .269$, *partial* $\eta^2 = .047$). There was a significant main effect for word type ($F(1, 26) = 40.67$, $p < .001$, *partial* $\eta^2 = .610$), such that participants responded significantly more slowly to words displayed in an incongruent text compared to a congruent text. Finally, a significant interaction was not present ($F(1, 26) = .00$, $p = .972$, *partial* $\eta^2 = .000$).

Table 7.3

Response Latency (in ms) for the Colour Naming Stroop Task

Group		Congruent Words	Incongruent Words
Errorless	Mean	856	974
	(SD)	*(223.81)*	*(281.11)*
Errorful	Mean	778	898
	(SD)	*(89.49)*	*(107.21)*

State-Trait Anxiety Inventory

Table 7.4 displays participants’ scores on the state anxiety scale at Time 1 (following the acquisition phase) and Time 2 (while under the influence of the stress manipulation). A 2 (Group) x 2 (Time) ANOVA with repeated measures revealed no significant main effect for group ($F(1, 26) = .64$, $p = .432$, *partial* $\eta^2 = .024$). There was a significant main effect for time ($F(1, 26) = 14.71$, $p = .001$, *partial* $\eta^2 = .361$), with participants reporting higher levels of state anxiety at Time 2 when they were under the influence of the stress manipulation. Finally, there was no significant interaction effect ($F(1, 26) = 2.33$, $p = .139$, *partial* $\eta^2 = .082$).

Table 7.4

Participants' Scores on the State Anxiety Scale at Time 1 (Following the Acquisition Phase) and Time 2 (While Under the Influence of the Stress Manipulation)

Group		Time 1 (Following Acquisition)	Time 2 (Under Stress)
Errorless	Mean	36.38	39.76
	(SD)	*(8.54)*	*(10.75)*
Errorful	Mean	36.68	44.46
	(SD)	*(6.07)*	*(10.09)*

Acquisition Putting Accuracy

Figure 7.2 displays participants' putting accuracy during the acquisition phase. The learning trials were broken down into blocks of 10 trials with the aim of observing a learning curve. A 2 (Group) x 15 (Acquisition Block) ANOVA with repeated measures revealed that there was a main effect for group ($F(1, 26) = 64.90$, $p < .001$, *partial* $\eta^2 = .714$). There was also a significant main effect of acquisition block ($F(14, 36) = 5.55$, $p < .001$, *partial* $\eta^2 = .176$) and a significant interaction effect

($F(14, 364) = 10.08$, $p < .001$, p*artial* $\eta^2 = .279$). Post-hoc analysis using paired-samples *t*-tests with Bonferroni adjustments showed that performance was significantly higher in the errorless condition than the errorful condition throughout learning, with the exception of Acquisition Block 13. As shown in Figure 7.2, the interaction between Group and Acquisition Block is explained by a significant increase in accuracy in the errorful condition during the acquisition period ($p < .001$), in the face of no significant change in performance in the errorless condition ($p = .771$). This finding can be explained by the requirement that the errorless group was required to putt from 25 cm, 50 cm, and 75 cm, whereas the errorful group were required to putt first from 175 cm, 150 cm, and 125 cm.

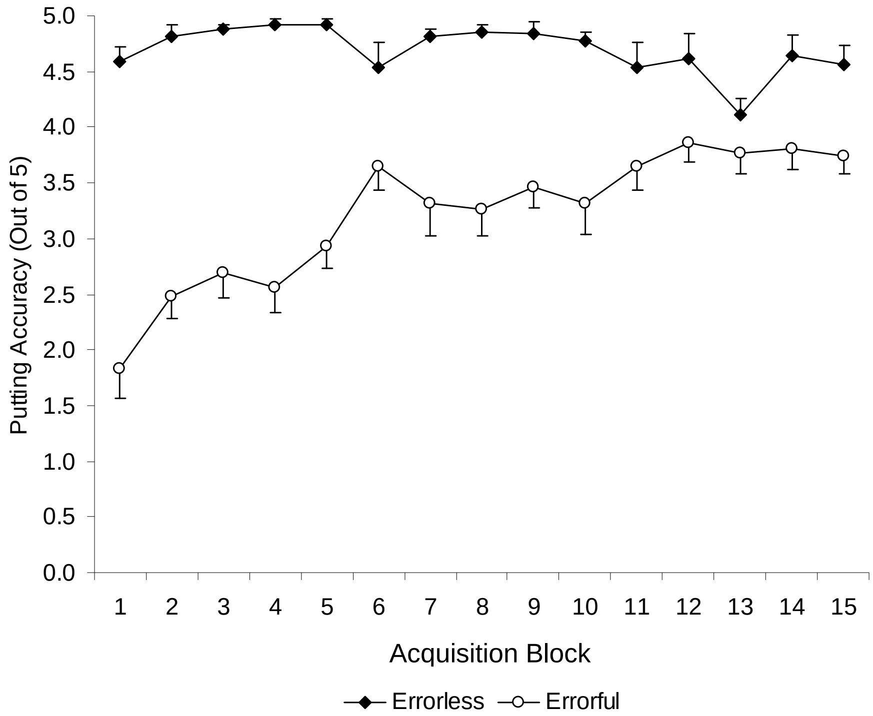

Figure 7.2. Participants' putting accuracy during the acquisition phase, with standard error bars.

Test Phase Putting Accuracy

Figure 7.3 displays participants' putting performance on the two retention tests and the transfer test. A 2 (Group) x 3 (Test) ANOVA with repeated measures revealed no significant main effect for group ($F(1, 26) = 2.18$, $p = .152$, *partial* $\eta^2 = .077$) or for test ($F(2, 52) = 1.75$, $p = .184$, *partial* $\eta^2 = .063$). There were also no significant interaction effect ($F(2, 52) = 0.56$, $p = .946$, *partial* $\eta^2 = .002$).

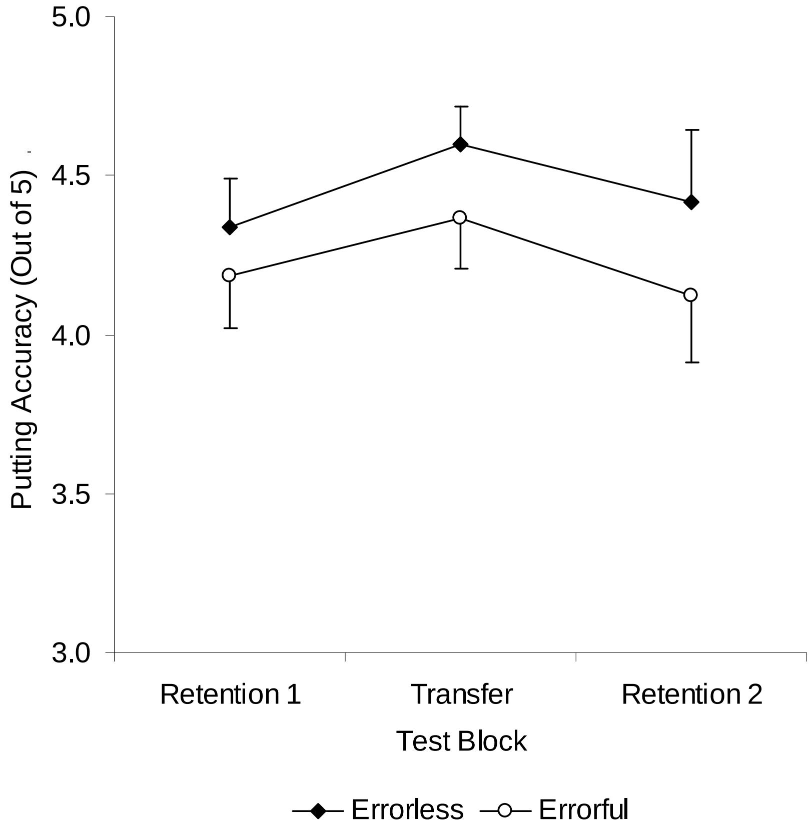

Figure 7.3. Participants' performance on the two retention tests and the transfer test, with standard error bars.

Movement Stroop Task

Table 7.5 shows the interferences indices (in ms) for the Movement Stroop task. A 2 (Group) x 2 (Time) ANOVA with repeated measures revealed no significant main effect for group (F(1, 26) = 2.14, p = .155, *partial* η^2 = .076) or for time (F(1, 26) = .01, p = .930, *partial* η^2 = .000). There were also no significant interaction effect (F(1, 26) = .55, p = .467, *partial* η^2 = .021).

Verbal Reports

The errorless group reported a mean of 3.30 (*SD* = 1.25) rules and hypotheses, whereas for the errorful group, the mean number of rules and hypotheses was 4.00 (*SD* = 1.71). An independent samples *t*-test revealed no significant difference in the number of rules/hypotheses reported (t(25) = 1.19, p = .244).

Table 7.5

Interferences Indices (in ms) for the Movement Stroop Task

Group		Time 1 (Following Acquisition)	Time 2 (Following Stress)
Errorless	Mean	22.77 ms	0.15 ms
	(SD)	*(108.06 ms)*	*(54.82 ms)*
Errorful	Mean	-28.46 ms	-10.67 ms
	(SD)	*(105.06 ms)*	*(84.66 ms)*

Note. A positive index indicates that naming the colour of the movement word was slower than naming the colour of the neutral word. A negative index indicates that naming the colour of the movement word was faster than naming the colour of the neutral word.

Discussion

The purpose of this experiment was to investigate whether a modified Stroop task could be used to differentiate implicit (errorless) and explicit (errorful) learners. Specifically, the experiment investigated whether errorful learners would respond more slowly to task-related words following acquisition than errorless learners, because of greater explicit processing and rehearsal of rules and hypotheses related information and words during errorful learning. Overall, the results did not differentiate between the two learning groups using the modified Stroop task.

The findings of this experiment generally are not consistent with previous research (e.g., Capio et al., 2010; Maxwell et al., 2001; Poolton et al., 2005), which has shown that relative to errorful practice, errorless practice enhances performance during retention. There were no observable differences between errorless and errorful learners on either of the two retention tests that were implemented. In addition, there were no between-group differences under stressful transfer conditions, although the data were in the expected direction. One possible reason for the lack of between-group findings was the relatively short acquisition period included in the current experiment (150 trials for each group incorporating three blocks of 50 trials from different distances). In a previous golf putting study showing the implicit benefits of errorless learning (Maxwell et al., 2001), the acquisition phase consisted of 400 trials (errorless learners progressed through eight blocks of 50 trials increasing from 25 cm to 200 cm, whereas errorful progressed through the same number of blocks of trials, but decreased from 200 cm to 25 cm). It is possible that the relatively short acquisition period was not of an adequate duration to observe differences in the way learners processed information during practice.

