Motor skill acquisition in childhood: Exploring the links between working memory, implicit learning and equipment modification

by

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ABSTRACT

The aim of this dissertation was twofold. First, this thesis explored the role that working memory plays in children's motor learning. Working memory is responsible for the temporary storage and manipulation of information in the mind, and is the primary mechanism underpinning the conscious acquisition of motor knowledge. However, working memory is still developing throughout childhood and, therefore, it is possible that most (if not, all) motor information learnt during childhood occurs sub-consciously. Indeed, the results showed that a person's working memory capacity influenced skill performance and learning. Children with larger working memory capacity had a greater tendency to test hypotheses (i.e., make alterations to technique) when performing a motor skill, were more likely to consciously control their movements as indicated by the Movement Specific Reinvestment Scale, and were advantaged when verbal instructions were provided. Further, studies with adults showed that working memory capacity predicted both performance in a pressured situation and the amount of EEG coherence between the motor regions of the brain and the verbal-analytical and visuo-spatial regions. The second main aim of this dissertation investigated the influence that modified equipment had on children's skill acquisition. As hypothesised, skill performance and learning was enhanced when using modified equipment (e.g., smaller racquets and lower compression balls) compared to using full-size equipment. Importantly, the use of modified equipment placed fewer demands on working memory during performance of a skill, which implies that it encourages an implicit mode of learning. Overall, this thesis contributes to the small but growing literature examining implicit motor learning in children and increases our understanding of the influence that working memory has on the acquisition of motor skills.

STUDENT DECLARATION

I, Tim Buszard, declare that the PhD titled 'Motor skill acquisition in childhood: Exploring the links between working memory, implicit learning and equipment modification' is no more than 100,000 words in length including quotes and 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 award of any other academic degree or diploma. Except where otherwise indicated, this thesis is my own work.

Signature: [redacted] Date: 27/8/2014

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There are three people I must thank first – Damian Farrow, Rich Masters and Machar Reid – my three supervisors. They proved to be the perfect combination. Typically, Rich was the theorist, always questioning what I was doing and the reasons why, and providing endless ideas. Machar, the high performance manager of Tennis Australia, ensured that I was constantly thinking about the applied element of my research. And Damian, my primary supervisor, was brilliant at understanding both the theoretical and applied nature of my work.

When I began my PhD in 2011, I entered an environment of academics, whereby I was the youngest with the least experience. Initially, I was unsure as to whether I had the skill set to match it with my superior peers. However, to the credit of Damian, he taught me (probably without realising it) to trust my intuition and to be confident with the decisions I made. To that end, I thank 'Damo' as that was as important as any 'academic knowledge' I learnt throughout my PhD. Damian's relaxed persona also allowed my PhD to be very stress-free and thoroughly enjoyable. My favourite 'supervisor meetings' occurred on the golf course… although, come to think of it, I am not sure if much was achieved during these meetings other than discover weaknesses with our golf! Importantly, however, Damian's ability to provide quick feedback regarding my work (despite wherever he was in the world) was a testament to his remarkable work ethic.

Rich was no different. There were two things I learnt from Rich that I will endeavor to carry with me with everything I pursue into the future. First, Rich taught me (and is still teaching me for that matter) the importance of being meticulous with my work. Rich is a master at spotting the smallest of errors in any paper that I write. Second, he taught me the value of thinking laterally. Usually I would start a conversation with Rich trying to narrow down my ideas but, instead, I would always walk away with more ideas than I began with! Although, ultimately, Rich was a great motivator and he has certainly inspired me to pursue a

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Finally, thank you to my family – Mum, Dad and Peter – for their support over the past three years. Given dad's professional sports coaching background, we have had endless discussions about implicit motor learning and the difficultly in implementing coaching strategies that encourage implicit learning when a parent is listening intently (and expecting) some explicit words of advice! However, we both agreed that traditional coaching methods should not impede the use of other more subtle coaching practices that encourage implicit learning. Thank you also to the Smith family (Wayne, Kate, Josh and Alex) in Northop Hall (UK) where I lived for 5 months at the beginning of my PhD. Similarly, thanks also to the Sparks' family (Tony, Carol and Maeve) for their support during my time living in the UK.

As I finished writing this thesis, I think back to the two things that I often heard from others who have completed a PhD. First, many talk about 'the end your social life' during the PhD years. Second, most talk of the relief they felt when they finally finished. For me however, I don't think I could have enjoyed my PhD years anymore. And, although I feel much satisfaction in completing this thesis, I actually feel like this might just be the beginning.

LIST OF PUBLICATIONS & PRESENTATIONS

Sections of this thesis have been published (or submitted for publication) and/or presented at relevant scientific conferences.

PUBLICATIONS

Chapter 3

Buszard, T., Farrow, D., Reid, M., & Masters, R. S. W. (in review). Hypothesis testing by children performing motor tasks: The influence of verbal working memory. *Quarterly Journal of Experimental Psychology.*

Chapter 4

Buszard, T., Farrow, D., Zhu, F. F., & Masters, R. S. W. (2013). Examining movement specific reinvestment ad working memory capacity in adults and children. *International Journal of Sports Psychology,* 44(4), 351-366.

Chapter 6

Buszard, T., Farrow, D., Reid, M., & Masters, R. S. W. (in press). Scaling sporting equipment for children promotes implicit processes during performance. *Consciousness and Cognition.*

Chapter 7

Buszard, T., Farrow, D., Reid, M., & Masters, R. S. W. (2014). Modifying equipment in early skill development: A tennis perspective. *Research Quarterly for Exercise & Sport, 85*(2), 218-225.

Other publications during my PhD

Buszard, T., Farrow, D., & Masters, R. S. W. (2013). What is the 'significance' of choking in sport? A commentary on Mesagno and Hill. *International Journal of Sports Psychology*, 44(4), 278-280.

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SPORTS COACHING PROFESSIONAL PUBLICATIONS

Buszard, T., Farrow, D., Reid, M., & Masters, R. S. W. (2013). Implicit motor learning: Designing practice for performance. *ITF Coaching & Sport Science Review*, *60,* 3-5.

MEDIA PUBLICATIONS

Buszard, T. (2014). Different strokes: How Rafael and Tiger hit the top of their games. Retrieved from http://the conversation.com/different-strokes-how-rafael-and-tiger-hit-the-top of-their-games-22238

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SCIENTIFIC CONFERENCE PRESENTATIONS

Buszard, T., Farrow, D., Reid, M., & Masters, R. S. W. (2012). *The benefits of modified equipment for children playing tennis.* Paper presented at the Australasian Skill Acquisition Research Group, Melbourne, Australia.

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INVITED PROFESSIONAL SEMINAR PRESENTATIONS

Buszard, T. (2013). *The modified approach to developing success in tennis*. Invited presentation at the Institute of Sport, Exercise and Active Living Seminar, Melbourne, Australia.

Buszard, T. (2013). *The modified approach to developing success in tennis.* Invited presentation at Dortmund University, Dortmund, Germany.

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CHAPTER 1

INTRODUCTION & OVERVIEW OF THESIS

Introduction

The acquisition of a motor skill is a complex process. Traditional theories of motor learning postulate that there is high conscious involvement in early skill acquisition (Fitts & Posner, 1967), whereby the performer is trying to discover the most effective and efficient movement patterns to execute the skill (i.e., testing hypotheses). Consequently, the performer acquires a set of explicit rules about how the skill should be performed. For example, a golfer learning to hit a 'drive' might develop the rule: "I hit the ball more accurately when I swing the club slower". The cognitive process supporting this 'rule-making' behavior is working memory (Maxwell, Masters, & Eves, 2003) – the construct responsible for the temporary storage and manipulation of information in the mind (Baddeley, 2010; Baddeley & Hitch, 1974; Gathercole, 2008). Over time, following substantial practice, performance of the skill improves and there is less working memory involvement. Eventually, when the skill is mastered, it is performed independent of working memory. This is also referred to as *automaticity* (Fitts & Posner, 1967).

While this theory of motor learning may provide an accurate account for the acquisition of many skills, it does not explain how some skills are acquired without conscious involvement. For instance, it is highly unlikely that a young child learning to walk develops explicit rules to acquire such movements. Masters (1992) proposed the implicit motor learning theory, which suggests that skills can be acquired with minimal conscious processing. As such, a performer that learns a skill implicitly has difficulty verbalising the processes involved in the execution of the skill (e.g., Hardy, Mullen, & Jones, 1996; Masters, 1992; Maxwell et al., 2003). While this theory has largely been applied to adults, the principles of implicit motor learning are likely to hold true for young children. Indeed, Reber (1992a, 1992b) argues that implicit processes are an older cognitive system than explicit processes and, therefore, skills acquired implicitly remain largely unaffected by factors such as age and intelligence.

If young children are more inclined to acquire motor skills implicitly, there must be a stage in a child's development whereby explicit (conscious) processes become more involved in the acquisition of a skill. For example, if a 4-year-old learns a skill using predominantly implicit processes, and a 20-year-old learns using predominantly explicit processes, when does the transition from implicit to explicit processing occur? Additionally, what are the mechanisms underpinning this transition? Given that working memory plays a critical role in explicit motor learning in adults, it is likely that the development of working memory throughout childhood (e.g., Gathercole, Pickering, Ambridge, & Wearing, 2004) increases the propensity for explicit processing of information. If this prediction is correct, then children's learning should be enhanced if practice places fewer demands on the developing working memory.

Capio, Poolton, Sit, Holmstrom, and Masters, (2013) argued that the reduction of errors during practice is one method of reducing demands on working memory to enhance skill acquisition in children. This typically involves the manipulation of the target to ensure successful outcomes (e.g., increasing the target size). Another potential method, based on a similar principle, is the use of modified equipment to simplify the skill for children. By simplifying the skill, children may be more inclined to perform the skill using unconscious processes. Conversely, using equipment that increases the skill's difficulty (e.g., a heavy tennis racquet) may encourage conscious processes. Given that the use of modified equipment is commonplace in junior sport, understanding this theoretical issue has important practical implications.

Aims of the Dissertation

General Aims

This thesis aims to increase our understanding of children's motor learning by examining the influence of working memory on the acquisition of motor skills. Furthermore, this thesis aims to extend the small but growing literature examining implicit motor learning in children by investigating whether the use of modified equipment reduces the reliance on working memory and, in turn, encourages an implicit mode of learning.

Specific Aims

1. To explore whether working memory capacity predicts the propensity to test hypotheses when acquiring a motor skill.
2. To examine the relationship between working memory capacity and the likelihood of consciously controlling movements.
3. To determine if working memory capacity predicts brain activity (electroencephalography coherence) between the regions of the brain associated with motor performance when executing a motor skill.
4. To investigate whether working memory capacity influences motor learning when the practice environment places large demands on working memory.
5. To discover if the use of modified equipment reduces demands on working memory during performance of a motor skill.
6. To assess whether the use of modified equipment enhances skill performance and learning.

Chapter Organisation

Chapter 1 has introduced the topic of the dissertation by providing a brief rationale for the research while discussing the specific aims of the thesis. Chapter 2 critiques research encompassing the study of motor learning in children, with a specific focus on its interaction with the children's cognitive development. In chapters 3 to 5, a series of experiments are presented that aim to examine the influence of working memory capacity on skill acquisition and skill performance. Chapters 6 to 8 present experiments that aim to establish whether the use of modified equipment reduces reliance on working memory during performance and, subsequently, whether it is beneficial to children's motor learning. The final chapter (Chapter 9) summarises the findings of each chapter and discusses the theoretical, practical and methodological implications of the study, as well as providing directions for future research.

Specifically, Chapter 3 investigated the relationship between working memory capacity and the propensity to test hypotheses when performing a motor skill. Results indicated that hitting accuracy and verbal working memory capacity were the most significant predictors of hypothesis-testing, with lower hitting accuracy and larger verbal working memory capacity associated with more hypotheses being tested. The findings of this study established the important role that working memory may play during children's motor learning.

In Chapter 4, two experimental papers are presented that further examine the relationship between working memory capacity and conscious control of movements. The first experimental paper explored the relationship between verbal and visuo-spatial working memory capacity, the propensity for conscious monitoring and control of movement, and performance of a novel tennis-hitting task. In both children and adults, verbal working memory capacity was positively associated with the score on a validated psychometric measure of the propensity for conscious monitoring and control of motor performance (the

Movement Specific Reinvestment Scale). Additionally, for adults, verbal working memory capacity predicted the amount of improvement in performance during a pressured situation, with lower capacity performers displaying greater skill improvements than higher capacity participants. The findings are discussed in the context of cognitive demands of problem solving and hypothesis testing during early skill acquisition and implicit motor learning theory.

The second experimental paper in Chapter 4 extends these findings by assessing whether individual differences in working memory capacity influenced the amount of EEG activity when performing a tennis-hitting task. Results showed that both verbal and visuo-spatial working memory were significant predictors of EEG coherence in the T3-Fz regions of the brain (i.e., the verbal-analytical and the motor planning regions). Larger verbal working memory capacity was associated with greater coherence while the opposite trend was observed for visuo-spatial working memory capacity. There was also some evidence that larger visuo-spatial working memory was associated with lower coherence in the T4-Fz regions (i.e., the visuo-spatial and the motor planning regions). These results indicate that larger verbal working memory capacity is associated with a greater tendency to use explicit processes during motor performance, whereas larger visuo-spatial working memory capacity encourages implicit processes.

Chapter 5 details a field-based experiment that assessed the influence of working memory capacity in young children on skill acquisition following the provision of (i) explicit verbal instructions or (ii) no explicit verbal instructions. Presumably, the provision of explicit instructions would place large demands on working memory, which should advantage children with larger working memory capacity as they can hold and process this information in their mind. Indeed, children with larger working memory capacity displayed greater improvements following a 5-week intervention that included the provision of explicit verbal instructions. For the practice groups that received no explicit instructions, there was no difference between low and high working memory children with regards to the amount of skill improvement from pre- to post-test. Ultimately, the findings of this study provide further evidence that working memory capacity plays a critical role during the acquisition of motor skills in children.

Based on Chapters 2-5, it seemed logical that children's motor learning would be enhanced if practice environments placed fewer demands on working memory. Subsequently, Chapters 6-8 present three experiments that aimed to examine the influence of children using modified equipment on skill acquisition and performance, and whether the use of such equipment reduces demands on working memory (i.e., encourages implicit motor learning). Chapter 6 investigates whether the use of modified equipment (smaller tennis racquet and lower compression ball) by children reduces conscious processing during performance, thus minimising working memory involvement, compared to the use of full size equipment. Results showed that hitting performance was not disrupted by a cognitively demanding secondary task when using modified equipment. Comparatively, performance was significantly worse when using full size equipment; although, this was only observed with the less skilled children. The results are discussed with relevance to implicit motor learning theory.

Chapter 7 assesses the influence that varying racquet sizes and ball compressions have on children's ability to play a forehand groundstroke. As predicted, hitting performance was best when the smallest racquet was used in combination with the ball with the least compression. The ball with the least compression also promoted two technique benefits: swinging the racquet from low-to-high and striking the ball in front and to the side of the body. Overall, this study demonstrated the benefits for young children playing with scaled racquets and low compression balls, and supports the contention that using modified equipment simplifies skills for children.

Chapter 8 compares the use of a small racquet versus a large racquet on children's skill acquisition over a five-week period. Specifically, the study aimed to discover whether the use of modified equipment evoked an implicit mode of learning. Results showed that the children practising with the small racquet displayed greater improvements in hitting technique than the children using the large racquet. However, there was no evidence of implicit-explicit learning differences between the use of the small and large racquet. This was likely due to certain limitations of the study.

The final chapter of this thesis (Chapter 9) provides a summary and a general discussion of the experimental series. Implications of the research are considered with specific reference to the two themes during this thesis: the role of working memory during children's skill acquisition and the influence of modified equipment on the learning process.

Please note that the majority of chapters in this dissertation have been written with the intention to publish (or have already been published) and, subsequently, the definitions of key terms (e.g., implicit motor learning, working memory) have been repeated in several chapters.

CHAPTER 2

A REVIEW OF THE CONSCIOUS (AND UNCONSCIOUS) PROCESSES ASSOCIATED WITH MOTOR LEARNING IN CHILDREN

Introduction

The study of motor learning, particularly in children, has interested researchers for over a century (for an overview of a century of motor skill acquisition research, see Adams, 1987). For instance, in the late 1890's, a series of studies were conducted which examined the motor behaviour and development of infants and young children (Moore, 1897; Tracy, 1896; Trettien, 1900). Interestingly, the cited observations are still of curiosity today. For example, Tracy (1896) reported: "children not only manifest more automatisms than adolescents on a whole, but are surprisingly more prodigal in the use of certain parts" (pp. 699). Ultimately, this observation reflects the main aim of this review: do children learn motor skills via unconscious processes (i.e., automatically/implicitly), or, like adults (and adolescents), do conscious processes play a role in the acquisition of motor skills? If young children do learn motor skills unconsciously, there must be a point in time where conscious processes begin to have an influence. I argue that this 'point in time' is a reflection of the child's cognitive development. There is further research in other domains showing that children tend to learn skills unconsciously (e.g., first-language learning, Chandler, 1993; second-language learning, Carr & Curran 1994; social skills, Reber, 1993); however, there is a lack of understanding of the manner in which children acquire motor skills. In this chapter, I begin by reviewing theories of skill acquisition and how these apply to children. I then explore cognitive development in children, and discuss how age and cognitive development may influence the manner in which information is processed. Finally, practical ideas of how to enhance children's motor learning are discussed.

Motor Learning in Children

Children display the ability to perform many complex tasks, such as striking a ball with a racquet, kicking a football, or climbing the monkey bars in the playground. However, despite this ability, could children (like adults) explicitly explain how they perform these skills? The answer to this question is likely to be related to the manner in which children acquired the skill. For instance, implicit motor learning research has shown that individuals who learn a skill implicitly (unconsciously) have difficulty verbalising how they executed the skill, whereas individuals who learn a skill explicitly (consciously) are able to report many ‘rules’ about how the skill was performed (Hardy et al., 1996; Lam, Maxwell, & Masters, 2009; Law, Masters, Bray, Eves, & Bardswell, 2003; Liao & Masters, 2001; Masters, 1992; Masters, Lo, Maxwell, & Patil, 2008; Masters, MacMahon, & Pall, 2004; Masters, Poolton, Maxwell, & Raab, 2008; Maxwell, Masters, & Eves, 2000; Maxwell et al., 2003; Maxwell, Masters, Kerr, & Weedon, 2001; Orrell, Eves, & Masters, 2006b; Poolton, Masters, & Maxwell, 2006; Poolton, Masters, & Maxwell, 2007a; Poolton, Masters, & Maxwell, 2007b). The relevant question therefore appears to be: are children more inclined to learn motor skills implicitly or explicitly? The following sections delve into the complexity of this question.

Theories of Skill Acquisition

Cognitive theories of skill acquisition (Anderson, 1983; Fitts & Posner, 1967; Proctor & Dutta, 1995) suggest that skills are initially acquired with substantial verbal engagement in the task, with the learner consciously devising strategies to achieve the desired outcome (i.e., hypothesis testing). After extensive repetition of the skill, performance becomes automatic, with reduced verbal engagement. Specific to motor learning, this model holds true for adults, as there is considerable research demonstrating that adults consciously accumulate declarative knowledge about the task during the initial stage of learning (Hardy et al., 1996; Lam et al., 2009; Masters, 1992: Maxwell et al., 2003; Orrell, Eves, & Masters, 2006a). For example, in the seminal paper by Masters (1992), young adults who learnt to golf put on their own accord (i.e., no verbal instructions – ‘discovery learning’) reported significantly more 'explicit' rules about how the skill should be executed compared to the participants who learnt the skill via an implicit practice method[1] (see also Hardy et al., 1996; Maxwell et al., 2000). Furthermore, discovery learners performed significantly worse under stressful conditions, which was presumably a consequence of a highly conscious learning style (Hardy et al., 1992; Masters, 1992). Studies have also shown that the declarative knowledge accumulated about skill performance was reflected in alterations made to technique during practice (Maxwell et al, 2001; Poolton, Masters, & Maxwell, 2005). For example, if a golfer reported that "I hit the ball more accurately when I changed my grip", not surprisingly, when examining video replay, they actually did change their grip!

Neuroscience research provides further evidence that the initial stage of learning involves a high degree of conscious involvement in adults. High electroencephalography (EEG) coherence between the verbal-analytical regions and the motor-planning regions of the cerebral cortex implies communication between these regions (Silverstein, 1995; Weiss & Mueller, 2003). For novice golfers learning to golf putt, there was high coherence between these regions during the initial stage of practice, indicating large conscious involvement (Zhu et al., 2010). Likewise, expert marksmen displayed lower coherence between these regions compared to novice shooters prior to shot execution, suggesting that there is less verbal-cognitive involvement as skill performance becomes automated (Deeny, Haufler, Saffer, & Hatfield, 2009). Thus, when we combine the research discussed above, there is considerable evidence to suggest that there is substantial conscious involvement when initially learning a motor skill during adulthood.

With regards to children however, the literature remains silent about whether learning also occurs in a similar conscious driven manner. There is strong rationale to believe that

[1] In the Masters (1992) study, the 'implicit learners' practised golf putting using the dual-task practice technique. This involved practising golf putting whilst concurrently performing a secondary task. By doing this, the performer had reduced opportunity to analyse their movement patterns; thus, accumulation of consciously accessible declarative knowledge about the skill was limited.

young children, whose important cognitive functions are still developing (Alloway, Gathercole, & Pickering, 2006; Best & Miller, 2010; Halford, Maybery, O'Hare, & Grant, 1994; Luciana, Conklin, Hooper, & Yarger, 2005; Luna, Garver, Urban, Lazar, & Sweeney, 2004; Markovitz, Fleury, Quinn, & Venet, 1998; Thomason et al., 2009; van Leijenhorst, Crone, & van der Molen, 2007), are more inclined to learn motor skills implicitly rather than explicitly. In the following section, I discuss the literature examining 'age of acquisition', drawing upon research from language learning.

Age of Acquisition: The Benefits of Learning Early

It is well documented that young children learn languages easier than adults, with faster reaction times and greater accuracy found when responding to words learnt in early childhood compared to in adulthood (Barry, Morrison, Ellis, 1997; Cuetos, Ellis, & Morrison, 1999; Ellis & Morrison, 1998; Gerhand & Barry, 1998, 1999; Gilhooly & Gilhooly, 1979; Lewis, 1999; Meschyan & Hernandez, 2002; Morrison, Chappell, & Ellis, 1997; Morrison & Ellis, 1995, 2000). Furthermore, neuroimaging studies show that late-learned words, compared to early-learned words, elicit greater activation in areas of the brain that are responsible for phonological word representations (Fiebach, Friederici, Muller, von Cramon, & Hernandez, 2003; Hernandez & Fiebach, 2006). This indicates that language learning in adulthood involves greater conscious processing involving explicit memory, whereas early-learned words elicit greater activation in the areas of the brain responsible for auditory processing.

Hernandez, Mattarella-Micke, Redding, Woods, and Beilock (2011) applied the language-learning research to motor learning and proposed that the manner in which motor skills are learnt in early childhood are different to adulthood. According to the sensorimotor hypothesis (Hernandez & Li, 2007), children process information implicitly rather than explicitly, involving more perceptual and motor processes than verbal-analytical processes. Adults, on the other hand, tend to rely on conscious hypothesis testing strategies that utilise explicit memory. Other developmental theorists also support the notion that children learn motor skills implicitly (e.g., Karmiloff-Smith, 1992). Hernandez et al. (2011) examined putting performance of two groups of golfers: those that learnt to play prior to the age of 10 (early learners) and those that learnt after the age of 10 (late learners). Golf putting was assessed in three conditions – a single-task condition (normal putting), a skill-focused condition (attention directed towards the skill mechanics) and a dual-task condition (attention directed to a non-relevant secondary task). There were no differences in putting performance between the groups in the single-task and dual-task conditions. However, there was a significant interaction between ‘age of acquisition’ and performance in the skill-focused condition. When attention was directed towards the skill mechanics, the putting of the early learners was worse than the late learners. This difference between groups corresponds with the differences found between experts and novices in a previous study (Beilock, Carr MacMahon, & Starkes, 2002) with experts performing worse when attention was directed towards the skill. Hernandez et al. (2011) therefore concluded that the early learners, like experts, relied more on implicit memory to perform the skill. Consequently, when attention was directed towards the skill mechanics, performance was disrupted. To perfectly replicate the expert-novice differences in the Beilock et al. (2002) study, the late learners would have performed worse than the early learners in the dual-task condition, as this would demonstrate that the late learners relied more on cognitive processes to perform the skill. However, no differences between the groups were found. This may indicate that late learners rely on a mix of implicit and explicit memories that do not lead to poor performance in skill focused or dual-task conditions (Savion-Lemieux, Bailey, & Penhune, 2009).

Despite the findings by Hernandez et al. (2011), we should interpret the results with caution. The authors claim that both groups were matched for skill level, age and years of golf experience. Although, if the groups were the same age during the experiment and had the same years of golf experience, how can their ‘age of acquisition’ be much different from each other? Also, each group had approximately 12 years of golf experience, but does this mean they were playing consistently on a weekly basis for 12 years? This is doubtful given that the handicaps of the two groups were 24 (early learners) and 18 (late learners), which are relatively high for persons playing golf consistently for 10 years. Thus, the measurement of ‘golfing experience’ must be questioned in this study given that we do not precisely know the amount of golf each group had played. Indeed, the variability in golfing experience among the participants was very high (6 to 22 years). When we add the small sample size (n = 20) to the list of limitations, the reliability and validity of the results in this study are difficult to infer.

Nevertheless, the sensorimotor hypothesis is supported by research in other motor domains. For example, musicians appear to only learn absolute pitch prior to the age of 6 (Deutsch, Henthorn, Marvin, & Xu, 2006; Trainor, 2005), and early music practice correlates with changes at the neural level (Elbert, Pantev, Weinbruch, Rockstroh, & Taub, 1995; Schlaug, Jancke, Huang, Staiger, & Steinmetz, 1995). Thus, early childhood appears to be a critical period for learning motor skills (for a discussion of ‘critical periods of learning’, see Knudsen, 2004). Collectively, this body of research suggests that differences in memory processes exist between people who learn skills early in life compared to later in life. The question still remains, however: what are the underlying differences between children and adults in cognitive functioning that cause the differences in memory processing?

Children's Cognitive Development

Important cognitive functions develop throughout childhood and these are likely to influence the manner in which motor skills are learnt. According to the classic work by Piaget (1937, 1954) and Bruner (1977, 1987, 1990), children's cognitive development can be divided into stages. The first stage occurs in the first one-to-two years of life, where memory and language begin to develop. Bruner specifically argued that information learnt in these years is stored as 'muscle memory' (i.e., implicit memory) rather than internal representations (i.e., explicit memory). From age 2 to 7, language becomes more mature and children learn to distinguish between past and future events, with information learnt being stored as sensory images. It should be noted however that neither Piaget nor Bruner suggested that children learn information using conscious explicit processes prior to the age of 7. From ages 7 to 12, Piaget argued that children developed 'operational thinking', which involves the ability to perform reversible mental actions and recognise one's own thoughts. Finally, the ability to formulate hypotheses and consider possibilities occurs after the age of 12. Bruner accounted for these developmental changes by proposing that after the age of seven, children develop the ability to store information as symbols (words) in verbal (explicit) memory. According to this view, it is after the age of 7 when children represent the world through language. Thus, if we relate these theories to motor learning, it would appear that children process information implicitly prior to the age of 7, and explicitly after this age. This conclusion sits well with the sensorimotor hypothesis (Hernandez & Li, 2007; Hernandez et al, 2011); however, unfortunately it is not this simple. Individual differences in the development of cognitive functions make it difficult to draw such precise conclusions. These theories, nevertheless, do provide a good framework for our understanding of children's cognitive development.

The behavioural changes in children's cognition, as outlined by Piaget and Bruner, are likely to be partially attributable to developments in executive functions – the cognitive processes that underlie goal-directed behaviour (Best & Miller, 2010). Executive functioning is thought to be comprised of three interrelated but separate components (Best & Miller, 2010; Miyake et al., 2000): inhibition, shifting and working memory. Inhibition refers to the ability to constrain a response to a certain stimulus; shifting is the skill of switching focus between multiple tasks; and working memory involves the maintenance and manipulation of information over brief periods of time. These three components are dissociable in early childhood (Hughes, 1998; Senn, Epsy & Kaufmann, 2004; Welsh, Pennington, & Groisser, 1991), and there is evidence showing that these components develop substantially after the age of five through to adolescence (for a comprehensive review of the development of executive function, at both the behavioural and neural level, see Best & Miller, 2010). Similarly, the speed of information processing has been shown to decrease exponentially throughout childhood until approximately 15 years of age (Adams & Lambos, 1986; Hale, 1990; Kail, 1993; Ruffer, Grapenthin, Huey, & Patterson, 1985; for a review of the development of processing speed, see Luna et al., 2004). Improvements in processing speed appear to assist the development of other cognitive functions such as working memory. Indeed, probably most relevant to motor learning is the development of working memory, as this function plays a key role in the explicit acquisition of motor skills (Maxwell et al, 2003).

Working Memory: An Overview

The notion of working memory evolved from the over-simplistic concept of short-term memory (e.g., Atkinson and Shiffrin, 1971). Working memory refers to the temporary storage of information while other cognitive tasks are being performed, whereas short-term memory only refers to the temporary storage of information (Baddeley, 2010; Gathercole, 2008). The most influential theoretical account of working memory was Baddeley and Hitch’s (1974) multicomponent model. This model has been refined and extended over the years (Baddeley, 1986, 2000; Burgess & Hitch, 1992, 1999) and now consists of four components (see Figure 2.1): the phonological loop, the visuospatial sketchpad, the central executive and the episodic buffer. The phonological loop and the visuospatial sketchpad are considered slave sub-systems that specialize in the temporary storage of information in particular domains (verbal and visuo-spatial, respectively). In contrast, the central executive is theorized to be responsible for a range of regulatory functions including attention, the control of action, problem solving and the retrieval of information from long-term memory. The fourth component, the episodic buffer, is thought to bind representations from different parts of the system (e.g., combining visual information with auditory information).

Alternative theories of working memory have been proposed with some highlighting the role of attention (Cowan, 1995, 2001; Engle, Tuholski, Laughlin, & Conway, 1999), others viewing working memory as a flexible resource system (Daneman & Carpenter, 1980, 1983; Just & Carpenter, 1992), and a few emphasizing time-based loss of information (Barrouillet, Bernadin, & Camos, 2004; Barrouillet & Camos, 2001; Towse & Hitch, 1995). Given that the multicomponent model (Baddeley, 2000; Baddeley & Hitch, 1974) is the most enduring and influential framework in the field, this discussion will focus predominately around this model.

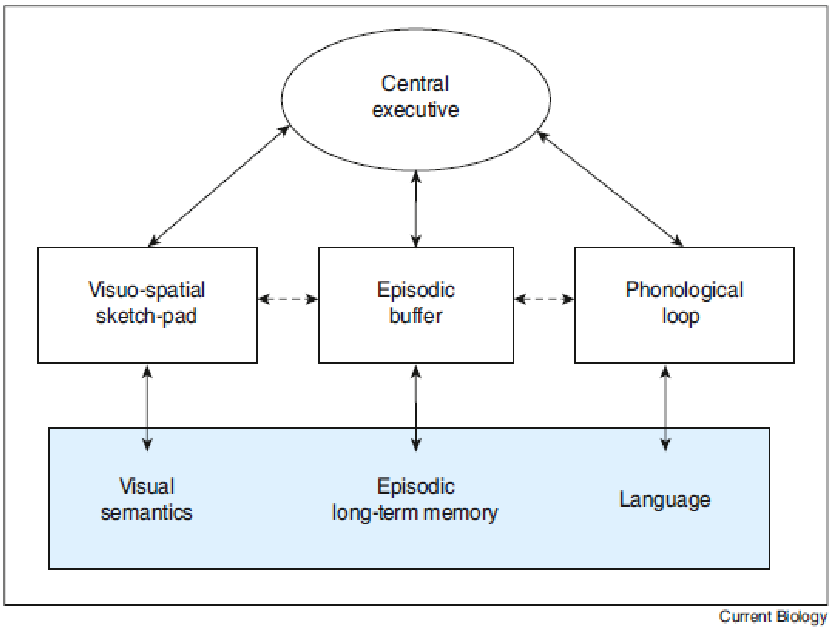


Figure 2.1. Baddeley's revised multicomponent model of the working memory. It includes links to long-term memory and a fourth component, the episodic buffer that is accessible to conscious awareness [extracted from Baddeley, 2010].

Before discussing the development of working memory and its potential influence on motor learning, it is important to first have a clear understanding of the two slave sub-systems.

(i) *The phonological loop (also referred to as verbal working memory)* has two components: a short-term store and a sub-vocal rehearsal process. Speech-coded information is stored for a temporary period of time in the short-term store, and this information decays rapidly if no sub-vocal rehearsal is applied. Information that is sub-vocally rehearsed can be maintained in the phonological loop indefinitely, provided that rehearsal continues. Information that is not presented verbally but still has a verbal label (e.g., printed words or a picture of an apple), can still be represented in the phonological loop if rehearsal occurs. However, this has only been observed in older children and adults (e.g., Hitch, Halliday, Schaafstal, & Schraagen, 1988), representing the developmental differences in working memory from young children to adults. This is discussed further in the next section.

(ii) *The visuo-spatial sketchpad (also referred to as visuo-spatial working memory)* is also comprised of two components; however, unlike its sister slave system, there is no rehearsal process as this would activate speech-motor planning. The two components are a visuo store and a spatial store, which stores visual and spatial information respectively.

The Development of Working Memory: From Birth to Adulthood

Working memory appears to emerge during late infancy, as evidenced by the ability to direct one's actions into the future (Diamond, 1990), and there is substantial literature showing that working memory gradually improves throughout early childhood (Alloway et al., 2006; Zelazo, Fry, Rapus, 1996; Zelazo & Resnick, 1991) and into adolescence (Bjorklund, 1987; Chelonis, Daniels-Showb, Blakea, & Paule, 2000; Conklin, Luciana, Hooper, & Yarger, 2007; Gathercole et al., 2004; Hitch, Towse, & Hutton, 2001; Kemps, de Rammaleare, & Desmet, 2000; Luciana et al., 2005; Luna et al., 2004).

The development of working memory is typically characterised by better literacy skills and problem solving ability (Siegal & Ryan, 1989; St Clair-Thompson & Gathercole, 2006; Swanson, 2011; Swanson, Orosco, Lussier, Gerber, & Guzman-Orth, 2011). Children display the ability to solve non-numeric (spatial) relations at the age of 5 and, typically at this age, children solve problems using simple 'trial-and-error' strategies (Davidson, 1987). However, between the ages of 5 and 7, children switch to anticipatory strategies, which involves mentally combining two sets of information (Davidson, 1987). If we apply this problem-solving strategy to motor learning, it would suggest that at approximately 7 years of age, children develop the ability to combine information about movement patterns in relation to performance outcomes and, thereby, develop the ability to learn explicitly.

The switch in problem solving strategies may specifically be related to the development of the verbal and visuo-spatial components of working memory respectively. Some researchers argue that the distinction between the verbal and visuo-spatial components of working memory become clear by age of 10 (Hale, Bronik, & Fry, 1997), while other researchers have shown that the two components are already separable between the ages of 4 and 6 (Alloway et al., 2006; Gathercole et al., 2004; Pickering, Gathercole, & Peaker, 1998). The separation between the verbal and visuo-spatial components can also be interpreted as hemisphere laterisation; meaning that the left hemisphere of the brain is activated during verbal working memory tasks (Henson, Burgess, & Frith, 2000; Smith & Jonides, 1997; Smith, Jonides, & Koeppe, 1996) and the right hemisphere is activated during visuo-spatial hemisphere tasks (Smith & Jonides, 1997). It is thought that hemisphere specialization is the yardstick for the organisation of mental functions (Thomason et al., 2009). Whilst it was previously argued that hemisphere laterisation develops slowly (Lenneberg, 1967), it now appears that even infants show some degree of hemisphere specialisation (Best, Hoffman, & Glanville, 1982; Holowska & Petitto, 2002; Molfese, Freeman, & Palermo, 1975) and, by the age of eight, there is no difference in laterisation from adults (Luna et al., 2004; Thomason et al., 2009). The main difference between children and adults is the inability of children to activate other areas of the brain when working memory load increases. This therefore represents the smaller working memory capacity of children compared to adults (Thomason et al., 2009). Indeed, working memory development can be attributed to the maturation of important brain processes (Changeux & Danchin, 1976; Diamond & Goldman-Rakic, 1989; Huttenlocher, 1990; Yakovlev & Lecours, 1967).