It is important to note that researchers have shown that a short period of errorless learning (of a golf putting task) can result in implicit learning outcomes despite subsequent explicit learning. Specifically, the provision of explicit instructions following 200 trials of errorless learning did not impede the beneficial performance characteristics of implicit learning (Poolton et al., 2005). What is not clear from previous research, however, is whether a short period of errorful learning results in observable differences in conscious processing compared to errorless learning. According to the data presented by Poolton et al., 200 trials of errorless learning were sufficient to observe implicit benefits. However, the data does not show whether a comparatively short period of errorful learning would be sufficient to observe the pitfalls of explicit learning. Perhaps in the current experiment, participants in the errorful learning condition did not have sufficient time to acquire task-relevant declarative knowledge. This proposition is corroborated by the relatively small amount of verbal knowledge reported by participants in the errorful learning condition (and the lack of between-group differences on this measure). This idea is also supported by a skill acquisition model presented by Sun, Merrill, and Peterson (2001) which suggests a bottom-up approach to skill learning in which procedural knowledge is developed first and declarative knowledge accrues only after the skill is at least partially developed.

It seems likely that the relatively short duration of acquisition in the current experiment was not sufficient to produce clear differences in the accumulation of consciously accessible task-relevant knowledge. This made it unlikely that between-group differences in response to the modified Stroop task would be observed. The results support this assertion – the errorless and errorful learners did not differ in their response times to the modified Stroop task. Given that there were no observable differences in the way the errorless and errorful groups processed information during learning, these findings do not lead to rejection of the idea that a modified Stroop task has potential as a measure of implicit and explicit processing. Future research should consider applying the current measure (the modified Stroop task) to cohorts of participants in which the magnitude of difference between the processing modes adopted is larger to see whether the task can be used in the manner suggested in the current experiment. For example, testing expertise differences using task-related words in a modified Stroop task (as done in the next experiment in this chapter – Experiment 2) could be one potential way of investigating the use of the Stroop task in motor learning research.

Researchers considering exploring this methodology should also consider a limitation in the current experiment. All participants in the experiment were students at a university based in Hong Kong and it is therefore reasonable to presume that most participants' native language was not English. The stimulus words for the modified Stroop task were presented in English, which might have influenced the results. If the participants were explicitly rehearsing rules and testing hypotheses during acquisition, it is possible that these rules and hypotheses were verbally encoded in their native language, rather than in English, which would have precluded the expected increase in response latency to task-related words during the modified Stroop task. In future, researchers should carefully consider the stimuli and the language of presentation to overcome this potential limitation.

A further limitation of the current experiment was the selection of stimulus words for the modified Stroop task. Words were selected on the basis that they related to the skill of golf putting (e.g., “posture”, “smooth”, and “grip”) with the expectation that the errorful learners would engage in more explicit processing and rehearsal of these golf putting words. It is possible that the selection of words did not correspond to the actual words that errorful learners verbally rehearsed during learning. The inherent nature of the Stroop task requires the selection of single-word stimuli. It is difficult to select words that are related to the rules underlying the skill of golf putting. Two possible methods of overcoming this limitation are: (1) to use a more systematic approach to the selection of words by, for example, asking an expert coach to be involved in the selection of the stimuli, or (2) to use a series of pictures as the stimuli for the Stroop task (i.e., use a pictorial Stroop task). Pictorial Stroop tasks have previously been used in a similar way to modified lexical Stroop tasks. For example, Constantine, McNally, and Horning (2001) used colour-filtered images of snakes (threat), cows (neutral), and bunnies (positive) on a computer screen to successfully test emotional valence in snake-fearful participants. Intensely snake-fearful individuals showed higher levels of interference for snake pictures compared to the other types of stimuli. The study by Constantine et al. established that a non-lexical version of the Stroop task can be used to evaluate selective processing of emotional cues. This methodology is worth exploring in future research investigating the use of Stroop as a measure of conscious processing of movement-related stimuli.

In summary, this experiment explored the use of a modified Stroop task as a measure of implicit and explicit learning. Two groups of participants (errorless and errorful) practised a golf putting task for 150 trials. Differences in the amount of conscious processing of task-relevant knowledge during learning on the measures of verbal reports, retention, or transfer to stressful conditions were not found. The lack of between-group differences made it unlikely that differences in response latency to the modified Stroop task would be found and the results supported this assertion. In future, researchers should explore the use of the modified Stroop task using a different cohort of participants (such as native English speakers) or different selection of stimuli to examine whether the proposed methodology outlined in the current experiment has merit as a means of differentiating between levels of conscious control of movements.

Experiment 2

In Experiment 1, the aim was to investigate whether a modified Stroop task could be used to differentiate implicit and explicit learners. The experiment employed two groups of participants (errorless and errorful learners). Based on the idea that errorful learners were likely to learn via an explicit mode of control, errorful learners were expected to produce slower response times to task-related words in a modified Stroop task compared to errorless learners. The results did not show differences between the errorless and errorful learners in their response latency to the modified Stroop task. This was most likely because the relatively short acquisition period used in the experiment was not sufficient to produce differences in processing modes amongst the two learning groups. The purpose of Experiment 2 was to explore the suggestion outlined in Experiment 1 that the modified Stroop task could be used as a measure of implicit/explicit processes in a different cohort of performers – in this case, in highly skilled performers. It was hypothesised that swimming related stimuli (words and pictures) would produce slower response times than matched neutral stimuli.

Method

Participants

Twelve highly skilled swimmers from the Australian Institute of Sport (10 female; 2 male) participated in the experiment. All participants were native English speakers. Ages ranged from 17 to 25 years (*m* = 21.00, *SD* = 2.57). Inclusion criteria were based on the official International Point Score (IPS) system employed by the governing body for swimming (Fédération Internationale de Natation Amateur). The mean time of the eight fastest ever swims in each event is given the value of 1000 points. Individual performances are then rated against this reference value allowing for comparison across different events. The IPS calculator is available at http://www.swimnews.com/ipspoints. Participants were required to have a minimum IPS of 870, making them highly skilled. Participants provided informed consent prior to starting the experiment (Appendixes N and O).

Tasks and Procedure

The experiment consisted of four tasks: simple colour naming task, colour naming Stroop task, swimming word Stroop task, and swimming pictorial Stroop task. All tasks were completed on a standard laptop computer and were run using custom designed software (AIS React). Participants were required to respond to the stimuli by verbally reporting their answer. Verbal reaction time (in ms) was recorded with the AIS React software and a wireless lapel-mounted microphone that transmitted to the laptop computer. Response accuracy was manually recorded by the experimenter. For all tasks, the stimulus remained on the screen until the computer registered the participant’s response and a standard black screen of 2 s duration appeared between pairs of consecutive trials.

Simple colour naming task and colour naming Stroop task. The simple colour naming task and colour naming Stroop tasks were identical to those used in Experiment 1, the only difference being that participants were required to respond by verbally articulating the name of the colour as quickly as possible rather than pressing a button to indicate their response.

Swimming word Stroop task. The swimming word Stroop task comprised 54 words (27 words were related to swimming and 27 words were neutral controls). The swimming words were selected via a three step process in an attempt to overcome issues related to selection of stimuli outlined in Experiment 1. First, key words were selected from checklists that were used by the participants during training. The checklists included cue phrases such as “high elbow at commencement of stroke”. The initial list of words was then given to two expert swimming coaches who were asked to rate the words for their relevance to swimming. The 27 most highly rated words were then used in the swimming word Stroop task. Each swimming word was then matched with a control word based on length, frequency of use, and orthographic neighbourhood size (see Experiment 1 for more information regarding these lexical characteristics). The final list comprised a larger selection of words than was used in Experiment 1 in an attempt create a list that better represented the skill. Table 7.6 shows the final list of stimuli used in the swimming word Stroop task.

Swimming pictorial Stroop task. The swimming pictorial Stroop task comprised 38 picture stimuli. Nineteen of the pictures consisted of “technically correct” swimming images. The remaining 19 pictures comprised someone moving in water in a non-swimming position (i.e., not in a position related to one of the four swimming strokes). See Figure 7.4 for examples of swimming and non-swimming stimuli. The pictures were extracted from a video recording that was captured by a waterproof camera that was mounted so that half of the video frame recorded above the waterline and half recorded under the water line. The still images were then colour filtered using Microsoft Publisher (2002) to appear in red, blue, green, or purple.

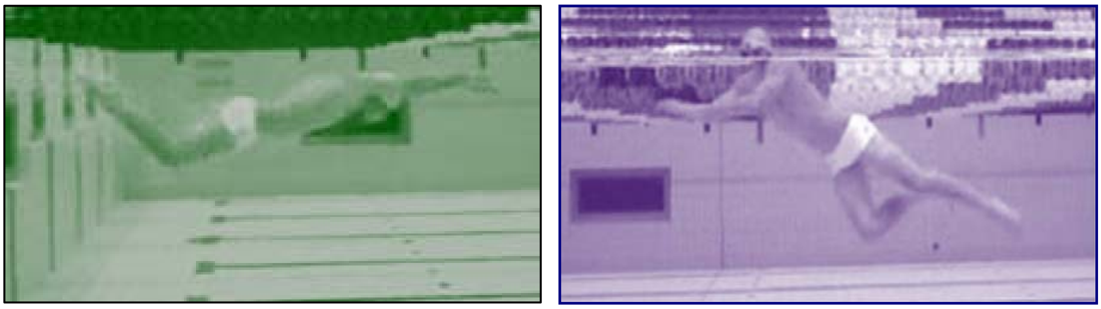

Figure 7.4. Examples of swimming and non-swimming related stimuli.

Note. On the left side is an example of a technically correct swimming picture with a green filter (athlete is pushing off the wall in a streamlined position). On the right side is an example of a non-swimming related picture with a purple filter (athlete is in a non-swimming related position).

Table 7.6

Stimulus Words Included in the Swimming Word Stroop Task with Information about Word Length ("Length"), Frequency of Use in the English Language ("Frequency"), and Orthographic Neighbourhood Size ("Ortho. Size")

Swimming Words				Matched Non-Swimming (Neutral) Words			
Word	Length	Frequency	Ortho. Size	Word	Length	Frequency	Ortho. Size
Abs	3	850	0	emu	3	991	0
elbow	5	3,401	0	vista	5	3,346	0
thumbs	6	1,793	0	suffix	6	1,800	0
finish	6	18,398	0	cities	6	17,909	0
platform	8	24,499	0	archives	8	23,186	0
shoulders	9	7,751	0	translate	9	7,754	0
extension	9	20,176	0	elemental	9	20,217	0
scull	5	81	1	exude	5	86	1
recovery	8	9,992	1	quantity	8	10,343	1
Eyes	4	58,027	2	beta	4	50,393	2
press	5	77,897	2	trade	5	76,384	2
speed	5	91,193	2	major	5	100,373	2
wrist	5	4,355	3	plots	5	4,086	3
strong	6	69,234	3	driver	6	69,007	3
pointed	7	19,379	3	printed	7	20,613	3
body	4	116,235	4	text	4	124,115	4
gluts	5	623	4	fuses	5	619	4
fingers	7	19,103	4	listing	7	22,521	4
Arm	3	20,427	5	nor	3	54,811	5
Palm	4	5,990	5	perm	4	8,527	5
Neck	4	14,841	5	salt	4	15,258	5
hands	5	58,004	5	basis	5	48,314	5
catch	5	22,587	6	bunch	5	30,310	6
Hips	4	6,726	7	raid	4	6,762	7
Long	4	273,917	7	give	4	230,878	7
Feet	4	40,143	8	chip	4	35,544	8
power	5	187,656	9	score	5	23,264	9
faster	6	49,451	9	paying	6	26,011	9
Kick	4	19,877	10	dust	4	18,645	10
Flat	4	26,256	11	lets	4	23,648	11
Head	4	109,089	13	mark	4	103,559	13
Pull	4	28,190	13	bell	4	24,815	13
Mean =	*5.22*	*43,941*	*4.4*	*Mean =*	*5.22*	*37,627*	*4.4*

Results

Colour Naming Stroop Task

Table 7.7 displays the response latency (in ms) to the colour naming Stroop task. A paired-samples *t*-test revealed that there were no significant differences in response times to the incongruent compared to the congruent words ($t(11) = .46$, $p = .657$).

Table 7.7

Response Latency (in ms) for the Colour Naming Stroop Task

	Congruent Words	Incongruent Words
Mean	670 ms	773 ms
(SD)	*(57 ms)*	*(40 ms)*

Swimming Word Stroop Task

Table 7.8 displays the response latency (in ms) to the swimming word Stroop task. A paired-samples *t*-test revealed that there were no significant differences in response times to the swimming compared to the matched neutral words ($t(11) = -1.88$, $p = .087$).

Table 7.8

Response Latency (in ms) for the Swimming Word Stroop Task

	Swimming Words	Matched Neutral Words
Mean	674 ms	690 ms
(SD)	*(57.01)*	*(61.31)*

Swimming Pictorial Stroop Task

Table 7.9 displays the response latency (in ms) to the swimming pictorial Stroop task. A paired-samples *t*-test revealed that there were no significant differences in response times to the swimming pictures compared to the matched non-swimming (neutral) pictures ($t(11) = -1.29$, $p = .224$).

Table 7.9

Response Latency (in ms) for the Swimming Pictorial Stroop Task

	Swimming Pictures	Non-Swimming (Neutral) Pictures
Mean	624 ms	635 ms
(SD)	*(64.78)*	*(64.73)*

Discussion

The aim of this experiment was to apply two versions of a modified Stroop task to assess explicit knowledge in a cohort of expert swimmers. It was hypothesised that swimming related stimuli (words and pictures) would produce slower response times than matched neutral stimuli if the swimmers had developed cognitive expertise for those words during skill acquisition. There were no significant differences in the response times of participants to swimming and non-swimming related stimuli, which contradicted the hypothesis.

The hypothesis was based on the assertion that the experts would have developed cognitive expertise for swimming-related stimuli over the course of skill development. This contention is supported by the coaching methods adopted in the sport of swimming, which typically involves a large amount of explicit instruction and feedback. Furthermore, the words selected as stimuli were taken from skill checklists that were used by the swimmers during training at the time of the experiment. In retrospect, it is perhaps not surprising that slower response times to task-related stimuli in the skilled swimmers were not found. According to motor learning theory, expert performers rely on automatic control which is subserved by procedural knowledge (see Chapter 2). Automatically controlled skills are performed with almost no access to declarative knowledge and are often controlled without concurrent conscious awareness of the specific information underlying movement production (e.g., Anderson, 1982; Fitts & Posner, 1973; Kahneman & Treisman, 1984; Shiffrin & Schneider, 1977).

Given that the participants in the current experiment were highly skilled, it is possible that the knowledge that the modified Stroop task tried to assess had become automated and hence did not produce the interference effect that was predicted. This is likely despite the explicit coaching methods to which participants were commonly exposed. The suggestion that the lack of significant differences in response latency to task-related stimuli in highly skilled swimmers is due to the inherent characteristics of their knowledge structures highlights the possibility that the modified Stroop task might be more successfully applied to a different cohort of participants. Specifically, special groups of participants who have a particular tendency to consciously focus on the movement information underlying the skill they are practising are perhaps more likely to exhibit an increase in response latency to task-related stimuli than the participants included in the current experiment.

A potential limitation in the current experiment is that a control group of novice performers was not included. A repeated measures design was used in which the skilled swimmers were tested on task-related stimuli and neutral stimuli as a means of measuring whether they were involuntarily drawn to the task-related information. It is possible that a control group of novice swimmers who were in the early stages of skill acquisition might have exhibited the interference effect that was predicted in highly skilled swimmers. In Australia, the cultural characteristics of the society dictate that the vast majority of adults are able to swim at a reasonable level. The most likely source of novice swimmers is young children who are involved in learn-to-swim programs; however, to include these participants as a control group would introduce an obvious confound with reference to the age of participants. In future, researchers interested in further investigating the suggestion outlined in this experiment should consider a between-group design comparing participants on a skill for which there is access to expert and novice participants who can be matched on demographic characteristics such as age.

In summary, the current experiment aimed to investigate the use of two versions of a modified Stroop task (incorporating word and picture stimuli) to measure cognitive expertise in highly skilled swimmers. The results showed that there were no significant differences in response times to swimming and non-swimming stimuli among the highly-skilled swimmers, perhaps because the swimmers had developed automatic control processes for task-related information.

GENERAL DISCUSSION OF STROOP EXPERIMENTS

The evidence accumulated from the two experiments presented in this chapter highlights the importance of participant selection in research using modified Stroop tasks. In Experiment 1, the aim was to use the modified Stroop task to compare the cognitive expertise of task-related information in implicit (errorless) and explicit (errorful) learners. It was predicted that errorful learners would have engaged in more explicit processing during learning – focusing heavily on task-specific information – that would manifest as slower response times to task-specific stimuli in the modified Stroop task. In Experiment 2, the aim was to use the modified Stroop task within a cohort of highly skilled swimmers, hypothesising that cognitive expertise for task-related information developed over a long period of skill acquisition would manifest as slower response times to task-specific stimuli in that population. In both cases, no significant differences were found in the direction that was hypothesised. The main reason seems to be that, despite the predictions, these particular participants did not exhibit more explicit processing (they did not consciously focus on task-specific information) and hence the stimuli were not especially meaningful to them. In the case of the errorful learners, it was suggested that this was due to the short acquisition period being insufficient to produce accrual of more explicit knowledge than the implicit learners. In the case of the highly skilled swimmers, it was suggested that this was due to an automation of their task-related information that is likely to have occurred over the long course of skill acquisition. Two cohorts of participants that offer potential in further exploring the modified Stroop task in the methodology suggested here, due to their tendency to consciously focus on their movements and hence their likely higher cognitive effort for task-related information, are: (1) people who suffer from the “yips” and (2) people who have a high trait tendency for “reinvestment”.

The yips is a psycho-neuromuscular disorder that affects individuals who perform finely controlled motor skills (e.g., golf putting). The yips present as involuntary movements that occur throughout the execution of a skill (e.g., jerks, tremors, or freezing). Previous research has concluded that the yips can emanate from either a neuromuscular or psychological foundation. Stinear, Coxon, Fleming, Lim, Prapavessis, and Byblow (2006), for example, suggested that Type 1 yips are cause by impairments of initiation and execution of movements, whereas, Type 2 yips are caused by performance anxiety. Other researchers (e.g., Smith, Malo, Laskowski, Sabick, Cooney III, Finnie et al., 2000) consider the aetiology of the yips as a continuum from choking (underpinned by anxiety) to dystonia (a movement related disorder). Only a small body of academic literature exists that specifically investigates the yips phenomenon, but the literature that does exist seems to suggest that movement disorders such as those observed in the yips have a partly psychological foundation (underpinned by anxiety) or at least are exacerbated by anxiety.

The modified Stroop task that has been detailed in the experiments outlined in this chapter provides a possible measure of the cognitive bias that is likely to be associated with psychologically founded yips-sufferers. The attention of anxious participants in Stroop studies is involuntarily drawn to threatening stimuli and such stimuli are processed with high selectivity and priority (Kolassa, Musial, Mohr, Trippe, & Miltner, 2005). If a word or picture stimulus in the Stroop test evokes anxiety in a participant, this will manifest in a delay in response latency. It is likely that task-related stimuli presented in the form of a modified Stroop task would offer a potential measure of selective processing in yips participants due to the increased anxiety directed towards task-related information amongst this population. This suggestion is further supported by the consideration that yips participants are likely to more closely relate to the participants in previous studies of emotional Stroop than the errorful learners used in Experiment 1 or the highly skilled swimmers used in Experiment 2. Previously studied populations in emotional Stroop studies include sufferers of disorders such as phobias (e.g., Kindt & Brosschot, 1997), eating disorders (e.g., Cooper, Anatasiades, *&* Fairburn, 1992; Stormack & Torkildsen, 2004); persecutory delusions (e.g., Bentall & Kaney, 1989), and alcohol abuse (e.g., Johnsen, Laberg, Cox, Vaksdal, & Hugdahl, 1994) which are all characterised by psychopathology related to anxiety. It is likely that the results found in previous studies would also transpire in those who suffer from the yips. One challenge in conducting research in this field is to obtain access to a sample of yips-sufferers that is large and homogenous enough for experimental studies. Researchers who have access to such a population should consider following up on the suggestion outlined here.

The proposition that a population of yips sufferers is likely to produce findings consistent with previous emotional Stroop studies is also true of people who suffer from high levels of movement specific reinvestment. As outlined in Chapter 2, reinvestment refers to a trait tendency to introduce conscious control of movements by focusing on particular task components (Masters, 1992; Masters et al., 1993; Masters & Maxwell, 2008). People who suffer from high trait levels of reinvestment are more likely to produce suboptimal movement solutions in situations where they experience anxiety (such as competition) due to their tendency to inwardly focus on task-related information. It follows logically then that the emotional Stroop tasks used in the studies outlined in this chapter are likely to offer a potential measure of this tendency to focus on task-related information. The suggestions to investigate sufferers of the yips and people with high reinvestment within the emotional Stroop methodology offer a potentially interesting line of research which has not previously been investigated in the motor learning domain. It is, however, outside the scope of the current thesis, which is specifically focused on the concept of cognitive effort in motor skill learning.

In conclusion, the two studies reported in this chapter outline a potential application for the modified Stroop task to the motor learning domain. Neither experiment successfully differentiated between processing modes using the methodology adopted here. However, the findings lay the foundation for a number of possible avenues for future research such as the investigation of Stroop as a measure of meaningfulness of task-related stimuli in people who suffer from the yips or high trait reinvestment. At a practical level, the Stroop measurement technique has the potential to be used to assess differences in task-related processing among various populations such as experts and novices or yips suffers and those without a movement disorder.

CHAPTER 8

GENERAL DISCUSSION

The general aim of this dissertation was to explore the paradoxical accounts of contextual interference and implicit motor learning from the perspective of cognitive effort. A second general aim was to provide practical recommendations based on the current research findings and existing literature. The following paragraphs summarise the conclusions that have become apparent through this thesis.