The differences between children and adults in working memory functioning can be further narrowed down to differences between young children and older children. It appears young children do not have the ability to code pictures as verbal information like older children and adults do. Children younger than 7 years typically rely on the visuo-spatial sketchpad to remember information presented visually, whereas older children tend to process this information using the phonological loop (Halliday, Hitch, Lennon, & Pettipher, 1990; Hitch & Halliday, 1983; Hitch et al., 1988; Hitch, Woodin, & Baker, 1989). For example, when looking at a banana, young children will remember the *image* of the banana, whereas older children will remember its *name*. Whilst the phonological loop is in place by the preschool period (i.e., about 4 years of age), it appears that the sub-vocal rehearsal process does not develop until the middle childhood years (i.e., after 7 years of age).

To summarise the working memory research, children learn the ability to solve problems in early childhood (e.g., Siegal & Ryan, 1989); however, information is typically processed in the visuo-spatial system (Hitch et al., 1988). At approximately 7 years of age, children begin solving problems using anticipatory strategies (Davidson, 1987). This is likely related to a switch in information processing, from the visuo-spatial system to the phonological loop (Hitch et al., 1988). The development of working memory is underpinned by the maturation of the brain (e.g., Huttenlocher, 1990), including the specialization of hemispheres (e.g., Thomason et al., 2009). Overall, this body of research provides further support that young children (prior to the age of 7) acquire information with little verbal involvement (i.e., implicitly), whereas older children tend to acquire information explicitly.

Individual Differences in Working Memory Capacity

Individual differences exist in working memory capacity and these differences affect performance in day-to-day cognitive tasks. For instance, studies have shown that people with high working memory capacity, compared to people with low working memory capacity, are better at controlling attention on a task to keep the relevant information in active memory (Conway, Cowan, & Bunting, 2001; Kane & Engle, 2002; Unsworth, Schrock, & Engle, 2004). Similarly, people with low working memory capacity are more likely to have their mind 'wander' when performing a complex task (Kane et al., 2007). Finally, working memory capacity has been shown to be a key predictor of academic achievement in later years, with higher working memory capacity correlating with greater academic success (Alloway et al., 2007; Nevo & Breznitz, 2011).

Given these findings, differences in working memory capacity may therefore also influence motor skill learning. Individuals with low working memory capacity are less likely to have the ability to assess their movement patterns in relation to performance outcome, and then keep this information in active memory to apply to the next performance. Perhaps this prediction is most relevant for children whose working memory capacity are still developing. For instance, imagine there are two children: Child *A* and Child *B*, and they are both eight years of age. Child *A*, however, has a large working memory capacity relative to their age, whereas child *B* has a small working memory capacity. When they both begin learning a novel motor skill, it is more likely that Child *A* will acquire the skill with some conscious involvement, by consciously comparing movement patterns with performance outcome, whereas Child *B* will probably learn the skill implicitly with no verbal engagement.

Enhancing Children's Motor Learning, *Implicitly*!

Based on the review of children's cognitive development, it appears that young children, who have immature working memory, are more likely to learn motor skills via unconscious/implicit processes. It therefore seems logical that children's learning of motor skills would be enhanced if the principles of implicit motor learning were adopted (Capio, Sit, Abernethy, & Masters, 2012). Implicit motor learning refers to the acquisition of a skill with little to no working memory involvement and, subsequently, minimal accrual of task-related declarative knowledge (Masters, 1992; for a recent review of implicit motor learning, see Masters & Poolton, 2012). A number of practice techniques have been developed to evoke the implicit acquisition of motor skills in adults, such as dual-task practice (Hardy et al., 1996; Masters, 1992; Maxwell et al., 2000), removing feedback (Maxwell et al., 2003), providing ‘subliminal’ feedback (Masters, Maxwell, & Eves, 2009) using analogies as instructions (Lam et al., 2009; Liao & Masters, 2001; Poolton et al., 2007b; Poolton et al., 2006) and limiting errors during practice (Masters et al., 2004; Masters, Poolton, & Maxwell, 2008; Maxwell et al., 2001; Orrell et al., 2006b; Poolton et al., 2007a; Poolton et al., 2005). The major benefit of learning implicitly, as opposed to explicitly, is that performance remains stable under psychological stress (Hardy et al., 1996; Liao & Masters, 2001; Masters, 1992) and physiological fatigue (Masters et al., 2008; Poolton et al., 2007a). Additionally, performance does not decline when a cognitively demanding secondary task is simultaneously included (e.g., Lam et al., 2009; Masters et al., 2004; Maxwell et al., 2001). These benefits are consistent with Reber’s (1992a, 1992b) evolutionary reasoning that implicit learning processes are phylogenetically older than explicit learning processes and, therefore, skills acquired implicitly remain mostly unaffected by factors such as age, intelligence, time and cognitively demanding scenarios.

To gain a better understanding of how children may benefit from implicit motor learning practice methods, we can look at research with older adults (over 60 years of age) who also (like children) have poorer cognitive functioning compared to young adults. Indeed, studies show that the implicit acquisition of skills is more effective than acquiring skills explicitly for older adults (Chauvel et al., 2012; Howard & Howard, 2001). For example, older adults were compared with young adults in the acquisition of a golf-putting task

(Chauvel et al., 2012). To evoke implicit-explicit learning differences, the errorless learning paradigm was applied. Errorless practice, as the name suggests, refers to practicing with minimal errors, which decreases cognitive demands during practice, thereby minimising declarative knowledge build-up (e.g., Maxwell et al., 2001; Orrel et al., 2006b; Poolton et al., 2007a; Poolton et al., 2005). Therefore, in the Chauvel et al. (2012) study, there were two errorless practice groups (for young and old adults respectively) which involved initially putting from a short distance from the hole and then gradually moving further away, and two errorful groups, which began further away from the hole and gradually moved closer. Results showed that for the errorless practice groups, the young adults and older adults showed similar performance (i.e., number of successful putts) throughout practice and also during a dual-task test following practice. Comparatively, in the errorful groups, the young adults displayed greater performance than the older adults during practice and during the dual-task test. These results imply that implicit learning (i.e., via errorless practice) is independent of age and cognitive deficits, whereas explicit learning (i.e., via errorful practice) is dependent upon working memory functioning. Thus, if we associate older adults working memory functioning with young children, it appears that the compromised working memory functioning observed in young children may hinder the ability to learn motor skills consciously via explicit processes (Steenbergen, van der Kamp, Verneau, Jongbloed-Pereboom, & Masters, 2010).

Recently, the errorless practice paradigm was applied to children aged nine years (Capio, Poolton, Sit, Holmstrom et al., 2013). Children learnt to throw using an errorless practice approach (initially aiming at a large target, and then gradually reducing the target size) or an errorful practice approach (initially aiming at a small target, and then gradually increasing the target size). The children who learnt with fewer errors achieved superior movement patterns and throwing accuracy after three practice sessions (over a two month period) compared to children that learnt with many errors. Further, the errorless practice group did not show a decline in performance when required to concurrently perform a secondary counting task, whereas the errorful group did. This infers that the reduction of cognitive demands during practice enhances learning in children. Although, because there was no measure of declarative knowledge accumulation in their study, we cannot be certain that the decline in performance under secondary-task conditions in the errorful condition was indeed due to an explicit mode of learning.

Capio extended her findings by conducting a similar experiment with intellectually disabled children (Capio, Poolton, Sit, Euiga, & Masters, 2013). Whilst working memory was not measured in their study, typically, children with intellectual disabilities have low working memory functioning (e.g., Hulme & Mackenzie, 1992; Jarrold & Baddeley, 1997; Jarrold, Baddeley, & Hewes, 1999, 2000; Russell, Jarrold, & Henry, 1996; van der Molen, van Luit, Jongmans & van der Molen., 2007). The results were almost identical to the initial study (i.e., Capio, Poolton, Sit, Holmstrom et al., 2013) with those who practised with fewer errors not only showing greater improvements from pre to post test, but also displaying the ability to perform the skill whilst concurrently performing a secondary task. Thus, based on the results of these two studies, it appears that the reduction of errors during practice facilitates an unconscious mode of learning, and this is particularly useful for children with immature working memory functioning.

Future research should look to explore the application of other implicit motor learning techniques to enhance children’s skill acquisition. For instance, the concept of analogy learning is commonplace in coaching and schooling contexts and is likely to be most effective for children. Analogy learning involves the provision of verbal instructions in the form of biomechanical metaphors that ‘chunk’ all the task-relevant rules about how the skill should be performed together. (Lam et al., 2009; Law et al., 2003; Liao & Masters, 2001;

Master et al., 2008; Poolton et al., 2007b; Poolton et al., 2006). For example, research with beginner table tennis players has shown that the analogy 'move the bat as if it is travelling up the side of a mountain' to evoke implicit learning benefits (Masters, Poolton, Maxwell, & Raab, 2008; Poolton et al; 2007b; Poolton et al., 2006). Whilst providing a performer with an analogy is explicit in nature, it is cognitively efficient – meaning it demands few attention resources. Liao and Masters (2001) argued that analogies are processed as images in the visuo-spatial component of working memory. Given that young children (less than seven years) tend to process information in the visuo-spatial system, the use of analogies seems fitting for children.

Another method of practice that may evoke implicit motor learning in children is the concept of equipment modification. The use of modified equipment to suit the physical capabilities of children is very common in junior sport (e.g., Orlick & Borterill, 1975; Parkin, 1980; Winter, 1980). It simplifies the task ensuring that skills are performed with greater success (e.g., Burton & Welch, 1990; Elliott, 1981; Elliott & Marsh, 1989; Farrow & Reid, 2010b; Hammond & Smith, 2006; Wright, 1967). For instance, in tennis children perform skills better when using smaller racquets compared to full-size (adult) racquets (Elliot & Marsh, 1989). Moreover, when lower compression balls are used, which bounce lower and travel slower through the air than standard tennis balls, children appear to strike the ball with more power and with a better technique (Hammond & Smith, 2006). Farrow and Reid (2010b) also showed that children experienced greater learning when a scaled (i.e., smaller) tennis court was coupled with lower compression balls as opposed to practice on a full-size court with standard tennis balls.

Based on the tenants of the errorless learning paradigm, the simplification of the skill possibly reduces demands on working memory, thereby allowing skills to be learnt implicitly (this theory is explored in chapters 6 and 8 of this thesis). Of course, the simplification of a skill may also have the opposite effect and encourage greater conscious exploration of movement patterns. This is indeed a conundrum; however, if the latter is the case, the conscious exploration of movements is likely to be dependent upon the cognitive development of the child, with high working memory capacity children more prone to consciously exploring movement patterns and low working memory capacity children tending to learn entirely via unconscious processes.

In summary, children's motor learning appears to be enhanced when the demands on working memory are reduced. Essentially, this theory is identical to that proposed by Gathercole, Durling, Evans, Jeffcock and Stone (2008) regarding children's acquisition of knowledge: "reducing working memory loads may provide an effective means of preventing task failures and the associated lost learning opportunities, and hence of improving the academic progress of these children' (pp. 1035). Replace the word 'academic' with 'motor learning' and it is fundamentally the same argument proposed by Capio and colleagues (Capio, Poolton, Sit, Euiga et al., 2013; Capio, Poolton, Sit, Holmstrom et al., 2013; Capio et al., 2012). While the errorless learning paradigm provides a useful method to enhance children's skill acquisition, future research should look to explore alternative methods, such as the provision of analogies (which has already been established in adults) and the use of modified equipment.

The Current Thesis

It appears that working memory capacity is influential during children's motor learning; although, its exact role remains unsubstantiated. Furthermore, there is a need to identify practice methods that enhance children's acquisition of motor skills by encouraging implicit learning. This thesis seeks to explore these issues through a series of interrelated studies that follow.

CHAPTER 3

HYPOTHESIS TESTING BY CHILDREN PERFORMING MOTOR TASKS: THE INFLUENCE OF VERBAL WORKING MEMORY

Introduction

Polietek (2001) describes hypothesis testing as “comparing internal thoughts to external facts in order to interact with the world” (p. 1). When applied to motor learning, hypothesis testing is considered to be a comparison of conscious thoughts or theories about how to move in order to achieve a desired motor solution, with feedback or facts about the movements and their outcomes (Masters & Maxwell, 2004). The significance of hypothesis testing within the motor learning domain stems from description of the stages of learning a person supposedly progresses through when acquiring a motor skill (e.g., Fitts & Posner, 1967). Initially, there is substantial verbal engagement in the task, as the learner consciously devises strategies to achieve the desired motor outcome (via hypothesis testing), but after a prolonged period of repetition performance of the task becomes automatic, with reduced verbal engagement. However, the literature remains silent about whether children learn in a similar hypothesis driven manner to adults.

It is well documented that cognitive functioning differs between children and adults. For instance, verbal working memory (sometimes referred to as phonological working memory), the mechanism responsible for maintaining and manipulating verbal information temporally in the mind (Baddeley & Hitch, 1974; Baddeley, 2012; Gathercole, 2008; Miyake & Shah, 1999), develops commensurate with language ability (e.g., Adams, 1996; Adams, Bourke, & Willis, 1999; Adams & Gathercole, 1995; Baddeley, 2003; Gathercole, Service, Hitch, Adams, & Martin, 1999; Hulme, Thompson, Muir, & Lawrence, 1984; Majerus, Poncelet, & Greffe, & van der Linden, 2006). Given that language ability develops throughout childhood (e.g., Otto, 2006; Szaflarski et al., 2006), it seems unlikely that young children have developed the verbal monitoring processes that are typically associated with early stages of motor learning. Indeed, developmental theorists argue that children tend to process information implicitly rather than explicitly (e.g., Karmiloff-Smith, 1992) involving more perceptual and motor processes than verbal-analytical processes (Hernandez & Li, 2007; Hernandez et al., 2011). Adults, on the other hand, tend to rely on conscious hypothesis testing strategies that utilise explicit memory.

Numerous studies have also shown that adults store information using phonological codes, whereas young children (5 years of age) store information visually (Halliday et al., 1990; Hitch et al., 1988). For example, when shown pictures of objects, adults tend to encode the name of the object, while young children are more likely to encode the image of the object. Even older children (10-11 years of age) tend to store information using phonological codes rather than visual images (Halliday et al., 1990; Hitch et al., 1988; Hitch et al., 1989). According to Piaget (1937/1954), it is not until children reach the age of about 11 years that the ability to formulate and test hypotheses develops. Nevertheless, it is unclear whether children have the cognitive capacity to consciously test hypotheses when learning a motor skill and, if so, when this ability occurs in a child's development?

Rieber (1969) directly examined hypotheses testing in children during a cognitive task and concluded that the propensity to test hypotheses was dependent upon age, with older children more likely to test hypotheses than younger children. However, an alternative to Rieber's conclusion is that the tendency to test hypotheses is dependent upon the working memory capacity of the child, rather than age. Indeed, research in cognitive psychology has shown that better working memory functioning is related to superior problem-solving abilities (e.g., Alloway, Gathercole, Kirkwood, & Elliott, 2009; Swanson & Sachse-Lee, 2001; Zheng, Swanson, & Marcoulides, 2011). Furthermore, and specific to motor learning, it has been shown that testing hypotheses requires the availability of working memory (Maxwell et al., 2003). Working memory uses feedback about the outcome of one's actions from visual, auditory, proprioceptive and tactile senses, to assess performance and form declarative knowledge about the task (Maxwell et al., 2003). This knowledge is stored in long-term memory and can be accessed by working memory at any time. The capacity of working memory develops throughout childhood (e.g., Alloway et al., 2006; Kemps et al., 2000; Luna et al., 2004), typically reaching maximum capacity during adolescence (e.g., Gathercole et al., 2004; Luciana et al., 2005; Luna et al., 2004). Individual differences exist in working memory capacity (e.g., Alloway et al., 2006) and Engle (2002, 2010) proposed that high working memory capacity is associated with a greater ability to control attention on a task to keep the most relevant information in active memory. Consequently, it is possible that working memory capacity, rather than age, moderates the propensity to explicitly test hypotheses.

The purpose of this study was therefore to examine whether children aged 6-11 years tested hypotheses when performing an unfamiliar motor-skill and to assess whether this ability was related to skill outcome (hitting accuracy), age, and/or working memory capacity. Hypothesis testing during motor learning has in the past been measured using verbal recall strategies (e.g., Hardy et al., 1996; Liao & Masters, 2001; Masters, 1992; Masters, Poolton, Maxwell, & Raab, 2008; Maxwell et al., 2001; Poolton et al., 2005) in which participants recall any mechanical rules or hypotheses that they formulated following a period of practice. This measurement is limited, however, as the process of recalling information may underestimate the amount of task-related knowledge that is actually present (Perruchet & Pacteau, 1990; Shanks & St Johns, 1994). Maxwell et al. (2001) suggested that a more objective measure of hypothesis testing is to observe the number of alterations made to technique during practice. An alteration was defined as a visible adjustment to movement that was utilised over more than one trial (Poolton et al., 2005). Importantly, Maxwell et al. (2001) showed that alterations to technique were closely related to the number of mechanical rules and hypotheses verbally recalled. In the present study, both verbal rules and alterations to technique were used as measures of hypothesis testing.

Both verbal and visuo-spatial components of working memory capacity were measured in the children (Alloway, 2007a). Given that the act of hypothesis testing involves the storage of verbal information, it was predicted that verbal working memory capacity would be a key predictor of the propensity to test hypotheses. Also, previous research has demonstrated that hypothesis testing is less likely to occur when skills are executed successfully (Capio, Poolton, Sit, Holmstrom et al., 2013; Lam, Masters & Maxwell, 2010; Maxwell et al., 2001; Poolton et al., 2005). Therefore, it was also expected that children who performed the skill with fewest errors would be least likely to test hypotheses, irrespective of their working memory capacity.

Method

Participants

Fifty-eight children (29 boys and 29 girls) aged between 6 and 11 years (boys, M = 9.1, SD = 1.6; girls, M = 9.0, SD = 1.5) participated in the experiment. The children had limited to no experience playing tennis. All participants and their parents or guardian gave written voluntary consent (see Appendix A and B). The Human Research Ethics Committee of the University where the study was conducted as well as the relevant Department of Early Childhood Development approved the study.

Working Memory Assessment

Working memory capacity was assessed using the Pearson Automated Working Memory Assessment (AWMA: Alloway, 2007a), with each child tested individually in a quiet room during a single session of approximately 30 minutes. Four memory measures were extracted from the assessment. Two of the measures assessed storage-plus-processing components and were referred to as working memory tasks. Of these, one measure tapped verbal ability and the other tapped visuo-spatial ability. The remaining two measures assessed storage-only components and were referred to as short-term memory tasks. One was verbal in nature and the other visuo-spatial. The tests were administered in a fixed sequence, beginning with the short-term memory tasks and finishing with the working memory tasks (verbal then visual for both). All tests were presented on a laptop computer with the screen resolution set to 1280 x 800 pixels. The AWMA program computed scores for each test. The specific tests used to measure each component of working memory are outlined below:

Verbal short-term memory (Digit recall task). Children were required to recall a sequence of digits in the correct order.

Visuo-spatial short-term memory (Dot matrix test). Red dots appeared in a 4 x 4 matrix one after the other. Each dot remained on the computer screen for two seconds. Children were required to recall the position of the red dots in the correct order.

Verbal working memory (Listening recall task). Children were presented with a series of spoken sentences and were required to say whether the sentences were “true” or “false” and then recall the final word of each sentence in sequence (e.g., ‘dogs have four legs’; the answer is true and legs).

Visuo-spatial working memory (Spatial recall test). Children viewed two shapes and were required to determine whether the shape on the right was the same or opposite to (i.e., a mirror-image of) the shape on the left. The shape on the right also featured a red dot and the children had to remember the position of the dot (or, when more than one set of shapes appeared, the position of several dots) until the end of the trial.

Experimental Design and Procedure

Hitting Task. Children were asked to hit tennis balls onto a target (see Figure 3.1 for dimensions) that was located at a distance of 6 metres. The only rule of the task was that the ball had to be hit before it bounced. All children used a Wilson 58 cm racquet and low compression red tennis balls (25% compression of standard tennis balls). Children were given

30 shots in total, broken down into two 15 shot conditions: without a net (Condition 1) and with a net (Condition 2). Condition 1 was always performed before Condition 2. The net was 0.8 metres high and positioned 4 metres away from the children. This distance corresponded with the modified court size recommended by the International Tennis Federation for 6 to 8 year old children learning to play tennis. The net was introduced to create an obstacle and possibly to induce hypothesis testing. Children performed the hitting task without any prior knowledge of what was expected of them (i.e., they did not see another child complete the task prior to performing). The researcher did not give a demonstration of how the task was to be performed.

Measuring hypotheses-testing. Two digital video cameras were set-up to allow for analysis of children's hypotheses-testing via video replay. Consistent with previous research, it was assumed that children were testing hypotheses when they altered their technique. An alteration to technique was defined as visible adjustments to movement that were utilised over more than one trial (Poolton et al., 2005). The number of verbally reported mechanical rules (e.g., "I kept my knees bent") and hypotheses tested (e.g., "when I hit the ball with an over-arm swing I was more accurate") were also assessed after each condition. Children were verbally asked to indicate whether they had tried anything differently after the first 15 shots and the last 15 shots, respectively, and whether they knew the difference between their best and worst attempts. A digital microphone was used to record verbal recall information. An independent rater assessed the number of alterations made to technique and the number of rules and hypotheses reported. For reliability purposes, a second independent rater also assessed alterations to technique and verbal rules reported. Intra-class correlation coefficients showed moderate to high correlations for both alterations to technique (ICC = .84, $p < .01$) and verbal rules and hypotheses reported (ICC = .89, $p < .01$). Given that young children may not have developed the language skills required to verbally recall information, children were divided into two groups: young children (6-7 years of age: n = 20) and older children (10-11 years of age: n = 17), for further analysis of verbal reports. This split in age group is similar to Piaget's stages of development theory (Piaget, 1937, 1954), with the 6-7 year old children progressing from a 'pre-operational' stage to a 'concrete-operational' stage (developing thought processes), and the 10-11 year old children progressing from a 'concrete-operational' stage to a 'formal-operational stage' (learning to test and formulate hypotheses about the world).

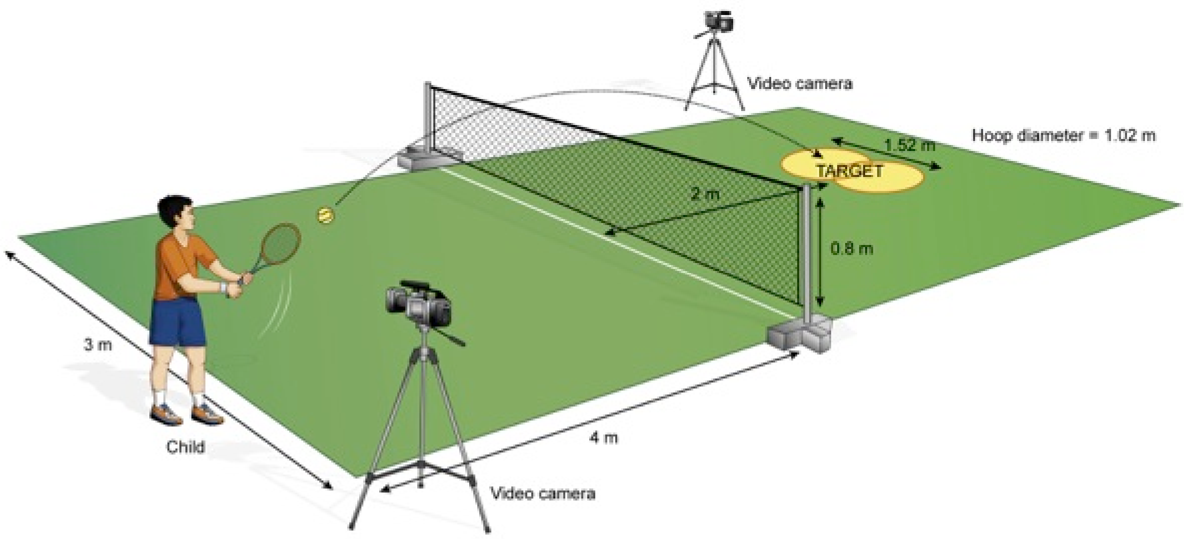


Figure 3.1. The hitting task set-up. The target was two hula-hoops that were placed next to each other, and crossed over in the middle. The net was introduced for the second condition (i.e., the last 15 shots).

Statistical Analysis

Paired t-tests were conducted to measure for differences between conditions 1 and 2 for hitting accuracy, number of alterations to technique, number of verbal rules reported. *P* values were adjusted to 0.016 using the Bonferroni method. In order to establish the best predictor variables of hypothesis testing in the current sample, a forced-entry regression analysis was performed, using number of alterations to technique as the dependent variable. The six predictor variables (age, hitting accuracy, and the four memory measures) were entered simultaneously to explore which variable would best predict the number of technical adjustments made. Additionally, a fixed-order hierarchical regression analysis was performed to establish which predictor variable shared unique variance with alterations to technique. Only the predictor variables that were found to be significant in the forced-entry regressions analysis were entered into this regression analysis.

To measure the agreement between the verbal hypotheses reported and visible adjustments to technique, associations between hypotheses and movement alterations were identified in relation to the body part that they specified. For example, the hypothesis "when I hit the ball with an over-arm swing I was more accurate" should match with observed adjustments to the swing arc (i.e., a change from an underarm swing to an over-arm swing). Percentage concordance was calculated as the number of hypotheses reported that were also evident as visible alterations to technique.

Results

Descriptive statistics

Paired *t*-tests revealed no differences between conditions 1 and 2 for hitting accuracy [t (57) = 0.13, p = .89, d = .02], number of alterations to technique [t (57) = 0.46, p = .65, d = .06], or number of verbal rules reported [t (57) = -1.47, p = .15, d = -.19]. Therefore, the introduction of the net did not have a significant influence on the performance of the skill, presumably because the skill was difficult enough without the net. For the remaining analyses, the conditions were summated for hitting accuracy, technique alterations, and verbal recall. The descriptive statistics for these variables as well as the AWMA measures are presented in Table 3.1. For all memory measures, the raw scores are reported.

Table 3.1

Means and standard deviations for hitting accuracy, alterations to technique, verbal rules reported and the four AWMA measures

	Condition 1	*Condition 2*	*Total*
Hitting Accuracy	1.97 (2.09)	1.93 (2.27)	3.90 (3.89)
Alterations to technique	1.60 (1.52)	1.93 (1.44)	3.10 (2.41)
Verbal rules	0.74 (0.89)	0.93 (0.99)	1.67 (1.60)
Verbal WM[a]	-	-	11.83 (4.85)
Verbal STM[a]	-	-	29.34 (4.21)
Visuo-spatial WM[a]	-	-	20.09 (6.47)
Visuo-spatial STM[a]	-	-	23.22 (4.97)

STM, short-term memory; WM, working memory; () standard deviation; [a], condition 1 and condition 2 do not apply to the memory measures.

The correlation coefficients among all measures (including age) are presented in Table 3.2. Of interest was whether any of the variables correlated with the number of alterations to technique or verbal rules, and whether the two hypothesis testing measures were correlated with each other. Verbal working memory, verbal short-term memory and hitting accuracy were all significantly correlated with the number of alterations made to technique. The number of verbal rules reported was not correlated with any of the memory measures, hitting accuracy or age, but was significantly related to alterations to technique.

Table 3.2

Correlation coefficients among all measures

	1	2	3	4	5	6	7	8
1. Age	1							
2. Hitting accuracy	.63 [a]	1						
3.Alterations to technique	.10	-.30*	1					
4. Verbal rules	.22	-.10	.42 [a]	1				
5. Verbal WM	.61 [a]	.36 [a]	.33 [b]	.04	1			
6. Verbal STM	.23	-.03	.26 [b]	-.04	.56 [a]	1		
7. Visuo-spatial WM	.67 [a]	.39 [a]	.06	.14	.67 [a]	.37 [a]	1	
8. Visuo-spatial STM	.52 [a]	.35 [a]	.01	.06	.61 [a]	.40 [a]	.66 [a]	1

STM, short-term memory; WM, working memory; [a] Correlation is significant at the $p = 0.01$ level (2-tailed); [b] Correlation is significant at the $p = 0.05$ level (2-tailed).

Regression analyses: Predictors of hypothesis testing

Forced-entry regression analysis. Model statistics, as well as standardised *beta* values and *t* statistics, are provided in Table 3.3. The linear combination of the predictor variables was significantly related to the number of alterations to technique [F (6, 57) = 5.36, $p < .01$], with 39% of variance in alterations to technique accounted for by the six predictor variables. Hitting accuracy accounted for the highest proportion of variance in alterations to technique (19%), followed by verbal working memory capacity (13%) and age (5%). Together, these accounted for 37% of the variance in alterations to technique, leaving only 2% explained by the remaining variables.

Table 3.3

Forced-entry regression analysis predicting alterations to technique

	R^2	β	t
All six variables	.39		
Age		.37	2.02 [b]
Hitting accuracy		-.59	-4.01 [a]
Verbal WM		-.01	3.23 [a]
Verbal STM		.58	-0.09
Visuo-spatial WM		-.17	-1.29
Visuo-spatial STM		-.23	-1.10

Note. STM, short-term memory; WM, working memory; [a] $p < .01$; [b] $p < .05$.

Fixed-order hierarchical regression analysis. Given that the findings of the initial regression analysis showed that hitting accuracy, verbal working memory, and age contributed the largest amount of variance in alterations to technique, only these three variables were included as predictor variables (see Table 3.4). Age was entered first as it was the least significant predictor of the three variables. Moreover, given that age was correlated with verbal working memory (r = .61), I wanted to establish the amount of variance in alterations to technique that could be accounted for by hitting accuracy and verbal working memory after taking into the account the variance shared with age. Hitting accuracy and verbal working memory were therefore entered as the second and third variables consecutively, and then in reverse order.

Age accounted for only a very small proportion of variance in alterations to technique (1%). Verbal working memory and hitting accuracy increased the variance accounted for significantly; regardless of which variable was entered first. Overall, hitting accuracy appeared to be the strongest predictor of alterations in technique as it accounted for most of the variance in both models. This was closely followed by verbal working memory capacity.

Table 3.4

Hierarchical regression analyses predicting alternations to technique

Dependent variable	R^2	R^2 *change*	*F change*	*B*	*t*
Model 1					
Step 1. Age	.01	.01	.46	.10	0.75
Step 2. Verbal WM	.12	.11	.01	.42	2.67 [a]
Step 3. Hitting Accuracy	.33	.21	<.01	-.59	-4.09 [a]
Model 2					
Step 1. Age	.01	.01	.46	.1	0.75
Step 2. Hitting accuracy	.23	.22	<.01	-.61	-3.97 [a]
Step 3. Verbal WM	.33	.10	<.01	.40	2.84 [a]

Note. STM, short-term memory; WM, working memory; [a] $p < .01$.

Agreement between the two hypothesis testing measures: verbal recall and adjustments to technique

Whilst a significant correlation was found between verbal rules and alterations to technique, a paired *t*-test revealed that the number of verbal rules reported was significantly fewer than the number of visible technical adjustments [t (57) = 4.79, $p < .01$, $d = .66$]. Percentage concordance showed that 36% of verbal rules reported were also evident as visible alterations to technique. Further analysis revealed that this difference between the number of verbal rules recalled and the number of visible technical adjustments could be accounted for by age. When the children were divided into two groups, young children (6-7 years of age) and older children (10-11 years of age), independent *t*-tests showed a difference between the two measures in young children [t (19) = 2.63, *p* = .016, *d* = .53], but not in older children ([*t* (16) = 1.30, *p* = .21, *d* = .32]. Moreover, 29% of verbal rules that young children reported matched the visible adjustments made to their technique, whereas 39% of verbal rules that older children reported matched their technique. This data suggests that young children were less able to verbalise the technical adjustments that they made to their technique, whereas older children were more able to identify the changes that they made.

Discussion

This study examined whether children aged between 6 and 11 years tested hypotheses when performing a motor skill, and whether their hypothesis testing was related to hitting accuracy, age, and/or working memory capacity. The results demonstrate that the propensity to hypothesis test was primarily dependent upon how successfully the skill was executed and the verbal working memory capacity of the individual. Age was found to have a small influence on the number of hypotheses tested, relative to hitting accuracy and verbal working memory capacity. This supports my hypotheses and provides an alternative explanation to the notion that age is the key variable moderating the propensity to test hypotheses (e.g., Rieber, 1969).

Children who made the fewest errors (i.e., hit the most balls onto the target) made the fewest adjustments to their technique, signifying that they rarely tested hypotheses. This is consistent with errorless learning research, which shows that when skills are learnt without errors there is minimal accrual of declarative knowledge, suggesting that explicit hypothesis testing is absent (Maxwell et al., 2001; Poolton et al., 2005; Orrell et al., 2006a, 2006b). Studies have shown that it is more cognitively demanding to process error feedback than success feedback (Koehn, Dickinson, & Goodman, 2008; Lam et al., 2010), which further implies that hypothesis testing is more likely to occur following unsuccessful performances. Moreover, the number of alterations to technique was significantly correlated with the number of verbal rules that were reported, supporting the view that greater hitting accuracy might have minimised the accrual of declarative knowledge. Learning motor skills without the build-up of declarative knowledge has been shown to evoke an implicit mode of learning (Masters, 1992; Maxwell et al., 2003; for a recent review of implicit motor learning, see Masters & Poolton, 2012), which has profound benefits for performance (e.g., Hardy et al., 1996; Liao & Masters, 2001; Masters, Poolton & Maxwell, 2008; Poolton et al., 2007a).

Most of the research examining the link between errorless practice and hypothesis testing has used adults as participants (Maxwell at al., 2001; Poolton et al., 2005; Orrell et al., 2006a, 2006b). To the authors' knowledge, only recently has the errorless learning paradigm been applied to children (see Capio, Poolton, Sit, Eguia et al., 2013; Capio, Poolton, Sit, Holmstrom et al., 2013). Capio, Poolton, Sit, Holmstrom et al. (2013) examined errorless versus errorful practice in children aged 9 years when learning to throw. Children who learnt to throw without experiencing many errors demonstrated lower dependence on conscious control processes (i.e., stable performance under secondary-task conditions), whereas children who learnt whilst experiencing numerous errors displayed the opposite behaviour. Capio, Poolton, Sit, Holmstrom et al. (2013) did not include a measure of hypothesis testing in their study, but speculated that those who practised in the face of many errors learnt their skills via an 'error-correction' hypothesis-testing approach. The findings of the current study suggest that children aged 9 years do test hypotheses when learning a motor skill, but only if the skill is performed unsuccessfully. Additionally, the propensity to test hypotheses appears to be co-related to the verbal working memory capacity of the child.

Working memory plays a critical role in explicit processes during skill acquisition (Maxwell et al., 2003). The fact that the verbal rather than the visuo-spatial component of working memory was a significant predictor of alterations to technique is consistent with electroencephalography (EEG) research, which shows that the initial ‘cognitive’ stage of motor learning involves co-activation between the verbal-analytical and the motor planning regions of the brain (Zhu et al., 2010). It therefore appears that hypotheses tested are stored verbally and children with larger verbal working memory capacity are more likely to test and formulate hypotheses about a motor skill.

There is a broad range of research in domains such as music (e.g., Elbert et al., 1995; Schlaug et al., 1995; Watanabe, Savion-Lemieux, & Penhune, 2007), vocabulary acquisition (e.g., Ellis & Morrison, 1998; Gerhand & Barry, 1998, 1999; Meschyan & Hernandez, 2002), and second language learning (e.g., Fledge, Yeni-Komshian, & Liu, 1999; MacKay & Fledge, 2004; Munro, Fledge & MacKay, 1996) which suggests that differences in memory processes exist between people who learn skills early in life compared to later in life (for an overview of this research, see Hernandez and Li, 2007). It is argued that young children tend to process information implicitly whereas adults are more inclined to process information explicitly (Hernandez & Li, 2007; Hernandez et al., 2011). Given the results of the current study, perhaps children initially rely on implicit memory whilst their verbal working memory capacity is still developing, and explicit hypothesis testing occurs once verbal working memory capacity has developed sufficiently. This rationale is similar to Reber’s (1993) proposition that implicit memory develops early in childhood and is invariant throughout a person’s life, whereas explicit memory develops during childhood and continues to increase well into adulthood. Thus, the gradual increase in explicit memory during childhood coincides with the gradual increase in verbal working memory during this time period.

Developmental stages of explicit memory were evident in the current study, with differences observed between the younger (6-7 years) and older (10-11 years) children with regards to the information verbally recalled. Young children reported significantly fewer verbal rules than the number of alterations that they made to their technique, and only 29% of the rules reported matched the alterations that were observed. It is therefore possible that the young children did not possess the required language skills to verbalise any information learnt about the motor skill. In comparison, older children reported a similar number of verbal rules and alterations to technique, and 39% of the rules matched the alterations. This is comparable to research in adults, with percentage concordance generally varying between 40-50% (Poolton et al., 2005). The difference between younger and older children may represent a difference in the manner in which information is acquired. Palmer (2000) argues that young children initially acquire information by automatically storing representations in long-term memory (i.e., no working memory involvement) and this is characterised by an inability to verbally recall any strategies adopted to complete the task at-hand. This could also be interpreted as the implicit acquisition of information. Following this period, Palmer (2000) proposes that children develop a dual visual-verbal coding system, and then finally the adult-like strategy of verbal coding (i.e., explicit learning). Likewise, Piaget (1937, 1954) proposed that children aged 6-7 years are in a transition period of developing their thought processes and therefore these children have difficulty verbalising their thoughts, whereas children aged 10-11 years are beginning to develop more adult-like thought processes, such as the ability to test and formulate hypotheses. With regards to the current study, this indicates that deliberate alterations to technique may not result in an accumulation of declarative knowledge about the skill for younger children (hence, the inability to verbalise the alterations). Studies have shown that children as young as 2 years of age are able to change strategies in order to achieve more efficient motor behaviour in pursuit of their goal (e.g., Koswowski & Bruner, 1972; McCarty, Clifton, & Collard, 1999, 2001), and it is unlikely that children aged 2 years accumulate declarative knowledge about the task.