The study detailed in Chapter 3 investigated whether implicit motor learning is beneficial to performers who already possess explicit knowledge. Two expert netball players undertook a training intervention in which they practised shooting to an adapted ring while performing a secondary task (responding to high and low pitched tones that had been digitally overlayed onto music). Pre and post-testing of shooting performance revealed a change in the maximum ball height following the intervention (albeit an unintended change). The players showed no increase in verbal knowledge, remained robust under secondary task load, and were unable to differentiate between pre- and post-test video footage of them shooting. These results demonstrate that players were unaware of the knowledge underlying their technique adaptations and provide preliminary evidence for the use of implicit motor learning in high performance sport.

The study in Chapter 4 applied a number of measures typically employed in studies of implicit motor learning to assess cognitive effort in blocked and random practice. Measures of cognitive effort included: primary task performance in acquisition and retention, probe reaction time, and self-report ratings of cognitive effort. Measures of implicit and explicit learning included: secondary task transfer and self-report verbal protocols. The results lead to a potentially new explanation for the contextual interference effect that has not previously been suggested in the literature – the implicit learning hypothesis. The hypothesis is that the benefits of random practice are based on the same principles as implicit learning. Random learners experience high levels of cognitive effort due to task switching and might therefore not have the processing capacity available to consciously focus on their movements during learning.

Chapter 5 reported on a study that further explored the implicit learning hypothesis for random practice by testing the effect of preventing explicit processing during random practice. Three groups practised serving forehand and backhand in table tennis: blocked, random, and random + secondary task. Retention, secondary task transfer, and verbal report tests were conducted following a one-day rest. Contrary to the traditional contextual interference effect, there were no significant differences between the groups during acquisition or at retention. The results did, however, indicate that the random groups learned more implicitly than the blocked group, reporting fewer rules and performing better on the transfer test. The findings provide further support for the implicit learning hypothesis for random practice.

Chapters 6 and 7 reported on studies which investigated alternative measures of cognitive effort and implicit/explicit processing. Firstly, the Chapter 6 study provided a post hoc analysis of data collected in Chapter 4 to investigate a potential measure of cognitive effort. The study assessed the time taken to prepare and execute skill trials among blocked and random learners. No differences were observed between the learning groups; however the chapter provided discussion regarding the time course of events that occurs during the inter-trial interval of blocked and random practice. The discussion drew links with a separate body of literature – task-switching – and provided additional detail regarding the processes that might be involved in the implicit learning hypothesis for random practice (which will be discussed in more detail in Theoretical Implications later in this chapter).

In Chapter 7, the use of a modified Stroop task as an alternative measure of implicit/explicit processing was examined. Experiment 1 investigated whether task related words would be more meaningful to errorful learners compared to errorless learners due to additional rehearsal of rules during learning. It was hypothesised that, for errorful learners, task related words would cause interference in the Stroop task which would materialise in slower response times. In Experiment 2, it was hypothesised that swimming-related stimuli would produce slower response times than control stimuli due to the cognitive expertise developed by the highly skilled swimmers over the course of skill acquisition. Neither Experiment 1 nor 2 successfully differentiated between processing modes. The findings did, however lay the foundation for future research.

Theoretical Implications

As stated previously, the overall aim of this thesis was to explore contextual interference and implicit motor learning in terms of the paradoxical role of cognitive effort. The studies presented in Chapters 4 and 5 provide the most relevant progress in this regard. As detailed in the literature review (see Chapter 2), much research interest has been directed towards the theoretical account for the interference effect observed between blocked and random learners. The two most prevalent theories are elaboration and reconstruction, which both contend that cognitive effort underlies the retention benefits of random practice. The studies presented in Chapters 4 and 5 offer an alternative, previously unexplored, account for the contextual interference effect – one that potentially explains the paradoxical findings between contextual interference and implicit learning – the implicit learning hypothesis. An example of how this hypothesis would emerge during random practice is as follows. As a random learner switches between different tasks, they must process information related to satisfying the task requirements. Depending on the skills they are practicing, their thoughts might include something similar to, "my next task goal is to hit the ball towards this other target, by getting the ball to connect with my foot/hand". The random learner is therefore engaged with thinking about the task switch, which is likely to prevent them from explicitly learning. Due to the demanding cognitive operations used to control task switching, random learners are unlikely to: (1) remember their performance on the previous trial of that skill, (2) test movement-related hypotheses about how to achieve the task goal more effectively, or (3) form conscious mechanical rules to support motor output. Hence, the available attention of random learners might be taken up with information related to the act of switching between two (or more) different skills preventing them from explicitly thinking about the rules underlying their movements. The studies reported in Chapters 4 and 5 provide research evidence to support this previously unexplored proposition of contextual interference, but equally highlight the need for further empirical verification.

The study presented in Chapter 6 added further detail to this theoretical account for random practice. Specifically, in Chapter 6, the time course of events that occurs during the inter-trial interval of blocked and random practice was contemplated. The study discussed the benefit of considering endogenous and exogenous processes. Endogenous processes involve retrieval or reinstatement of a participant's task-set and shifting their goal, whereas exogenous processes involve the activation of rules. From a theoretical standpoint, Chapter 6 suggested that according to the implicit learning hypothesis, random learners only engage in endogenous processes, whereas blocked learners are not required to retrieve or reinstate the task-set or shift their goal and are able to activate the rules regarding the upcoming trial in working memory. This suggestion contradicts Shea and Zimny's (1983) elaboration hypothesis because it does not allow for learners to make comparisons between the movements they are practicing. The implicit learning hypothesis is more similar to Lee and Magill's (1985) reconstruction hypothesis insofar as it suggests that skill switching prevents learners from thinking about the solution they used on a previous attempt of that skill (i.e., forgetting). Where the new theoretical proposition differs from the reconstruction hypothesis is that it does not propose an active reconstruction of the movement solution, but instead it suggests that learners adopt a more passive mode of control and hence learn implicitly.

Practical Implications

One of the general aims of this thesis was to provide recommendations for practitioners in the field. The application of research to practice is an important component of the development of sports coaches. A key challenge that must be overcome, however, is that the research needs of coaches and scientists differ. With reference to coaches, the primary concern is with sports performance – scientific knowledge is seen as valuable only if it applies to the daily activities of a coach. In contrast, researchers studying the acquisition of sport skills serve two agendas – one is to unearth principles that enhance performance amongst athletes who share a common set of characteristics (this is the case for sports science researchers who work in the applied field) and the other is to increase the scientific body of knowledge by developing and testing theories (in the case of university-based researchers) (Williams

& Kendall, 2007). One way of bridging the gap between the scientific and coaching domains is for researchers to explain how their findings can be applied to coaching.

The application of contextual interference and implicit motor learning research has previously been limited by the contradictory conclusions regarding cognitive effort and, in the case of the implicit motor learning literature, by the reliance on novice participants. First, based on existing literature, coaches often question whether it is preferential to promote cognitive effort during learning (by including random practice) or limit the conscious hypothesis testing behaviour of athletes (by including, for example, errorless practice). Second, coaches question whether the conclusions of the implicit motor learning literature, which were largely based on novice performers, can be applied to more highly skilled performers. Chapters 4 and 5 provide insight regarding the first question, while Chapter 3 offers potential recommendations regarding the second question.

The Cognitive Effort Paradox

The existing contextual interference literature suggests that the organisation of practice repetitions in a random manner maximises skill learning due to the engagement of cognitively effortful processing when random learners switch between different skills. The implicit learning hypothesis detailed in this thesis supports the contention that relative to blocked practice, random practice results in higher levels of cognitive activity; however, it also contends that random practice may share characteristics with implicit learning that have not previously been identified. The practical implication of this hypothesis is that random practice may serve as a means of bringing about implicit learning. This suggestion has a number of applied benefits. Specifically, if random practice does indeed promote implicit learning, then adopting such a schedule of practice is likely to benefit not only the retention of skills (a finding typically associated with random practice), but also promote other beneficial outcomes associated with implicit motor learning such as reducing susceptibility to pressure and reducing attentional control requirements.

The results of the study in Chapter 4, which supported an implicit basis for the retention of randomly practised skills, were founded on the outcomes of learning a complex motor skill (ARF kicking) whereas a more simple motor skill (ARF handball) did not elicit the same effects. This finding highlights the importance of task difficulty in the application of the contextual interference effect. From a practical perspective, it seems possible that learners must experience a threshold level of interference in order to create the conditions in which working memory in random learners is loaded to a sufficiently high degree to prevent hypothesis testing and rule formation. If a task is too simple, then learners might be availed with a sufficient amount of attention capacity to enable hypothesis testing to occur[17]. Based on the current findings, coaches interested in using random practice to promote implicit learning could consider using complex skills from an early stage of learning, or in the case of simple skills, the level of interference could be enhanced by other means such as by including a complex schedule of task switches incorporating a greater number of skills.

According to the implicit learning hypothesis, it is possible that novice performers might benefit from high interference practice. Specifically, if random practice promotes implicit benefits, then both novice and expert performers would benefit from the reduction in explicit processes. From a practical perspective, coaches would be encouraged to include random schedules within practice as a means of by-

[17] This suggestion contradicts existing research asserting that complex learning environment can be too challenging for novice performers (e.g., Guadagnoli & Lee's, 2004, challenge point framework) – see the following paragraph regarding skill level of the performer for a more detailed discussion.

passing explicit motor learning during early stages of skill development. This suggestion goes against recommendations established in the existing literature and so it should be considered with caution until further scientific data is collected.

Existing research contends that novice performers may only be able to cope with low levels of interference and this would be achieved by engaging the performer in blocked practice that would either: (1) enable them to rely exclusively on within-task processing (according to the elaboration hypothesis), or (2) allow them to hold the movement-plan in working memory for consecutive practice trials (according to the reconstruction hypothesis). According to Bjork's (1994, 1999) perspective of "desirable difficulties", contextual interference can be incorporated into practice as a means of engaging the learner in effortful processing to introduce a desirable level of difficulty. The challenge point hypothesis (Guadagnoli & Lee, 2004) further developed this concept by proposing that novices are likely to benefit more from low contextual interference, whereas skilful performers are likely to benefit more from higher contextual interference. The possible advantage of this approach is that early repeated experiences provide opportunities for error correction – a suggestion that is consistent with the learning stage model presented by Gentile (1972), which states that performers need an opportunity to get an idea of the movement early in learning before more complexity is added to the practice environment (Porter & Magill, 2010). The manipulation of practice schedules was also recently explored by Choi, Qi, Gordon, and Schweighofer (2008) who suggested advantages in using a computer controlled adaptive scheduling based on immediate and delayed retention performance as a means of scheduling practice. The algorithms presented might provide a potential means of accounting for the effects of learning over an extended period of time. If the implicit learning hypothesis for random practice is supported by further evidence, then it will be valuable to consider the effects of random practice over longer periods of learning (taking into account, for example, the psychological factors that might accompany such an approach).

A further consideration in applying random practice according to the findings of this thesis is whether or not a performer is prone to reinvestment (Masters et al., 1993). Reinvestment tends to occur in situations where people are highly motivated to make successful movements. Such scenarios include when an athlete is recovering from a serious injury or performing in an important game. According to the findings of this thesis, random practice is likely to be beneficial to performers who are prone to reinvestment due to the implicit benefits that have been suggested. Coaches could be encouraged to use random practice in these situations as a means of switching the cognitive control mechanisms of performers from conscious to more automatic.

A caveat to these applied recommendations is that the increase in interference is likely to be accompanied by an increase in errors[18] (particularly in novice performers), which, over time, might influence the level of confidence experienced. Hence a key consideration that might reasonably direct the practical recommendations for random practice centres on whether or not there is a need to improve confidence. For instance, after a period of practice (either within a single session or across a number of sessions) re/establishing a learner’s confidence may take priority to ensure the motivation to learn remains intact or is sufficiently challenged. Similarly, in the case of a skilled performer who is currently experiencing a performance slump, the need to utilise a different practice method may be most practical. For instance, coaches could reasonably be encouraged to reduce the interference experienced by the

[18] The data presented in Chapters 4 and 5 did not reveal significant differences in error rates between blocked and random learners during the acquisition phases, however higher levels of interference are typically associated with higher error rates (in line with the typical contextual interference effect).

performers during these specific scenarios and/or consider introducing implicit learning via an errorless learning model. These real-world issues again highlight one of the challenges of skill development and the need to be able to blend science and coaching. Table 8.1 presents a summary of the practical recommendations for random practice based on the implicit learning hypothesis.

Table 8.1.

Summary of Practical Recommendations for Constructing Practice Based on the Implicit Learning Hypothesis for Random Practice

Feature	Recommended Practice Schedule	
	Blocked	Random
Novice skill level [19]	No	Yes
Expert skill level [18]	No	Yes
Practice objective is to learn [20]	No	Yes
Session is during the pre-season [19]	No	Yes
Athlete has a tendency for reinvestment [21]	No	Yes
Athlete is recovering from an injury [20]	No	Yes
Practice objective is to improve confidence [22]	Yes	No
Athlete is experiencing a performance slump [21]	Yes	No
Session is before an important game [21]	Yes	No

[19] Refer to the discussion beginning on page 179 for clarification regarding these recommendations.
[20] Recommendations are based on a learning emphasis.
[21] Based on the implicit benefits of random practice illustrated in this thesis.
[22] Based on improving confidence by reducing errors during practice.

Implicit Motor Learning in Expert Performers

The results presented in Chapter 3 add knowledge regarding the question of applying implicit motor learning to highly skilled performers. A dual-task approach was adopted to prevent athletes having adequate availability of working memory resources to allow for hypothesis testing. Two methodological approaches were employed which addressed the challenges with using such an approach in an applied environment. Firstly, the use of a tone digitally overlaid onto music as the secondary task was amenable to players in the applied environment. Players found that listening to music and responding to the tones was a somewhat enjoyable approach and arguably was received more favorably than if players had been asked to perform one of the traditional secondary tasks, such as counting backwards, generating random letters, or responding to a tone on its own. The fact that players were able to select the music that they listened to added to the positive experience.

The second methodological consideration that made the intervention suitable to an applied environment was that the dual-task approach was coupled with the implementation of a task constraint (in this case, a metal barrier attached to the ring which aimed to impose an advantageous increase in the steepness of the shooting trajectory). The manipulation of a task constraint coupled with a dual-task is a concept that can easily be included into a range of applied settings by coaches. Other examples of task constraints that have previously been suggested include: (1) practicing with blindfolds, (2) using modified equipment, or (3) bending the rules of a game (Davids et al., 2008). Depending on the specific task requirements of a given sport, there are an endless number of task constraints that can be manipulated to bring about a desired outcome. A possible result of such task manipulations is that a change in task constraints might encourage players to consciously search for new movement solutions, which according to the implicit motor learning literature, can result in potential issues, such as movement reinvestment (refer to Masters & Maxwell, 2008). The methodology adopted in Chapter 3 offers a means of overcoming this issue and has the potential to be applied in a range of real-world settings.

From an applied perspective, the study highlighted an additional issue of carefully designing the particular task constraint that is implemented. The practical advice emerging from the study is that coaches should devote time and careful thought to the effects of task constraint manipulations to ensure that the movement solutions that players uncover as a result of practicing in the adapted environment are favourable to the specific needs of the sports skill. This careful consideration might include a period of exploration in which coaches try a range of manipulations and observe how players respond before including a particular task constraint into the training environment for an extended period of time.

A final consideration for coaches interested in adopting this methodology is that athletes should be provided with opportunities to switch between the constrained environment and an environment that more closely represents the competition setting during the practice intervention. The logic behind this recommendation is that players will be availed with the opportunity to re-calibrate their movement solutions to the actual performance situation, thus, increasing the likelihood of positive transfer from practice to competition performance. While this practical recommendation requires confirmation from scientific data, it is likely to be beneficial to coaches who might otherwise be reluctant to adopt the training methods suggested here.

The study detailed in Chapter 3 demonstrated that the use of implicit learning techniques offers a potential method of changing well-learned technique without the need to revert to step-by-step control procedures that characterise novice sensorimotor skill execution. The players who participated in the study were amongst the very best in their chosen sport, suggesting that, even at an elite level, players might benefit from implicit practice to adapt well-learned skills. This provides an alternative to the traditional approach to skill modification, which typically involved engagement in novice-like conscious control, followed by a gradual return to procedural control.

Methodological Considerations

One of the specific aims of this thesis was to investigate alternative measures of cognitive effort and implicit/explicit processing. The purpose of this section is to summarise the methodological considerations that arose. A number of studies presented in this thesis have endeavoured to advance the methodological approaches previously adopted in studies of contextual interference and implicit motor learning. These include: (1) the application of a battery of measures to assess cognitive effort and implicit/explicit processing in blocked and random practice (Chapter 4); (2) the investigation of movement preparation and movement execution times, as well as careful discussion of processing during the intertrial interval, as indicators of cognitive effort in blocked and random learners (Chapter 6); and (3) the exploration of a modified Stroop task as a novel method for assessing implicit and explicit processing (Chapter 7).

The application of a battery of measures in the Chapter 4 study showed a systematic attempt to investigate the type of cognitive processing that occurs during blocked and random practice. Researchers who have studied the contextual interference effect have, over many years, implemented varied and novel measures in an attempt to explore the theoretical underpinnings of the benefits of random practice.

The studies detailed in the Literature Review (Chapter 2) provided examples of such research. The wide variety of methods is illustrated in the following sample of studies: the inclusion of mental imagery by Gabriele et al. (1989); the addition of interpolated activities during the inter-trial interval by Young et al. (1993); Li and Wright’s (2000) application of secondary task paradigm; and the use of fMRI methods by Cross et al. (2007). In Chapter 4, measures that have typically been used within a different body of literature were applied in an attempt to provide further insight regarding this topic. The findings of the Chapter 4 study highlighted a previously unexplored theoretical account for the contextual interference effect, but also highlighted the need for advancements in research methods and measurement techniques. Innovation in the area of neuroscience provides exciting possibilities in this regard and researchers who have access to these methods are likely to unearth new knowledge in the future (see, for example, the work of Lin et al., 2008, using TMS; see also Kantak, Sullivan, Fisher, Knowlton, & Winstein’s, 2010, brief communication regarding the neural substrates of motor memory consolidation).

The exploration of movement preparation and movement execution times that were presented in Chapter 6 highlights the role of behavioural observation in the methodological approaches applied to this research area. Historically, scientific enquiry was founded on reasoning from observation (e.g., Aristotle mentions a number of sources of observational evidence). It is therefore important to consider both experimental and observational approaches to the study of motor learning and the combination of these methods is likely to provide insight into the role that cognitive effort and implicit/explicit processing play in motor learning. The task switching literature discussed in Chapter 6 also provides an interesting avenue for researchers who wish to conduct experiments aimed at understanding the cognitive processing underlying the contextual interference effect.

Finally, the methods explored in Chapter 7, which rely on the use of a modified Stroop task, provided a novel attempt to assess implicit and explicit processes. As was discussed in detail in the chapter, the methods offer a potential means of assessing the type of processing that is adopted by various cohorts of participants. A number of methodological considerations were highlighted, such as the careful selection of stimuli and accompanying experimental design. It is hoped that the modified Stroop task is further explored by researchers working in the motor learning domain in the future.

Future Research

This thesis has raised a number of questions that provide a suitable foundation for future research. Four main avenues for research have emerged. First, in Chapter 3, the possibility that implicit learning can be used to adapt well-learned skills in expert performers was highlighted. Researchers have previously discussed this as a theoretical possibility (e.g., Poolton & Zachry, 2007), but the study presented in this chapter provides an initial attempt to collect some empirical data to address this topic. Researchers should endeavour to both replicate the findings of the study using a larger cohort of participants and explore other methods of introducing implicit learning to gather further support for the application of implicit learning in skilled performers. As detailed in the Literature Review (Chapter 2), analogy learning offers promise in this regard (e.g., Liao & Masters, 2001). Coaches commonly report using analogies in practice, but a scientific study is required to see whether analogy learning can prevent skilled athletes from consciously focusing on their movements. At a practical level, coaches should be reminded that if they do intend to draw on analogies during training, then they should not provide the biomechanical detail underlying the analogy in order to give the best chance of implicit learning.

The second avenue for research is to explore the theoretical proposition that the benefits of random practice might be subserved by implicit processing. Errorful and errorless learning provide a potentially effective means of conducting further research due to the similarities with blocked and random practice (both have an effect on how many errors a learner produces during learning). Researchers could consider exploring the effect of combining the different conditions (e.g., including the following experimental groups: blocked-errorless, blocked-errorful, random-errorless, and random-errorful) to explore the cognitive processing that occurs during the different conditions. It is possible that if the implicit account for contextual interference is correct, then the conditions could be considered on a continuum from highly implicit (random-errorless) to highly explicit (blocked-errorful). Similarly, the variability of practice hypothesis (Schmidt, 1975) could be merged with either the random-blocked or errorless-errorful practice schedules to explore whether there are potentially positive outcomes of combining these themes. For instance, an example of errorless learning is shooting a netball starting very close to the post – such as from 1 m. It would be interesting to consider what would happen if a learner practised in this way but from variable angles. Would this achieve the positive outcomes of errorless practice (implicit control) while also producing a more adaptable movement solution?[23]

The third avenue for research is to further consider the variables that influence the contextual interference effect and what influence these variables have on the

[23] This is not to say that movement control is necessarily less adaptable using errorless compared to errorful practice schedules – research is required to investigate this question.

cognitive processing of learners. A number of researchers have highlighted variables, such as skill level (e.g., Del Rey, Wughalter, & Whitehurst, 1982; Guadagnoli, Holcomb, & Weber, 1999), task complexity (e.g., Albaret & Thon, 1998; Wulf & Shea, 2002), task similarity (e.g., Boutin & Blandin, 2010; Magill & Hall, 1990), and level of interference (e.g., Landin & Herbert, 1997) but further work – particularly involving real-world motor tasks – is required before the application of the contextual interference effect can be effective. The importance of using applied tasks is highlighted by the different findings in laboratory research (e.g., Gabriele et al., 1989; Goodwin & Meeuwsen, 1996; Poto, 1988) and applied research (e.g., Boyce & Del Rey, 1990; Hall, Domingues, & Cavazos, 1994) with reference to task similarity. While laboratory-based research suggests that the contextual interference effect is more robust when the skills being learned are from different motor programs, the applied research does not support this trend and the data presented in Chapter 4 is further evidence of this. The issue of using applied skills is also highlighted by the discussion of contextual interference in applied settings by Barreiros et al. (1997). Research using real-world skills is paramount to the success of applying motor learning research to sports performance.