Of course, the significant difference between the number of verbal rules reported and number of alterations to technique may simply have been due to the young children possessing a more variable technique, meaning that they were not actually testing hypotheses. However, given the nature of the ‘alteration to technique’ measurement, it would appear that the changes to technique were deliberate as they were more pronounced than those of a variable movement system (e.g., Bootsma, Houbiers, van Wieringen, & Whiting, 1991). Nonetheless, future studies should seek to include a more robust examination of movement kinematics, such as the use of a 3-D motion analysis system, as this will objectively quantify the significance of the alterations.

To summarise, it was evident that some children (between the ages of 6 to 11 years) made deliberate alterations to their technique when performing a motor task and this was dependent upon the verbal working memory capacity of the child and the performance outcome. Unless the task was performed successfully, children with high verbal working memory capacity were more likely to test hypotheses. Whilst this study provides an insight into children’s cognitive processes during motor performance, it also opens the door to a number of questions, such as: do young children (< 8 years) accumulate declarative knowledge about a motor skill when exploring new techniques or is this information stored subconsciously (implicitly)? Additionally, when does verbal working memory capacity reach a level whereby information is stored explicitly, using the phonological loop, rather than implicitly? Future research should continue to explore the cognitive aspect of motor learning in children as this will help in the development of practical recommendations for schools and sports organisations. Researchers should also seek to understand whether explicit motor learning in children is influenced by individual differences in language ability. The next chapter will further examine the relationship between working memory capacity and the propensity to consciously control movements.

CHAPTER 4

THE RELATIONSHIP BETWEEN WORKING MEMORY CAPACITY AND CONSCIOUS CONTROL OF MOVEMENTS

This chapter includes two experimental papers:

1. *Examining movement specific reinvestment and working memory capacity in adults and children (2 experiments, p. 53-68)*
2. *The relationship between working memory capacity and EEG coherence during a motor task (1 experiment, p. 69-80)*

Examining movement specific reinvestment and working memory capacity in adults and children

‘Working memory’ is conceptualized as a cognitive capacity to retain and process relevant information for short periods of time when performing tasks, and to disregard irrelevant information (Baddeley, 2010; Baddeley & Hitch, 1974). Working memory underpins the computations required to solve mathematical problems (e.g., St Clair-Thompson & Gathercole, 2006) or the reasoning necessary to generate movement related hypotheses on the basis of feedback (e.g., Maxwell et al., 2003). Research shows that a positive association exists between working memory capacity and academic achievement (Alloway et al., 2007; Nevo & Breznitz, 2011), which is not surprising, given that high working memory capacity is associated with better reasoning skills (e.g., Engle, 2002). Working memory capacity has also been shown to be a factor in poor academic performance in pressure situations. In pressure situations, anxiety is thought to cause distracting thoughts, such as worry, which consume working memory resources and therefore reduce the resources available for performance (e.g., Ashcraft & Kirk, 2001; Eysenck & Calvo, 1992; Schmader & Johns, 2003). Beilock and Carr (2005), however, found that only people with high working memory capacity were negatively influenced by pressure when solving mathematical problems. Subsequently, Beilock and DeCaro (2007) showed that this phenomenon arose because people with high working memory capacity used sophisticated resource demanding computations to solve the mathematics problems. Consequently, when pressure caused distracting thoughts (e.g., worry) that depleted working memory resources, too few resources remained available to execute the sophisticated computations successfully. In contrast, people with low working memory capacity used less sophisticated strategies, or even short-cuts, to solve the problems. Under pressure, their working memory resources were also depleted by distracting thoughts, but enough resources remained available to execute the less demanding strategies or short-cuts.

Working memory also plays a role in motor learning and performance under pressure, although the underlying processes of performance may differ. Unlike mathematical problem solving, which relies upon working memory for effective performance, motor performance often is best when working memory is not involved. Stages of learning models of skill acquisition (e.g., Fitts & Posner, 1967) suggest that in the early stages of learning, control of performance is attention demanding and highly cognitive, presumably drawing heavily upon working memory resources. However, in the later stages of learning when skills are well practised, control of performance is proceduralised and runs without attention, presumably drawing far less on working memory resources (e.g., Berry & Broadbent, 1988; Curran & Keele, 1993). Beilock et al. (2002) showed that, for skills that were not well-learned, a concurrent task that focused attention on movement execution was beneficial for performance. However, for skills that were well-learned (e.g., expert-like), a concurrent task that diverted attention away from movement execution was beneficial for performance. Conscious processing theories (Masters, 1992; Hardy et al., 1996), which are sometimes described under the rubric of explicit monitoring (e.g., Beilock et al., 2002), suggest that pressure situations can also focus attention on movement execution. This can lead to potentially disruptive attempts to consciously control the processes of performance (e.g., Baumeister, 1984; Masters & Maxwell, 2008). The Theory of Reinvestment (Masters & Maxwell, 2008; Masters, Polman, & Hammond, 1993) proposes that relatively automated motor processes can be disrupted if they are managed using consciously accessed, task-relevant knowledge to gain step-by- step control of performance. The propensity to do this is thought to be a function of individual personality differences that can be measured using the

Reinvestment Scale (Masters et al, 1993) or the Movement Specific Reinvestment Scale (see Masters & Maxwell, 2008). Additionally, a Decision Specific Reinvestment Scale (Kinrade, Jackson, Ashford, & Bishop, 2010) has been developed, which assesses the same predilection in the context of decision-making. The Scales have been shown to identify people who are likely to display disrupted performance under pressure (Chell, Graydon, Crowley, & Child, 2003; Jackson, Ashford, & Nosworthy, 2006; Kinrade, Jackson, & Ashford, 2010; Malhotra, Poolton, Wilson, Ngo, & Masters, 2012; Masters et al, 1993; Maxwell, Masters, & Poolton, 2006) and to discriminate people with and without movement-related problems in populations such as elderly fallers (Wong, Masters, Maxwell, & Abernethy, 2008), stroke (Orrell, Masters, & Eves, 2009) or Parkinson disease (Masters, Pall, MacMahon, & Eves, 2007).

The process of drawing upon task-relevant verbal knowledge to gain conscious control over motor performance (i.e., reinvestment) seems likely to consume working memory resources, yet the role of working memory capacity in the propensity for reinvestment has not been examined. Working memory capacity may be positively associated with propensity for reinvestment because greater ability to hold and manipulate information increases the opportunity for conscious processing of movement. Alternatively, a negative association may exist, with high working memory capacity reflecting greater ability to inhibit conscious processing. In order to gain insight into the relationship, the association between movement specific reinvestment and working memory capacity was examined in a sample of children (Study 1) and in a sample of young adults (Study 2). Children were tested because their natural inclination for movement specific reinvestment can be considered to be relatively less affected by their motor performance history than adults – there is accumulating evidence that contingencies related to a person's movements experiences (e.g., coaching, physiotherapy, important skill failures, injury or illness) have a powerful effect on the propensity for movement specific reinvestment (see Masters & Maxwell, 2008). When adults were tested in Study 2, not only the association between working memory capacity and propensity for reinvestment was assessed, but also performance of a novel motor task under pressure. It was expected that working memory capacity would be positively associated with propensity for reinvestment in both children (Study 1) and adults (Study 2). Consequently, a negative association between working memory capacity and change in motor performance under pressure was expected (Study 2), because participants with high capacity should have more resources available for disruptive conscious monitoring and control of their movements (movement specific reinvestment).

Study 1

Working memory capacity was quantified using the Automated Working Memory Assessment (AWMA: Alloway, 2007a). Assessment included tasks that measured both verbal and visual components of memory. Reinvestment involves the conscious retrieval and application of task-relevant verbal information (see Masters & Maxwell, 2008), so it was expected that primarily verbal working memory capacity, rather than visual working memory capacity, would be associated with scores on the Movement Specific Reinvestment Scale. The Scale can be divided into two components, conscious motor processing (CMP) and movement self-consciousness (MS-C). CMP refers to the conscious monitoring and control of the mechanics of movement, whereas MS-C is characterized by concern about the impression given when moving. Children generally display self-presentational concerns, such as public self- consciousness (e.g., Banerjee, 2002), so it was expected that both CMP and MS- C would be associated with verbal working memory.

Method

Participants

Fifty-five children (28 boys and 27 girls) aged between 8 and 12 years (*M* = 10.6 years, *SD* = 0.9) participated in the study. Written voluntary consent was given by all participants and their parents/guardian (see Appendix A & B). The study was approved by the Human Research Ethics Committee of the University where the work was conducted.

Measures

Working Memory Assessment. Children completed the same two working memory tasks from the AWMA (Alloway, 2007a) that were used in Chapter 3; *listening recall,* which measured verbal working memory, and *spatial recall,* which measured visuo-spatial working memory (for a detailed description of these tests, see page 34).

Movement Specific Reinvestment Scale. A children's version of the Movement Specific Reinvestment Scale (Masters & Maxwell, 2008) was completed. The Scale included 5 adult-equivalent CMP statements (e.g., *'I remember the times when my movements have failed me'* became *'I remember the times when I could not do well in certain movements'*) and 5 adult-equivalent MS-C statements (e.g., *'I am self-conscious about the way I look when I am moving'* became *'I am aware of the way I look when I move'*) (see Appendix D). The statements were answered on a 4-point Likert Scale ranging from *strongly agree* to *strongly disagree*. The total score for CMP and MS-C, respectively, was tallied. On-going work in the laboratory demonstrates the validity of the MSRS for use with children. The two factor model is supported by confirmatory analysis of 312 Chinese children aged 6 to 12 years (χ^2[31] = 31.12, SRMR = .03, RMSEA = .00, TLI = 1.00, CFI = 1.00) and 172 English-speaking children aged 7 to 12 years (χ^2[30] = 22.44, SRMR = .04, RMSEA = .00, TLI = 1.06, CFI = 1.00).

Statistical Analysis

Pearson's product moment correlation coefficient was used to assess the association between verbal and visual working memory capacity and scores on the Movement Specific Reinvestment Scale. Significance was set at $p \leq 0.05$.

Results and Discussion

Descriptive statistics for verbal and visual working memory and for the two components of the Movement Specific Reinvestment Scale are presented in Table 4.1. Pearson's correlation coefficient showed that CMP and MS-C were significantly correlated with one another ($r = 0.29$, $p = 0.02$), as were visual and verbal working memory capacity ($r = 0.34$, $p = 0.01$).

Significant associations were evident between verbal working memory and both components of the Movement Specific Reinvestment Scale (CMP, $r = 0.27$, $p = 0.04$; MS-C, $r = 0.28$, $p = 0.03$), indicating that children with high verbal working memory capacity tended to display high propensities for both conscious motor processing and movement self-consciousness. No significant association was found between visual working memory and either CMP ($r = -0.07$, $p = 0.60$) or MS-C ($r = 0.16$, $p = 0.26$). The findings suggest that the process of movement specific reinvestment draws upon the resources of verbal working memory, which is responsible for the short-term encoding, retrieval and application of verbal information that is relevant to performance of on-going tasks. This is consistent with the Theory of Reinvestment (see Masters & Maxwell, 2008), which describes the process in which task- relevant verbal information is explicitly retrieved and applied during conscious control of motor performance. The findings do not speak to the causality of the relationship, however. Children with high verbal working memory capacity are better at explicit problem solving and analysis (e.g., Swanson, 2011), so perhaps they are more able to use these abilities to gain conscious control over their movements. Alternatively, perhaps a high propensity for conscious control (i.e., reinvestment) may cause children to develop higher verbal working memory capacity via constant practice at explicit problem solving and analysis.

Table 4.1

Means and standard deviations for the verbal and visual tests of working memory capacity and for the conscious motor processing and movement self-conscious components of the Movement Specific Reinvestment Scale in children

Measure	**Mean (SD)**
Verbal WM	14.2 (3.3)
Visuo-spatial WM	23.0 (5.1)
CMP	12.1 (3.9)
MS-C	15.1 (2.1)

WM, working memory; CMP, conscious motor processing; MS-C, movement self-consciousness.

Study 2

Working memory capacity in children aged between 8 and 12 years is still developing (e.g., Gathercole et al., 2004). To examine whether age-related changes occur in the relationship between working memory capacity and reinvestment, Study 1 was replicated using young adults. Additionally, in order to gain an insight into the interaction between movement specific reinvestment and working memory capacity during motor performance, young adults were asked to perform a novel tennis hitting task in pressured and unpressured conditions. The early stages of learning a motor skill generally are considered to require a high degree of conscious control of movement by all learners, so individual differences in the propensity for movement specific reinvestment were not expected to be solely associated with performance changes. However, it was predicted that participants with high working memory capacity would be more susceptible to performance change in the pressured condition than participants with low working memory capacity because they would rely more on working memory involvement during performance of the motor task. Thus, participants with high working memory capacity were expected to be more affected by depletion of their working memory resources under pressure, as was shown by Beilock and Carr (2005) for performance of difficult mathematics tasks. The tennis-hitting task was considered to also be a difficult task (a complex skill), given the combination of the task demands and the low skill level of the participants (novice tennis players).

Beilock, Rydell, and McConnell (2007) showed that performance of mathematics tasks containing high verbal rather than visual demands was more likely to be disrupted under pressure. They argued that pressure caused verbal rather than visual distractions (e.g., worry), so verbal working memory resources were depleted, leaving fewer resources available for performance of the primarily verbal mathematics task. Given that motor tasks, such as hitting a tennis ball, involve visuo-spatial and verbal components (Liao & Masters, 2001), no predictions were made regarding whether verbal or visual working memory capacity would be associated with performance degradation under pressure.

Method

Participants

Forty-eight undergraduate University students (21 males and 27 females) aged between 17 and 26 years (*M* = 21.4 years, *SD* = 1.2) participated in the study. All participants reported limited experience of playing recreational tennis (zero to 2 hours throughout their life) with none ever having received professional coaching. Written voluntary consent was given by all participants (see Appendix C). The study was approved by the Human Research Ethics Committee of the University where the work was conducted (see Appendix C). An honorarium of HKD50 was awarded to each participant.

Procedure

Working Memory Assessment and the Movement Specific Reinvestment Scale. Similar to Study 1, all participants completed the MSRS and the working memory tests. The only differences were that the MSRS used a six-point Likert Scale for the adults (see Appendix E) and verbal working memory was assessed using the *counting recall* test, rather than the *listening recall* test (Alloway, 2007a). The counting recall test was deemed to be more appropriate for mixed ethnicity participants because it could be completed in the language of choice. Alloway et al. (2006) reported a strong correlation between the counting recall test and listening recall test ($r = 0.74$). Participants were presented with a series of shapes and were required to count aloud the number of red circles that appeared in each set of shapes. Afterwards, they had to recall the number of red circles in each set of shapes in the correct sequence. Scores were derived by the AWMA program. The Movement Specific Reinvestment Scale was administered to participants after the hitting task was completed.

Hitting Task Procedure. Participants were asked to perform a tennis-hitting task. The aim was to hit the ball over a 3m high net so that it landed on a 1m x 1m target located 9m away. The net was positioned 7m from the participant's hitting location. All participants used a 19 inch Wilson tennis racquet and Wilson 'red' low compression balls (25% compression of a standard tennis ball). Participants were instructed that they could hit the ball in any way that they preferred (e.g., forehand, back- hand, over arm, underarm), but they had to strike the ball before it bounced. The balls were self-fed by the participants. Hitting performance was assessed by the number of shots that landed on the target. The hitting task was performed in an unpressured condition (10 attempts to land the ball on the target) followed by a pressured condition (a further 10 attempts after a brief rest period of 5 minutes).

Pressure Manipulation. In the pressured condition, participants were informed that each attempt that landed on the target would prompt a payment of HKD50, up to a maximum of HKD200, but each attempt that missed the target would prompt a deduction of HKD50. Counterbalancing was not used because it was felt that participants would display little or no motivation during the unpressured condition if previously their performance had been linked to a financial reward. An anxiety thermometer (Houtman & Bakker, 1989) was used to register the amount of anxiety that participants experienced before each hitting condition. Participants were asked to place a cross on a 10cm line, with one end of line representing "not at all anxious" and the opposite end "extremely anxious".

Statistical Analysis

Paired t-tests were used to test for differences in hitting performance and anxiety between the unpressured and pressured conditions. Pearson's product moment correlation coefficients were used to assess the associations between change in anxiety, change in hitting performance, verbal working memory capacity, visual working memory capacity, and the conscious motor processing (CMP) and movement self-conscious (MS-C) components of the Movement Specific Reinvestment Scale. Step-wise regression analysis was performed to establish the best predictor of change in hitting performance between the pressured and unpressured conditions. The predictor variables included the five remaining variables listed above. For all tests, significance was set at $p \leq 0.05$.

Results and Discussion

Descriptive Statistics

Paired t-tests revealed significant differences between the unpressured condition and the pressured condition with respect to both anxiety [t (47) = -5.31, $p < 0.01$] and hitting performance [t (47) = -2.65, $p = 0.01$]. Both anxiety (unpressured, $M = 3.13$, $SD = 2.29$; pressured, $M = 4.50$, $SD = 2.28$) and hitting performance (unpressured, $M = 1.13$, $SD = 1.16$; pressured, $M = 1.69$, $SD = 1.37$) were significantly higher in the pressured than the unpressured condition, suggesting that increased anxiety was a consequence of the pressure manipulation, but that performance improved rather than declined. The anxiety thermometer scores were generally low, but were consistent with other studies that have used the anxiety thermometer (e.g., Zhu, Poolton, Wilson, Maxwell, & Masters, 2011). Mesagno, Harvey, and Janelle (2011) reported that monetary incentives did not necessarily increase anxiety and it is perhaps not surprising that the anxiety scores were low, given that for many people the chance to earn money when performing may create opportunity rather than anxiety. Mean scores and standard deviations on the working memory tests and the Movement Specific Reinvestment Scale are presented in Table 4.2.

Correlation Coefficients

The correlation coefficients among all measures are presented in Table 4.3. Verbal working memory was positively correlated with MS-C, but not CMP. Both verbal and visual working memory capacity correlated positively with performance during the unpressured condition, suggesting that just as working memory capacity is associated with superior performance of academic tasks (e.g., Beilock & Carr, 2005; Engle, Kane, & Tuholski, 1999) it may also be associated with superior performance of motor tasks. Fitts and Posner (1967) conceived the early stages of motor learning as highly ‘cognitive’, so perhaps good reasoning and problem-solving abilities are advantageous when people first perform a motor task. Verbal working memory was negatively correlated with change in hitting performance under pressure, suggesting that larger improvements in performance under pressure were associated with lower verbal working memory capacity, whereas smaller improvements in hitting performance under pressure were associated with higher verbal working memory capacity. It is possible that individuals with higher verbal working memory capacity were more prone to movement specific reinvestment in the pressured condition, which may have disrupted their performance compared to low working memory capacity performers.

Table 4.2

Means and standard deviations for the verbal and visual tests of working memory capacity and for the conscious motor processing and movement self-conscious components of the Movement Specific Reinvestment Scale in adults

Measure	**Mean (SD)**
Verbal WM	29.5 (5.9)
Visuo-spatial WM	31.8 (6.3)
CMP	21.8 (4.2)
MS-C	18.2 (4.6)

WM, working memory; CMP, conscious motor processing; MS-C, movement self-consciousness.

Step-Wise Regression Analyses

Model statistics for the regression analysis as well as standardized beta values and *t* statistics are provided in Table 4.4. Variables were entered into the regression model if the probability of *F* was < 0.05 and were removed if the probability of *F* was > 0.10. Neither CMP nor MS-C was a significant predictor of change in hitting performance under pressure, as expected. Indeed, of the five variables that were considered (verbal working memory, visual working memory, CMP, MS-C and Δ anxiety), only verbal working memory capacity was a significant predictor of change in hitting performance [F (1, 47) = 4.88, p = 0.03], accounting for 9% of the change between the unpressured condition and the pressured condition. It seems that verbal aspects of performing the tennis hitting task may have been more salient than visuo-spatial aspects, at least for novices in the highly cognitive stages of first performing a tennis hitting task (e.g., Fitts & Posner, 1967).

Table 4.3

Correlation coefficients among all measures

	1	**2**	**3**	**4**	**5**	**6**
1. Hitting performance	-					
2. Δ hitting performance	.49**	-				
3. Δ anxiety	.17	.01	-			
4. Verbal WM	.38**	-.31*	.05	-		
5. Visual WM	.50**	-.13	.12	.32*	-	
6. CMP	-.06	< .01	.11	-.15	.04	
7. MS-C	.09	.01	.17	.41**	.08	.39**

WM, working memory; CMP, conscious motor processing; MS-C, movement self-consciousness; ** Correlation is significant at the p = 0.01 level (2-tailed); * Correlation is significant at the p = 0.05 level (2- tailed).

Table 4.4

Step-wise regression analysis predicting change in hitting performance from the unpressured test to the pressured test

	R^2	β	t
Variables entered			
Verbal WM	0.09	-0.31	-2.22*
Variables excluded			
Visual WM		-0.03[a]	-0.21
CMS		-0.05[a]	-0.33
MS-C		0.06[a]	0.39
Δ anxiety		0.02[a]	0.15

WWM, working memory; CMP, conscious motor processing; MS-C, movement self-consciousness; $p < 0.05$; [a] Beta-In value: Predictors in the model – Verbal WM.

General Discussion

These studies are the first that have examined the possible interaction between working memory capacity and propensity for conscious monitoring and control of motor performance as conceptualized by the Theory of Reinvestment (e.g., Masters & Maxwell, 2008). Study 1 revealed that for children aged between 8 and 12 years, a positive association existed between verbal working memory capacity and propensity for both conscious motor processing and movement self-consciousness. Study 2 revealed that for young adults aged between 17 and 27 years, a positive association existed between verbal working memory capacity and the propensity for movement self-consciousness, but not conscious motor processing. It is unclear why this was the case, although for young adults self-presentational issues may be more important than at any other time of life (e.g., Hingson & Howland, 1993). Nevertheless, the results do suggest that movement specific reinvestment is predominantly a process that is associated with verbal working memory, rather than visual working memory; reinvestment is an attempt to consciously supervise performance by deploying task-relevant verbal knowledge to control ones movements, and verbal working memory underpins the recall and manipulation of verbal knowledge.

Despite evidence that the pressure manipulation in Study 2 caused a significant increase in self-reported anxiety, performance of the tennis-hitting task improved significantly. It is likely that the apparent improvement under pressure was confounded by learning, given that the lack of counterbalancing meant that the pressured condition always followed the unpressured condition. Nevertheless, verbal working memory capacity was the only predictor of change in hitting performance. The association was negative, implying that higher capacity was associated with smaller improvements in performance. If the improvements in performance were merely a consequence of learning, then perhaps people with lower verbal working memory capacity simply learned better than people with higher verbal working memory capacity. This seems unlikely, given that early stages of skill learning in adults are generally thought to be highly cognitive and resource demanding. The superior hypothesis testing and problem solving abilities of learners with higher working memory capacity (St Clair-Thompson & Gathercole, 2006) should therefore provide them an advantage over people with lower working memory capacity, as was suggested by their better performance during the unpressured condition.

It is unclear why the advantage disappeared in the pressured condition. One explanation resembles the explanation provided for previous findings that only people with high working memory capacity are negatively affected by pressure when solving difficult mathematics problems (Beilock & Carr, 2005; Beilock & DeCaro, 2007). When trying to resolve motor problems, people with high working memory capacity may use resource demanding, rule based algorithms. Consequently, if pressure depletes their working memory resources, too few resources may be left to execute the demanding algorithms effectively. On the other hand, people with low working memory capacity may use less resource demanding procedures to resolve motor problems, so when pressure depletes their working memory resources, enough remain available to execute the procedures effectively.

Markman, Maddox and Worthy (2006; see also Worthy, Markman, & Maddox, 2009) showed that when pressure consumed working memory capacity so that hypothesis testing was impaired, performance of an explicit, rule based categorization task was poor, yet performance of an implicit, non-rule based categorization task was good. Markman et al (2006) argued that reduced working memory resources are problematic when performing an explicit, rule based task, but make people less likely to deploy a “suboptimal rule-based hypothesis-testing strategy” (p. 947) when performing an implicit, non-rule based task. It is possible, therefore, that participants with low working memory capacity performed differently to participants with high working memory capacity, because they were left with so few resources that they were unable to engage in sub-optimal hypothesis testing strategies. Implicit motor learning theory (Masters, 1992; see Masters & Poolton, 2012, for a recent review) suggests that this is an advantage for motor performance. Implicit motor learning paradigms designed to prevent hypothesis testing strategies by disrupting working memory during practice have been shown to result in stable performance under pressure (e.g., Hardy et al, 1996; Liao & Masters, 2001; Masters, 1992; Mullen, Hardy, & Oldham, 2007), as well as under other challenges, such as multi-tasking or fatigue (e.g., Masters, Lo et al., 2008; Masters, Poolton, & Maxwell, 2008; Orrell et al., 2006b; Poolton et al., 2007a).

The findings of the current study do not speak directly to the nature or extent of hypothesis testing strategies used by participants; however, Maxwell et al. (2000) and Poolton, Maxwell and Masters (2004) reported that propensity for reinvestment was positively associated with the accumulation of task-relevant, verbal knowledge when learning a motor task. Given that a positive association between reinvestment and working memory capacity was found, it seems plausible that people with high working memory capacity accumulated more task- relevant, verbal knowledge about the hitting task than people with low working memory capacity. Consequently, I speculate that people with high working memory capacity learned the tennis hitting task more explicitly, and were more prone to movement specific reinvestment in the pressured condition, than people with low working memory capacity. I also speculate that people with low working memory capacity may learn their skills more implicitly than people with high working memory capacity.

The findings contribute to our understanding of the relationship between working memory and movement specific reinvestment in both adults and children. Despite limitations of the work, such as the lack of counterbalancing, some insight is afforded to the collective role that reinvestment and individual differences in working memory capacity play in early learning and/or performance under pressure. Intriguing questions must be answered by the work that follows. Is high working memory capacity associated with a greater tendency to formulate and test hypotheses when solving a motor problem? Do people with low verbal work memory capacity tend to learn skills more implicitly? Does movement specific reinvestment represent a failure by working memory to inhibit processing of information that is irrelevant for effective motor performance or is it an outcome of inappropriately controlled shifting of attention by working memory? To gain a greater understanding of the role that working memory plays during motor skill performance, the next study presented in this chapter measures neural activity during performance of a novel motor skill.

The relationship between working memory capacity and EEG coherence during a motor task

Working memory is responsible for the storage and manipulation of temporary information in the mind (Baddeley, 2000, 2010; Baddeley & Hitch, 1974). It plays a key role in the conscious processing of information when acquiring a motor skill (Maxwell et al., 2003). Engle and colleagues (Engle, 2010; Kane & Engle, 2002; Unsworth et al., 2004) have shown that individual differences exist in working memory capacity, and this influences performance on many day-to-day tasks. In Chapter 3 of this thesis, verbal working memory capacity was shown to be related to the number of alterations that children made to their technique when performing a motor task. Additionally, earlier in this chapter verbal working memory capacity was positively associated with score on a validated psychometric measure of the propensity for conscious monitoring and control of motor performance (the Movement Specific Reinvestment Scale). It is therefore possible that working memory capacity influences the amount of conscious processing that occurs when performing a motor skill.

Conscious processing can be monitored using electroencephalography (EEG) measures. For example, Zhu et al. (2010) measured EEG activity before and after a short-term period of practice of a finger-tapping task, and found that rapid improvements in performance were accompanied by increases in EEG coherence in the (T4) visuo-spatial and (Fz) motor planning regions of the brain (i.e., T4-Fz). Zhu et al. (2010) hypothesised that this represented the visuo-spatial processes beginning to automate. Unexpectedly, no differences were found between the pre- and post-test in EEG coherence between the verbal-analytical (T3) and motor planning regions of the brain (i.e., T3-Fz); however, this was likely because verbal involvement in performance had not yet begun to decrease following the short period of practice. In another study, expert marksmen displayed lower coherence between the T3-Fz regions compared to novice shooters, suggesting that there was less verbal-cognitive involvement as skill performance became automated (Deeny et al., 2009).

Changes in EEG activity during the acquisition of a motor skill are likely to be a consequence of the level of dependency on working memory to perform the skill. It was therefore hypothesised that a person's working memory capacity would be a predictor of EEG coherence in the T3-Fz and T4-Fz regions when performing a motor skill. Both verbal and the visuo-spatial components of working memory were measured and, therefore, it was also of interest to ask whether verbal and/or visuo-spatial working memory capacity had a unique relationship with coherence in the T3-Fz and T4-Fz regions respectively. To further evaluate these hypotheses, participants performed the motor skill in two conditions: a normal condition that involved no external pressure, and a pressured condition. It was expected that the pressured condition would increase EEG activity (e.g., Zhu et al., 2011) and subsequently performance would deteriorate. This was based on the theory that poor performance under pressure often is a consequence of increased conscious attention to the skill mechanics (e.g., Baumeister, 1984; Masters & Maxwell, 2008; Masters et al., 1993; see previous study in this chapter for a detailed discussion about performance under pressure). Consequently, it was predicted that larger working memory capacity would be correlated with poorer performance under pressure.

Method

Participants

Eighteen young adults (7 males and 11 females) aged between 19 and 24 years (*M* = 21.2 years, *SD* = 1.4) participated in the study. All participants reported limited experience of playing recreational tennis (zero to 2 hours throughout their life) with none ever having received professional coaching. Written voluntary consent was given by all participants (see Appendix C). The study was approved by the Human Research Ethics Committee of the University where the work was conducted.

Experimental Design

First, participants' working memory was measured using the Automated Working Memory Assessment (AWMA). Second, participants performed a tennis task in two conditions (no pressure, pressure) whilst wearing an EEG monitor. The task required participants to hit a tennis ball with a tennis racquet towards a target on the ground. The number of shots that hit the target was recorded for each condition.

Working Memory Assessment

Participants completed the same two working memory tasks from the AWMA (Alloway, 2007a) as detailed in Chapter 3. The two tasks were *counting recall,* which measured verbal working memory (see page 57 for a description of this test), and *spatial recall,* which measured visuo-spatial working memory (see page 34 for a description of this test). Scores were computed by the AWMA program.

Hitting Task Procedure

The hitting task procedure replicated the task used in the study presented earlier in this chapter (see page 57). The aim of the hitting task was to hit the ball over a 3m high net so that it landed on a 1m x 1m target located 9m away. The net was positioned 7m from the participant's hitting location. The hitting task was performed in two conditions: no pressure and under pressure. Pressure was also created using the same monetary incentives as detailed earlier in this chapter (see page 58 for a detailed description of the pressure manipulation). All participants used a standard Wilson 19 inch racquet and Wilson 'red' low compression balls (25% compression of a standard tennis ball). Each condition consisted of 10 attempts to land the ball on the target. Participants performed the hitting task without any prior knowledge of what was expected of them (i.e., they did not see another participant complete the task prior to performing). The researcher did not give a demonstration of how the task was to be performed. Hitting performance was assessed by the number of shots that landed on the target.

EEG Activity

Throughout hitting performance during each condition, EEG was recorded from 14 scalp locations (AF3, F7, F3, FC5, T3, P7, O1, O2, P8, T4, FC6, F4, F8, AF4) in accordance with the standard international 10-20 system (Jasper, 1958) using a wireless EEG headset (Emotiv Technology Inc., USA; see Figure 4.1), and then stored (bandpass filter, 0.2-45 Hz; notch filter, 50 Hz; sample rate, 128 Hz) on a notebook for offline processing and analysis. The validity of this EEG system has been demonstrated in recent studies (Badcock et al., 2013; Debener, Minow, Emkes, Gandras, & de Vos, 2012). Prior to each recording, the impedance at each location was checked to ensure an appropriate signal-to-noise ratio (i.e., contact quality). During the offline signal processing, EEG artifacts caused by eye blinks was removed by independent component analysis (ICA, Delorme & Makeig, 2004). In addition, an experienced EEG technician visually inspected the recordings and removed potential biologic artifacts (e.g., muscle activation or glosso-kinetic artifacts). Artifacts were distinguished from cortical activity according to the duration, morphology, and rate of firing. A Hamming window (128 sample and 50% overlap) was applied to the data in preparation for coherence analysis.

Coherence was defined as $|C_{xy}|^2$ of the EEG signals at electrode sites x and y, where:

$$C_{xy}(f) = \frac{|P_{xy}(f)|^2}{P_{xx}(f)P_{yy}(f)}$$

and where P_{xx} and P_{yy} represent the power spectral density of x and y, respectively, and P_{xy} represents the cross power spectral density of x and y. Coherence is a function of frequency with values between 0 and 1 indicating how well x corresponds to y at each frequency.

EEG T3–Fz and T4–Fz coherence were calculated in 1-Hz frequency bins and averaged across the appropriate frequencies to obtain the coherence values for Alpha2 (10–12 Hz) and Beta1 (13-20 Hz) frequency bandwidths (e.g., Deeny, Hillman, Janelle & Hatfield, 2003). The frequency bandwidths alpha2 (8–12 Hz) and beta1 (13-20 Hz) were selected as they are more likely to reflect global cortico-cortical communication sensitive to the frontal and temporal regions, whereas coherence in higher frequency bandwidths is sensitive to more localized activation of the cortex (Nunez, 1995; Von Stein & Sarnthein, 2000). All coherence estimates were subjected to Fisher's z transformation prior to analysis to ensure normal distribution. The processing and analysis steps described above were implemented with the EEGLAB toolbox (Delorme & Makeig, 2004) and custom scripts in MATLAB (MathWorks, USA).

Figure 4.1. The EEG monitoring system.

Statistical Analysis

Paired t-tests were used to measure whether differences existed between the two conditions in EEG coherence and hitting performance. The standardised mean differences were reported using Cohen's *d*. Pearson's product moment correlation coefficients were used to assess the associations between verbal working memory, visuo-spatial working memory, hitting performance and the four EEG measures within the two conditions. Additionally, stepwise linear regression analyses were used to measure if any of the variables (verbal working memory, visuo-spatial working memory, and hitting performance) were predictors of T3-Fz and T4-Fz coherence in the two conditions. Variables were only entered into the regression analysis if the probability of $F < 0.05$.

Results

Descriptive statistics

The mean score for the counting recall test (verbal working memory) was 30.1 (SD = 5.3), while the mean score for the spatial recall test (visuo-spatial working memory) was 33.4 (SD = 5.0). The descriptive statistics for hitting performance and EEG coherence within the two conditions are presented in Table 4.5. With the significance level adjusted to 0.01 using the Bonferroni method, the difference between the no pressure and the pressured conditions was not significant for hitting performance [$t\ (17) = -2.20$, $p = .04$, $d = .52$] nor EEG coherence [Beta1 T3-Fz, $t\ (17) = 0.53$, $p = .64$, $d = .12$; Alpha2 T3-Fz, $t\ (17) = 0.48$, $p = .61$, $d = .12$; Beta1 T4-Fz, $t\ (17) = -1.27$, $p = .66$, $d = .32$; Alpha2 T4-Fz, $t\ (17) = 0.44$, $p = .66$, $d = .10$].

Table 4.5

The means and standard deviations for hitting performance and EEG coherence in the two conditions

Variable	*Condition 1 (no pressure)*	*Condition 2 (pressure)*
Hitting Performance	1.3 (1.3)	2.2 (1.6)
Beta1 T3-FZ coherence	.14 (.13)	.13 (.14)
Alpha2 T3-FZ coherence	.10 (.08)	.09 (.12)
Beta1 T4-F4 coherence	.28 (.14)	.32 (.19)
Alpha2 T4-F4 coherence	.33 (.19)	.32 (.20)

Correlation Coefficients

The correlation coefficients among verbal working memory, visuo-spatial working memory, hitting performance, and the four EEG coherence measures, are presented in Table 4.6 (no pressure condition) and Table 4.7 (pressure condition). Of interest were the significant correlations between verbal working memory and EEG coherence between the verbal-analytical and motor planning regions (Beta1 T3-Fz and Alpha2 T3-Fz) in the pressure condition. Significant correlations were also found between coherence in these regions and visuo-spatial working memory in the no pressure condition. Visuo-spatial working memory was also significantly correlated with EEG coherence between the visuo-spatial and motor planning regions (Beta1 T4-Fz) in the pressure condition.

Table 4.6

Correlation coefficients during Condition 1 (no pressure)

	1	2	3	4	5	6
1. Verbal WM	-					
2. Visuo-spatial WM	.18	-				
3. Hitting performance	-.08	.17	-			
4. Beta1 T3-Fz	.45	-.53*	.11	-		
5. Alpha2 T3-Fz	.28	-.54*	-.35	.80**	-	
6. Beta1 T3-Fz	-.06	-.23	.05	.10	.25	-
7. Alpha2 T4-Fz	-.17	-.17	.09	.03	.03	.78**

WM, working memory; ** Correlation is significant at the p = 0.01 level (2-tailed); * Correlation is significant at the p = 0.05 level (2- tailed).

Table 4.7

Correlation coefficients during Condition 2 (pressure)

	1	2	3	4	5	6
1. Verbal WM	-					
2. Visuo-spatial WM	.18	-				
3. Hitting performance	.08	.45	-			
4. Beta1 T3-Fz	.49*	-.36	-.19	-		
5. Alpha2 T3-Fz	.51*	-.28	-.13	.86**	-	
6. Beta1 T4-Fz	-.17	-.49*	-.38	.06	.10	-
7. Alpha2 T4-Fz	-.27	-.43	-.37	-.15	-.03	.89**

WM, working memory; ** Correlation is significant at the p = 0.01 level (2-tailed); * Correlation is significant at the p = 0.05 level (2- tailed).

Stepwise Regression Analyses

Predicting EEG coherence during Condition 1 (no pressure)

For predicting Beta1 T3-Fz coherence, visuo-spatial working memory was entered into a stepwise linear regression first [F (1, 17) = 6.32, p = 0.02] which accounted for 28% of the variance in coherence. Verbal working memory was entered second, [F (1, 17) = 10.49, p = 0.001] and these two variables accounted for 58% of the variance. Similarly, when predicting Alpha2 T3-Fz coherence, visuo-spatial working memory was entered into the equation [F (1, 17) = 6.46, p = 0.02] accounting for 29% of the variance. Given that visuo-spatial working memory was negatively correlated with all EEG measures, the results show that larger visuo-spatial working memory was associated with less coherence between the verbal-analytical and motor planning regions (i.e., T3-Fz). Comparatively, larger verbal working memory was associated with greater coherence in the T3-Fz regions (see Figure 2).

With regards to Beta1 T4-Fz coherence, none of the predictor variables were entered into the equation; thus, none were found to be significant predictors of the variance in Beta1 T4-F4. However, for Apha2 T4-Fz, visuo-spatial working memory was entered into the regression analysis [F (1, 17) = 5.06, p = 0.04] accounting for 24% of the variance. Thus, larger visuo-spatial working memory was associated with less coherence between the visuo-spatial and motor planning regions. Hitting performance was not a significant predictor of T3-Fz or T4-Fz coherence for Beta1 or Alpha2 in this condition.

Predicting EEG coherence during Condition 2 (pressure)

For predicting Beta1 T3-Fz coherence, verbal working memory was the first predictor entered into the regression analysis [F (1, 17) = 5.16, p = 0.04], which accounted for 24% of the variance (see Figure 4.3). Visuo-spatial working memory was entered second [F (1, 17) = 6.11, p = 0.01] and these two combined accounted for 44% of the variance. Verbal working memory was also a significant predictor of Alpha2 T3-Fz coherence [F (1, 17) = 5.15, p = 0.03], accounting for 26% of the variance.

When predicting Beta1 T4-Fz coherence, visuo-spatial working memory was entered into the equation [F (1, 17) = 5.05, p = 0.04] accounting for 24% of the variance. None of the predictor variables were entered into the equation when predicting Alpha2 T4-Fz coherence. Similar to the first condition, hitting performance was not a significant predictor of T3-Fz or T4-Fz coherence for Beta1 or Alpha2 in the pressured condition.

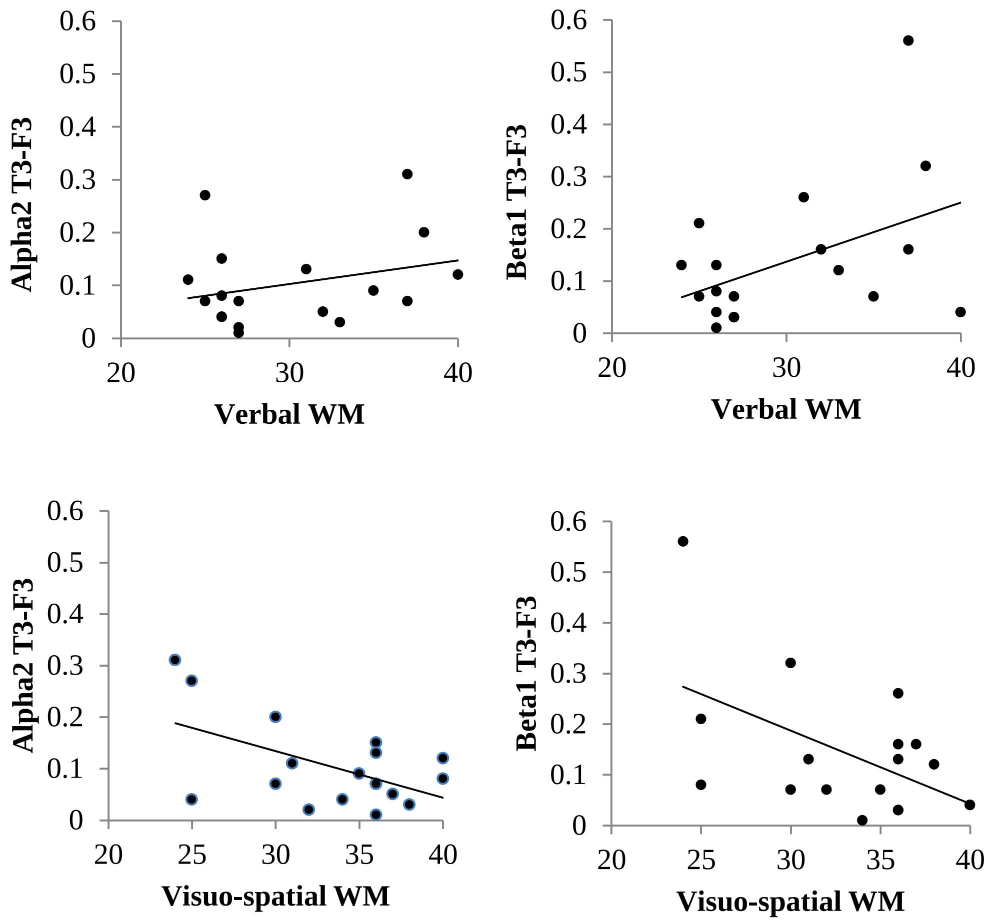


Figure 4.2. The relationship between verbal and visuo-spatial working memory and EEG coherence between the T3-Fz regions during Condition 1 (no pressure).

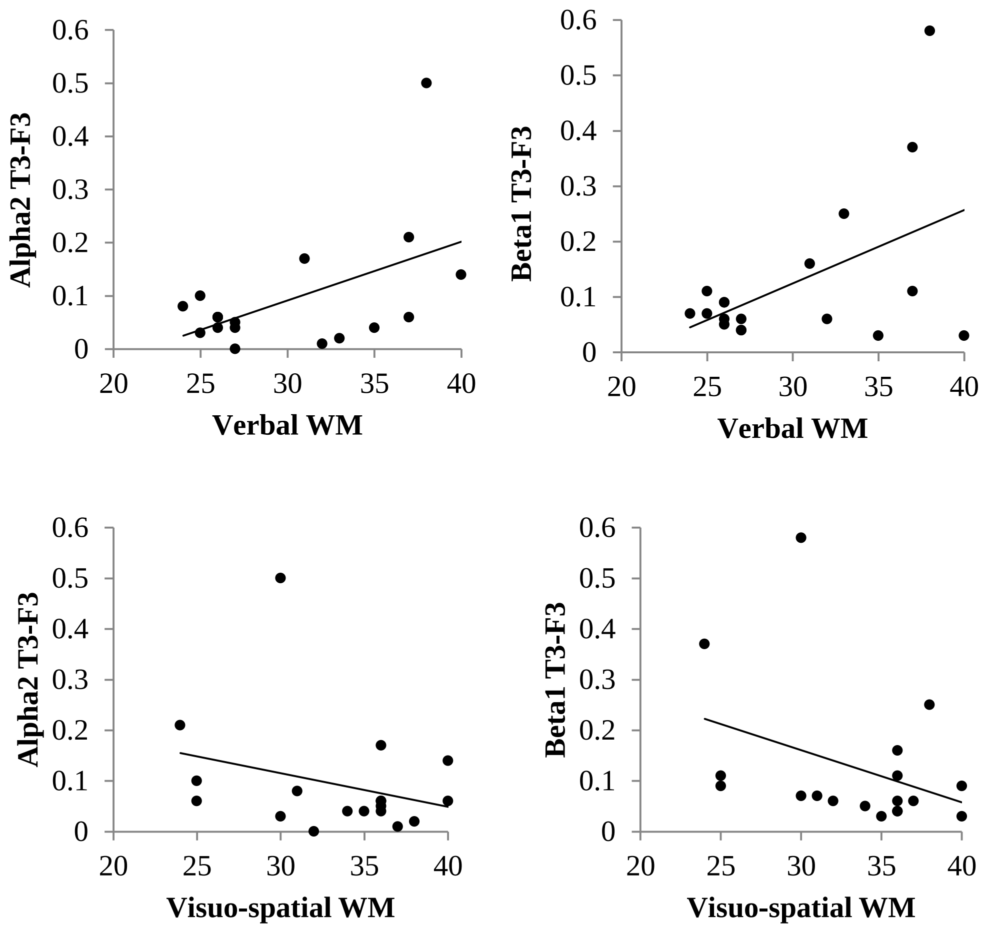


Figure 4.3. The relationship between verbal and visuo-spatial working memory and EEG coherence between the T3-Fz regions during Condition 2 (pressure).

Discussion

The main aim of this study was to examine whether working memory capacity influenced EEG activity when performing a motor skill. While the results confirmed the hypothesis, a clear distinction between verbal and visuo-spatial working memory was observed. Larger verbal working memory capacity was associated with greater EEG coherence in the T3-Fz regions, whereas larger visuo-spatial working memory was associated with lower coherence in the T3-Fz regions. It appears that larger verbal working memory results in greater verbal involvement during early skill learning (as expected), but larger visuo-spatial working memory reduces the tendency for verbal involvement.

Coherence between the T3-Fz regions is thought to represent verbal-analytical processes during the planning of movement (Deeny et al., 2003; Zhu et al., 2010; Zhu et al., 2011). Therefore, the results infer that people with larger verbal working memory capacity are more likely to engage verbal processes when performing a novel motor skill. This concept is consistent with the findings discussed in Chapter 3, in which children with larger verbal working memory capacity showed a greater tendency to test-hypotheses (i.e., use explicit processes) when performing a novel motor skill. Furthermore, earlier in this chapter a positive relationship was found between verbal working memory capacity and the Movement Specific Reinvestment Scale (MSRS) in both children and adults. Indeed, research has shown that people who score high on the MSRS scale display higher coherence in the T3-Fz regions (Zhu et al., 2011). Thus, the findings of the current study provide further evidence that verbal working memory capacity is associated with the propensity to use explicit processes, such as consciously controlling and monitoring movement ('reinvesting'), and this is evidenced by greater coherence between the T3-Fz regions of cerebral cortex in the brain.

An interesting finding in this study was the relationship between visuo-spatial working memory and coherence in the T3-Fz regions. It appears that larger visuo-spatial working memory is associated with less verbal-analytical involvement during motor performance. Acquiring a skill with minimal verbal involvement is referred to as implicit motor learning (Masters, 1992; Masters & Poolton, 2012). Indeed, a negative relationship was also found between visuo-spatial working memory and coherence between the T4-Fz regions (visuo-spatial and motor planning regions), and coherence between the T4-Fz regions has been shown to be less for implicit learners compared explicit learners (Zhu et al., 2011). The results therefore indicate that larger visuo-spatial working memory may encourage a more implicit mode of learning – although, this theory requires further exploration in which more participants are tested on a greater number of trials. Additionally, to assess implicit motor learning, measures of declarative knowledge accumulation and performance under dual-task conditions should be included (e.g., Hardy et al., 1996; Lam et al., 2009; Liao & Masters, 2001; Maxwell et al., 2001).

A secondary aim of the study was to examine the relationship between working memory, EEG coherence and performance under pressure. However, there was no difference between the no pressure condition and the pressure condition in EEG coherence or performance. This was likely due to limitations of the pressure condition. If the pressure condition did indeed replicate a high-pressure environment, an increase in EEG coherence from the baseline (no pressure) condition would be expected (e.g., Zhu et al., 2011). However, this was not found. Monetary incentives were used to manipulate pressure, which Mesagno et al. (2011) argue do not always increase anxiety. Future research therefore should look to explore alternative methods to evoke pressure.

In sum, this study provided evidence that working memory capacity influenced EEG coherence during performance of a motor skill. Specifically, the results support the theory that larger verbal working memory capacity is associated with a greater tendency to use explicit processes when performing a motor skill. The results also pose the question as to whether larger visuo-spatial working memory capacity is associated with a greater tendency to learn motor skills implicitly. Future research should explore this question, as it will increase our understanding of the influence that working memory has on the learning process.

The next chapter details an experiment that examines whether children with larger working memory capacity are advantaged when the practice environment places large demands on working memory (e.g., when a coach provides multiple instructions).

CHAPTER 5

COACHING INSTRUCTIONS ADVANTAGE CHILDREN WITH LARGER WORKING MEMORY CAPACITY: EVIDENCE FROM A FIELD-BASED STUDY

Introduction

As discussed previously, working memory is the primary mechanism responsible for many day-to-day cognitive tasks, such as reading and listening (e.g., Daneman & Carpenter, 1980). Working memory has a limited capacity (e.g., Carpenter, Just, & Shell, 1990; Cowan, 2001, 2005; Hitch at al., 2001; Oberauer & Kliegl, 2006) and the size of the capacity differs for every person (Engle et al., 1999; Just & Carpenter, 1992). Research has consistently shown that children with low working memory capacity (relative to their age) struggle with activities that place large demands on working memory (Gathercole, Alloway, Willis, & Adams, 2006; Gathercole, Lamont, & Alloway, 2006). Typically, these children have shorter attention spans, have difficulty monitoring their own work, show an inability to formulate solutions to problems, and forget lengthy instructions (Alloway, Gathercole, Kirckwood, & Elliot, 2009; Engle, Carullo, & Collins, 1991; Gathercole & Alloway, 2008; Gathercole et al., 2008; Gathercole, Lamont et al., 2006). Consequently, children with low working memory capacity generally progress slower in the classroom compared to their peers (Gathercole & Alloway, 2008; Swanson, 2011; Swanson et al., 2011). Indeed, measures of working memory have shown to be better predictors of a child's academic success than general tests of intelligence (Alloway 2009; Alloway & Alloway, 2010).

Although the relationship between a person's working memory capacity and performance on cognitive tasks has been well documented, there is little research that examines the influence that working memory capacity has on motor learning. Theories of skill acquisition suggest that motor learning is initially a highly conscious process (Fitts & Posner, 1967), relying heavily on working memory (Maxwell et al., 2003). For instance, when learning to play a tennis forehand, a player might consciously realise that they hit the ball more accurately when the racquet is swung from low-to-high. Similarly, when a coach provides verbal instructions to the player regarding their technique, the player becomes consciously involved in the learning process. While it is open to debate whether children acquire motor skills quite as consciously as adults (see Hernadez & Li, 2008; Hernandez et al., 2011), the ability to interpret and implement verbal instructions is strongly associated with working memory capacity (Engle et al., 1991; Gathercole et al., 2008). Children with low working memory capacity often fail to cope with the demands placed on working memory when multiple instructions are given and, subsequently, these children forget task-relevant information (Gathercole et al., 2008).

The provision of verbal instructions is common practice during physical education classes in primary school. Typically, verbal instructions regarding skill mechanics produce quick short-term improvements in skill performance (e.g., Hardy et al., 1996; Masters, 1992). It was therefore hypothesised that a child's working memory capacity would influence the rate of learning produced by verbal instructions. Specifically, it was predicted that children with high working memory capacity would learn motor skills faster when following explicit coaching instructions compared to children with low working memory capacity. No difference were expected in the rate of learning between high and low working memory capacity children when no coaching instructions were provided, as this places fewer demands on working memory resources.

Method

Participants

Forty-three children aged 6 to 7 years (*M* = 6.7 years, *SD* = 0.5) with limited to no tennis experience participated in the experiment. To ensure all children were of similar skill standard, children were excluded from the study if they had (i) been exposed to more than one school term of tennis coaching prior to the commencement of the study, (ii) had received no tennis coaching in the six months prior to the study, or (iii) were being coached at the time of the intervention. Children were then randomly assigned to the ‘Instruction group’ (n = 21; 11 boys and 10 girls) or the ‘No Instruction group’ (n = 22; 9 boys and 13 girls). Prior to the commencement of the training, children’s working memory was assessed. A median split of working memory scores within each group was performed, and children were subsequently divided into a high working memory group (HWM) or a low working memory (LWM) group. Thus, there were four groups: Instruction/HWM (n = 11), Instruction/LWM (n = 10), No Instruction/HWM (n = 10), and No Instruction/LWM (n = 12). Written voluntary consent was provided by all of the children and their parents or guardian (see Appendix F & G). The Institution’s Human Research Ethics Committee and the Department of Early Childhood Development approved the study.

Experimental Design

A pre-test post-test design was used, with a five-week training period in between. Both training and testing were conducted outdoors on synthetic grass during physical education classes in a school setting. For the Instruction group, explicit coaching instructions regarding the technical aspects of each tennis stroke were provided during the practice sessions, whereas none were provided to the No Instruction group. Throughout the experiment, all children used junior Wilson tennis racquets (length = 48.3 cm, mass = 200 g, grip circumference = 9.2 cm) and low compression balls (compression = 25% of standard tennis ball; diameter = 71.6 cm; mass = 44.0 g; rebound height = 100.0 cm).

Working Memory Assessment

Working memory capacity was assessed using two memory measures extracted from the Pearson Automated Working Memory Assessment (AWMA: Alloway, 2007a). These included the listening recall task and the spatial recall test (for a detailed description of these two tests, see page 34). A score was computed for each test, with higher scores representing larger working memory capacity. The combined total of the scores from the two tests became the overall working memory score.

Tennis Skill Testing Procedure

The pre- and post-tests were conducted one-week prior to and one week after the training program. Testing included a hitting performance assessment and measures of technique for the basic strokes of tennis (forehand, backhand and starting a rally). Two digital video cameras capturing at 25 Hertz and placed behind and to the side of the players recorded the hitting actions of players to allow for analysis of hitting technique and hitting accuracy via video replay.

Hitting performance task: The researcher threw the ball under-arm so that it landed in a target area on the child’s forehand side (see Figure 5.1). If the ball did not land in the target area, the throw was repeated. Children were asked to play forehand shots only and to score as many points as possible by making contact with the ball (1 point) and then landing the ball on specific zones on the court (see Figure 5.1). Four points were awarded for balls that landed in the deepest zone of the court (regulation and attainment of depth represents a fundamental tactic in tennis), whereas shots landing in zones that were less deep were awarded 3, 2 or 1 point, incrementally. Two bonus points were also awarded if the ball was hit over the net but lower than 2 metres above the ground. Shots hit at this height were considered as representative of better tennis shots. This was measured via video replay. Children were given 3 practice shots followed by 10 shots that were assessed. The test-re-test reliability of this task is detailed in Chapter 7 (see page 115).

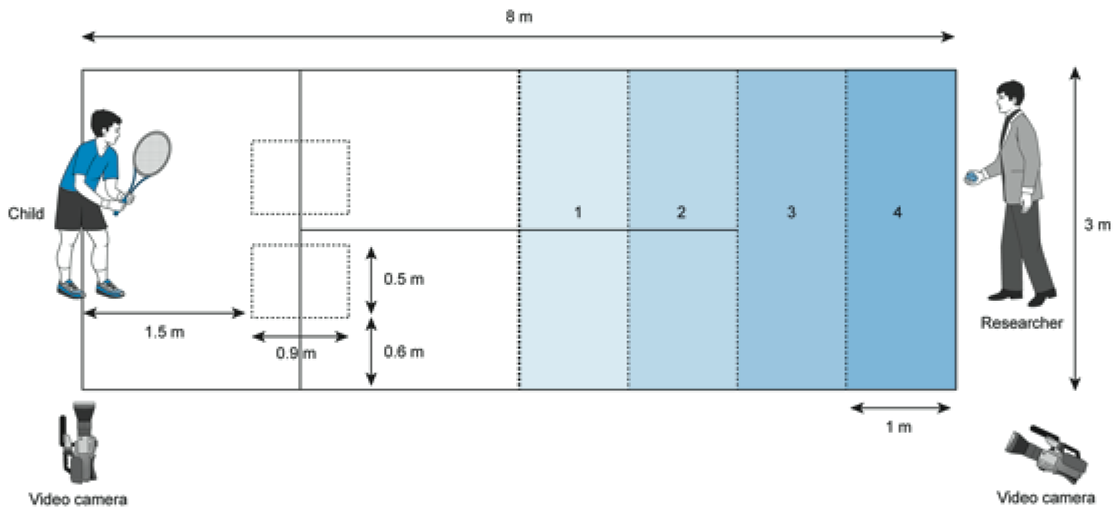


Figure 5.1. The court dimensions for the hitting task.

Technique measures. Children played three forehands, three backhands and three underarm serves (i.e., 'starting a rally'). For the forehands and backhands, the researcher threw the balls underarm to the children. An independent rater assessed children's technique via video replay using Tennis Australia's technical fundamentals checklist (Tennis Australia, 2012). For each shot type, the checklist comprised of six technical points (see Appendix J for an outline of the technical points). For every trial, children were given a 1 or a 0 for each technical point depending if their movements corresponded with the criteria. The score for the three shots were combined to give a final score out of 18. To assess reliability, a second independent rater assessed the technique of all children. Intra-class correlation coefficients indicate moderate to high correlations for each stroke type during the pre-test (forehand, ICC = .82, $p < .01$; backhand, ICC = .84, $p < .01$; underarm serve, ICC = .79, $p < .01$) and post-test (forehand, ICC = .73, $p < .01$; backhand, ICC = .82, $p < .01$; underarm serve, ICC = .82, $p < .01$).

Practice Procedure

Children participated in five 30-minute practice sessions over a five-week period. The practice sessions were based on Tennis Australia's junior modified program, 'Hot Shots' (see

Appendix H). Each practice session had a specific focus (e.g., learn to start a rally, learn to build a rally by playing the forehand, learn to incorporate the backhand into a rally) and the activities were selected accordingly (see Appendix I for an outline of each practice session). There were three 10-minute activities for each session and the same coach administered every session. For the Instruction groups, the coach was advised to provide explicit technical instructions about the skills being performed in every activity. Examples of explicit instructions provided were "stand side on… have the tip of racquet pointing behind you in preparation to hit the ball… swing through the ball… have the face of the racquet facing the target… stretch out towards the target when hitting the ball". The coach was asked to provide no explicit technical instructions to the No Instructions group. The number of forehands, backhands, underarm serves, and 'other touches' (e.g., bouncing the ball on the racquet) were counted for two randomly selected children in each session to ensure that each group hit a similar number of balls during the intervention.

Statistical Analysis

Independent t-tests measured if any differences existed in working memory scores between the two HWM groups and the two LWM groups respectively, and one-way ANOVA's measured if there were any differences between the four groups in the skills' tests during the pre-test. To assess if there were any interactions between skill learning (i.e., pre-post-test performance), the provision of instructions and working memory capacity, a series of split-plot ANOVA's were conducted for the four skill measures. The within-subject variable was Time (pre and post-test performance) and the between subjects variable was Group. Statistical significance was set a priori at $p < .05$. Partial eta square (η_p^2) was reported as the effect size for main effects, while Cohen's *d* was used to report the standardised mean differences. Magnitudes of effects were interpreted using Cohen's (1988, 1992) thresholds for partial eta square (< .01, trivial; .01 – .06, small; .06 – .14, moderate; > .14, large) and

Cohen's *d* (< .2, trivial; .2 – .5, small; .5 – .8, moderate; > .8, large). The raw mean differences and 95% confidence intervals were reported where appropriate. To examine that no differences existed between the groups in relation to practice opportunities a sub-set of participants practice volumes were analysed (Instruction groups, *n* = 6; No Instruction groups, *n* = 4). This was completed using non-parametric statistical tests. Mann-Whitney U tests (two-tailed) measured for differences between the groups in the number of forehands, backhands, serves, and other touches during each practice session.

Results

Working Memory Scores

There were no significant differences in scores between the two HWM groups for the listening recall task [t (16.9) = 1.88, *p* = .08] and the spatial recall test [t (18.2) = 0.75, *p* = .46]. Although, there was a large effect size for the listening recall test (*d* = .84) with the Instruction/HWM group (*M* = 10.6, *SD* = 2.9) having a score of 1.9 (95% CI [-0.2, 4.1]) better than the No Instruction/HWM group (*M* = 8.6, *SD* = 1.8). Comparatively, the effect size was small (*d* = .33) for the spatial recall test with the mean difference in scores between the two groups being only 0.9 (95% CI [-1.8, 3.7]) (Instruction/HWM group, *M* = 17.2, *SD* = 2.8; No Instruction/HWM group, *M* = 16.2, *SD* = 3.2)

For the two LWM groups, a significant difference was found for the listening recall task [t (16.7) = 3.45, *p* = .003] with the Instruction/LWM group (*M* = 7.4, *SD* = 2.4) having a score of 3.2 (95% CI [1.2, 5.1]) better than the No Instruction/LWM group (*M* = 4.3, *SD* = 1.8). A large effect size confirmed this difference (*d* = 1.51). For the spatial recall test, there was no difference between these two groups [t (19.9) = -0.7, *p* = .47] and the effect size was small (*d* = .32). The Instruction/LWM group had a score of only 1 (95% CI [-1.8, 3.9]) greater than the No Instruction/LWM group.

Group Equality at Pre-Test

One-way ANOVA's showed that there were no differences between the four groups during the pre-test for hitting performance [F (3, 42) = 0.63, p = .60, η_p^2 = .05], forehand technique [F (3, 42) = 1.14, p = .35, η_p^2 = .08], backhand technique [F (3, 42) = 1.10, p = .36, η_p^2 = .08] or underarm serve technique [F (3, 42) = 0.39, p = .76, η_p^2 = .03]. See Figure 5.2 (hitting performance data) and Table 5.1 (technique data) for the descriptive statistics of the pre-test.

Group Equality During Practice Sessions

All groups had a similar number of hitting opportunities during practice. Mann-Whitney U tests revealed no differences between the Instruction Groups and No Instruction groups for the number of forehands, backhands, underarm serves and other touches. This implies that all children had an equal number of hitting opportunities.

Forehands: (session 1, [U = 7.0, p = .28]; session 2, [U = 9.0, p = .61]; session 3, [U = 10.0, p = .76]; session 4, [U = 5.0, p = .71]; session 5, [U = 5.0 p = 0.11]).

Backhands: (zero backhands during sessions 1, 2 and 3; session 4, [U = 11.5, p = .91]; session 5, [U = 6.5 p = .21]).

Underarm serves (zero underarm serves during session 1; session 2, [U = 10.5, p = .76]; session 3, [U = 11.0, p = .91]; session 4, [U = 11.0, p = .91]; session 5, [U = 6.0 p = .26]).

Other touches (session 1, [U = 6.5, p = .26]; session 2, [U = 4.5, p = .11]; session 3, [U = 6.5, p = .26]; session 4, [U = 6.0, p = .26]; session 5, [U = 8.0 p = .48]).

Pre- Post-Test Performance

Hitting performance. A split-plot ANOVA revealed a main effect for Time [F (1, 39) = 14.84, p < .001, η_p^2 = .28]. Further examination showed that this effect was mainly due to the large pre- to post-test improvements by the Instructions/HWM group (see Figure 5.2).

Indeed, a significant Group x Time interaction was found [F (3, 39) = 3.32, p = .03, η_p^2 = .20]. The Instruction/HWM group improved by a score of 7.5 (95% CI [3.4, 11.7]) and the effect size confirmed that this was a large improvement (d = 1.22). Comparatively, the Instruction/LWM group improved by a score of 2.6 (95% CI [-0.1, 5.3]) and this had a small effect size (d = .25). The two No Instruction groups showed trivial to small improvements (No Instruction/HWM, d = .07; No Instruction/LWM, d = .22). The mean differences between the pre- and post-tests scores were 0.5 (95% CI [-2.8, 3.8]) for the No Instruction/HWM group and 2.1 (95% CI [-1.7, 5.9]) for the No Instruction/LWM group.

To clearly establish the difference between the HWM and LWM Instruction groups, another split-plot ANOVA was performed but only for these two groups. As expected, a main effect was found [F (1, 19) = 19.89, p < .001, η_p^2 = .51]. Additionally, there was a significant Group x Time interaction [F (1, 19) = 4.73, p = .04, η_p^2 = .19], with the HWM group showing a significantly greater improvement than the LWM group.

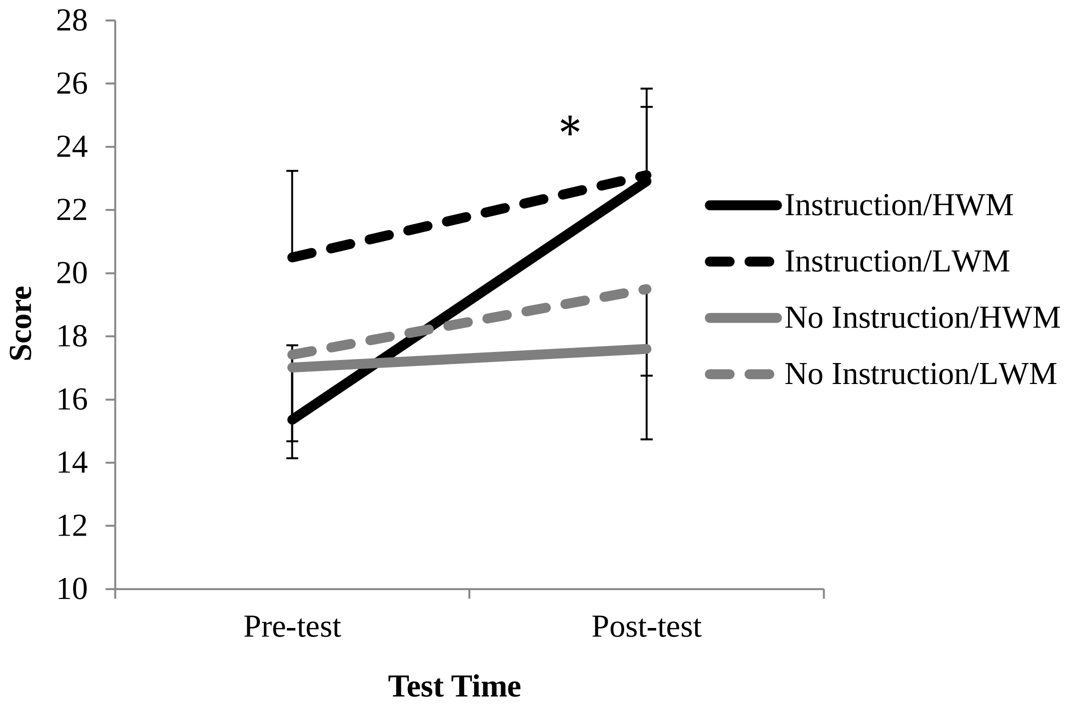


Figure 5.2. Hitting performance scores during the pre- and post-test for the four groups. * represents a significant Group x Time interaction (p < .05). Error bars represent the standard error. For ease of viewing, the two 'Instruction' groups have positive error bars and the two 'No Instruction' groups have negative error bars.

Forehand technique. A main effect was found for Time [F (1, 39) = 10.94, p = .002, η_p^2 = .22], but no Group x Time interaction [F (3, 39) = 1.38, p = .26, η_p^2 = .09]. Three of the four groups showed improvements from pre- to post-test, with large effect sizes found for the two No Instructions groups (No Instruction/HWM, d = 1.31; No Instruction/LWM, d = 1.26) and a small effect for the for the Instruction/HWM group (d = .37). The only group to show no improvement was the Instruction/LWM group (d = .03). See Table 5.1 for descriptive statistics.

Backhand technique. There was a main effect for Time [F (1, 39) = 15.31, p < .001, η_p^2 = .28], but no significant Group x Time interaction [F (1, 39) = 1.05, p = .38, η_p^2 = .08]. The No Instruction/LWM group (d = 1.53) and the Instruction/LWM group (d = .77) showed that largest improvement, while small effect sizes were found for the two HWM groups (Instruction/HWM, *d* = .38; No Instruction/HWM, *d* = .23). See Table 5.1 for descriptive statistics.

Underarm serve technique. A main effect was again found for Time [F (1, 39) = 8.91, p = .005, η_p^2 = .19], but there was no Group x Time interaction [F (1, 39) = 0.15, p = .93, η_p^2 = .01]. Effect sizes were large for the No Instruction/LWM group (*d* = 1.02), moderate for the Instruction/LWM group (*d* = .74), and small for the Instruction/HWM group (*d* = .26) and No Instruction/HWM group (*d* = .44). See Table 5.1 for descriptive statistics.

Table 5.1

The means and standard deviations of the technique scores for each stroke type during the pre- and post-test

	Pre-test	*Post-test*
Forehand technique*		
Instruction/HWM	9.9 (2.3)	10.9 (2.1)
Instruction/LWM	10.2 (2.5)	10.3 (2.8)
No Instruction/HWM	8.6 (1.8)	10.7 (1.7)
No Instruction/LWM	9.6 (1.6)	10.9 (3.2)
Backhand technique*		
Instruction/HWM	9.7 (2.9)	10.8 (1.8)
Instruction/LWM	8.4 (1.8)	10.7 (2.8)
No Instruction/HWM	7.8 (2.4)	8.5 (2.2)
No Instruction/LWM	8.3 (2.5)	10.9 (2.3)
Underarm serve technique*		
Instruction/HWM	9.7 (1.7)	10.7 (3.2)
Instruction/LWM	10.2 (3.3)	11.9 (3.2)
No Instruction/HWM	10.1 (2.3)	11.3 (2.2)
No Instruction/LWM	10.8 (1.8)	12.5 (3.1)

* represents a main effect for Time ($p < .05$)

Discussion

This study examined whether working memory capacity influenced the acquisition of tennis skills in children following practice with or without explicit coaching instructions. Some evidence was found to support our hypothesis that children with high working memory capacity would show greater improvement in hitting performance compared to children with low working memory capacity following the provision of coaching instructions. I speculated that the high working memory capacity children had a greater capacity to remember and execute the coaching instructions, whereas the low working memory capacity children likely forgot the instructions and therefore were unable to implement them (e.g., Engle et al., 1991; Gathercole et al., 2008). Indeed, Gathercole et al. (2008) demonstrated that the critical constraint limiting children with low working memory capacity from executing instructions was inefficient formation, maintenance and accessibility of the representations in working memory. In the practice groups where no explicit coaching instructions were provided, there was no difference between high and low working memory children with regards to the amount of improvement from pre- to post-test – although, the improvements were very little for the No Instruction groups (see Figure 5.2), highlighting the ineffectiveness of simply providing no instructions as a practice technique. With regards to the hitting technique data, all groups showed similar improvements from pre- to post-test. Interestingly however, the only group that showed no improvement in technique for any one of the strokes (based on effect sizes) was the Instruction/LWM group (forehand). Although weak, it provides further evidence that children with low working memory capacity acquire skills slower than their peers when learning places heavy demands on working memory.

A potential issue with this study was that the Instruction/LWM group scored better on the listening recall test than their counterpart No Instruction/LWM group. The listening recall test targets the verbal component of working memory (Alloway et al., 2006), which implies that the children in the Instruction/LWM group had a greater capacity to store and process verbal information than children in the No Instruction/LWM group. However, this cannot be viewed as a limitation as this should, if anything, benefit the Instruction/LWM group following the provision of verbal instructions. Another limitation of the study was the assessment of practice by examining two randomly selected children in each group. Whilst this provided a reasonable account of the amount of practice amongst the four groups, we cannot be certain that these children provided an accurate representation of their respective group. To accurately measure practice every participant needs to be examined.