Two areas which require careful manipulation in future research are: (1) task switching and (2) duration of learning/retention. The effect of task switching in the understanding of the contextual interference effect has typically been considered at a basic level (e.g., truly random – serial – blocked), but researchers should carefully consider the effect of a switch on each consecutive practice trial. Some researchers have begun exploring these types of questions (e.g., Porter & Magill, 2010, recently investigated the effect of systematically increasing contextual interference), but further work is required. Researchers should also be encouraged to consider the duration of the acquisition period given that a number of existing studies seem to rely on single sessions of acquisition, which are difficult to interpret in terms of the real-world application. Similarly, the period of time between post-test and retention testing seems to be arbitrarily selected in some studies of contextual interference and it would be beneficial for researchers to explore the duration of retention as a variable in future studies. A further avenue for research which has both theoretical and applied consequences is the study of learner-driven practice schedules and feedback (self-regulated practice). This is an area that has been gaining research attention in recent times (e.g., Chiviacowsky & Wulf, 2005; Keetch & Lee, 2007). It would be interesting to consider what effect this type of practice has on random learners through the viewpoint of the implicit learning hypothesis. Previous research has shown that learners find explicit practice more comfortable than implicit practice because of the relatively rapid outcomes. It would be worthwhile to investigate whether the mechanism supporting self-regulated practice is consistent across different practice approaches within the motor learning research domain.

Finally, the methodological approach presented in the Chapter 7 study (the modified Stroop task) provides an interesting avenue for researchers in the motor learning domain. As discussed in detail in the chapter, future research looking at the use of the modified Stroop task in different cohorts of participants – such as those suffering from the yips or movement reinvestment – is a possible new avenue for research. Another method that might help to tap into the cognitive processes that subserve blocked and random practice is to use concurrent verbal protocols such as the “think-aloud” or “talk-aloud” methods, which ask participants to describe their actions at the time they are completing the tasks (e.g., Ericsson & Simon, 1984, 1987). Such methods might help to unveil the cognitive processes that random learners experience during practice and help to explore whether there are differences between blocked and random learners in their reliance on endogenous and exogenous processes during the inter-trial interval[24].

Concluding Remarks

In the Introduction (Chapter 1), the premise of this thesis was given – a question from an astute coach highlighted the divergent implications of implicit motor learning and contextual interference and this led to the series of studies presented in this thesis. The findings provide the beginnings of a potential resolution to the question posed by the coach. Random practice might involve less mental effort than previously thought – but only less effort in terms of explicit processing of the skills being learned. The cognitive effort that accompanies random practice following a skill switch might surprisingly result in the learner practicing in a more implicit manner.

A second key advance from this thesis – one that has both theoretical and practical implications – is the finding that implicit motor learning has potential application in expert performers. Although the study addressing this topic was based on a single case design (Chapter 3), it presented an applied methodology that can be directly used by coaches. The study also implemented a practice intervention with high skilled performers, which is an undertaking rarely attempted in the motor learning literature due to the numerous challenges surrounding the control of training methods with athletes who have an elite performance focus.

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[24] Researchers should carefully consider, however, what effect this method is likely to have on participants' mode of learning. The very nature of concurrent verbal protocols means that participants could potentially be guided to use more explicit processing. Therefore, researchers should carefully select the instructions they give. For example, the instruction: "Try to think aloud. I guess you often do so when you are alone and working on a problem", as used by Duncker (1926; in Ericsson & Simon, 1987) would be preferable to the following instruction, "Think, reason in a loud voice, tell me everything that passes through your head during your work searching for the solution to the problem" (Claparède, 1934; in Ericsson & Simon, 1987).

Finally, the thesis investigated novel methods for measuring cognitive effort and implicit/explicit learning. The outcome of this work lays the foundation for future research which might generate measures that have both scientific and applied value. A battery of measures typically used in implicit motor learning research was applied to blocked and random practice in the study presented in Chapter 4. A behavioural analysis of the time taken to prepare and execute movements as a measure of cognitive effort was reported in Chapter 6 and two experiments presented in Chapter 7 investigated whether a modified Stroop task could be used as a measure of implicit/explicit processing.

The thesis has contributed to the scientific knowledge of both the contextual interference and implicit motor learning research domains as well as providing research using highly skilled performers, which is an area that is often criticised in the existing motor learning literature. It is hoped that other researchers will be inspired to further explore the issues raised in this thesis.

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Appendix A: Information Statement for the Study in Chapter 3

Australian Government
Australian Sports Commission

AUSTRALIAN INSTITUTE OF SPORT
SKILL ACQUISITION

INFORMATION TO PARTICIPANTS[25]

We would like to invite you to be a part of a study investigating the implementation of implicit re-learning in highly skilled netball shooters to improve performance under pressure.

The study will involve a pre-test phase, a training phase and a post-test phase.

During the pre- and post-tests, you will undergo a series of performance conditions in which you will be asked to complete 60 goal shots. We will monitor your performance during these conditions. We will measure: where you are looking using special glasses that you wear over your eyes, your movement kinematics using a fabric sleeve that you wear on your arm, your shooting accuracy using a video camera and your level of anxiety using a short questionnaire. In one of the conditions you will also be asked to respond to an auditory tone presented through speakers, in which we will measure your reaction time.

In addition to the on-court shooting tests, you will be asked to estimate the height of a netball goal post from a series of different height post. You will also be asked to report your thoughts, movement and strategies involved in shooting, both under typical conditions and also under conditions shown to you on video (from matches that you have previously played). Finally, in the pre-test condition only, you will be asked to fill in 3 different questionnaires that will be fully explained to you during the course of the session.

The training phase of the study will involve you practicing three sessions per week for four weeks. You will practice shooting in time with an auditory rhythm that is presented through speakers. Your task will be to try to shoot in time with the rhythm. One session each week will be supervised by an AIS Skill Acquisition staff member or an AIS Skill Acquisition PhD student.

You will be free to withdraw from the study at any time and that this withdrawal will not jeopardise you in any way. All information provided during the course of the study may be shared with the Head Coach of Australian Netball and your Club coach, but except from these people, will be kept confidential.

Any queries about your participation in this project may be directed to the principle researcher:

Dr Damian Farrow
Skill Acquisition Specialist, Australian Institute of Sport
Tel: 0408 445 701
Email: damian.farrow@ausport.gov.au

If you have any queries or complaints about the way you have been treated, you may contact the Secretary, Human Research Ethics Committee, Australian Institute of Sport, PO Box 176, Belconnen, ACT 2616, Phone: 02 6214 1111.

[25] The study reported in Chapter 3 details one aspect of a larger project aimed at improving the shooting skills of skil members of the Australian Netball Squad. This project included the use of a fabric sleeve to measure movement kinematics.

Appendix B: Participant Consent Form for the Study in Chapter 3

‘INFORMED CONSENT’ FORM (Adult)

Project Title: Implicit Re-Learning in Highly Skilled Netball Shooters To Improve Performance Under Pressure

Principal Researchers: Dr Damian Farrow (Australian Intitute of Sport) and Megan Rendell (Australian Intitute of Sport; Victoria University)

This is to certify that I, hereby agree to participate as a volunteer in a scientific investigation as an authorised part of the research program of the Australian Sports Commission under the supervision of Dr Damian Farrow.

The investigation and my part in the investigation have been defined and fully explained to me by Megan Rendell and Damian Farrow and I understand the explanation. A copy of the procedures of this investigation and a description of any risks and discomforts has been provided to me and has been discussed in detail with me.

- I have been given an opportunity to ask whatever questions I may have had and all such questions and inquiries have been answered to my satisfaction.
- I understand that I am free to deny any answers to specific items or questions in interviews or questionnaires.
- I understand that I am free to withdraw consent and to discontinue participation in the project or activity at any time.
- I understand that any data or answers to questions will remain confidential with regard to my identity.
- I certify to the best of my knowledge and belief, I have no physical or mental illness or weakness that would increase the risk to me of participating in this investigation.
- I am participating in this project of my (his/her) own free will and I have not been coerced in any way to participate.

Signature of Subject: ________________________________ Date: ___/___/___

I, the undersigned, was present when the study was explained to the subject/s in detail and to the best of my knowledge and belief it was understood.

Signature of Researcher: ______________________________ Date: ___/___/___

Appendix C: Demographic and Previous Experience Questions for the Study in Chapter 3

DEMOGRAPHIC AND PREVIOUS EXPERIENCE QUESTIONS

Please provide the following information about yourself:

1. Name: ______________________
2. DOB: ______________________
3. Current squad: ______________________
4. How many years have you been a member of this squad? __________________
5. What age did you first play in organised netball (i.e., not in the backyard at home, but in a team)? __________________
6. What is the highest level of netball you have played: _____________________

Appendix D: Information Statement for the Study in Chapter 4

VICTORIA UNIVERSITY | A NEW SCHOOL OF THOUGHT

"PRACTICE METHODS OF TWO AUSTRALIAN RULES FOOTBALL SKILLS"

INFORMATION TO PARTICIPANTS

We would like to invite you to be a part of a study investigating effective practice methods of two Australian Rules football skills (handball and drop punt). The project will take place over five weeks with approximately two 30-minute sessions per week (see below for specific details).

During the sessions, you will practice two tasks: the Australian Rules handball and drop punt. In the handball task, you will be asked to hold the ball stationary in front of you with one hand and punch the ball with the clenched fist of the other hand toward a target grid on a wall (situated 5 m in front of you). In the drop punt task, you will be asked to hold the ball vertically and drop and kick the ball before it hits the ground, toward a target grid on a wall (situated 15 m in front of you). Following is a summary of the study:

<u>WEEK 1:</u> You will be asked to attend one 30-minute session in which you will complete 20 handballs and 20 drop punts. During this session, you will also be asked to complete a short survey.

<u>WEEK 2 to WEEK 4:</u> Over the next three weeks, you will be asked to attend two 30-minute sessions in which you will complete 50 handballs and 50 drop punts. In the second session of Week 4, you will be asked to perform an additional 20 handballs and 20 drop punts (therefore this session will take approximately 45 minutes).

<u>WEEK 5:</u> In the final week, you will be asked to attend one 30-minute session in which you will complete 40 handballs and 40 drop punts. During 20 of the handballs and drop punts, you will also be asked to respond to a simple counting task in which you will count the number of auditory tones you hear.

If you are willing for us to do so, we will record your sessions on videotape for analysis at a later time.

RISKS AND SAFEGUARDS

We would like to make you aware that due to the physical nature of the tasks you will be exposed to a low level of risk by your involvement, in terms of possible physical symptoms such as muscle soreness and tiredness. To minimise the risk, you will be monitored by the researchers and will be free to cease performing the tasks. In addition, you will be asked to report whether you have any existing injuries that would make you susceptible to injury. To further minimise the risk of injury, ***please ensure that you wear comfortable clothing (e.g. shorts and t-shirt) and sports footwear (trainers) to all sessions***.