In summary, this study provides evidence that working memory capacity influences the extent of motor learning following provision of verbal instructions. I extend this argument and propose that children with high working memory capacity are advantaged in any learning scenario that places large demands on working memory. Although, given that working memory capacity was defined as the sum of scores from verbal and visuo-spatial working memory tests, future research should examine the two sub-systems of working memory separately. A strength of this study was that it was conducted during physical education classes in a school setting and therefore there was high ecological validity. However, future research should examine this hypothesis in a more controlled environment with simpler outcome measures (i.e., learning only one skill rather than many). Additionally, transfer measures such as a dual-task test should be included in future studies to assess the adaptability of the acquired skill. Importantly, various practice methods should also be explored in an attempt to reduce load on working memory and subsequently enhance the acquisition of motor skills (e.g., errorless practice, Capio, Poolton, Sit, Euiga et al., 2013), especially for children with low working memory capacity. It must be remembered that the provision of no instructions does not necessarily result in low working memory involvement as the exploration of movement patterns can engage explicit processes (e.g., discovery learning, Hardy et al., 1996; Masters, 1992). The theory of implicit motor learning provides an appropriate framework to examine practice methods that reduce working memory involvement (e.g., Lam et al., 2009; Masters, 1992; for a recent review of implicit motor learning, Masters & Poolton, 2012). The following three chapters will examine the use of modified equipment as a means to reduce demands on working memory.

CHAPTER 6

SCALING SPORTING EQUIPMENT FOR CHILDREN PROMOTES IMPLICIT PROCESSES DURING PERFORMANCE

Introduction

Cognitive models of learning (e.g., Fitts & Posner, 1976) suggest that learning a motor skill is initially a conscious process, and only after prolonged repetition does skill performance become unconscious (i.e., automatic control). The initial cognitive stage is characterised by the formulation of rules about how the skill should be performed. As such, explicit rule-maps develop that can be applied during future performances of the skill (Maxwell et al., 2003). This formulation of rules, also known as ‘hypothesis testing’, occurs in working memory, the mechanism responsible for the processing and storage of verbal, visual and episodic information during a cognitive task (Baddeley, 2012; Baddeley & Hitch, 1974; Gathercole, 2008; Miyake, & Shah, 1999). Masters and colleagues (e.g., Masters, 1992; Maxwell et al., 2003; Poolton et al., 2007a) argue that a conscious mode of learning is heavily dependent on the availability of working memory resources and, consequently, the learner becomes reliant on working memory availability in order to execute the skill. This form of learning becomes problematic when the learner is placed in an environment that demands working memory resources. In such cases, if working memory is occupied with information other than the skill itself, performance of the motor skill deteriorates (Maxwell et al., 2003).

Another challenge for learner’s, particularly children, is that working memory capacity is still developing throughout childhood (e.g., Alloway et al., 2006; Gathercole et al., 2004; Luciana et al., 2005; Luna et al., 2004; Thomason et al., 2009). Children process information slower than adults (Ferguson & Bowey, 2005), and therefore it is unlikely that children learn as effectively via conscious methods as adults do. Indeed, the sensorimotor hypothesis suggests that young children rely more on implicit (unconscious) memory rather than explicit (conscious) memory to learn skills, whereas the opposite occurs for adults (e.g., Hernandez & Li, 2007; Hernandez et al., 2011). Thus, to optimise motor learning in children, practice should be designed to minimise explicit processes such as working memory involvement (e.g., Capio, Poolton, Sit, Holmstrom et al., 2013). Implicit motor learning theory provides a framework for such practice (for a recent review of implicit motor learning, see Masters & Poolton, 2012).

Implicit motor learning refers to the acquisition of a skill with little to no conscious awareness of the information that underlies the learnt behaviour (Magill, 1998; Masters, 1992; Hardy et al., 1996; Pew, 1974; Reed, McLeod, & Dienes, 2010); hence, learning occurs with minimal working memory involvement (Maxwell et al., 2003). Several practice techniques have been proposed that aim to promote implicit motor learning (e.g., analogy learning, Liao & Masters, 2001; dual task practice, Maxwell et al., 2000; errorless practice, Maxwell et al., 2001; marginally perceptible feedback, Masters et al., 2009; and reduced feedback, Maxwell et al., 2003). Another technique that may evoke implicit learning, specifically for children, is the use of modified equipment. Modifying equipment to suit the physical size of children allows skills to be performed with greater ease (Burton & Welch, 1990; Elliott, 1981; Elliott & Marsh, 1989; Farrow & Reid, 2010b; Hammond & Smith, 2006; Wright, 1967). Based on the errorless learning paradigm, which suggests that the reduction of errors during performance limits explicit hypothesis testing (Masters et al., 2004; Maxwell et al., 2001; Orrell et al., 2006b; Poolton et al., 2005; Poolton et al., 2007a), the use of modified equipment by children was predicted to reduce working involvement during skill performance.

Maxwell et al. (2001) demonstrated the implicit learning benefits of errorless practice during a golf-putting task. The participants who experienced many errors accumulated numerous rules about the skill and performed significantly worse when required to concurrently perform a cognitively demanding secondary task. They argued that this was because the accumulation of errors causes a person to analyse their movements, which consequently places additional demands on working memory resources. Comparatively, participants who practised relatively error-free reported fewer rules and their performance was not disrupted by a secondary task. This suggests that they did not explicitly test hypotheses about the task and therefore were less reliant on working memory resources to perform the skill. This argument has since been supported by further research in golf putting (Poolton et al., 2005), children learning to throw (Capio, Poolton, Sit, Holmstrom et al., 2013), and patients rehabilitating from stroke (Orrell et al., 2006b) and Parkisnon’s desease (Masters et al., 2004). It therefore appears that hypothesis testing is less likely to occur when skills are executed successfully. In the Maxwell et al. (2001) study, an ‘errorless’ practice environment was created by initially putting the golf ball from a very short distance and then gradually increasing the putt length. I propose that another method to achieve a relatively errorless environment is to modify the equipment used in order to increase the probability of successful outcomes. For example, Wulf, Shea, and Whitacre (1998) improved performance on a ski simulator by providing ‘poles’ to assist the participants’ balance. Whilst achieving a ‘true’ errorless environment through equipment scaling is improbable, as children will always make mistakes, I predicted that there would be fewer demands on working memory resources when using modified equipment compared to when using full size (adult) equipment.

Indeed, designing practice techniques that minimise working memory involvement may be most beneficial for children with low motor skill ability (e.g., Capio, Poolton, Sit, Eguia et al., 2013), as studies have shown that children with developmental coordination disorders typically also have underdeveloped working memory resources (e.g., Alloway, 2007b; Alloway & Archibald, 2008). Whilst movement-impaired children were not targeted in the current study, I divided children into skilled and less skilled groups based on their hitting performance and measured their working memory capacity to assess whether differences in cognitive development also existed between the groups. The skilled children were hypothesised to display higher scores on the working memory assessment, indicating greater working memory capacity. I therefore predicted that the less skilled children would display greater performance disruption in a dual-task condition than higher skilled children when using equipment that placed larger demands on working memory resources (i.e., full size equipment). It was also expected that all children would hit more accurately and with better technique when using modified equipment compared to full size equipment, thus demonstrating the benefits of modified equipment for all children, regardless of skill level or working memory capacity.

Method

Participants

Forty children (19 boys and 21 girls) aged 9 to 11 years (boys, *M* = 10.6 years, *SD* = 0.2; girls, *M* = 10.5 years, *SD* = 0.2) were divided into two groups based on their hitting performance (median split) in the single task condition: a more skilled group and a less skilled group. One girl from the less skilled group was considered an outlier based on box-plot analyses of her hitting performance in multiple conditions and, consequently, her data was removed from the study. This left 20 participants in the skilled group (boys, *n* =13; girls, *n* =7) and 19 in the less skilled group (boys, *n* = 6; girls, *n* = 13). None of the children had played competition tennis or were involved with a tennis club. Furthermore, none of the children had been diagnosed with a developmental condition. All participants and their parents and/or guardian gave written voluntary consent (see Appendix A and B). The Human Research Ethics Committee of the University where the study was conducted as well as the relevant Department of Early Childhood Development approved the study.

Experimental Design

There were two distinct aspects of the experiment: (a) assessment of working memory capacity and (b) measurement of motor skill performance. Working memory was measured prior to the motor skill component using the Pearson Automated Working Memory Assessment (Alloway, 2007a). For the motor skill, a tennis forehand test was set up. Children were required to perform this task using two types of equipment (modified equipment and full size equipment) in two attention conditions (single task and dual-task). Post-hoc, children were divided into two groups (skilled and less skilled) based on hitting performance. The two groups were analysed separately with regard to their performance in the single task compared to the dual-task conditions. Differences in working memory capacity between two groups were examined.

Working Memory Assessment

Two memory measures were taken from the Automated Working Memory Assessment (Alloway, 2007a); *listening recall,* which measured verbal working memory, and *spatial recall,* which measured visuo-spatial working memory (for a detailed description of these tests, see pages 34).

Hitting task procedure

Hitting task. Children were required to hit a tennis forehand to a target on a mini-tennis court (11 m x 3 m) using both full size and modified equipment (see Figure 6.1 for the court set-up). The full size equipment included a full size Wilson racquet (length = 68.6 cm; mass = 249.0 g; grip circumference = 10.5 cm) and standard ‘yellow’ tennis balls (compression = 100%; diameter = 65.4 cm; mass = 56.0 g; rebound height = 139.0 cm) while the modified equipment included junior Wilson racquet (length = 58.4; mass = 200.0 g; grip circumference = 9.2 cm) and low compression ‘red’ Wilson balls (compression = 25%; diameter = 71.6 cm; mass = 44.0 g; rebound height = 100.0 cm). The researcher threw the ball under-arm so that it landed in a defined area (see Figure 6.1) on the child's forehand side. If balls did not land in this area, the throw was repeated. To ensure no bias existed in the ball feeding among the four conditions, the time taken from ball release to when the ball bounced was measured for every shot via video replay for a subset of 20 participants. Cronbach's Alpha for the four conditions was 0.95, indicating that the ball feeding was very consistent.

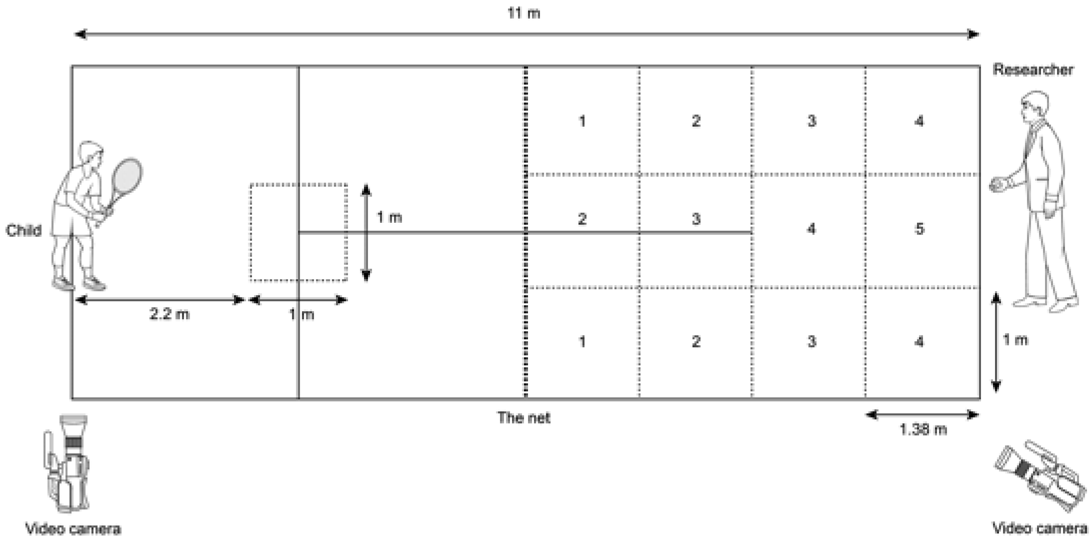


Figure 6.1. The court set-up and dimensions.

Attention conditions. Children performed the hitting task in two attention conditions – a single-task condition (i.e., hitting task only) and a dual-task condition. In the dual-task condition, children executed the hitting task while simultaneously counting backwards from 150 in 'ones' to the beat of a metronome (one beat per second). If children lost count, the researcher provided assistance to ensure the counting continued from where they lost count. Similarly, if the counting was too fast or too slow, the researcher reminded the children to keep counting to the tone of the metronome. In such situations, the researcher stopped feeding the balls until the child began counting correctly again. Secondary task performance was assessed via video replay and it was observed that all children performed the counting task correctly during all trials.

Children performed the hitting task in the two conditions using both modified and full size equipment. Each condition consisted of two blocks of 15 trials: one block using full size equipment and one block using modified equipment. The single task condition was always performed first. The order that the two types of equipment were used was counterbalanced amongst the participants.

Hitting task assessment

Hitting performance. This was measured as the total number of points accumulated for each block of 15 trials. The opposite half of the court was divided into 12 areas, with each area representing a certain number of points (see Figure 6.1). The children's aim was to score as many points as possible by playing a tennis forehand. More points were rewarded for shots that were played deeper and straighter. Balls were fed by the researcher and landed in the marked area (the chequered box). Children were instructed to stand slightly off-centre to favour their forehand side since the chequered box was in the centre. Two digital video cameras capturing at 25 Hertz and placed behind and to the side of the players recorded the hitting actions of players to allow for analysis of hitting technique and hitting accuracy via video replay.

Hitting technique. This was assessed using Tennis Australia's technical fundamentals checklist (Tennis Australia, 2012). The checklist comprised of six technical points (see Appendix J): (1) grip – an eastern forehand grip to a semi western forehand grip was required; (2) circular swing – a circular-like motion had to be created in the backswing with the racquet; (3) low-to-high swing – the racquet had to be swung from low to high during the forward swing but with an arc that was more horizontal than vertical; (4) step forward - children were expected to step forward into the shot with the opposite leg to their hitting hand; (5) impact - the ball needed to be struck in front and to the side of the body; and (6) follow through - the follow through needed to be considered a natural extension of the swing (i.e., extension and flexion of the elbow). For every trial, children were given a 1 or a 0 for each technical point depending if their movements corresponded with the criteria. The hitting technique of all children were analysed by a second independent rater for reliability purposes. To assess reliability, the scores for each technique variable were tallied across the four conditions to allow for an assessment of each variable individually. Intra-class correlation coefficients indicated moderate correlations for each technique variable (grip, ICC = .89, $p < .01$; circular swing, ICC = .60, $p < .01$; low-to-high swing, ICC = .66, $p < .01$; step forward, ICC = .77, $p < .01$; impact, ICC = .62, $p < .01$; follow through, ICC = .71, $p < .01$).

Statistical Analysis

Differences in working memory scores (verbal and visuo-spatial) between the skilled and less skilled groups were measured using independent t-tests. Analysis of hitting performance and each hitting technique variable was conducted using 2 (equipment type) x 2 (attention condition) x 2 (skill group) mixed ANOVA's. Where main effects were present, post-hoc analyses were conducted using the Bonferroni method to adjust *p* values ($p \leq .016$). Significance was set at $p \leq .05$. Partial eta square (η_p^2) was reported as the effect size for main effects, while Cohen's *d* was used to report the standardized mean difference between specific groups or conditions. Magnitudes of effects were interpreted using Cohen's (1988, 1992) thresholds for partial eta square (< .01, trivial; .01 – .06, small; .06 – .14, moderate; > .14, large) and Cohen's *d* (< .2, trivial; .2 – .5, small; .5 – .8, moderate; > .8, large). Magnitude-based inferences were made about true (population) values of the effects by expressing the uncertainty in the effects as 90% confidence limits.

Results

Working memory assessment

Moderate effects were found between the skilled and less skilled group for both verbal (mean difference ± 90% confidence interval: 0.64 ± 0.59) and visuo-spatial (mean difference 0.62 ± 0.67) working memory, with the skilled group demonstrating greater working memory capacity in both tests (verbal: skilled group mean = 15.7 ± 3.9, less skilled mean = 13.6 ± 2.9; visuo-spatial: skilled mean = 25.4 ± 6.3, less skilled mean = 23.2 ± 4.0). Paired t-tests indicated a tendency for a difference for the verbal component [t (18) = 1.85, p = .07] but no difference in the visuo-spatial component [t (18) = 2.39, p = .24].

Hitting performance

The mean scores for hitting performance are presented in Figure 6.2. A significant main effect was found for Equipment [F (1, 36) = 29.31, $p < .001$, $\eta_p^2 = .44$], with modified equipment producing better performance than full size equipment (mean difference ± 90% confidence intervals: 1.00 ± 0.38). There was no Equipment x Group interaction [F (1, 36) = 1.17, p = .29, $\eta_p^2 = .03$] nor was there an Equipment x Condition interaction [F (1, 36) = 0.62, p = .44, $\eta_p^2 = .02$], suggesting that the greater hitting performance with modified equipment was not dependent upon these variables.

A significant 3-way interaction was found, however, among Equipment, Condition and Group [F (1, 37) = 11.67, $p = .002$, $\eta_p^2 = .24$]. Paired t-tests showed that the less skilled group of children performed significantly worse in the dual-task condition than the single task condition when using full size equipment ([t (18) = 2.86, p = .01] mean difference 0.73 ± 0.42). Comparatively, there was no difference in performance between the two attention conditions when using modified equipment ([t (18) = -1.80 p = .09] mean difference 0.39 ± 0.46). For the skilled group of children, no differences were observed for either modified [t

(19) = 0.60 p = .56] or full size [t (19) = -1.45 p = .16] equipment between the single task and dual-task conditions.

a) Modified equipment *b) Full-size equipment*

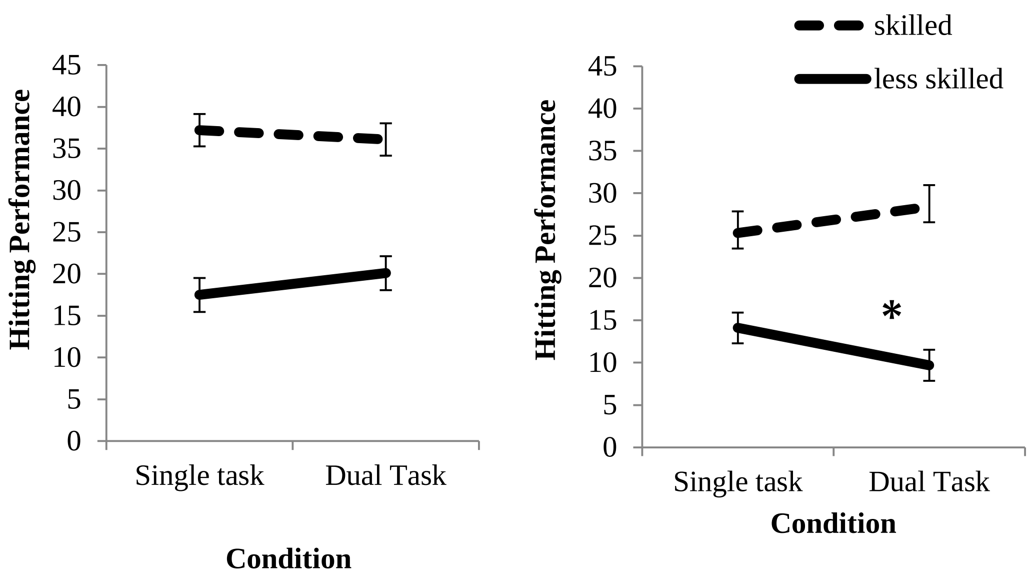


Figure 6.2. Mean hitting performance for the skilled group and less skilled group in the two attention conditions when using (a) modified equipment and (b) full size equipment. *represents significantly poorer performance in the dual task condition than the single task condition ($p \leq .016$). Error bars represent the standard error.

Hitting technique

The descriptive statistics for the six hitting technique variables are presented in Table 6.1. Main effects for Equipment were found in low-to-high swing [F (1, 33) = 23.26, p < .001, η_p^2 = .41], stepping forward [F (1, 33) = 8.51, p = .006, η_p^2 = .21], and impact [F (1, 33) = 6.06, p = .02, η_p^2 = .16] with modified equipment linked to better technique. For these three variables, there were no Equipment x Group or Equipment x Condition interactions. Hence, regardless of condition or skill level, children stepped forward more often (mean difference ± 90% confidence intervals: 0.47 ± 0.27), swung the racquet from low-to-high on more occasions (mean difference 0.69 ± 0.26) and made correct impact with the ball more frequently (mean difference 0.77 ± 0.41) when they used modified equipment. No further main effects or interactions were found among the other technique variables.

Table 6.1

The means and standard deviations for the six hitting technique variables

Variable	Attention condition			
	Single task		Dual-task	
	Modified	*Full size*	*Modified*	*Full size*
Skilled group				
Grip	13.2 (4.9)	12.4 (5.9)	13.2 (4.9)	12.4 (5.9)
Circular swing	4.5 (6.1)	4.0 (6.1)	4.4 (5.7)	2.4 (5.1)
Low-to-high swing*	11.3 (4.8)	7.6 (5.6)	11.1 (4.7)	8.4 (4.9)
Step Forward*	9.9 (4.9)	7.8 (5.6)	8.8 (5.6)	8.0 (5.9)
Impact*	14.8 (0.5)	13.9 (2.7)	14.1 (2.9)	13.2 (2.4)
Follow through	7.8 (5.6)	4.4 (4.8)	5.8 (6.0)	3.9 (4.7)
Less skilled group				
Grip	9.3 (6.9)	9.7 (6.3)	7.7 (7.2)	8.3 (7.2)
Circular swing	3.4 (6.1)	3.5 (5.6)	2.6 (5.7)	2.6 (5.0)
Low-to-high swing*	5.8 (4.2)	3.3 (3.9)	6.0 (4.5)	2.7 (2.4)
Step Forward*	7.6 (5.7)	6.6 (5.5)	7.9 (6.2)	7.1 (5.8)
Impact*	10.5 (5.2)	8.6 (5.0)	10.0 (5.6)	8.8 (5.0)
Follow through	3.5 (3.9)	5.6 (5.2)	3.64 (3.9)	5.6 (4.6)

* represents a main effect for Equipment in these variables ($p < .05$).

Discussion

The aim of this study was to examine whether the use of modified equipment by children aged 9 to 11 years promoted less conscious processing when performing a tennis-hitting task. It was hypothesised that using modified equipment, as compared to full size equipment, would simplify the task allowing skills to be performed with greater ease, thereby reducing conscious processing during performance. The results support the hypothesis with the less skilled children performing significantly worse in the dual-task condition (as compared to the single task condition) when using full size equipment but not modified equipment.

Finding that the less skilled children, rather than the skilled children, showed a decline in performance when using full size equipment in the dual-task condition becomes more meaningful when the working memory capacity of the two skill groups is compared. Measures of working memory showed that the less skilled children had slightly smaller working memory capacity than their skilled counterparts. While the difference was not statistically significant for the verbal component (p = .06), the effect size and 90% confidence intervals suggest that a meaningful difference existed (d = 0.64 ± 0.54). Smaller verbal working memory capacity represents a reduced ability to process phonological items in the mind (Alloway et al., 2009; Alloway et al., 2006; Baddeley, Gathercole, & Papagno, 1998). Therefore the less skilled children would have experienced greater difficulty processing the secondary task (counting backwards in 1's) when performing with equipment that placed larger loads on working memory (i.e., the full size racquet and adult ball).

Impaired performance of a motor skill when simultaneously completing a cognitively demanding secondary task suggests that working memory is overloaded (Maxwell et al., 2003). It is therefore feasible to assume that children were more dependent on conscious resources to control their movements when using full size equipment, and the decline in performance by the less skilled children may be explained by their smaller working memory capacity. In contrast, children with larger working memory capacity were more likely to be able to cope with the extra demands of the secondary task and still have enough resources to devote attention to the motor skill performance. When using modified equipment, there was no performance decline in the dual-task condition for either the skilled or less skilled children. This implies that overloading working memory had no impact on performance when using modified equipment (Maxwell et al., 2003). Using modified equipment, which simplifies the task for children, therefore seems to promote less cognitive processing to execute skills.

One important question arises following the findings of this study: what mechanisms underpin the reduced cognitive processing when using modified equipment? While my hypotheses are based on the tenets of the errorless learning paradigm, I acknowledge that an obvious difference exists: modifying equipment for children does not minimise errors to the same degree as errorless practice techniques. Nevertheless, I argue that children will be less likely to consciously control their movements when skills are easier to perform. Indeed, studies have shown that it is more cognitively demanding to process error feedback than success feedback (Koehn et al., 2008; Lam et al., 2010). Importantly, scaling equipment still allows children to explore their movement patterns in an attempt to find the most effective solution, which is considered an integral aspect of skill acquisition (Davids, Button, & Bennet, 2008; Handford, Davids, Bennet, & Button, 1997; Renshaw, 2010). There is a fine line between the conscious exploration of movement patterns and the sub-conscious alterations of technique when learning a skill, with conscious exploration resulting in the skill being acquired explicitly rather than implicitly (e.g., Hardy et al., 1996; Lam et al., 2009; Masters, 1992; Orrell et al., 2006b). I therefore argue that when children use modified equipment, movement patterns are more likely to be explored and adopted sub-consciously. This hypothesis, however, requires further research.

The findings of the current study can also be interpreted using an expertise approach. It has been well established by research in adults that experts and novices have different attention-focus when executing skills. Experts can execute skills as effectively (if not more so) whilst performing a concurrent secondary task, whereas novices experience a significant decline in performance, both in accuracy and technique, when required to perform a secondary task (Beilock, Bertenthal, McCoy, & Carr, 2004; Gray, 2004). This infers that experts perform skills relatively automatically and do not require conscious thought, whereas novices rely heavily on conscious processing in skill execution. Whilst the skilled group were not ‘expert’ junior tennis players, it is plausible that these children performed the basic hitting task relatively unconsciously (i.e., without conscious control of movements), whereas the less skilled children required conscious thought to execute the task.

The prediction that hitting performance and hitting technique would be better when using modified equipment for all children in this cohort (aged 9 to 11 years) was also confirmed. As demonstrated by the hitting performance scoring system, children displayed better ball control when using modified equipment. This finding is consistent with previous research examining equipment scaling in children (Elliott, 1981; Farrow & Reid, 2010b; Hammond & Smith, 2006). In the current study, there were three distinct technique benefits of using modified equipment: (1) swinging the racquet from low-to-high, (2) striking the ball in front and to the side of the body, and (3) stepping forward. The first two of these points are considered critical for executing a topspin forehand (Elliott & Marsh, 1989; Knudson, 2006). The third point – stepping forward – although no longer considered a necessity for playing a forehand at the elite level, is still taught by coaches as a fundamental component of striking a ball (e.g., Kelley, 2006). The lower bouncing, low compression ball, appeared to encourage children to 'step into the shot'.

In sum, the findings presented here demonstrate that simplifying a motor task via equipment scaling is a valid method to minimise working memory involvement during motor learning. The importance of reducing working memory involvement is particularly important for children (see review article by Capio et al., 2012) given that working memory capacity is still developing during childhood **(**e.g., Gathercole et al., 2004)**.** Furthermore, learning motor skills without reliance on working memory (i.e., implicit motor learning) has many long-term benefits to skill performance (e.g., Hardy et al., 1996; Liao & Masters, 2001; Masters, Poolton & Maxwell, 2008; Poolton et al., 2007a). Future studies should investigate the influence that modifying equipment has on the learning process over a period of practice, rather than only assessing performance on a small number of trials. Moreover, the hypothesis that the use of modified equipment with children reduces cognitive processing in the same manner as the errorless learning paradigm needs to be critically evaluated and tested. Potentially, the findings from this study may provide important practical applications for sports coaches, physical education teachers and parents with respect to the enhancement of children's motor learning.

The following chapter will examine the influence of various racquet sizes and ball compressions on children's performance of a tennis skill.

CHAPTER 7

MODIFYING EQUIPMENT IN EARLY SKILL DEVELOPMENT:

A TENNIS PERSPECTIVE

Introduction

In response to concerns over the physical demands imposed on children by adult constraints in sport, the potential to scale equipment and modify games to suit the physical capabilities of children was first mooted in the 1970's (Orlick & Borterill, 1975; Winter, 1980). Combined with an emphasis on competition and, in particular, winning, rather than skill development and fun, authorities felt that this accounted for the large proportion of children who 'dropped' out of sport before reaching adolescence (Robertson, 1991). Consequently, modified games and scaled equipment were advocated in school sports programs (e.g., Orlick & Borterill, 1975; Parkin, 1980; Winter, 1980).

In tennis, modified equipment, including light racquets, low compression balls, reduced net heights and smaller courts have all been in existence for several decades (Winter, 1980). However, these modifications have been introduced on the basis of rational argument rather than scientific evidence. A recent International Tennis Federation (ITF) campaign designed to promote children's tennis ('Play and Stay') endorsed the use of three different sized racquets, balls and courts (ITF, 2011), but there is a lack of objective research to substantiate this endorsement. According to the constraints-led approach to skill learning, the task, the environment and the performer interact to influence motor performance (Davids et al., 2008; Newell, 1986). Thus, by modifying equipment, the task constraints are altered, which subsequently can confine a learner's movement pattern to expedite skill acquisition. For example, playing tennis with a ball that bounces too high constrains a child's movements to only striking the ball above their head. Alternatively, using a ball that bounces lower allows children to strike the ball at a more comfortable height, thereby increasing the likelihood of developing suitable movement patterns to perform a tennis groundstroke.

The extant research examining task/equipment scaling in tennis has demonstrated the potential benefits for children using lighter racquets on smaller courts with lower compression balls (e.g., Elliott, 1981; Farrow & Reid, 2010b; Groppel, 1977; Hammond & Smith, 2006). A lower compression ball moves slower through the air and bounces lower than a standard ball, which appears to allow learners to strike the ball with better technique and with more power without the fear of the ball travelling out of court (Farrow & Reid, 2010b; Hammond & Smith, 2006). Some research has also examined the influence of racquet size on skill performance, and it appears that scaling a racquet to a child's size promotes better hitting performance (Elliott, 1981, Groppel, 1977). Specifically, it has been reported that scaled racquets encourage greater horizontal velocity and less vertical movement compared to larger racquets (Groppel, 1977). However, research examining equipment scaling in tennis has been limited by a failure in some cases to control for the influences of coaching or to match control and experimental groups for age and skill level (e.g., Hammond & Smith, 2006). Consequently, empirical evidence is needed to guide task and equipment scaling for beginners learning to play tennis and, furthermore, to inform the progression of scaling as skill develops – as Farrow and Reid (2010a) explained, "the challenge now lies in establishing some practical scaling recommendations that help to foster a love for the game and expedite skill acquisition" (p. 232).

The aim of this study was, therefore, to examine the influence of different combinations of racquet size (n = 3) and ball compression (n = 3) on young children playing tennis. There were three variables that were of specific interest: hitting performance, hitting technique, and children's preference for racquet and ball. The racquet sizes ranged from smaller in length to larger, while the compression of the balls varied from 25% to 100% compression relative to the standard tennis ball (ITF, 2013). Based on previous research (Elliott, 1981; Farrow & Reid, 2010b), it was hypothesised that children would hit most accurately and with better technique when using the most scaled racquet and the lowest compression ball. It was also predicted that children would prefer playing with the scaled equipment compared to the full size (adult) equipment (Farrow & Reid, 2010b). Additionally, children's height was expected to moderate the influence of varying racquet/ball combinations, with taller children finding it easier to wield the larger racquets and to cope with the higher compression, higher bouncing balls.

Method

Participants

Eighty children aged 6 to 8 years (boys, n = 45, M = 7.7 years, SD = 0.9; girls, n = 35, M = 7.8 years, SD = 0.8) with limited to no experience of playing tennis participated in the study. The height of all children was measured prior to participation (boys, M = 130.1 cm, SD = 7.2; girls, M = 128.6 cm, SD = 7.6). Written voluntary consent was provided by all of the children and their parents and/or guardian (see Appendix A & B). A University's Human Research Ethics Committee and the relevant Department of Early Childhood Development approved the study.

Experimental Design and Apparatus

Children performed a forehand hitting task using each of the nine combinations of tennis racquets and balls (i.e., 3 sizes x 3 compressions). The tennis racquets were all standard Wilson racquets that varied in length – 48.3 cm (mass = 200 g; grip circumference = 9.2 cm), 58.4 cm (mass = 220 g; grip circumference = 9.2 cm) and 68.6 cm (mass = 249 g; grip circumference = 10.5 cm). For the purpose of this study, the racquets will be referred to as small (48.3 cm), medium (58.4 cm) and large (68.6 cm). The balls were also manufactured by Wilson and included a standard compression *yellow* ball (compression = 100%; diameter = 65.4 cm; mass = 56.0 g; rebound height = 139.0 cm), a low compression *green* ball (compression = 75%; diameter = 65.4 cm; mass = 50.0 g; rebound height = 121.0 cm), and a very low compression *red* ball (compression = 25%; diameter = 71.6 cm; mass = 44.0 g;

rebound height = 100.0 cm). The ball rebound heights when dropped from 2.54 m were consistent with the ITF's recommendations (ITF, 2013). The hitting task was performed on a scaled court (size: 8 x 4 m) with an asphalt surface and a net that was 0.8 m high, as recommended by the ITF for children of this age and skill level. Two digital video cameras capturing at 25 Hertz and placed behind and to the side of the players recorded performance of the hitting task.

Hitting Task Procedure

The hitting performance test replicated that which was used in the study in Chapter 5. The researcher threw the ball under-arm to the child whose aim was to score maximum points by hitting the ball to certain locations on the court (see page 83 for an outline of the scoring system). Unlike the study in Chapter 5 however, this study included a frame that was 2 metres above the ground to explicitly show the children the required height of shots to receive the two bonus points (as in Chapter 5, two bonus points were awarded if the ball was hit over the net but lower than two metres above the ground) (see Figure 7.1). To ensure that researcher's throws were of equivalent difficulty in the nine racquet/ball combinations, the time taken from ball release to landing was calculated for each shot of a random subset of 20 participants. Cronbach's alpha for the nine conditions was 0.93, suggesting that throws were consistent. Children were only allowed to have one hand on the racquet when hitting the ball and all were required to hold the racquet at the same position (relative to the racquet size) to ensure that they did not artificially reduce the length. Order of presentation of each racquet/ball combination was counterbalanced using a Latin Square design.

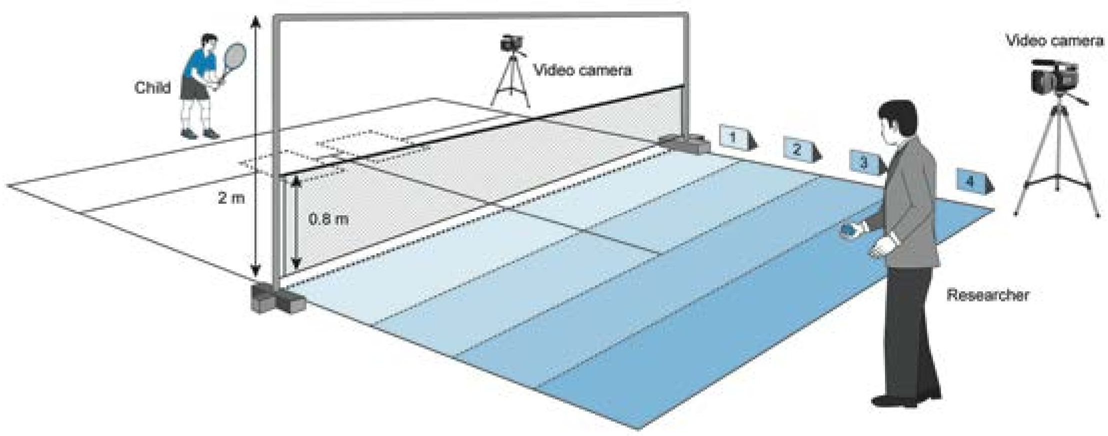


Figure 7.1. The court-set up for the hitting task.

Hitting Task Assessment

Hitting performance. The number of points accumulated for each racquet/ball combination was measured via video replay. The test-retest reliability of this measurement was assessed with a sample of 20 participants who performed the hitting task again one week later. Intra-class correlation coefficients indicate moderate to high reliability for all combinations. The ICC value was between .75 and .90 for five of the nine combinations, while four combinations had ICC values between .64 and .75. These four combinations were the red ball / large racquet, green ball / small racquet, green ball / medium racquet, and yellow ball / small racquet.

Hitting technique. An independent rater assessed children's hitting technique via video replay using Tennis Australia's technical fundamentals checklist (Tennis Australia, 2012). The checklist comprised of the same six technical points as detailed in Chapter 6 (pages 99-100): (a) grip, (b) circular swing, (c) low-to-high swing, (d) step forward, (e) impact and (f) follow through (see Appendix J for a description of each of these points). For each trial, children were given a score of 1 or a 0 depending if their movements corresponded with the checklist. The hitting technique of 28 randomly selected participants were reanalysed by a second independent rater for reliability purposes. To assess reliability, the scores for each technique variable were tallied across the seven conditions to allow for an assessment of each variable individually. Intra-class correlation coefficients indicate moderate to high correlations for each technique variable (grip, ICC = .91, $p < .01$; circular swing, ICC = .90, $p < .01$; low-to-high swing, ICC = .85, $p < .01$; step forward, ICC = .81, $p < .01$; impact, ICC = .83, $p < .01$; follow through, ICC = .84, $p < .01$). Children were not informed that their hitting technique was being assessed.

Racquet preference. On completion of the experiment, children were asked which racquet and ball they most preferred to use.