We would also like to acknowledge that you could potentially experience some anxiety as you perform the football skills in front of the researchers. We would like to make you aware that you only need to try your best and there is no particular level of performance that you need to reach. If you feel uncomfortable at any time, you should feel free to cease participating, take a break form participating, or discuss your concerns with the researchers.

You will be free to withdraw from the study at any time and that this withdrawal will not jeopardise you in any way. All information provided during the course of the study (including the video recordings of the practice sessions) will be kept confidential.

Any queries about your participation in this project may be directed to the researcher:

Prof Tony Morris, Principle Investigator
Victoria University
Telephone: (03) 9919 5353 Email: tony.morris@vu.edu.au

If you have any queries or complaints about the way you have been treated, you may contact the Secretary, Victoria University Human Research Ethics Committee, Victoria University, PO Box 14428, Melbourne, VIC, 8001 phone (03) 9919 4710

Principle Investigator:

- Name: Prof Tony Morris
- Role: Principle Investigator – oversee project
- Institution: Victoria University
- Telephone Number: (03) 9919 5353
- E-Mail Address: tony.morris@vu.edu.au

Associate Investigator/s:

- Name: Megan Rendell
- Role: Student Investigator – undertake and co-ordinate project
- Institution: Victoria University; Australian Institute of Sport
- Mobile Number: 0430117 454
- E-Mail Address: megan.rendell@ausport.gov.au

- Name: Dr Damian Farrow
- Role: External Investigator – involved in the design and planning of the study
- Institution: (External) – Australian Institute of Sport
- Mobile Number: 0408 445 701
- E-Mail Address: damian.farrow@ausport.gov.au

- Name: Dr Rich Masters
- Role: External Investigator– involved in the design and planning of the study
- Institution: (External) – University of Hong Kong
- Telephone Number: 0011 852 2589 0581
- E-Mail Address: mastersr@hku.hk

Appendix E: Participant Consent Form for the Study in Chapter 4

VICTORIA UNIVERSITY | A NEW SCHOOL OF THOUGHT

"PRACTICE METHODS OF TWO AUSTRALIAN RULES FOOTBALL SKILLS"

CERTIFICATION BY PARTICIPANT

I, ________________________________ (participant's name)

of ________________________________ (participant's suburb)

certify that I am at least 18 years old* and that I am voluntarily giving my consent to participate in the study into "Effective Practice Methods of Two Australian Rules Football Skills (Handball and Drop Punt)", being conducted at Victoria University by Tony Morris.

I certify that the objectives of the study, together with any risks and safeguards associated with the procedures listed hereunder to be carried out in the research, have been fully explained to me by Megan Rendell.

and that I freely consent to participation involving these procedures:

- Practice sessions over 5 weeks in which I will perform two Australian Rules football skills (drop punt and handball) as outlined below:
  Week 1: 1 x 30 min session; Week 2: 2 x 30 min sessions; Week 3: 2 x 30 min sessions; Week 4: 1 x 30 min; 1 x 45 min sessions; In the second session of Week 4, you will be asked to perform an additional 20 handballs and 20 drop punts (therefore this session will take approximately 45 minutes).Week 5: 1 x 30 min sessions
- A short survey
- A simple auditory tone counting task
- Recording of my practice sessions on videotape

I certify that I have had the opportunity to have any questions answered and that I understand that I can withdraw from this study at any time and that this withdrawal will not jeopardise me in any way.

I have been informed that the information I provide will be kept confidential.

Signed: ____________________________

Witness: ____________________________ *(other than the researcher)*

Date: ____________________________

Any queries about your participation in this project may be directed to the researcher:

Prof Tony Morris
Principle Investigator
Victoria University
Telephone: (03) 9919 5353
Email: tony.morris@vu.edu.au

If you have any queries or complaints about the way you have been treated, you may contact the Secretary, Victoria University Human Research Ethics Committee, Victoria University, PO Box 14428, Melbourne, VIC, 8001 phone (03) 9919 4710

Principle Investigator:

- Name: Prof Tony Morris
- Role: Principle Investigator – oversee project
- Institution: Victoria University
- Telephone Number: (03) 9919 5353
- E-Mail Address: tony.morris@vu.edu.au

Associate Investigator/s:

- Name: Megan Rendell
- Role: Student Investigator – undertake and co-ordinate project
- Institution: Victoria University; Australian Institute of Sport
- Mobile Number: 0430117 454
- E-Mail Address: megan.rendell@ausport.gov.au

- Name: Dr Damian Farrow
- Role: External Investigator – involved in the design and planning or the study
- Institution: (External) – Australian Institute of Sport
- Mobile Number: 0408 445 701
- E-Mail Address: damian.farrow@ausport.gov.au

- Name: Dr Rich Masters
- Role: External Investigator– involved in the design and planning or the study
- Institution: (External) – University of Hong Kong
- Telephone Number: 0011 852 2589 0581
- E-Mail Address: mastersr@hku.hk

Appendix F: Demographic and Previous Experience Questions for the Study in Chapter 4

"PRACTICE METHODS OF TWO AUSTRALIAN RULES FOOTBALL SKILLS"

DEMOGRAPHIC AND PREVIOUS EXPERIENCE QUESTIONS

Please provide the following information about yourself:

7. What is your name? ______________________

8. Age? (Years) __________ (Months) ___________

9. Gender? (please circle) Male Female

10. Have you played Aussie Rules before? (please circle) Yes No

    If yes, what level of Aussie Rules you have been involved in? (please circle). Below each one, please estimate the number of years you have played at that level.

LEVEL:	Backyard	Recreational	Club	Representative
YEARS:	________	________	________	________

11. Have you played any other types of football (soccer, rugby league, or rugby union)?

    (please circle) Yes No

    If yes, please outline the type of football you have been involved in (please circle). Below each one, please estimate the number of years you have played at that sport.

TYPE:	Soccer	League	Union	Other
YEARS:	________	________	________	________

Appendix G: Self-Report Cognitive Effort Questions for the Study in Chapter 4

"PRACTICE METHODS OF TWO AUSTRALIAN RULES FOOTBALL SKILLS"

Name (initials only): ________ *Participant Number:* ________ *Date:* ________

Please place a cross on the line to indicate your rating to each question:

TITLE	DESCRIPTION	RATING
Mental Demand	How much mental activity was required during this session (e.g. thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the session easy or demanding, simple or complex?	Low ⊢┴┴┴┴┴┴┴┴┴┴┴┴┴┴┴┴┴⊣ High
Effort	How hard did you have to work (mentally and physically) to accomplish your level of performance?	Low ⊢┴┴┴┴┴┴┴┴┴┴┴┴┴┴┴┴┴⊣ High
Performance	How successful do you think you were in accomplishing the goals of the session set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?	Low ⊢┴┴┴┴┴┴┴┴┴┴┴┴┴┴┴┴┴⊣ High
Frustration Level	How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the session?	Low ⊢┴┴┴┴┴┴┴┴┴┴┴┴┴┴┴┴┴⊣ High

Appendix H: Information Statement for the Study in Chapter 5

VICTORIA UNIVERSITY | A NEW SCHOOL OF THOUGHT

"EFFECTIVE PRACTICE METHODS IN TABLE TENNIS"

INFORMATION TO PARTICIPANTS INVOLVED IN RESEARCH

You are invited to participate

We would like to invite you to be a part of a study investigating effective practice methods in Table Tennis.

This project is being conducted by a student researcher Megan Rendell as part of a PhD study at Victoria University under the supervision of Professor Tony Morris from the School of Recreation, Human Movement and Performance.

Project explanation

We are interested in comparing different methods of scheduling practice to find out which method is likely to assist athletes to learn in a time-efficient and effective manner. We will ask you to practice two table tennis serves in a prescribed schedule.

What will I be asked to do?

You will be asked to attend 4 x 1 hour sessions, during one week. During these sessions you will be asked to practice forehand and backhand table tennis serves.

You will be asked to provide demographic information such as your age, gender and handedness.

During the first three sessions, we will ask you to complete a counting task at the same time as you are practicing the table tennis serves. *(Note. This statement will only appear on information statements for the "Random + Filled" group).*

During the final session, you will be asked to perform a simple tone counting task at the same time as you perform the table tennis skills. During this session you will also be asked to complete a short survey in which you will be asked to describe the skills that you learned (by describing the technique you adopted).

If you are willing for us to do so, we will record your sessions on videotape for analysis at a later time.

What will I gain from participating?

The knowledge gained from this study will provide important insight into the design of skill acquisition environments to ensure that learners practice in a time-efficient and effective manner. During the final session, the experimenter will provide a brief overview of the information that is currently available in this area. This knowledge has wide implications and you may find it of interest as it relates to teachers, instructors, and coaches from various disciplines.

How will the information I give be used?

It is intended that the information gathered in this research will be published in a scientific journal and in presentations to the sports science and coaching community. Only group data will be presented and no individual will be identifiable.

What are the potential risks of participating in this project?

We would like to make you aware that due to the physical nature of the tasks you will be exposed to a low level of risk by your involvement, in terms of possible physical symptoms such as muscle soreness and tiredness. To minimise the risk, you will be monitored by the researchers and will be free to cease performing the tasks. In addition, you will be asked to report whether you have any existing injuries that would make you susceptible to injury. To further minimise the risk of injury, *please ensure that you wear comfortable clothing (e.g., shorts and t-shirt) and sports footwear (trainers) to all sessions*.

We would also like to acknowledge that you could potentially experience some anxiety as you perform the table tennis skills in front of the researchers. We would like to make you aware that you only need to try your best and there is no particular level of performance that you need to reach. If you feel uncomfortable at any time, you should feel free to cease participating, take a break from participating, or discuss your concerns with the researchers.

You will be free to withdraw from the study at any time and this withdrawal will not jeopardise you in any way. All information provided during the course of the study (including the video recordings of the practice sessions) will be kept confidential.

How will this project be conducted?

- □ Day 1: You will be asked to practice 150 forehand and 150 backhand table tennis serves (a total of 300 serves). The session will last for approximately 1 hour.
- □ Day 2: This session will be the same as Session 1.
- □ Day 3: This session will be the same as Session 1.
- □ Day 4: This will be a rest day. There will be no session on Day 4.
- □ Day 5: You will be asked to complete 20 forehand serves and 20 backhand serves in two different schedules: a blocked schedule (all serves in one skill completed before switching to the other skill) and a random schedule (random completion of the forehand and backhand serves, such that one skill is not repeated for more than three consecutive trials). You will also be asked to complete 20 forehand serves and 20 backhand serves in a blocked order while also completing another task in which you will count the number of ‘tones’ presented from a computer. The session will last for approximately 1 hour.

Who is conducting the study?

Principal Investigator:

- Name: Prof Tony Morris
- Role: Principal Investigator – oversee project
- Institution: Victoria University
- Telephone Number: (03) 9919 5353
- E-Mail Address: tony.morris@vu.edu.au

Associate Investigators:

- Name: Megan Rendell
- Role: Student Investigator – undertake and co-ordinate project
- Institution: Victoria University; Australian Institute of Sport
- Mobile Number: 0430117 454
- E-Mail Address: megan.rendell@ausport.gov.au

- Name: Dr Damian Farrow
- Role: External Investigator – involved in the design, planning, and analysis of the study
- Institution: (External) – Australian Institute of Sport
- Mobile Number: 0408 445 701
- E-Mail Address: damian.farrow@ausport.gov.au

- Name: Dr Rich Masters
- Role: External Investigator– involved in the design, planning, and analysis of the study
- Institution: (External) – University of Hong Kong
- Telephone Number: 0011 852 2589 0581
- E-Mail Address: mastersr@hku.hk

Any queries about your participation in this project may be directed to the Principal Researcher listed above.

If you have any queries or complaints about the way you have been treated, you may contact the Secretary, Victoria University Human Research Ethics Committee, Victoria University, PO Box 14428, Melbourne, VIC, 8001 phone (03) 9919 4781.

Appendix I: Participant Consent Form for the Study in Chapter 5

VICTORIA UNIVERSITY | A NEW SCHOOL OF THOUGHT

"EFFECTIVE PRACTICE METHODS IN TABLE TENNIS"

CONSENT FORM

CERTIFICATION BY PARTICIPANT

I, ________________________________ (participant's name)

of _______________________________ (participant's suburb)

certify that I am at least 18 years old* and that I am voluntarily giving my consent to participate in the study into "Effective Practice Methods in Table Tennis", being conducted at Victoria University by Tony Morris, Megan Rendell, Damian Farrow and Rich Masters.

I certify that the objectives of the study, together with any risks and safeguards associated with the procedures listed hereunder to be carried out in the research, have been fully explained to me by Megan Rendell.

and that I freely consent to participation involving these procedures:

- Four 1-hr sessions over 1 week in which I will practice two Table Tennis skills (forehand and backhand serves)
- A short survey providing details about my gender, age and handedness
- A simple tone counting task (at the same time as performing the table tennis skills during the final session)
- A simple counting backwards task *(Note. This statement will only appear on consent forms for the "Random + Filled" group).*
- Recording of my practice sessions on videotape

I certify that I have had the opportunity to have any questions answered and that I understand that I can withdraw from this study at any time and that this withdrawal will not jeopardise me in any way.

I have been informed that the information I provide will be kept confidential.

Signed: ____________________________

Date: ____________________________

Any queries about your participation in this project may be directed to the researcher:

Prof Tony Morris
Principal Investigator
Victoria University
Telephone: (03) 9919 5353
Email: tony.morris@vu.edu.au

If you have any queries or complaints about the way you have been treated, you may contact the Secretary, Victoria University Human Research Ethics Committee, Victoria University, PO Box 14428, Melbourne, VIC, 8001 phone (03) 9919 4710

Principle Investigator:

- Name: Prof Tony Morris
- Role: Principal Investigator – oversee project
- Institution: Victoria University
- Telephone Number: (03) 9919 5353
- E-Mail Address: tony.morris@vu.edu.au

Associate Investigator/s:

- Name: Megan Rendell
- Role: Student Investigator – undertake and co-ordinate project
- Institution: Victoria University; Australian Institute of Sport
- Mobile Number: 0430 117 454
- E-Mail Address: megan.rendell@ausport.gov.au

- Name: Dr Damian Farrow
- Role: External Investigator – involved in the design and planning or the study
- Institution: (External) – Australian Institute of Sport
- Mobile Number: 0408 445 701
- E-Mail Address: damian.farrow@ausport.gov.au

- Name: Dr Rich Masters
- Role: External Investigator– involved in the design and planning or the study
- Institution: (External) – University of Hong Kong
- Telephone Number: 0011 852 2589 0581
- E-Mail Address: mastersr@hku.hk

Appendix J: Demographic and Previous Experience Questions for the Study in Chapter 5

"EFFECTIVE PRACTICE METHODS IN TABLE TENNIS"

DEMOGRAPHIC AND PREVIOUS EXPERIENCE QUESTIONS

Please provide the following information about yourself:

1. What is your name? ______________________

2. Age? (Years) __________ (Months) ___________

3. Gender? (please circle) Male Female

4. Handedness? (please circle) Left Right

5. Have you played Table Tennis before? (please circle) Yes No

   If yes, what level of Table Tennis you have been involved in? (please circle). Below each one, please estimate the number of years you have played at that level.

Level:	At Home	School	Club	Representative
Frequency:	________	________	________	________
Years:	________	________	________	________

6. Have you played tennis before?

   (please circle) Yes No

   If yes, please outline the type of tennis you have been involved in (please circle). Below each one, please estimate the number of years you have played at that sport.

Level:	At Home	School	Club	Representative
Frequency:	________	________	________	________
Years:	________	________	________	________

Appendix K: Information Statement for Experiment 1 (Chapter 7)

Institute of Human Performance
University of Hong Kong

INFORMATION TO PARTICIPANTS

We would like to invite you to be a part of a study investigating the Stroop test and golf putting performance.

During the course of the experiment you will be required to perform both a golf putting task and several computer based reaction time tasks.

The experimenter will guide you through the study and provide you with pre-determined rest periods. If at any time you require additional rest or have any other problems please inform the researcher. A summary of the results will be made available to you upon request.

The testing session will take no longer than one hour.

You will be free to withdraw from the study at any time and that this withdrawal will not jeopardise you in any way. All information provided during the course of the study will be kept confidential.

Any queries about your participation in this project may be directed to the principle researcher:

Dr Rich Masters
University of Hong Kong
Telephone Number: 0011 852 2589 0581
E-Mail Address: mastersr@hku.hk

Appendix L: Participant Consent Form for Experiment 1 (Chapter 7)

Institute of Human Performance
University of Hong Kong

INFORMED CONSENT FORM

Title of research:
The Stroop Test & Golf Putting Performance

Purpose of research:
Staff research

Investigators:
Megan Rendell
Rich Masters
Rob Jackson
Jamie Poolton

Procedure:
During the course of the experiment you will be required to perform both a golf putting task and several computer based reaction time tasks. The experimenter will guide you through the study and provide you with pre-determined rest periods. If at any time you require additional rest or have any other problems please inform the researcher. A summary of the results will be made available to you upon request.

I agree to participate in the study.

I understand that I am free to withdraw at any time.

I understand that participation in the study is anonymous and confidential and my name will not be used in connection with the results in any way.

Signature of participant: ______________________________

Date: ______________________________

Participant number: ______________________________

Appendix M: STAI-Form Y

SELF-EVALUATION QUESTIONNAIRE

STAI Form Y-1

Please provide the following information:

Name______________________________ Date__________ S_____

Age____________ Gender (*Circle*) **M** **F** T_____

DIRECTIONS:

A number of statements which people have used to describe themselves are given below. Read each statement and then circle the appropriate number to the right of the statement to indicate how you feel *right* now, that is, *at this moment*. There are no right or wrong answers. Do not spend too much time on any one statement but give the answer which seems to describe your present feelings best.

	NOT AT ALL	SOMEWHAT	MODERATELY SO	VERY MUCH SO
1. I feel calm	1	2	3	4
2. I feel secure	1	2	3	4
3. I am tense	1	2	3	4
4. I feel strained	1	2	3	4
5. I feel at ease	1	2	3	4
6. I feel upset	1	2	3	4
7. I am presently worrying over possible misfortunes	1	2	3	4
8. I feel satisfied	1	2	3	4
9. I feel frightened	1	2	3	4
10. I feel comfortable	1	2	3	4
11. I feel self-confident	1	2	3	4
12. I feel nervous	1	2	3	4
13. I am jittery	1	2	3	4
14. I feel indecisive	1	2	3	4
15. I am relaxed	1	2	3	4
16. I feel content	1	2	3	4
17. I am worried	1	2	3	4
18. I feel confused	1	2	3	4
19. I feel steady	1	2	3	4
20. I feel pleasant	1	2	3	4

Appendix N: Information Statement for Experiment 2 (Chapter 7)

Australian Government
Australian Sports Commission

AUSTRALIAN
INSTITUTE OF SPORT
SKILL ACQUISITION

INFORMATION TO PARTICIPANTS

We would like to invite you to be a part of a study investigating the use of a modified Stroop task as a measure of cognitive expertise in highly skilled swimmers.

The study will involve two types of computer tasks.

In the first task, you will be asked to name the colour of some letters and words on a computer screen while trying to ignore their meaning. These words will include the names of colours as well as other words such as ‘emu’ or ‘abs’. Your responses will be recorded by a microphone that is connected to a computer.

In the second task, you will be asked to name the colour of pictures that are presented on a computer screen. The pictures will be of people swimming. The pictures have been digitally altered to appear in a certain colour.

You will be asked to perform the tasks as quickly as possible. The testing session will take about 30 minutes including time for questions.

You will be free to withdraw from the study at any time and that this withdrawal will not jeopardise you in any way. All information provided during the course of the study may be shared with the Head Coach of Swimming, but except from this person, will be kept confidential.

Any queries about your participation in this project may be directed to the principle researcher:

Dr Damian Farrow
Skill Acquisition Specialist, Australian Institute of Sport
Tel: 0408 445 701
Email: damian.farrow@ausport.gov.au

If you have any queries or complaints about the way you have been treated, you may contact the Secretary, Human Research Ethics Committee, Australian Institute of Sport, PO Box 176, Belconnen, ACT 2616, Phone: 02 6214 1111.

Appendix O: Participant Consent Form for Experiment 2 (Chapter 7)

'INFORMED CONSENT' FORM (Adult)

Project Title: Exploring the Use of A Modified Stroop Task As a Measure of Cognitive Expertise in Highly Skilled Swimmers

Principal Researchers: Dr Damian Farrow (Australian Intitute of Sport) and Megan Rendell (Australian Intitute of Sport; Victoria University)

This is to certify that I, hereby agree to participate as a volunteer in a scientific investigation as an authorised part of the research program of the Australian Sports Commission under the supervision of Dr Damian Farrow.

The investigation and my part in the investigation have been defined and fully explained to me by Megan Rendell and Damian Farrow and I understand the explanation. A copy of the procedures of this investigation and a description of any risks and discomforts has been provided to me and has been discussed in detail with me.

- I have been given an opportunity to ask whatever questions I may have had and all such questions and inquiries have been answered to my satisfaction.
- I understand that I am free to deny any answers to specific items or questions in interviews or questionnaires.
- I understand that I am free to withdraw consent and to discontinue participation in the project or activity at any time.
- I understand that any data or answers to questions will remain confidential with regard to my identity.
- I certify to the best of my knowledge and belief, I have no physical or mental illness or weakness that would increase the risk to me of participating in this investigation.
- I am participating in this project of my (his/her) own free will and I have not been coerced in any way to participate.

Signature of Subject: ________________________________ Date: ___/___/___

I, the undersigned, was present when the study was explained to the subject/s in detail and to the best of my knowledge and belief it was understood.

Signature of Researcher: ______________________________ Date: ___/___/___