Statistical Analysis

Preliminary analysis indicated that none of the dependent variables interacted with gender, so males and females were collapsed. Repeated measures ANCOVA's, using height as a covariate, were used to assess differences in hitting performance and hitting technique in each of the nine racquet/ball combinations, respectively. Greenhouse-Geisser adjustments were used to correct for violations of the sphericity assumption where appropriate. Where main effects were present, post-hoc comparisons were conducted using the Bonferroni method to adjust the *p* values (the adjusted *p* values are reported in the paper). Chi square tests were used to assess differences between the children's preferred racquet and balls selections. For all tests, statistical significance was set at $p < .05$. Effects between conditions for all variables were also reported. Partial eta square ($\eta_p{}^2$) was reported as the effect size for main effects, while Cohen's *d* was used to report the standardised mean difference between specific conditions. Magnitudes of effects were interpreted using Cohen's (1988, 1992) thresholds for partial eta square (< .01, trivial; .01 – .06, small; .06 – .14, moderate; > .14, large) and Cohen's *d* (< .2, trivial; .2 – .5, small; .5 – .8, moderate; > .8, large). Cramer's *V* was reported as the effect size for the chi square test.

Results

Hitting Performance

A main effect for hitting performance [F (8, 624) = 6.63, p < .001, η_p^2 = .08] was found among the nine racquet/ball combinations. Height, the covariate, did not have a significant influence on the results. The most scaled combination (small racquet/red ball) produced significantly greater hitting performance than all other racquet/ball combinations involving the yellow ball (standard adult ball). Overall, it appeared that the very low compression red ball had the greatest positive influence on hitting performance, especially when combined with the small or medium racquets (see Figure 7.2). The low compression green ball also had a positive influence on hitting performance but only when combined with a small racquet. It was evident that the large racquet and the standard yellow ball had a deleterious effect on hitting performance.

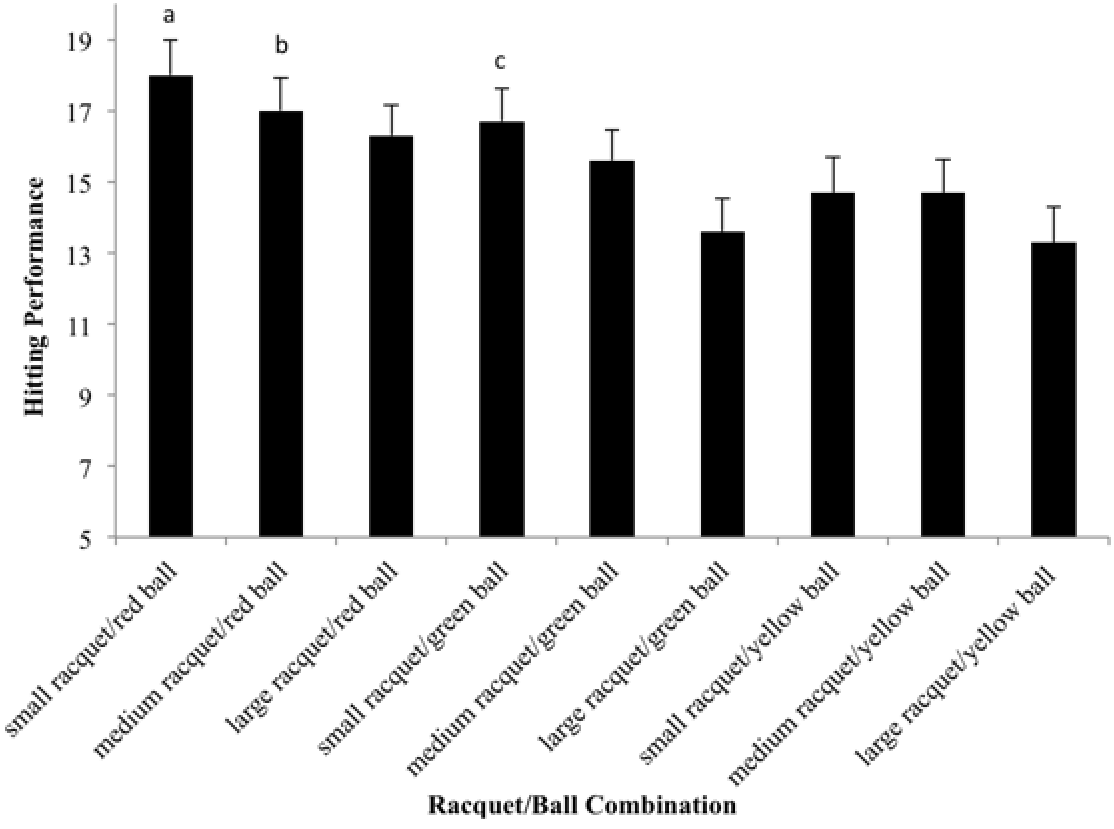
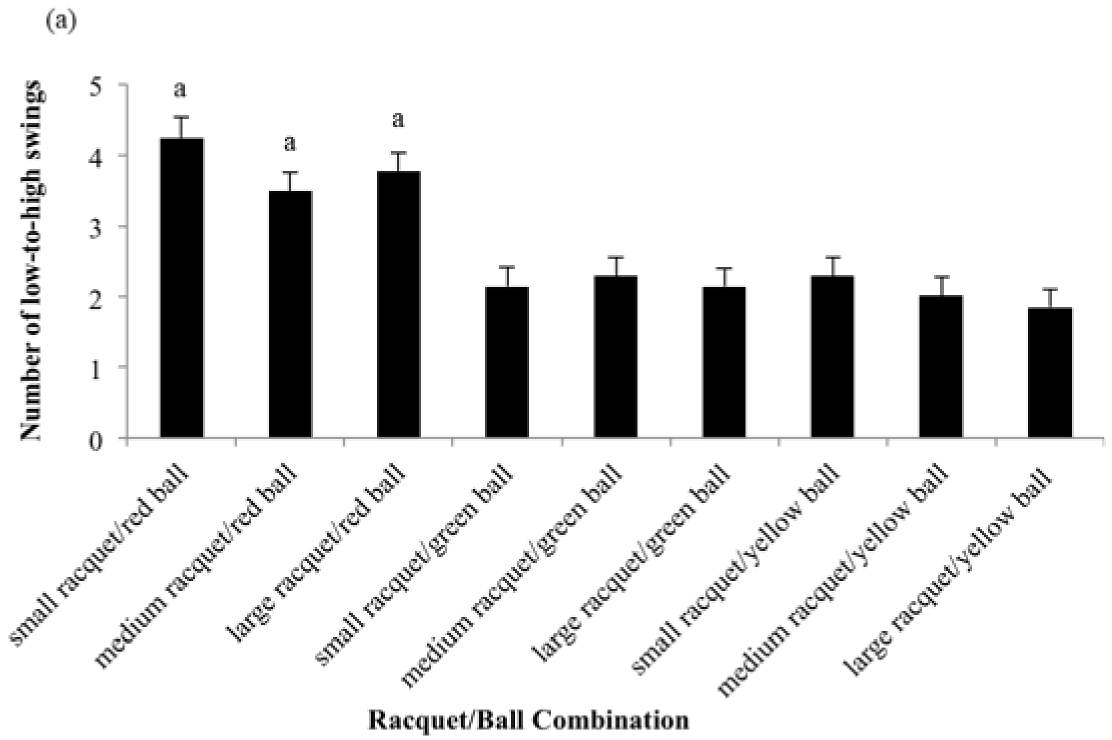


Figure 7.2. The mean points scored (hitting performance) for the nine racquet/ball combinations; [a] represents a significantly higher score than the large racquet/green ball combination (*d* = 0.64), the large racquet/yellow ball combination (*d* = 0.60), the medium racquet/yellow ball combination (*d* = 0.40) and the small racquet/yellow ball combination (*d* = 0.38); [b] represents a significantly higher score than the large racquet/green ball combination (*d* = 0.48) and the large racquet/yellow ball combination (*d* = 0.46); [c] also represents a significantly higher score than the large racquet/green ball combination (*d* = 0.37) and the large racquet/yellow ball combination (*d* = 0.38). Significance level was $p < 0.05$. Error bars represent the standard error.

Hitting Technique

Main effects were found for low-to-high swing [F (6.0, 398.7) = 24.13, $p < .001$, $\eta_p^2 = .27$], impact [F (6.5, 429.7) = 16.15, $p < .001$, $\eta_p^2 = .20$] and step [F (6.4, 416.9) = 2.97, p

= .006, η_p^2 = .04]. Post-hoc analysis showed that there were significantly more low-to-high swings when the low compression red ball was used, regardless of the racquet size, compared to every other racquet/ball combination (see Figure 7.3). Similarly, when the red ball was used, children made impact with the ball in front and to the side of their body more often than when the yellow ball was used, regardless of racquet size. It was also found that when the green ball was used in combination with either of the two scaled racquets (small or medium), children made correct impact with the ball more often than when any combination involving the yellow ball was used, or when the large racquet/green ball combination was used (see Figure 7.3). For step, post-hoc analysis revealed only one difference among the nine conditions, with stepping forward occurring significantly more often for the small racquet/red ball combination than the large racquet/green ball combination (d = .49, p = .007). There was no main effect for grip [F (4.7, 316.4) = 2.04, p = .07, η_p^2 = .03], with most children adopting the correct grip for all combinations. Likewise, there was no main effect for follow through [F (5.9, 390.2) = 1.34, p = .22, η_p^2 = .02], with children adopting a follow-through on approximately 50% of the trials for all combinations. A circular swing was displayed by only 17 children, for whom no main effect was evident across combinations [F (4.5, 62.6) = 1.53, p = .20, η_p^2 = .09]. Clearly, a circular swing is not a common attribute for children with limited tennis experience.



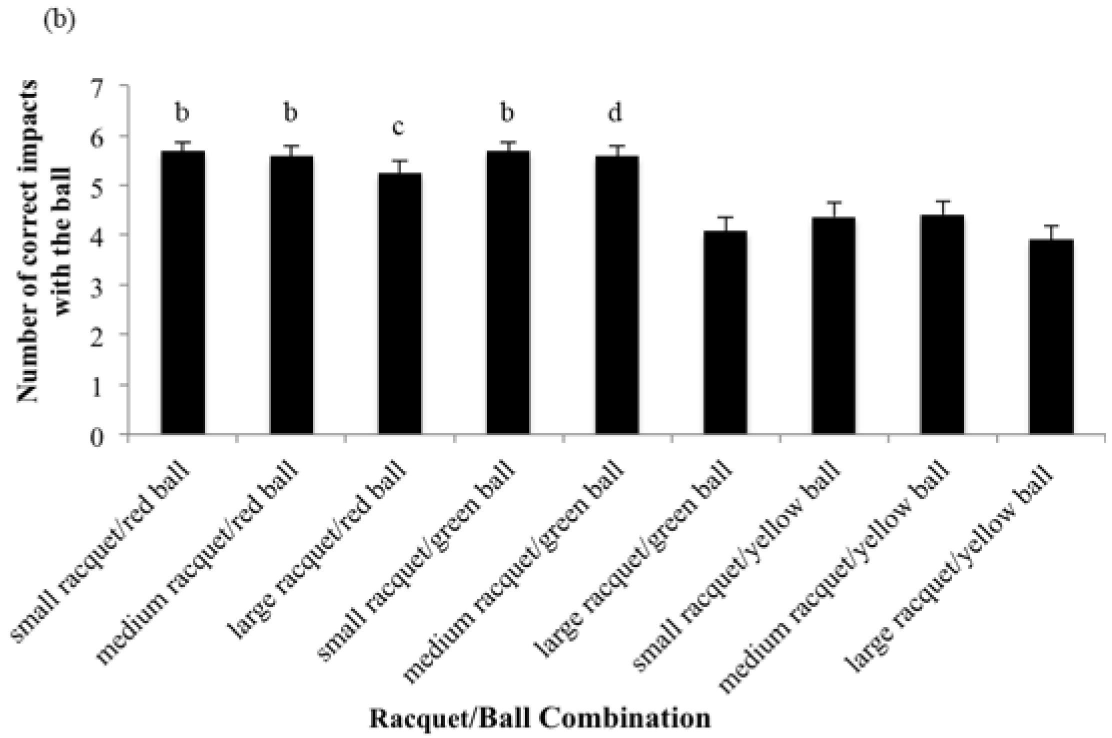


Figure 7.3. The mean number of occurrences of (a) low-to-high swings and (b) impacts with the ball in front and to the side of the body. [a] represents significantly more low-to-high swings than all combination involving the green ball (d ranged from 0.62 to 0.90) and yellow

ball (d ranged from 0.66 to 0.96); [b] represents significantly more correct impacts with the ball than all combinations involving the yellow ball and the large racquet/green ball combination (d ranged from 0.59 to 0.85); [c] represents significantly more correct impacts than the large racquet/green ball combination (d = 0.51), small racquet/yellow ball combination (d = 0.43) and large racquet/yellow ball combination (d = 0.62); [d] represents significantly more correct impacts than the large racquet/green ball combination (d = 0.47) and large racquet/yellow ball combination (d = 0.59). Significance level was $p < 0.05$. Error bars represent the standard error.

Chi square tests revealed a main effect for preferred racquet [X^2 (2, *N* = 76) = 7.05, *p* = .03, Cramer's *V* = .22], with children preferring to use the medium racquet (*n* = 36) more than the small (*n* = 18) and large (*n* = 22) racquets. No main effect for ball preference was found [X^2 (2, *N* = 76) = 3.50, *p* = .17, Cramer's *V* = .15], although more children preferred the red ball (n = 33) than the green (*n* = 22) and yellow (*n* = 21) balls.

Discussion

The aim of the study was to examine the influence of equipment scaling in tennis for children aged 6-8 years. Performance was better when children used scaled (i.e., modified) equipment rather than unscaled (i.e., full-size) equipment. Performance was best when the modified red ball was used, which had 75% less compression than the standard yellow ball and was 10% bigger. Consequently it bounced much lower (rebound height was 39 cm less than the standard ball). Children's height did not influence performance among the varying racquet/ball combinations, which refuted the hypothesis that taller children would find it easier to swing the larger racquets and cope with the higher bouncing balls. Additionally, the majority of children in the current study preferred using the medium size racquet. While this racquet was not the smallest, it still supports Farrow and Reid's (2010b) finding that young children learning to play tennis had more fun playing with scaled equipment in a modified space. The results have important practical implications for parents, teachers and coaches alike, when deciding what sports equipment to provide for children.

Two important improvements in technique resulted when the softest (red) ball was used. First, children swung the racquet from low-to-high more often, regardless of the racquet size that they used. Second, the red ball was struck in front and to the side of the body more often than when the yellow ball was used. Research suggests that both of these qualities are critical for the development of top-spin when performing a forehand shot (Elliott & Marsh, 1989; Knudson, 2006; Takahashi, Elliott, & Noffal, 1996). Children also struck the ball in front and to the side of their body when the low compression green ball was used, but only when in combination with the small or medium racquet (not with the adult sized large racquet). Tennis coaching manuals suggest that children should not play with balls that either bounce above their strike zone or travel too fast, as this may impair the biomechanical development of their strokes (Barrel, 2008), but it appears that it may be the interaction between racquet and ball that most affects biomechanical development. In essence the children were able to develop a functional movement solution as a result of self-organisation under the interacting task constraints. Importantly, this movement solution was also consistent with tennis coaching literature in terms of preferred swing patterns. The findings of the current study are consistent with literature that supports the use of modified equipment in other sports, such as basketball (Arias, Argudo, & Alonso, 2012) and cricket (Elliott, Plunkett, & Anderson, 2005).

From a theoretical perspective, modifying equipment has many potential benefits for children's skill acquisition. For instance, altering task constraints (i.e., scaling equipment) to allow the skill to be performed with greater ease may encourage learners to focus on key perceptual variables, which facilitates the development of coordinated and controlled movement patterns (Davids et al., 2008). Similarly, the use of a lighter racquet and a slower moving ball may allow children to focus on the tactics of where to hit the next shot rather than focusing internally on their movements (Chow et al., 2007). Proponents of the constraints-led approach argue that modifying the task allows children to search for new solutions by exploring the practice environment, which ultimately facilitates unconscious processes of learning (e.g., Renshaw, 2010). It is unclear whether this is the case, as proponents of implicit motor learning theory (e.g., Masters & Poolton, 2012) suggest that ‘searching for new solutions’ may sometimes result in hypothesis testing, which is likely to cause conscious aggregation of explicit knowledge about performance. Clarification of this issue requires further investigation.

Implicit motor learning theory can also be used as a framework to support the use of modified equipment. Implicit motor learning involves the acquisition of motor skills without conscious access to the information or knowledge that underlies their performance (Masters, 1992; for a recent review of implicit motor learning, see Masters & Poolton, 2012). Skills learned implicitly have been shown to be resistant to psychological stress (e.g., Liao & Masters, 2001), physiological fatigue (e.g., Masters, Poolton, & Maxwell, 2008), and cognitively demanding secondary tasks (e.g., Maxwell et al., 2003). Research in both adults and children has shown that practising skills with few errors reduces hypothesis testing during the motor learning process, which limits the likelihood that performers become aware of knowledge underlying their performance (e.g., Capio, Poolton, Sit, Holstrom et al., 2013; Maxwell et al., 2001). Hence, the skills are learned implicitly. Learners commit errors regardless of the equipment that they use (as demonstrated by hitting performance in the current study); but simplifying the task may at least reduce conscious processing during performance. Consequently, it is plausible that children playing with modified equipment experience implicit motor learning benefits.

The finding that children preferred using the medium size racquet relates to recent work investigating children's attunement to 'affordances' (i.e., opportunities for action) [2]. Beak, Davids, and Bennett (2000) showed that children were sensitive to changes in racquet characteristics, preferring to use racquets with lower moment of inertia; although, only when their vision was occluded. This may explain why the medium racquet was preferred to the smallest racquet in the current study - the smallest racquet may have been perceived as 'beginner' equipment by children who preferred to mimic their idols on television (Beak et al., 2000). In support of the concept that children are attuned to affordances when wielding a tennis racquet, it was observed that 50% of children tried to use a double-handed grip (despite instructions not to) when using the large (68.6 cm) racquet during the experiment. Comparatively, only two children used the double-handed grip with the medium (58.4 cm) racquet and none needed to when using the small (48.3 cm) racquet. Hence, many children found the adult sized racquet too difficult to swing with one hand, and appeared to be aware of the affordances provided when using two hands. This observation is consistent with previous research examining the use of scaled racquets for children learning to play tennis (Elliott, 1981; Groppel, 1977).

In summary, this study demonstrated benefits for young children playing with scaled racquets and low compression balls. Specifically, the low compression red ball provided the most benefits – both for hitting performance and technique. The study also provided further insight into the preferences of young children, adding support to previous literature that children prefer playing with equipment scaled relative to adult equipment (e.g., Farrow & Reid, 2010b). Future research needs to examine the influence that modified equipment has on learning and distinguish the predominant nature of the learning (implicit or explicit). The

[2] The term 'affordance' is used in the ecological approach to motor learning. Theorists argue that everything is an affordance, but some things have a greater affordance than others, depending on the task, the individual and the environment. For example, a small racquet would likely provide greater affordance than a large racquet for a child playing tennis, but the opposite would probably be found for an adult (for a review of the ecological approach to skill acquisition, see Handford et al., 1997).

results add support to a small but growing literature base that examines the benefits of equipment scaling for children. I therefore argue that the use of developmentally appropriate equipment by children may result in the acquisition of motor patterns that will allow them more success as adult players.

The final experiment presented in this thesis (Chapter 8) will compare the use of modified equipment versus full-size equipment over a specified practice period. Specifically, the study will examine whether implicit-explicit learning differences exist between the two equipment types.

CHAPTER 8

USING A MODIFIED RACQUET IMPROVES HITTING TECHNIQUE IN YOUNG CHILDREN LEARNING TENNIS

Introduction

It has been well documented that children perform sport skills better when using modified equipment as opposed to full-size (adult) equipment (Elliott, 1981; Farrow & Reid, 2010b; Groppel, 1977; Hammond & Smith, 2006; Larson & Guggenheimer, 2013; Regimbal, Deller, & Plumpton, 1992; see also Chapter 7 of this thesis). Specific to tennis, children strike the ball with a better technique and with greater accuracy when playing with low compression balls and smaller racquets (Elliott, 1981; Groppel, 1977; Hammond & Smith, 2006; see also Chapter 7). A low compression ball moves slower through the air and bounces lower than a standard ball (e.g., Mehta, Alam, & Subic, 2008). This promotes the use of a more fundamentally correct technique, such as striking the ball from low-to-high, making contact with the ball in front of the body, and stepping forward when hitting the ball (see Chapter 7). Additionally, these benefits are most prevalent when the low compression ball is combined with a smaller racquet (see Chapter 7). Similarly, the use of a smaller racquet encourages greater horizontal racquet velocity (rather than vertical velocity) when striking the ball (Groppel, 1977), which is advantageous for groundstrokes. Overall, there is growing evidence that the use of modified equipment provides direct benefits to children’s tennis skill performance.

Recently, the benefits for children using modified equipment were extended to the acquisition of skills over a period of practice. Farrow and Reid (2010b) examined the influence of ball compression and court size on the acquisition of tennis skills in children over five weeks of practice. The combination of a low compression ball and a small court during practice resulted in the greatest improvements, especially when compared to practising with standard balls on a full-size court. Practising on a smaller court provided more hitting opportunities during practice, which appeared to be the critical factor for expediting learning. While Farrow and Reid (2010b) probed the learning benefits of scaling the court and modifying the balls, the influence of modifying the racquet – the primary piece of equipment in tennis – remains unsubstantiated. The current study therefore examined the influence of racquet size on children's skill learning, as inferred by skill improvements over a period of practice.

The manner in which skills are acquired when using modified equipment also remains unknown. Masters and colleagues (e.g., Liao & Masters, 2001; Masters, 1992; Masters & Poolton, 2012; Maxwell et al., 2003; Poolton et al., 2005) argue that motor skills can either be acquired implicitly or explicitly, and this influences subsequent performance of the skill. Implicit motor learning refers to the acquisition of skills with little to no working memory involvement (Masters & Poolton, 2012) – the construct responsible for the temporary storage and manipulation of information in the mind (Baddeley & Hitch, 1974; Baddeley, 2010). Consequently, a person that learns a skill implicitly has minimal conscious awareness of how the skill is executed. In comparison, explicit motor learning is a highly conscious process and the performer can clearly verbalise the methods used to perform the skill (e.g., Hardy et al., 1996; Masters, 1992; Maxwell et al., 2001). Learning a skill implicitly rather than explicitly has been shown to be advantageous to future performances. For instance, performance of a skill learnt implicitly is resilient to psychological stress (Hardy et al., 1996; Liao et al., 2001; Masters, 1992) and physiological fatigue (Masters, Poolton, & Maxwell, 2008; Poolton et al., 2007a), and performance does not decline when required to complete a cognitively demanding secondary task (e.g., Maxwell et al., 2003; Maxwell et al., 2001). Perhaps most relevant to children, however, is that implicit learning places minimal demands on working memory, which is still developing throughout childhood (Gathercole et al., 2004; Luciana et al., 2005). Indeed, skill acquisition is enhanced in children when practice places fewer demands on working memory (Capio, Poolton, Sit, Holmstrom et al., 2013).

In the experiment discussed in Chapter 6 of this thesis, there was evidence that the use of modified equipment encouraged implicit learning processes during skill performance. The less skilled children performed significantly worse in the hitting task when required to concurrently perform a secondary task (counting backwards) when using full-size equipment, but not when using modified equipment. It was surmised that the full-size equipment placed larger demands on working memory resources. However, that study only assessed performance over a small number of trials and, subsequently, it remains unclear whether the use of modified equipment induced implicit learning over a period of practice.

Therefore, the current study aimed to examine whether implicit-explicit learning differences existed after five weeks of tennis practice following the use of modified and full-size equipment respectively. Children in the modified equipment group used a small racquet while children in the full-size equipment group used a large racquet. It was predicted that the children practising with the small racquet would demonstrate greater learning after five weeks of practice, which would be represented by larger improvements in movement proficiency (technique), hitting performance (i.e., hitting control) and general hand-eye coordination tests involving the tennis racquet. To measure implicit motor learning, a dual-task test was performed at the conclusion of the practice period. It was hypothesised that the children practising with the small racquet would show stable performance under these conditions, whereas children that practised with the large racquet would display a decline in performance with a concurrent secondary task.

Method

Participants

Sixty-two primary students (grades 1 and 2) from 4 physical education (PE) classes participated in the study. Each PE class was randomly allocated to one of two groups: a small racquet (SR) group (*n* = 32), or a large racquet (LR) group (*n* = 30). Following the intervention, the data of 16 children were removed from the analysis as they either (a) played tennis or participated in external tennis coaching during the intervention (*n* = 6), (b) had been exposed to more than one school term of tennis coaching prior to the study (*n* = 1), or (c) were absent for either the pre- or post-test (*n* = 9). Consequently, the data of 46 children were considered for analysis. There were 23 children (9 boys and 14 girls) in the SR group (mean age = 6.5 y ± 0.4; mean height = 122.5 cm ± 4.8), and 23 children (13 boys and 10 girls) in the LR group (mean age = 7.1 y ± 0.7; mean height = 127.1 cm ± 5.8). Written voluntary consent was provided by all of the children and their parents and/or guardian (see Appendix F & G). A University's Human Research Ethics Committee and the relevant Department of Early Childhood Development approved the study.

Experimental Design

This study included a five-week intervention with pre- and post-tests occurring in the week before and after the intervention respectively. Of the four PE classes that participated, two were randomly allocated to the SR group and two were assigned to the LR group. All groups followed the same practice protocol. The only difference between the two groups was the racquet size used during practice. The SR group used a modified 'small' racquet (length = 48.3 cm; mass = 200 g; grip circumference = 9.2 cm) while the LR group used an adult sized 'large' racquet (length = 68.6 cm; mass = 249 g; grip circumference = 10.5 cm). The tennis program followed the guidelines of Tennis Australia's junior modified 'Hot Shots' program (see Appendix H for an outline of the program). The same professional coach and his assistant administered the program for every PE class. Both the professional coach and his assistant were registered Tennis Australia coaches.

Test Procedures

The pre-test phase involved six tests, which ranged from measuring children's fundamental hand-eye coordination to tennis-specific skills. Children completed each test using both the small racquet and the large racquet. For all tests, and throughout the entire intervention, Wilson low compression 'red' tennis balls (compression = 25%; diameter = 71.6 cm; mass = 44.0 g; rebound height = 100.0 cm) were used. Two digital video cameras capturing at 25 Hertz recorded performance of each test. The six tests were repeated in the post-test, along with a dual-task test. The order of testing was the same as outlined below. Children performed each test with the same assigned racquet order (i.e., SR-LR or LR-SR) and this was repeated during the post-test. Half of the children in each group performed each test using the small racquet first and the other half of children performed each test using the large racquet first. The tests were divided into four categories:

1. *Hand-eye coordination measures.* Two tests were used to measure children's basic hand-eye coordination: (1) bouncing the ball on the ground with the racquet, and (2) bouncing the ball on the racquet. Three attempts were provided for each test, with the maximum number of consecutive times that children could achieve each task recorded. For the first of the two tests, the ball was only allowed to bounce once before touching the racquet again. For the second test, the ball had to continuously bounce on the racquet without touching anything else (e.g., the ground). The tests were stopped if children reached 30 consecutive hits. No children achieved this in the pre-test, but seven children did so in the post-test.
2. *Tennis skills hitting technique.* The same protocol as detailed in Chapter 5 was adopted (see page 84). Children played three forehands, three backhands and three underarm serves (i.e., starting a rally). Hitting technique was assessed via video replay using Tennis Australia's technical fundamentals checklist (Tennis Australia,

2012). For each shot type, the checklist comprised of six technical points (see Appendix J for detailed description of these points). For every trial, children were given a 1 or a 0 for each technical point depending if their movements corresponded with the criteria. The score for the three shots were combined to give a final score out of 18. To assess reliability, a second independent rater assessed the technique of all children. Intra-class correlation coefficients varied between .80 and .91 for the analysis of forehand, backhand and underarm serve technique.

3. *Hitting performance task.* This was the same task as detailed in Chapter 5. The researcher threw the ball underarm to the child whose aim was to score maximum points by hitting the ball to certain zones on the court (see page 83 for an outline of the task).
4. *Dual-task test.* Completed during the post-test, this involved the same procedure as the hitting performance task, with the inclusion of a secondary task. While performing the hitting task, children had to count – so that it was audible – in one's beginning at one. Children were asked to count at a pace that was similar to counting seconds. If children counted too fast or too slow, or were not counting aloud, the researcher stopped feeding the balls until the child began counting correctly again. If children reached a number that was clearly too difficult to count, the researcher stopped the feeding and asked the child to begin counting from one again.

Practice Procedures

The same practice sessions as detailed in Chapter 5 were used (see Appendix J for a detailed description of each practice session). All groups completed one 30-min practice session per week for 5 weeks. The practice sessions were based on Tennis Australia's 'Hot Shot's' manual for PE teachers (see Appendix H). The coaches administering the sessions provided no explicit technical instructions regarding the skill mechanics, but rather ensured that all children were performing each activity. Consequently, the type of feedback provided to the children was primarily words of encouragement. The number of forehands, backhands, underarm serves, and 'other touches' (e.g., bouncing the ball on the racquet) were counted for two randomly selected children in each class.

Statistical Analysis

A series of independent t-tests (two-tailed) measured whether differences existed between the two groups for each pre-test measure. To account for the multiple comparisons and alleviate the risk of subsequent type I error, Bonferroni correction adjusted the *p* value to 0.006 for these tests. To examine the pre/post-test differences for each group, a 2 x 2 (group x test occasion) factorial ANOVA with repeated measures on the second factor was performed. Significant interactions as a result of these analyses were investigated through the use of t-tests with Bonferroni correction where appropriate. Partial eta square ($\eta_p{}^2$) was reported as the effect size for main effects, while Cohen's *d* was used to report the standardised mean difference between pre- and post-test performance for each group. Magnitudes of effects were interpreted using Cohen's (1988, 1992) thresholds for partial eta square (< .01, trivial; .01 – .06, small; .06 – .14, moderate; > .14, large) and Cohen's *d* (< .2, trivial; .2 – .5, small; .5 – .8, moderate; > .8, large).

A portion of the data (hand-eye coordination tests, preferred racquet and practice data) was not normally distributed and therefore non-parametric statistical tests were used. Mann-Whitney U tests examined whether differences existed between the two groups for 'bouncing ball on ground' and 'bouncing ball on racquet' during the pre-test, while the pre/post-test differences were assessed using Wilcoxon Signed Ranks Tests. Mann-Whitney U tests were also used to measure for differences between the two groups in shot opportunities during practice (i.e., number of forehands, backhands, serves, and other touches). For all non-parametric analyses, effect sizes were described using Pearson's *r*, and medians were reported rather than means.

Results

Group Equality at Pre-Test

Tennis-specific measures. Independent t-tests showed that there were no differences between the two groups during the pre-test in forehand technique (using small racquet [t (44) = -0.58, *p* = .56, *d* = .12], using large racquet [t (44) = -1.93, *p* = .06, *d* = .58]), backhand technique (using small racquet [t (44) = -1.62, *p* = .11, *d* = .48], using large racquet [t (44) = -0.75, *p* = .08, *d* = .22]), underarm serve technique (using small racquet [t (44) = -0.18, *p* = .86, *d* = .06], using large racquet [t (44) = -0.81, *p* = .42, *d* = .24]), and hitting performance (using small racquet [t (44) = -0.53 *p* = .59, *d* = .16]). The only difference between the groups during the pre-test was for hitting performance when using the large racquet [t (44) = -2.32, *p* = .03, *d* = .68], where the LR group scored 6.5 points (95% CI [0.6, 12.5]) more than the SR group.

Hand-eye coordination measures. There were no differences between the two groups for bouncing ball on the ground with the small racquet [*U* = 196.5, *p* = 0.13], but there was a difference when using the large racquet [*U* = 174.0, *p* = 0.04] with the LR group performing better (see Table 8.1 for descriptive statistics). There was no significant difference between the groups for bouncing ball on the racquet with both the small [*U* = 183.0, *p* = 0.07] and large racquet [*U* = 199.0, *p* = 0.14].

Table 8.1

The median number of times each group could perform the two hand-eye coordination skills during the pre- and post-test

		Using small racquet		Using large racquet	
	Group	*Pre test*	*Post test*	*Pre test*	*Post test*
Bouncing ball on ground					
	SR	4.0	5.0	2.0	3.0
	LR	5.0	8.0 [a]	4.0[b]	6.0
Bouncing ball on racquet					
	SR	2.0	3.0	2.0	2.0
	LR	3.0	3.0	3.0	4.0

[a] represents significant difference between pre- and post-test scores ($p < .05$). [b] represents a significant difference between the two groups in pre-test scores ($p < .05$).

Group Equality During Practice Sessions

Mann-Whitney U tests revealed that there were no differences between the groups during any of the sessions in the number of forehands, backhands, underarm serves or other touches. This implies that all children had an equal number of hitting opportunities. See Table 8.2 for descriptive statistics.

Forehands: (session 1, [$U = 4.0$, $p = 0.24$, $r = .41$]; session 2, [$U = 7.0$, $p = 0.77$, $r = .10$]; session 3, [$U = 7.0$, $p = 0.76$, $r = .10$]; session 4, [$U = 2.0$, $p = 0.08$, $r = .62$]; session 5, [$U = 4.0$, $p = 0.22$, $r = .44$]).

Backhands: (no backhands in sessions 1 and 3; session 2, [$U = 6.0$, $p = 0.32$, $r = .35$]; session 4, [$U = 4.0$, $p = 0.25$, $r = .41$]; session 5, [$U = 4.0$ $p = 0.21$, $r = .45$]).

Underarm serves: (no serves in session 1; session 2, [U = 4.0, p = 0.24, r = .41]; session 3, [U = 3.5, p = 0.17, r = .48]; session 4, [U = 3.0, p = 0.15, r = .51]; session 5, [U = 4.0 p = 0.22, r = .43]).

Other touches: (session 1, [U = 4.5, p = 0.31, r = .36]; session 2, [U = 2.5, p = 0.11, r = .57]; session 3, [U = 6.5, p = 0.66, r = .16]; session 4, [U = 6.0, p = 0.56, r = .21]; session 5, [U = 6.5 p = 0.66, r = .15]).

Table 8.2

The median number of hitting opportunities during each session for the two groups

		Practice Session				
	Group	*1*	*2*	*3*	*4*	*5*
Forehands	SR	7.5	6.5	15.5	6.5	3.5
	LR	9.5	7.0	16.0	11.5	5.0
Backhands	SR	0	0	0	16.0	0
	LR	0	0	0	17.9	1
Serves	SR	0	12.5	12.0	10.5	7.5
	LR	0	11.0	14.0	12.9	8.0
Other touches	SR	17.0	19.0	19.5	8.0	45.5
	LR	20.5	17.0	19.0	9.1	52.5

Pre- post-test differences: Hitting technique

For ease of reading, a summary of the significant pre- post-test findings is provided in Table 8.3. Furthermore, the following results are presented in sections based on the racquet used during testing (*Note: The two groups used both racquets during testing).*

Using the small racquet in testing. Main effects were found for the forehand technique [F (1, 44) = 9.13, p = .004, η_p^2 = .17], backhand technique [F (1, 44) = 9.62, p = .003, η_p^2 = .18] and underarm serve technique [F (1, 44) = 14.63, p < .001, η_p^2 = .25], with both groups showing some improvement from pre- to post-test for all of these variables. There was a Group x Time interaction for forehand technique [F (1, 44) = 4.03, p = .05 η_p^2 = .08] and there was a significant interaction for backhand technique [F (1, 44) = 15.65, p = .02, η_p^2 = .11]. For both of these variables, the SR group showed greater improvement than the LR group from pre- to post-test. This was supported by large effect sizes for the SR group (forehand technique, d = 1.13; backhand technique, d = .87) compared to small-to-trivial effect sizes for the LR group (forehand technique, d = .12; backhand technique, d = .05) (Figures 8.1 and 8.2). There was no significant Group x Time interaction for underarm serve technique [F (1, 44) = 1.69, p = .19, η_p^2 = .04] (Figure 8.3). Moderate effect sizes were found for both the SR group (d = .55) and the LR group (d = .63), suggesting that both groups improved their underarm serve technique score by a similar amount.

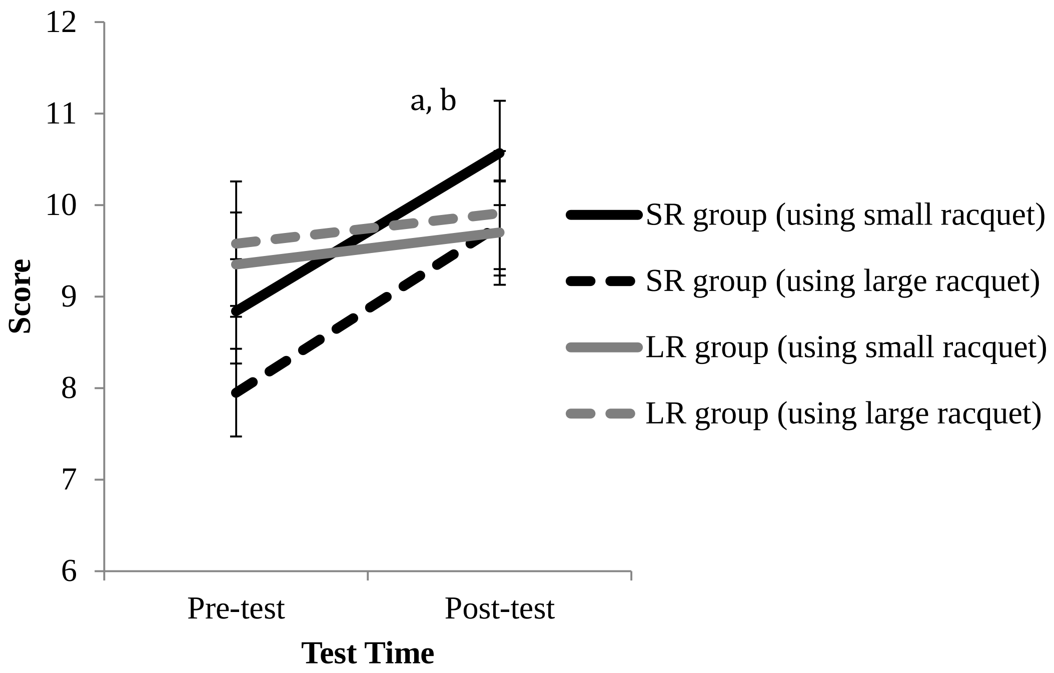


Figure 8.1. The mean forehand technique scores for the SR group and the LR group when using the small and large racquet during the pre- and post-test. [a] represents a significant Group x Time interaction when using the large racquet (p < .05). [b] represents a significant Group x Time interaction when using the small racquet (p < .05). Error bars represent the standard error.

Using the large racquet in testing. Main effects were again found for forehand technique [F (1, 44) = 9.50, p = .004, η_p^2 = .18], backhand technique [F (1, 44) = 4.96, p = .03, η_p^2 = .10], and underarm serve technique [F (1, 44) = 32.25, p < .001, η_p^2 = .42]. A significant interaction between Group x Time was also found for forehand technique [F (1, 44) = 12.87, p = .04, η_p^2 = .09], with the SR group improving more than the LR group from pre- to post-test (SR group, d = .79; LR group, d = .10) (Figure 8.1). There was no significant interaction for backhand technique [F (1, 44) = 0.47, p = .49, η_p^2 = .01] (Figure 8.2) and underarm serve technique [F (1, 44) = 3.97, p = .25, η_p^2 = .03] (Figure 8.3), with both groups showing similar improvements from pre- to post-test for the backhand (SR group, *d* = .50, LR group, *d* = .23) and underarm serve (SR group, *d* = .57, LR group, *d* = .76).

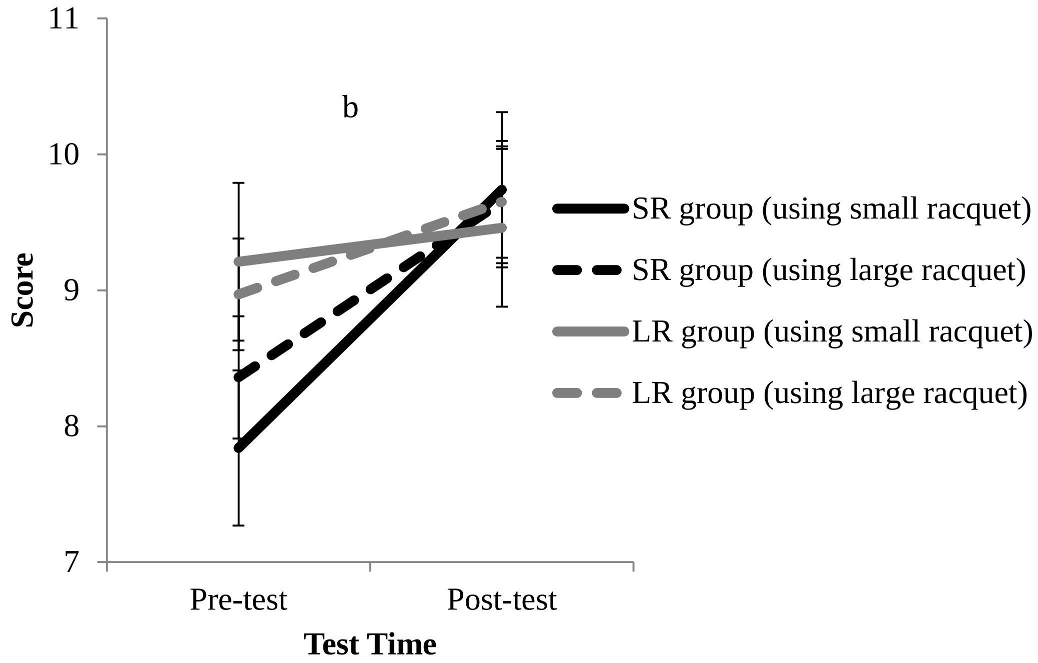


Figure 8.2. The mean backhand technique scores for the SR group and the LR group when using the small and large racquet during the pre- and post-test. [b] represents a significant Group x Time interaction when using the small racquet ($p < .05$). Error bars represent the standard error.

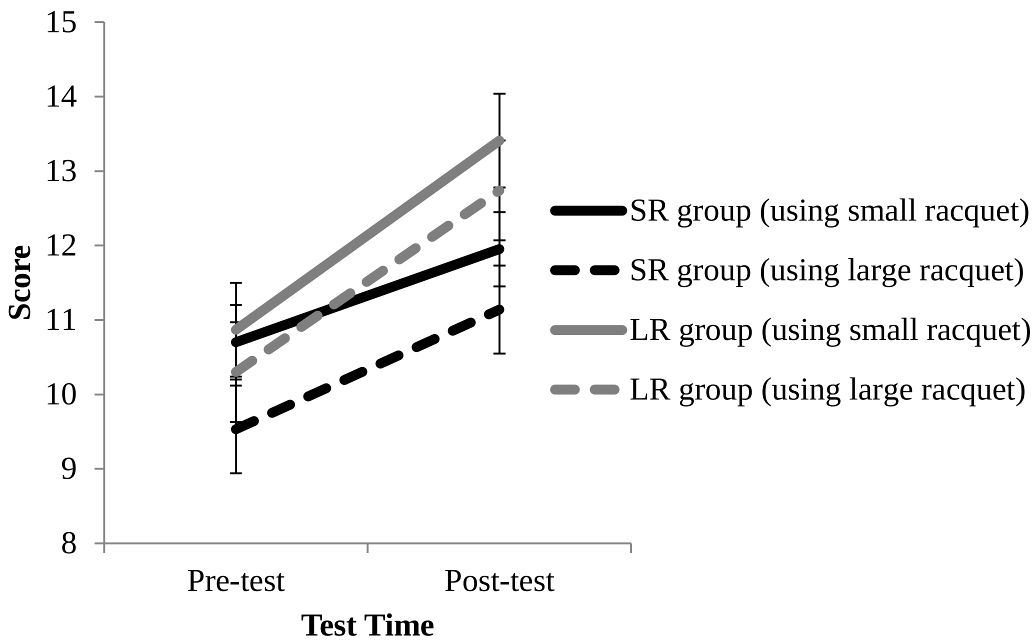


Figure 8.3. The mean serve technique scores for the SR group and the LR group when using the small and large racquet during the pre- and post-test. Error bars represent the standard error.

Pre- post-test differences: Hitting performance

Using the small racquet in testing. For the small racquet, there was a main effect for Time [F (1, 44) = 7.01, p = .01, η_p^2 = .14], but there was no significant Group x Time interaction [F (1, 44) = 2.49, p = .12, η_p^2 = .05], suggesting that both groups improved by similar amounts. The effect size was moderate for the LR group (d = .52) and small for the SR group (d = .24)**.**

Using the large racquet in testing. When using the large racquet during testing, there was no main effect for Time [F (1, 44) = 1.92, p = .17, η_p^2 = .04], nor was there a Group x Time interaction [F (1, 44) = 0.68, p = .41, η_p^2 = .02]. Although, effect sizes indicate that the SR group (d = .59) improved hitting performance with the large racquet more than the LR group (d = .06). See Figure 8.4 for descriptive statistics.

Dual-task test

Using the small racquet in testing. A main effect was found [F (1, 44) = 5.78, p = .02, η_p^2 = .12] with both groups performing worse in the dual-task test compared to the initial hitting performance post-test. There was no Group x Time interaction [F (1, 44) = 0.00, p = 1.00, η_p^2 = .00]. Indeed, similar effect sizes were found both in the SR group (d = .40) and the LR group (d = .35).

Using the large racquet in testing. There was no main effect [F (1, 44) = 0.02, p = .90, η_p^2 < .01], nor a Group x Time interaction [F (1, 44) = 1.29, p = .85, η_p^2 < .01]. Trivial effect sizes were found (SR group, d = .01; LR group, d = .04) which further indicate that there was minimal difference in performance when a secondary task was concurrently performed. See Figure 8.4 for descriptive statistics.

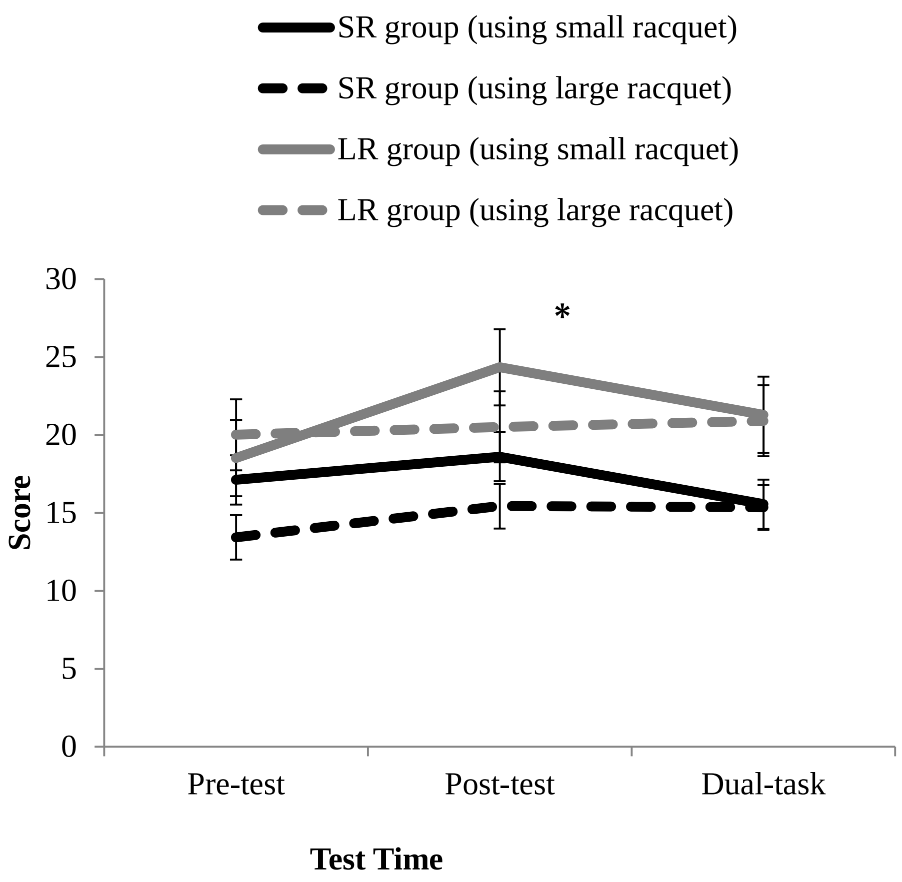


Figure 8.4. The mean hitting performance scores for the SR group and the LR group when using the small and large racquet during the pre-test, post-test and the dual-task test. * represents main effects for Time when using the small racquet ($p < .05$). Error bars represent the standard error.

Hand-eye coordination measures

The descriptive statistics for bouncing the ball on the ground and bouncing the ball on the racquet are outlined in Table 8.2.

Using the small racquet in testing. Wilcoxon Signed Ranks Tests suggest that there was an inclination of an improvement for the SR for bouncing the ball on the ground [z = -1.7, *p* = .09, *r* = .35] and bouncing the ball on the racquet [z = -1.7, *p* = .09, *r* = .35] Comparatively, the LR group showed significant improvement for bouncing the ball on the ground [z = -3.5, $p < .001$, $r = .73$] but not for bouncing the ball on the racquet [z = -1.4, $p = .15$, $r = -.30$].

Using the large racquet in testing. The SR group improved significantly from pre- to post-test for bouncing the ball on the ground [z = -3.5, $p = .001$, $r = .72$] but not for bouncing the ball on the racquet [z = -0.9, $p = .39$, $r = .18$]. The LR group also displayed significant improvement for bouncing the ball on the ground [z = -2.7, $p = .007$, $r = .56$] but not for bouncing the ball on the racquet [z = -1.5, $p = .14$, $r = .31$].

Table 8.3

Summary of the significant differences for each measure

Measure	*LR Group*	*SR Group*
Forehand technique [a]	↑	↑↑
Forehand technique [b]	↑	↑↑
Backhand technique [a]	↑	↑↑
Backhand technique [b]	↑	↑
Underarm serve technique [a]	↑	↑
Underarm serve technique [b]	↑	↑
Hitting performance [a]	↑	↑
Hitting performance [b]	-	-
Dual-task performance [a]	↓	↓
Dual-task performance [b]	-	-
Bouncing ball on the ground with racquet [a]	↑↑	-
Bouncing ball on the ground with racquet [b]	↑	↑
Bouncing ball on the racquet [a]	-	-
Bouncing ball on the racquet [b]	-	-

[a] represents when using the small racquet during testing, [b] represents when using the large racquet during testing, ↑ represents a significant improvement from pre to post test, ↑↑ represents a significantly greater improvement than its counterpart group, ↓ represents a significant decrease in performance during the hitting performance test when concurrently performing a secondary task.

Discussion

The aim of this study was to examine the influence of racquet size on children's skill learning and to discover whether implicit-explicit learning differences existed between playing with a small racquet versus a large racquet. It was evident that the children who practised with the small racquet showed greater improvement in movement proficiency (forehand and backhand technique) compared to children who practised with the large racquet. The smaller racquet allowed children to strike the ball with greater ease and this appeared to assist the development of a more technically desirable technique. It is likely that the larger racquet constrained children's movements to a certain swing path, which ultimately limited improvement. However, despite the learning benefits from using the smaller racquet, there was no evidence of implicit-explicit learning differences between the SR group and the LR group. Strangely, both groups displayed a decline in performance under secondary-task conditions when using the small racquet during testing but not the large racquet. There are three conceivable explanations for these results.

First, the 'stable' performance (i.e., no decline in performance) in the dual-task test when using the large racquet (by both groups) may demonstrate that the use of large racquet does not actually place larger demands on working memory as hypothesised. It was predicted that children would become dependent on working memory when using the large racquet and this would be reflected by significantly worse performance in the dual-task test. This was based on the finding in Chapter 6, in which children's performance deteriorated in a dual-task condition when using full-size equipment but not modified equipment. However, in that study, full size equipment included both a large racquet and a standard tennis ball. Perhaps it is the combination of the large racquet and standard ball that increases demands on working memory, rather than only the manipulation of the racquet as in the current study.

A more likely explanation, however, is due to the limitations associated with the dual-task test. There was no measure of secondary task performance and, consequently, it cannot be certain that the dual-task was eliciting the appropriate effect. When the dual-task test is performed correctly, the secondary task occupies working memory resources, leaving performance of the primary skill to occur independent of working memory (e.g., Maxwell et al., 2003). However, without a measure of secondary task performance, it is possible that children were ‘cheating’ on the secondary task when using the large racquet, thereby allowing some working memory resources to be devoted to the tennis skill. For instance, perhaps children counted slower just prior to hitting the ball to allow conscious thought to be directed towards the tennis shot. Alternatively, counting in one’s may have been not demanding enough.

Finally, the poorer dual-task performance when using the small racquet likely indicates that the hitting performance test was quite challenging for these children. While the smaller racquet made the task easier to perform (as indicated by the better performance in the test when using the small racquet compared to the large racquet by both groups during the post-test), the task itself may have represented such a challenge that it evoked conscious processing when performing the test. The test used in this study was the same as that used during the study in Chapter 6; however, the children in this study were younger than in the study in Chapter 6 and therefore were probably less capable of performing the task.

An interesting finding from the study was that the large racquet group displayed greater improvement in the hand-eye coordination measure of bouncing the ball on the ground with the racquet. This was not expected, as presumably the small racquet would allow children to have more control of bouncing the ball. However, perhaps the larger surface area on the head of the large racquet made the skill of repeatedly bouncing the ball on the ground easier to perform. Furthermore, surprisingly both groups improved hitting performance by a similar amount. Previous research has demonstrated greater improvements in various hitting performance tests following practice with modified equipment such as low compression balls (Farrow & Reid, 2010b; Hammond & Smith, 2006) and, therefore, it was hypothesised that the same would be observed when children practise with smaller racquets. While this was not found, it is possible that the volume of practice was not sufficient enough to evoke differences between groups. Farrow and Reid (2010b) also conducted a five-week intervention; however, in their study, children were provided with at least twice as many forehand opportunities. The mean number of forehand opportunities per session in the Farrow and Reid (2010b) study was 19.80 for the lowest group (33.66 for the highest group), whereas in the current study it was 8.85 (combined mean of the two groups). The reason for the large discrepancy was due to the type of practice activities being conducted in the current study, which included a broader range of shots, including ‘starting a rally’ (underarm serve) and other touches such as bouncing the ball on the racquet. Nonetheless, future research should carefully consider the type of practice activities used when planning an intervention to ensure children are exposed to a sufficient amount of practice.

In sum, this study showed that children’s hitting technique improved significantly more when practising with the small racquet compared to a large racquet. However, no evidence was found to support the contention that the use of modified equipment encourages implicit motor learning. Perhaps the use of the large racquet alone did not place large enough demands on working memory, unlike the study in Chapter 6 that combined the large racquet with the standard ball (rather than a low compression ball). Alternatively, perhaps the dual-task test in the current study was not eliciting the appropriate effect. Future research should address the limitations associated with this study in a quest to further understand the interaction between modified equipment and implicit motor learning.

CHAPTER 9

GENERAL DISCUSSION

This dissertation aimed to explore two questions: (1) what role does working memory play during the acquisition of motor skills in children, and (2) does the use of modified equipment reduce demands on working memory during skill performance and, subsequently, encourage an implicit mode of learning? This final chapter will summarise the findings from each experiment and discuss their theoretical and practical implications in relation to these two questions. Additionally, the methodology used throughout the thesis will be critically evaluated and suggestions for future research will be provided. Finally, conclusions will be drawn in response to the aims as outlined at the beginning of the thesis.

The Experimental Series

Phase 1: The role of working memory in children's skill acquisition

The experiments conducted in Chapters 3-5 explored the role of working memory when performing and acquiring motor skills. Specifically, the experiments examined whether individual differences in working memory capacity (both the verbal and visuo-spatial components) influenced the propensity to test hypotheses (Chapter 3), the likelihood of consciously controlling movements (Chapter 4), performance in high pressure situations (Chapter 4), EEG coherence during performance (Chapter 4) and the rate of learning when practice placed larger demands on working memory (Chapter 5).

In Chapter 3, hypothesis testing was primarily measured as alterations to technique. It was evident that some children between the ages of 6 and 11 years made deliberate alterations to their technique and this was dependent upon the verbal working memory capacity of the child and the performance outcome. Unless the task was performed successfully, whereby hypothesis testing was minimised, children with larger verbal working memory capacity were more likely to make alterations to their technique. Based on this finding, it was theorised that the development of verbal working memory throughout childhood influences the propensity to use explicit processes (i.e., test hypotheses) when learning motor skills. This theory draws parallels with Reber's (1993) proposition that explicit memory develops during childhood and continues to increase well into adulthood.

The studies discussed in Chapter 4 increased our understanding of the relationship between working memory and movement specific reinvestment. For both children and adults, positive correlations were found between verbal working memory capacity and the Movement Specific Reinvestment Scale, which is a measure of conscious control of movements (Masters & Maxwell, 2008). Furthermore, it was found that verbal working memory capacity was negatively related with change in performance under pressure in adults. Participants with larger verbal working memory capacity showed less improvement in a pressured condition and, consequently, it was concluded that persons with larger verbal working memory capacity were more likely to engage in explicit processes when performing a task. Ultimately, the findings supported the theory proposed in Chapter 3, offering further insight into the salient role that the verbal component of working memory plays during skill performance and learning. Evidence was also found for the relationship between working memory capacity and EEG coherence during performance of a motor skill. Both verbal and visuo-spatial working memory capacity predicted EEG coherence between the motor planning and verbal-analytical regions of the brain; however, larger verbal working memory was associated with greater coherence whereas greater visuo-spatial working memory was associated with lower coherence. This therefore supports the notion that verbal working memory is related to explicit processes during motor performance, but also offers the interesting prospect of larger visuo-spatial working memory reducing the inclination for conscious processing.

Chapter 5 provides evidence that working memory capacity influences motor learning following the provision of verbal instructions. In this study, the verbal and visuo-spatial components of working memory were combined to generate an overall working memory score. Children with larger working memory capacity showed greater learning following a five week period of practice which included the provision of explicit verbal instructions. Comparatively, when no explicit verbal instructions were provided, all children showed a similar amount of learning, regardless of working memory capacity. It was therefore concluded that children with larger working memory capacity are advantaged in learning scenarios that place large demands on working memory.

Phase 2: The influence of using modified equipment on skill performance and learning

Chapters 6 to 8 detailed three experiments that broadly aimed to examine whether the use of modified equipment simplifies motor skills for children and subsequently encourages implicit motor learning. To learn a motor skill implicitly means to learn with minimal working memory involvement. Therefore, in Chapter 6, a dual-task methodology was adopted to measure children's skill performance when working memory resources were occupied by a secondary task. Children performed a basic tennis hitting task in two attention conditions (single task and secondary task) using two types of equipment (modified and full size). The modified equipment included a small tennis racquet and a low compression ball, while the full size equipment included an adult-sized racquet and a standard tennis ball. Two groups were formed based on hitting performance scores: a skilled group and a less skilled group. Working memory capacity was also measured, with the skilled group displaying greater working memory capacity than the less skilled group. Results showed that hitting performance and hitting technique were better when modified equipment was used, indicating the use of modified equipment did indeed simplify the skill for children. For the less skilled children, hitting performance was not disrupted by a cognitively demanding secondary task when using modified equipment; however, performance was significantly worse when using full size equipment. This implies that the use of full size equipment (i.e., equipment that increases skill difficulty) places larger demands on working memory resources compared to the use of modified equipment. While this study only assessed conscious processes during performance on a small number of trials (as opposed to measuring learning), the results do support the theory that the modification of equipment to simplify a skill for children encourages a mode of learning that has minimal reliance on working memory. This is also referred to as implicit motor learning.

Chapter 7 presented an experiment that further investigated the effect that modified equipment had on skill performance. Specifically, the study examined the influence that varying racquet sizes and ball compressions had on children's ability to play a forehand groundstroke. Children performed a forehand hitting task using each of nine combinations of tennis racquets and balls (i.e., 3 racquet sizes x 3 ball compressions). It was clear that hitting performance was best when the smallest racquet combined with the ball of the least compression was used. Moreover, the lowest compression ball promoted two technique benefits: swinging the racquet from low-to-high and striking the ball in front and to the side of the body. The findings of this study provided more evidence that modifying equipment for children allows skills to be performed with greater ease.

Finally, the experiment in Chapter 8 explored the learning differences between using a small racquet (modified equipment) compared to a large racquet (full size equipment) following five weeks of practice. It was hypothesised that using the small racquet during practice would encourage implicit learning, whereas using the large racquet would evoke explicit learning. While no evidence was found to support this assertion, results did show that the children who practised with the small racquet displayed greater improvements to their hitting technique from pre- to post-test compared to children who practised with the large racquet. This adds to the findings of Chapters 6 and 7 by showing that the use of modified equipment not only has direct benefits to performance but also enhances motor learning in children. A likely reason for the lack of implicit-explicit learning difference between the two equipment types related to limitations with the dual-task test.

Theoretical Implications

Two distinct theoretical implications were evident throughout this dissertation: (1) the relationship between working memory and explicit processes in children, and (2) the interaction between children using modified equipment and implicit motor learning. These are discussed separately in the following sections.

Working memory and explicit processes in children

As stated previously, a major difference between implicit and explicit learning is the amount of dependence on working memory (e.g., Maxwell et al., 2003). However, prior to this dissertation, it was unsubstantiated as to whether children have the working memory capacity to learn explicitly per se. It was apparent in the literature review (Chapter 2) that children’s cognitive functioning undergoes many changes at approximately the age of 7 and this affects the manner in which information is processed (e.g., Hitch & Halloway). The findings in Chapters 3 and 4 suggest that the verbal component of working memory is responsible for explicit hypothesis testing. Importantly, it appears that the development of verbal working memory capacity is related to the ability to use explicit learning processes. This conclusion is in line with the sensorimotor hypothesis, which suggests that young children are more likely to process information implicitly whereas adults tend to process information explicitly (see Chapter 2 for a discussion on the sensorimotor hypothesis).

When discussing the relationship between working memory and explicit processes, it is also important to consider the phenomenon of ‘reinvestment’ (Masters & Maxwell, 2008).

The process of drawing upon task-relevant verbal knowledge to gain conscious control over motor performance (i.e., reinvestment) seems likely to consume working memory resources. Indeed, in Chapter 4, scores on the Movement Specific Reinvestment Scale were related to scores on a verbal working memory test for both children and adults. The Movement Specific Reinvestment Scale is comprised of two components: conscious motor processing (CMP) and movement self-consciousness (MS-C). For children, verbal working memory capacity was related to both CMP and MS-C and, for adults, verbal working memory capacity was related to MS-C. Interestingly, there was no relationship between visuo-spatial working memory and CMP or MS-C. This therefore suggests that movement specific reinvestment is predominantly a process that is associated with verbal working memory, rather than visuo-spatial working memory.

There are two possible explanations for the relationship between verbal working memory and reinvestment. Either (1) large verbal working memory capacity increases the propensity to consciously control movements, or (2) a high propensity for conscious control (i.e., reinvestment) may aid the development of verbal working memory capacity via constant practice at explicit problem solving and analysis. The answer to this predicament will add to our understanding of the relationship between verbal working memory and explicit hypothesis testing. Perhaps verbal working memory capacity is related to the tendency to test hypotheses, but the propensity to reinvest task-related knowledge (which is typically accumulated via hypothesis testing) is a function of personality as argued by Masters and colleagues (Masters et al., 1993; Masters & Maxwell, 2008).

An interesting topic of discussion is the influence of visuo-spatial working memory on motor learning. Chapter 4 provided evidence using EEG measures that larger visuo-spatial working memory capacity was associated with less verbal engagement and less visuo-spatial mapping during motor performance. Both of these traits have been observed with performance of implicitly learnt skills (Zhu et al., 2011). Therefore, the findings in Chapter 4 imply that larger visual-spatial working memory capacity encourages implicit processes during motor performance. Further research is required to explore this theory.

Modified equipment, task simplification and implicit motor learning

The findings in Chapter 6 provided evidence that there is less conscious processing when children use equipment that allows skills to be performed with greater ease. It was evident that children had difficulty multi-tasking when using full size equipment but not when using modified equipment. This infers that the use of equipment that increases the skill difficulty (i.e., using a full size racquet and a standard tennis ball) results in greater conscious processing during performance of the skill, whereas using modified equipment reduces conscious processing during performance. This finding draws parallels with the errorless learning paradigm, whereby skills are acquired implicitly (i.e., with less conscious processing) when practice involves minimal errors (e.g., Maxwell et al., 2001; Poolton et al., 2005). Seemingly, there are two possible methods of achieving an errorless practice environment: (1) manipulating the task (e.g., reducing distance from the target: Maxwell et al., 2001) or (2) controlling the body’s degrees of freedom (e.g., a regulated hit with a hammer: Masters et al., 2004). Given that the use of modified equipment does not appear to control the body’s degrees of freedom, I argue, based on the tenants of the errorless learning paradigm, that modifying equipment is another method of manipulating the task to increase success, which ultimately reduces conscious processing during performance. Of course, there is an obvious difference between the errorless learning paradigm and the modification of equipment, with the errorless learning techniques ensuring minimal errors (see Maxwell et al., 2001), whereas the modification of equipment does not guarantee such success. For instance, whilst skills are performed with greater success and with a better technique when using modified equipment (see Chapters 6, 7 and 8), children still make errors. Nonetheless, it seems that the use of modified equipment by children reduces conscious processing during motor performance compared to the use of full-size equipment.

Practical Implications

There are several practical implications from the findings of this dissertation. First (as extensively discussed previously), children's motor learning appears to be enhanced when the practice environment places fewer demands on working memory. This argument stems from research examining children's learning during classroom activities (Gathercole et al., 2008), but has since been supported by research in children's motor learning (e.g., Capio, Poolton, Sit, Euiga et al., 2013; Capio, Poolton, Sit, Holmstrom et al., 2013). Specifically, it appears that this can be achieved by the reduction of errors via manipulating the target size (Capio, Poolton, Sit, Euiga et al., 2013; Capio, Poolton, Sit, Holmstrom et al., 2013) or modifying the equipment used (see Chapters 6 to 8).

Second, reducing the demands on working memory during learning appears most beneficial for less skilled children or children with lower working memory capacity. (Note: it is common that these two traits go together, see Alloway, 2007b). Such children have a reduced ability to hold information in the mind (e.g., Gathercole et al., 2008). Consequently, these children are likely to experience lost learning opportunities when they are required to hold multiple items of information in the mind (e.g., comparing multiple *errorful* performances to discover the most effective movement solution).

Third, this thesis supports the International Tennis Federation's (ITF) guidelines regarding the use of modified equipment in children's tennis. The ITF recommend that children aged between 6 and 8 years should use both low compression balls (25% compression of the standard ball) and 48.3 cm to 58.4 cm racquets. Indeed, the experiment detailed in Chapter 7 showed that children aged between 6 and 8 years performed a forehand task better when using the lowest compression ball combined with a 48.3 cm racquet. Moreover, children acquired better movement proficiency when practising with a 48.3 cm racquet compared to a 68.6 cm racquet (Chapter 8) over a five-week practice period. The findings in Chapter 7 also support the alternative recommendation that children should select their own equipment given that they appear to be attuned to the ‘affordances’ provided by the equipment (Beak et al., 2000; Headrick et al., 2012).

Ultimately, physical education (PE) teachers and tennis coaches should be cognisant of performance benefits for young children when coupling accepted implicit instructional approaches (such as the provision of analogies) with the use of scaled equipment. Similarly, parents should be aware of the benefits of modified equipment when purchasing equipment for their child. And importantly, Tennis Clubs and Associations should take heed of the results and continue to encourage the ‘modified approach’ in their junior programs.

Methodological Implications

The purpose of this section is to summarise the methodological considerations that arose from the experiments conducted. In Chapter 3, hypothesis testing was measured by counting the number of alterations made to technique via video replay along with a verbal recall of any rules accumulated during the task. While these two measures provide a reasonably reliable and valid account of hypothesis testing, more objective measures should be explored in the future. For instance, Zhu et al. (2011) showed that explicit learners display greater EEG coherence in the regions of the brain responsible for verbal-analytical processing and motor planning compared to implicit learners. Therefore, the use of EEG monitoring may provide objective evidence that hypothesis testing has occurred if greater activity is found in the region of the brain responsible for verbal-analytical processes.

In Chapter 4, monetary incentives were used to create a pressured environment. This was based on previous research that has employed this method successfully (e.g., Gucciardi & Dimmock, 2008; Hardy et al., 1996; Masters, 1992; Mullen & Hardy, 2000; Mullen, Hardy, & Tattersall, 2005). However, the studies detailed in Chapter 4 did not find a decline in performance when performing ‘under pressure’. In fact, the opposite trend was observed. While participants reported greater anxiety levels, it was more likely that the monetary incentives increased the participant’s motivation. Undoubtedly, replicating a pressured environment in the lab is a dilemma for researchers. Perhaps the combination of monetary incentives with other methods, such as the inclusion of video cameras/teachers/coaches for the pressured condition (but not the unpressured condition) and creating stories that emphasise the importance of the pressured condition (e.g., Liao & Masters, 2001), will provide a more effective technique of raising anxiety and subsequently hampering performance. Ultimately, however, pressure will only be truly created if performance of the skill is made meaningful to the participant.

Chapters 5 to 8 included performance measures of tennis skills. The skills tests used in these studies were original as there is a dearth of research examining tennis skills in novice tennis players aged less than 10 years. Test-re-test reliability of the hitting performance test was moderate to strong (as reported in Chapter 7) and therefore this test should be considered for use by other researchers if examining tennis skills of young children. With regards to the measurement of hitting technique, whilst the subjective ratings provided a good guide, this measurement could be improved by using Motion Analysis Software, allowing for more rigorous three-dimensional biomechanical analysis. However, given the extensive process associated with such an analysis, Motion Analysis Software is only recommended when there is a specific question being addressed (e.g., examining whether the smaller racquet increases racquet speed).

Finally, Chapters 6 and 8 included dual-task tests to measure how well the participants could perform the skill without relying on working memory involvement. The secondary task in Chapter 6 involved counting backwards from 150 in one's. The children in this study were aged 9 to 11 years and, via observation, were able to perform this task appropriately. In Chapter 8, the children were aged 6 to 8 years and consequently the secondary task was made slightly easier – counting upwards from zero in one's. However, a limitation of both of these tests was that secondary task performance was not measured and, therefore, it was possible that the dual-task test did not elicit the appropriate effect. Future research adopting the dual-task methodology with children should also seek to incorporate more meaningful secondary tasks other than counting numbers.

Future Directions

The findings of this dissertation give rise to a number of intriguing research questions. For instance, is better working memory functioning beneficial to motor learning? Children with better working memory functioning have a greater ability to hold information in the mind and are more likely to engage in explicit hypothesis testing, which generates fast improvements to skill performance. Typically children with impaired working memory functioning have low motor skill ability (e.g., Alloway, 2007b; Alloway & Archibald, 2008). Indeed, in Chapter 7, less skilled children displayed lower working memory capacity than skilled children. Therefore, it is possible that children with better working memory functioning are more likely to acquire motor skills faster than children with poorer working memory functioning. However, it is also possible that children with larger working memory are more likely to learn skills explicitly, which is less beneficial (than implicit motor learning) when performing in stressful situations. To add further complexity to this question, how does visuo-spatial working memory influence this process? This question clearly represents a conundrum that should be addressed in future research.

Another question that requires further examination is: what are the underlying mechanisms that encourage implicit motor learning when children use modified equipment? This was discussed in the 'Theoretical Implications' section of this chapter. To gain an understanding of this question, a future study should compare the learning differences between the use of modified/full size equipment with errorless/errorful learning. Furthermore, if the use of modified equipment does indeed evoke implicit motor learning over a period of practice, future research should examine the efficacy of a longitudinal practice program that incorporates the use of modified equipment with other implicit learning strategies (e.g., the provision of analogies as instructions). The purpose of such a study would be to identify a program that can be applied to coaching and physical education settings with the intention of encouraging implicit motor learning.

Concluding Remarks

The main aims of this dissertation were to understand how children acquire motor skills and, thereby, understand how to enhance the acquisition of motor skills in children. The general consensus amongst researchers is that children acquire motor skills implicitly, whereas adults tend to learn explicitly (e.g., Hernandez et al., 2011). The question I therefore asked in Chapter 1 of this thesis was: "when does the transition from implicit to explicit processing occur? Additionally, what are the mechanisms underpinning this transition?"

Reber (1993) proposed that implicit memory develops early in childhood and is invariant throughout a person's life, whereas explicit memory develops during childhood and continues to increase well into adulthood. I argue, based on the findings outlined in this thesis, that the gradual increase in explicit memory during childhood is facilitated by the gradual increase in verbal working memory during this time period. Substantial evidence has been provided to show that the verbal component of working memory is associated with explicit processes such as testing hypotheses and consciously controlling movements in children.

Using this knowledge, it seemed logical that children's motor learning would be enhanced if the practice environment reduced demands on the developing working memory, thereby encouraging implicit rather than explicit learning. The use of modified equipment (i.e., smaller tennis racquets and lower compression balls) was examined as a potential method to achieve such a practice environment. Indeed, the use of modified equipment reduced demands on working memory (as opposed to using full size equipment) during performance of a motor skill. Moreover, skills were performed better when using modified equipment and greater learning was observed over a five-week period of practice.

In summary, this dissertation has contributed to the understanding of motor learning in children and provides an insight into the salient role that working memory plays during the acquisition of skills. As such, I anticipate that the ideas proposed throughout the thesis will lead to further exploration of implicit and explicit motor learning in children. In fact, with advances in technology, maybe our understanding of cognitive processes will be sufficiently advanced to an extent that the use of learning strategies to encourage implicit motor learning will be understood explicitly.

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INFORMATION TO PARTICIPANTS INVOLVED IN RESEARCH

You are invited to participate

Your child is invited to participate in a research project titled 'Children are not little adults! The influence of task and equipment scaling for children learning motor-skills'.

This project is part of a PhD study at Victoria University being conducted by student researcher, Tim Buszard. Prof Damian Farrow (Institute of Sport, Exercise and Active Living) will be the supervisor.

Project explanation

This research is examining the influence that modified equipment has on children's skill development. It aims to establish guidelines related to the size of tennis equipment and its appropriateness for children of varying ages and sizes. Additionally, this study will analyse children's thought processes when performing motor-skills.

What will your child be asked to do?

Children will be withdrawn from their P.E. class in groups of six for a maximum of 30 minutes per week over a three-week period to perform a variety of tennis skill tasks. Your child will be filmed when performing these skills, and will occasionally be required to respond to questions from the researcher regarding his or her thought process when performing the skill. Your child will also be required to complete the Automated Working Memory Assessment which will be administered during class time by his/her teacher. This is a 10 -15 minute assessment and has been shown to be a reliable and valid indicator of children's learning capabilities. The assessment involves tasks such as remembering specific patterns or numbers. This study will be conducted over a three-week period in Term 1 and 2, 2012.

What will your child gain from participating?

Potentially, the findings of this research will help teachers better understand your child's learning capabilities and provide information regarding your child's motor skill development. It is our intention to present the findings of the group data in the form of a journal publication. This means other schools and teachers will be able to benefit from the knowledge gained from this study. Please note that your child will not be named within this report and no one outside the team of researchers and the school's principal will be able to identify your child's results at any time during or following the study. Your child's results will be identified by an assigned identification number known only by the researchers.

How will the information from your child be used?

The information gained from this research will ultimately be a part of the student's PhD thesis. It is also of our intention to publish a journal article from the data collected.

What are the potential risks of participating in this project?

There are no foreseeable risks outside those of a normal P.E. class.

How will this project be conducted?

The project will be divided into four phases: 1) assessment of working memory; (2) identification of appropriate racquet size and ball compression for children of varying ages and sizes; (3) examination of children's ability to consciously correct movement patterns; and (4) investigation of children's awareness of internal movements and external factors when performing a motor-skill.

Working memory will be assessed using a validated assessment – the 'Automated Working Memory Assessment' – while phases two, three and four will require children to perform the fundamental tennis skill of playing a forehand to a target.

Who is conducting the study?

Should you have any questions regarding this project, please contact the chief investigator or the student researcher:

Chief Investigator
Prof Damian Farrow
Telephone (03) 9919 5001
Victoria University

Student Researcher
Tim Buszard
Telephone 0431 734 392
Victoria University

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

If you have any queries or complaints about the way you have been treated, you may contact the Research Ethics and Biosafety Manager, Victoria University Human Research Ethics Committee, Victoria University, PO Box 14428, Melbourne, VIC, 8001 or phone (03) 9919 4148.

Regards,

[redacted]

Damian Farrow
(Chief Investigator)

CONSENT FORM FOR PARTICIPANTS INVOLVED IN RESEARCH

INFORMATION TO PARTICIPANTS:

We would like to invite you to be a part of a study that will examine the influence that modified equipment has on children's motor-skill development.

CERTIFICATION BY SUBJECT

I, *(parent/guardian's name)*..

certify that my child, *(child's name)*.., of

....Primary School can participate in the study: 'Children are not little adults! The influence of task and equipment scaling for children learning motor-skills' being conducted at Victoria University by: Prof Damian Farrow (Chief Investigator).

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 Tim Buszard (student researcher), and that I freely consent to my child's participation which may involve the below mentioned procedures:

- *Completing the Automated Working Memory Assessment during class time*
- *Performing tennis skill tasks using a variety of racquets and balls while being filmed during PE classes.*
- *Answering any questions the researchers may ask regarding my performance following each shot I hit.*

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

I have been informed that the information my child provides will be kept confidential.
Parent/Guardian's signature:...

Date: ....

Child's signature:..

Date:.......................................

Any queries about your participation in this project may be directed to the chief investigator or the student researcher:

Prof Damian Farrow (chief investigator)
9919 5001.

Tim Buszard (student researcher)
0431 734 392

If you have any queries or complaints about the way you have been treated, you may contact the Research Ethics and Biosafety Manager, Victoria University Human Research Ethics Committee, Victoria University, PO Box 14428, Melbourne, VIC, 8001 or phone (03) 9919 4148

Participants Consent Form

01/05/2012

Dear Participants,

I am Professor Rich Masters of the Institute of Human Performance at the University of Hong Kong. I will conduct a research project on ‘Brain activity in young adults performing a simple motor task’ and would like to invite you to participate.

Those who participate in this research will complete a series of tennis shots while wearing a cap that monitors brain activity. There are no foreseeable risks for you other than those associated with playing a tennis forehand. Please complete the reply slip below to indicate whether you would like to participate in this research soon. The information gained from this research will be most beneficial for teachers and coaches alike, as it will increase our understanding of how people perform motor skills and how we should teach motor skills. Participation is entirely voluntary, and all information obtained will be used for research purposes only. If you have any questions about the research, please feel free to contact Rich Masters on 28315261. If you want to know more about the rights as a research participant, please contact the Human Research Ethics Committee for Non-Clinical Faculties, the University of Hong Kong (2241-5267).

Your help is very much appreciated.

Yours sincerely,

Professor Rich Masters

Institute of Human Performance,

The University of Hong Kong

Reply Slip

I ________________________________ (Name of Participant) understand the procedures described above and agree to participate in this study.

______________________________________ ____________________

Signature of Participant Date

THE MOVEMENT SPECIFIC REINVESTMENT SCALE FOR CHILDREN

Full name:______________________________ Class:________
Date of birth:________(day)________(month)____________(year)

Below are a number of statements about your movements in general. Circle the answer that <u>best</u> describes how you feel for each question.

1. **I remember the times when I could not do well in certain movements.**

   strongly disagree | somewhat disagree | somewhat agree | strongly agree

2. **I try to figure out why I cannot do well in certain movements.'**

   strongly disagree | somewhat disagree | somewhat agree | strongly agree

3. **I think a lot about the movements I have done.**

   strongly disagree | somewhat disagree | somewhat agree | strongly agree

4. **I try to think about my movements when I carry them out.**

   strongly disagree | somewhat disagree | somewhat agree | strongly agree

5. **I am aware of the way I look when I am moving.**

   strongly disagree | somewhat disagree | somewhat agree | strongly agree

6. **I sometimes have the feeling that I am watching myself move.**

   strongly disagree | somewhat disagree | somewhat agree | strongly agree

7. **I am aware of the way my body works when I am moving.**

   strongly disagree | somewhat disagree | somewhat agree | strongly agree

8. **I am concerned about the way I move.**

   strongly disagree | somewhat disagree | somewhat agree | strongly agree

9. **If I see my reflection in a shop window, I will check out my movements.**

   strongly disagree | somewhat disagree | somewhat agree | strongly agree

10. **I am concerned about what people think about me when I am moving.**

    strongly disagree | somewhat disagree | somewhat agree | strongly agree

THE MOVEMENT SPECIFIC REINVESTMENT SCALE

Name______________________ Date: _________ Age:__________ Hand: L/R

DIRECTIONS: Below are a number of statements about your movements. The possible answers go from 'strongly disagree'. There are no right and wrong answers so circle the answer that best describes how you feel for each question.

1. I rarely forget the times when my movements have failed me
   - ☐Strongly disagree
   - ☐Moderately disagree
   - ☐Weakly disagree
   - ☐Weakly agree
   - ☐Moderately agree
   - ☐Strongly agree

2. I am always trying to figure out why my actions failed
   - ☐Strongly disagree
   - ☐Moderately disagree
   - ☐Weakly disagree
   - ☐Weakly agree
   - ☐Moderately agree
   - ☐Strongly agree

3. I reflect about my movement a lot
   - ☐Strongly disagree
   - ☐Moderately disagree
   - ☐Weakly disagree
   - ☐Weakly agree
   - ☐Moderately agree
   - ☐Strongly agree

4. I am always trying to think about my movements when I carry them out
   - ☐Strongly disagree
   - ☐Moderately disagree
   - ☐Weakly disagree
   - ☐Weakly agree
   - ☐Moderately agree
   - ☐Strongly agree

5. I am self conscious about the way I look when I am moving
   - ☐ Strongly disagree
   - ☐ Moderately disagree
   - ☐ Weakly disagree
   - ☐ Weakly agree
   - ☐ Moderately agree
   - ☐ Strongly agree

6. I sometimes have the feeling that I am watching myself move
   - ☐ Strongly disagree
   - ☐ Moderately disagree
   - ☐ Weakly disagree
   - ☐ Weakly agree
   - ☐ Moderately agree
   - ☐ Strongly agree

7. I am aware of the way my body works when I am carrying out a movement
   - ☐ Strongly disagree
   - ☐ Moderately disagree
   - ☐ Weakly disagree
   - ☐ Weakly agree
   - ☐ Moderately agree
   - ☐ Strongly agree

8. I am concerned about my style of moving
   - ☐ Strongly disagree
   - ☐ Moderately disagree
   - ☐ Weakly disagree
   - ☐ Weakly agree
   - ☐ Moderately agree
   - ☐ Strongly agree

9. If I see my reflection in a shop window, I will examine my movements
   - ☐ Strongly disagree
   - ☐ Moderately disagree
   - ☐ Weakly disagree
   - ☐ Weakly agree
   - ☐ Moderately agree
   - ☐ Strongly agree

10. I am concerned about what people think about me when I am moving
    - ☐ Strongly disagree
    - ☐ Moderately disagree
    - ☐ Weakly disagree
    - ☐ Weakly agree
    - ☐ Moderately agree
    - ☐ Strongly agree

VICTORIA UNIVERSITY
MELBOURNE AUSTRALIA

INFORMATION TO PARTICIPANTS INVOLVED IN RESEARCH

You are invited to participate

Your child is invited to participate in a research project titled 'The affect of using scaled equipment on children's skill acquisition, and the influence working memory has on learning'.

This project is part of a PhD study at Victoria University being conducted by student researcher, Tim Buszard. Prof Damian Farrow (Institute of Sport, Exercise and Active Living) will be the supervisor.

Project explanation

This research is examining the influence that modified equipment has on children's skill acquisition over a period of practice. It aims to establish guidelines related to the size of tennis equipment and its appropriateness for children of varying ages and sizes. Additionally, this study will assess how children's memory influences their motor-skill learning.

What will my child be asked to do?

Children in grade 1 and 2 will participate in Tennis Australia's 'Hot Shots' program during their PE classes for 5 weeks during Term 1, 2013. Your child will be randomly assigned to a group (based on their PE class) that will involve either coaching or no coaching, or the use of a 19-inch racquet or a 23-inch racquet. Children's skill level will be measured at the beginning (pre-test) and the end (post-test) of the program.

NB: Your child will be filmed during the pre- and post-tests of the program. ***This footage will be stored on the primary researcher's hard drive. It will only be used for data analysis. No other person will have access to the footage and it will not be used for presentation purposes.***

**Please note that if you do not want your child to participate in the study, they will still participate in the program as part of the PE curricular, but they will not be required to perform the pre- and post-tests; hence, they will not be filmed and no data will be recorded about your child.

Your child will also be required to complete the Automated Working Memory Assessment which will be administered during class time by the student researcher at the beginning of the program. A school teacher will supervise this assessment. This is a 10 -15 minute assessment and has been shown to be a reliable and valid indicator of children's learning capabilities. The assessment involves tasks such as remembering specific patterns or numbers. If you would like to find out your child’s results, please speak to the school principle following the project.

What will my child gain from participating?

Potentially, the findings of this research will help teachers better understand your child’s learning capabilities and provide information regarding your child’s motor skill development. It is our intention to present the findings of the group data in the form of a journal publication. This means other schools and teachers will be able to benefit from the knowledge gained from this study. Please note that your child will not be named within this report and no one outside the team of researchers and the school’s principal will be able to identify your child’s results at any time during or following the study. Your child’s results will be identified by an assigned identification number known only by the researchers.

How will the information my child gives be used?

The information gained from this research will ultimately be a part of the student’s PhD thesis and it is of our intention to publish a journal article from the data collected. A summary of each child’s results will also be provided to the school principle as it may provide beneficial information regarding your child’s cognitive and motor-skill development.

What are the potential risks of participating in this project?

1. The physical risks associated with the motor skill testing and tennis coaching lessons are extremely minimal (i.e., no more than the risks associated with children playing tennis during a P.E. class). These risks include:

- Tripping over a ball/racquet/cone/net
- Being hit by a tennis racquet if another child swings their racquet whilst standing too close

The coaches running the sessions will ensure that the activities are conducted in a safe manner.

2. Children may feel concerned their ability to execute various physical and skill related tasks as part of the data collection procedure may highlight any real or perceived physical and/or skill deficiencies, thus leading to potential embarrassment. The researchers will reinforce that all data will remain strictly confidential with both school names and individual participant names de-identified through the use of codes and/or pseudonyms.

3**.** Situation could arise where children feel embarrassed to perform in front of their peers or where children watching may make fun of the participant. Subsequently, the student researcher will tell all children before the start of the testing that they must show good sportsmanship.

NB: There are procedures in place to ensure appropriate management of any issue that may arise.

How will this project be conducted?

The project will involve children in grade 1 participating in Tennis Australia's junior 'Hot-Shots' program for five weeks. All tennis will be played outdoors on synthetic grass within the school grounds during their physical education classes. Some of the sessions will be filmed (see above); however, it must be reinforced that this footage will only be used for data analysis purposes. Children will also complete the Automated Working Memory Assessment. This will be conducted during class time by the student researcher with the supervision of a school teacher.

Who is conducting the study?

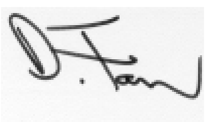
Should you have any questions regarding this project, please contact the chief investigator or the student researcher:

Chief Investigator
Prof Damian Farrow
Telephone (03) 9919 5001
Victoria University

Student Researcher
Tim Buszard
Telephone 0431 734 392
Victoria University

Any queries about your participation in this project may be directed to the Chief Investigator or student researcher listed above. If you have any queries or complaints about the way you have been treated, you may contact the Research Ethics and Biosafety Manager, Victoria University Human Research Ethics Committee, Victoria University, PO Box 14428, Melbourne, VIC, 8001 or phone (03) 9919 4148.

Regards,



Damian Farrow
(Chief Investigator)

VICTORIA UNIVERSITY
MELBOURNE AUSTRALIA

CONSENT FORM FOR PARTICIPANTS INVOLVED IN RESEARCH

INFORMATION TO PARTICIPANTS:

We would like to invite you to be a part of a study that will examine the influence modified equipment has on children's motor-skill development.

CERTIFICATION BY SUBJECT

I, *(parent/guardian's name)*..

certify that my child, *(child's name)*.., of

....Primary School can participate in the study: 'The affect of using scaled equipment on children's skill acquisition, and the influence working memory has on learning' being conducted at Victoria University by: Prof Damian Farrow (Chief Investigator).

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 Tim Buszard (student researcher), and that I freely consent to my child's participation which may involve the below mentioned procedures:

- *Completing the Automated Working Memory Assessment during class time (supervised by a teacher).*
- *Being involved in Tennis Australia's 'Hot Shots' program. This requires participation in one 30-minute session per week for 5 weeks. Tennis Australia coaches will run this program.*
- *Being filmed during the pre- and post-tests to allow for analysis of skill development following the program.*

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

I have been informed that the information my child provides will be kept confidential.

Parent/Guardian's signature:...

Date: ....

Child's signature:...

Date:..

Any queries about your participation in this project may be directed to the chief investigator or the student researcher:

Prof Damian Farrow (chief investigator)
9919 5001.

Tim Buszard (student researcher)
0431 734 392

If you have any queries or complaints about the way you have been treated, you may contact the Research Ethics and Biosafety Manager, Victoria University Human Research Ethics Committee, Victoria University, PO Box 14428, Melbourne, VIC, 8001 or phone (03) 9919 4148.

The practice sessions in the experiments presented in Chapters 5 and 8 were based on Tennis Australia's Hot Shots Program. The following 12 pages have been extracted from the MLC Tennis Hot Shots in Schools Manual, 2013.

Introduction to MLC Tennis Hot Shots

Welcome to the MLC Tennis Hot Shots (MLCTHS) program, Tennis Australia's official development program for primary aged children. The MLCTHS program is a critical component of Tennis Australia's strategy, which is focused on **getting more kids playing tennis more often**.

At the core of MLCTHS is an innovative, practical philosophy call "learning through play". This means that playing the game of tennis, or modified versions of the game, is the central feature of all sessions.

The use of tailored equipment, including smaller courts, racquets and low-compression tennis balls ensures children are introduced to tennis in an environment that is suited to their age and skill level and makes learning tennis fun and easy.

In the past 12 months, more than 300,000 children have participated in the MLCTHS program via Tennis in Schools, coaching programs and promotional events around Australia. This participation number will only strengthen as we focus on our program strategy.

The strategy of MLCTHS revolves around four major pillars of delivery:

- MLC Tennis Hot Shots Schools (Introduce)
- MLC Tennis Hot Shots Coaching (Teach)
- MLC Tennis Hot Shots Community (Play)
- MLC Tennis Hot Shots Tournaments (Compete)

The four major pillars will ensure every child in this country has the opportunity to participate in MLC Tennis Hot Shots at a level that they choose.

We are all excited about the year ahead for MLCTHS and appreciate your schools support and commitment to the program. We look forward to working with you to help grow participation and give all children the opportunity to experience what this great program has to offer.

Craig Morris
Hot Shots Leader
Tennis Australia

A game-centred approach

The MLC Tennis Hot Shots in Schools resource adopts a game-centred approach to teaching tennis. Playing the game of tennis (or modified versions of the game) is the central feature of the lessons. Students are encouraged to serve, rally and score in each lesson. This game-centred approach serves to promote game sense. Students are encouraged to 'play with purpose' and this involves guided play using questions and direct instruction to promote tactical understanding and technical development.

Game Sense is knowledge in action, in three parts. Students will improve their tennis by:

1. Knowing *what* to do in the context of play (decision making)
2. Knowing *how* to do it (movement knowledge)
3. Being able to execute the 'how' and 'what' successfully (movement capability).

Using guided or open ended questions to think about the game

A key strategy in achieving game sense in tennis is the use of focus questions which are designed to guide the student's game appreciation and understanding. This indirect teaching style encourages students to learn how to search and select information from the game environment and to solve problems and explore solutions to various movement challenges.

Guide more, direct less

An indirect teaching style encourages teachers to guide more and direct less, allowing the students to make more decisions about their learning. However, depending on the developmental readiness of the students, you may need to adopt a more direct teaching style to ensure students have enough repetition of motor skills to build and refine their technical skills to allow them to maintain a rally.

When do we get to play a game?

A game-centred approach addresses the students desire to play with students serving, rallying and scoring which is playing the game of tennis. The game may be modified to match the developmental readiness of the students. For example, the serve for younger players may be an overarm throw or a bounce hit forehand to start the point.

When students are playing the game it is not 'free play.' Play with a purpose is required. This is an important teaching consideration as the teacher must know the purpose (tactical and technical development) of the game play and how the choice of activities within the lesson contributes to the development of a specified aspect of play.

How to progress or regress an activity or game - CHANGE IT

The CHANGE IT philosophy directs attention to the constraints that can be modified to focus tennis learning.

C – coaching style
H – how scoring occurs or the scoring system
A – area or dimensions of the play space
N – numbers of players
G – game rules
E – equipment
I – inclusion by modifying activities for learning needs
T – time of the game or time allowed in possession

For example, if an activity is too difficult for a student, you can modify the activity by changing the **Area** (e.g., making the court smaller) or changing the **Equipment** (e.g., changing from an orange to a red ball or to a foam ball). You can reduce decision making by changing the **Game rules** (e.g., first to 3 rather than playing a tiebreak).

The building blocks

Fundamental Movement Skills

Fundamental Movement Skills (FMS) are the basic building blocks or precursor patterns of the more specialised, complex skills used in games, sports and recreational activities (Hands, 2012).

Students need to learn FMS such as bouncing, catching, throwing and striking and practice them regularly. Students also need to experience regular opportunities to run, balance and develop good spatial awareness as a basis for these skills. Playing carefully selected games will help them to do this in a fun way while progressively learning to understand the basic constraints and tactical strategies needed to play more successfully.

Perceptual Motor skills

Perceptual Motor Skills (PMS) such as receiving, interpreting and responding to particular information and environments is essential to the personal development of the student. Students need to understand how to interpret information when playing in games or activities and respond accordingly to develop their movement skills and competence.

A modified tennis environment

Through research it has become apparent that students learn best when the equipment is scaled and appropriate to their age, size and skill level. It is for this reason Tennis Australia is investing heavily in the supply of tailored or modified tennis equipment to schools.

The MLC Tennis Hot Shots program has four progressive stages but for the schools program we have introduced a fifth stage, which complements the 5 primary bands of the national shaping paper for Health and Physical Education curriculum.

Band	Colour	Description	Court size	Ball	Racquet
Foundation	Purple	Students are introduced to tennis through learning basic FMS & PMS skills which will assist them in grasping the key skills required to play tennis	Defined spaces which can be determined by the teacher and student	Large soft balls of varying sizes Wilson foam ball	Paddle bat, 19 or 21 inch racquet
Years 1 - 2	Blue	Students are introduced to the general principals of tennis through participating in a range of challenging activities	Defined spaces which can be determined by the teacher and student	Large soft balls of varying sizes Wilson foam ball Wilson red ball 25% compression	Paddle bat, 19 or 21 inch racquet
Years 3 - 4	Red	Students will learn the basic groundstrokes, volley and serve skills required to rally the ball and play games	3m wide x 8.23m long or 6m wide x 10.97m long or students to define their own space	Wilson foam ball Wilson red ball 25% compression	Paddle bat, 19, 21 or 23 inch racquet
Years 5 - 6	Orange	Students will refine their skills through games which focus on tactics and all court play	6.4m wide x 18.29m long or a red court 6m wide x 10.97m long	Wilson orange ball 50% compression	23 or 25 inch racquet
Years 7 - 8	Green	Students will bring all elements of playing the game of tennis into practice; with students strategically deciding on shot making and participating in singles and doubles play.	8.23m wide (singles) or 10.97m wide (doubles) x 23.78m long Note: this is a full size tennis court Alternatives such as a red court 6m wide x 10.97m long can also be used	Wilson green ball 75% compression	25, 26 or 27 inch racquet

Court dimensions

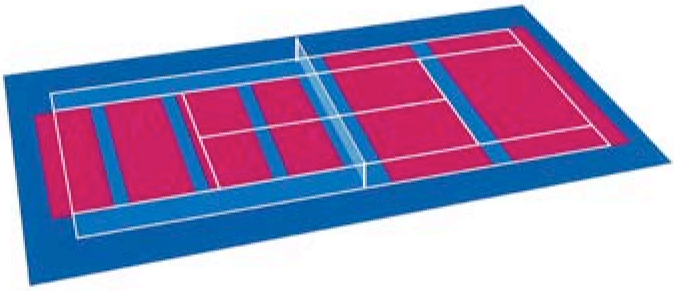
The outlined court space is a guide to ideal court sizing. In the school setting the court size will be determined naturally by the space and surface available as well as the number of students who are participating.

The size of the court being used will also be determined by the year levels and stage of development of the students. Starting on a smaller space and progressing to larger spaces is part of the progressions in the MLC Tennis Hot Shots program and is important as it helps build the students competence and confidence with playing tennis.

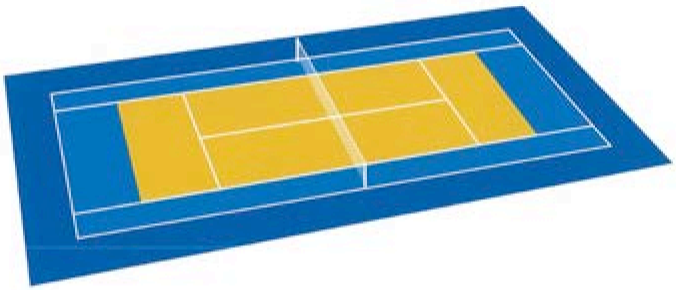
Purple & Blue

Teacher and students can define their own court space with markers or cones. A hard flat surface is all that is required such as a basketball court, indoor gym space or grassed area.

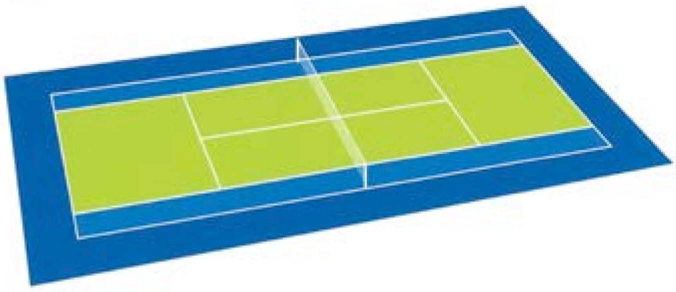
Red



Orange



Green



About this resource

The MLC Tennis Hot Shots (MLCTHS) in Schools resource has been designed to assist primary classroom and specialist teachers to engage students in a fun and safe tennis experience. There is an emphasis on helping students understand the game of tennis as well as being able to play a range of modified tennis games suited to the school environment.

The activities and games selected in this resource are the best available to assist students to understand the game of tennis whilst aligning with the MLCTHS program. The activities and games can be modified as suggested by the 'CHANGE IT' philosophy to make them less or more difficult. Students should always be asked whether they can think of ways to change a game to make it more interesting and challenging.

Lesson format

The resource provides five detailed stages (F/P through to year 7/ 8) with 10 lessons in each stage. The time of each stage lengthens as the students develop their understanding of the game and skills.

Purple and blue stage: 30 minutes per lesson
Red and orange stage: 35 minutes per lesson
Green stage: 45 minutes per lesson

The activities in each lesson and stage are progressive with challenging modified tennis games to help students develop skills and a tactical sense. All lessons have a particular focus and game play theme and include three or four activities that are sequentially built on previous lessons and stages.

The format of the lesson is designed so that it is easy to see the focus and tactical theme of that particular lesson. Importantly, the lessons also provide suggestions for variations and progressions that can make an activity more interesting and challenging.

The 'guide more, direct less' approach which underpins all lessons reflects the need for students to have ample opportunities to hit the ball. By doing so and by being challenged in tactical situations students will often discover for themselves how manipulation of the ball (where they hit it or how hard) becomes the basis for their tennis skill development.

Scoring

In some activities basic scoring principles will be introduced which will assist the students in achieving a holistic understanding of the game of tennis. Moving through the stages, students may be asked to score with pegs, play first to five points, a tiebreak, first to four games or even a set. Scoring will also focus on rewarding students for playing and displaying certain strokes or shots. For example, two points awarded for hitting a volley at the net if the focus of the activity is to work on the volley stroke.

Variations

Variations in a lesson are based on the 'CHANGE IT' philosophy. Teachers and students are encouraged to vary different aspects of the game such as changing the court space, rules, equipment and scoring system. The activities in the lesson can be modified to make them more or less difficult by the teacher or the students. Variations can extend more capable students or provide a range of practice options to choose from. There is no sequential order to the variations suggested.

Focus questions

Focus questions lend themselves to guide the student's understanding and have them assess and think about how they are playing an activity and what they could change to make their performance better or the game more interesting. This approach helps teachers in accessing the student's understanding of the game.

Tips and did you knows

Tips are designed to help teachers in facilitating the student's learning by providing ideas on technical or tactical aspects of the sport. The did you knows provide specific information on a new shot or element being introduced into the game. Teachers can use both tips and did you knows to guide students into further learning.

Student reflection

At the completion of a lesson, students can be asked to reflect on what they have learnt during the activities which will help facilitate their learning and understanding of the game. Challenging the students to think about how they played a particular shot, how they were able to rally for a number of shots or how they were able to change an activity to make it more or less difficult are all part of this reflection process.

Key end games

Each stage has a key end tennis game. The key game is what we would like to see every student have the confidence and competence to play and enjoy at the completion of the stage. These games can be introduced early in the stage so that students get a feel for them and then re-introduced when they have greater understanding and confidence in their skills. At the end of the formal lessons it is a good idea to spend time playing these games in a structured competition, such as a round robin event, or informal way such as during lunchtimes.

Key End Game

Foundation	Istanbul rolling rally
Years 1-2	New York classic
Years 3-4	Melbourne Open backyard classic
Years 5-6	Paris Open singles
Years 7-8	London doubles Championships

Point to note

Growing children need regular (daily) movement opportunities and while the lessons are designed with the developmental stages of students in mind, it is important for teachers to assess student progress and be prepared to repeat lessons and perhaps substitute an activity when necessary.

Achievement reports and certificates

Achievement reports are provided at the end of each stage so that a student's progression and understanding of the game can be assessed. These are a great tool for you as a teacher to use to assess their development.

A certificate of completion of the stage is also provided which can be provided to the student upon successfully advancing on the stage.

Assessment can be linked to the Australian Curriculum Achievement Standards but the expectation is that students will have improved their movement confidence and competence, have developed a tactical sense in relation to the stage of tennis they are playing and have developed a respect for themselves as well as their partners, opponents and umpires.

Alignment to the Australian Health and Physical Education Curriculum shaping paper

While this resource has been developed to align with the 'Movement and Physical Activity' strand of the Australian Health and Physical Education Curriculum shaping paper, it also recognises opportunities for learning linked to the General Capabilities.

- The Australian Health and Physical Education Curriculum shaping paper emphasises the importance of movement competence and confidence as a basis for students developing sport specific skills and understanding.
- In particular learning in, about and through the game of tennis will address the development of personal and social capabilities and ethical behaviour.
- Personal and social competence involves students recognising and regulating their emotions, developing concern for and understanding of others, establishing positive relationships, making responsible decisions, working effectively in teams, and handling challenging situations constructively.
- Ethical behaviour develops and provides understanding of the ethical principles, values and virtues in human life; acting with moral integrity; acting with regard for others; and having a desire and capacity to work for the common good.
- Recognised games and sports provide the ideal contexts in which to do this and this resource lends itself to the exploration of moral principles and codes of practice as well as a vehicle to teach and reinforce communication, respect, negotiation, teamwork and leadership skills.

Planning and organising

MLC Tennis Hot Shots (MLCTHS) in schools is part of the Health and Physical Education Curriculum. It should be taught in a safe, active and supportive environment. Students want to enjoy their participation and see that they are learning and develop new skills whilst playing the game with their friends.

It is the role of the teacher to ensure that the structure of the activities in a lesson meets the goals of that session and the environment in which the students are participating in will help them achieve these goals.

When planning for your lesson, think about the year level you are taking and what stage of the resource you should be using. The stage of the resource will determine what court size, and equipment that you will use. The MLCTHS program is focused on using tailored or modified equipment such as smaller courts, nets and racquets as well as low compression tennis balls.

Smaller court space

Schools can be extremely limited by the available space to participate in sport. As a teacher, be creative in your thinking when arranging the court space as you do not require a full tennis court to participate. Smaller courts actually make it easier for students to play as it encourages them to cooperatively rally. It also provides a challenge to the more competent students as it challenges them to use all available space. This ensures everyone is on a level playing field.

Defining your court and space

You do not necessarily require the physical lines of a tennis court to define your playing area. Alternatives such as a soft cone, drop down marker, chalk line or even sticky tape are all more than satisfactory. As long as the students understand what is in and out then you are set to go.

Nets

Smaller nets that are not as high complement the smaller court space. Choose a net which suits the year level and abilities of the students. And don't forget you do not need a physical net to be able to play. Nets may be a line on the ground, a bench to hit over or a piece of string. Facilitate the students learning by asking them how they would set up a potential net.

Racquets

As the students grow and get older so do the racquets in which they play with. Racquets can be anything from a grip pad to a paddle bat to a tennis racquet. Some of the activities even use throwing and catching as hitting and receiving the ball. When using racquets, make sure the students are able to grip the racquet comfortably and that it is not too heavy otherwise they will find it difficult to hold and swing.

Low compression tennis ball

The low compression tennis balls are fundamental to the MLCTHS program and provide teachers and students with the opportunity to play the game as the ball bounces lower and slower allowing more time to execute shots with control. For large groups of students this is fantastic as they will not spend their time chasing balls that bounce over their head and instead rally which makes it easier to manage for all teachers.

Providing a rich learning environment

It is very important to take a flexible approach to delivering the lessons provided. Students will be at varying stages of skill development within a class even though they will improve quickly by using the smaller courts, racquets and low compression tennis balls.

There are a number of things that you can do as a teacher to maximise the enjoyment and learning that will occur:

- Make sure students have a racquet and ball in their hand for most of the lesson. This will help them get used to it and will make them *want* to play.
- Make sure students hit the ball 'hundreds of times' during the lesson.
- Some teachers like to begin a lesson with 5-10 minutes of cooperative rallies. This is one good way to start your lesson, alternatively ask students to choose an activity from a previous lesson to reinforce their learning.
- Be aware of any skill imbalance between students in your class. This is inevitable and while allowing them to choose their playing partner is a good thing, sometimes it is better to put them with someone with similar ability and purpose (for example, don't match an under 10 champion with a novice learner) and encourage changing of partners during a lesson.
- There are 10 lessons in each stage but you can decide that you will take 12 or 14 lessons to cover off what you want to achieve. You may want to spread your unit over multiple terms.
- Don't be afraid to vary the time you spend on an activity even though you are provided with an indicative time.
- Use some of the warm up activities and games from a previous stage or previous lesson, particularly those that students like.
- Allow students to use the different low compression tennis balls that suit their height and movement abilities.
- You can also use different court sizes during a lesson if you feel this is appropriate. Some students can be playing on red court whilst other students may be playing in their own made space.
- Refer to the diagrams to help you follow the activities. Each is on a court of some description and you can easily see the student's position and the direction that the ball will follow.

Managing large participant numbers

As a teacher you may be initially thinking 'how can I manage many students participating in a tennis activity, I just don't have the space'. The MLCTHS in Schools program ensures that each and every student in your class is able to experience maximum participation and involvement.

It is the role of the teacher to ensure that the environment is safe for all students to be able to participate. Some ideas on how to handle a large group include:

- Ensure students are spread out with clear space available. This will ensure no-one is struck by racquets or balls.
- Construct activities in a way that minimises the chances of students being hit by a ball from another student.
- Ensure students are fully engaged in the activity which they are participating in.
- Provide instructions and demonstrations if required so that students understand how to participate in an activity.
- When required, ask students how they would change or modify a game if progression or regression is required.
- Ensure students have sufficient space to practice swings.
- Place left-handed students in appropriate positions to avoid racquet collisions with right-handed students (generally on the end of the court space).
- Ensure balls are regularly cleared from the court surface to prevent students from stepping on them.
- Ensure the court surface is dry, clean and clear of foreign objects.
- Ensure each session takes place in a safe and healthy environment. The teacher must be a firm leader on this aspect of the session. Accidents and injuries can be minimised by closely scanning the tennis environment and maintaining control of the session.

Practice sessions for the 5-week training study in Chapter 8

The practice session were based on the MLC Hot Shots in School curricular program for years 1 and 2. Most of the activities used in each session have been taken directly from the manual or have been modified slightly. Each session is outlined below.

Practice Session 1

Session Aim: Develop hand-eye coordination

Table A1

The activities conducted in session 1

	Activity 1	**Activity 2**	**Activity 3**
Name:	Tennis dribble relay	Keep control	Throw, bounce, hit & catch
Duration:	10 min	10 min	10 min
Description:	Students formed teams of 4-6 and lined-up behind a starting line. The first student on each team had a racquet and a ball. On signal from the coach, the first student put the ball on the ground, tapped it towards a marker 10m away, then picked up the ball, ran back and gave it to the next team member. The next team member followed the same sequence.	Each student had a racquet and a tennis ball and found open space. Standing on the spot, the student tried to balance the ball on their racquet. When the coach called “green”, the student walked around balancing the ball on their racquet. When the coach called “red”, the student stopped whilst still balancing the ball on their racquet. When the coach called “orange”, the students turned around in a full circle whilst balancing the ball on their racquet.	Students formed pairs. One student had a racquet and the other held a cone whilst standing 2m apart. The student with the cone threw the ball underarm to their partner, who then hit the ball back to the student with the cone. The aim for the student with the cone was to catch the ball in the cone.

Practice Session 2

Session Aim: How to use space to move your opponents

Table A2

The activities conducted in session 2

	Activity 1	**Activity 2**	**Activity 3**
Name:	Home run	Throw, bounce, hit & catch	Double trouble
Duration:	10 min	10 min	10 min
Description:	Children were divided into groups of 4 and were allocated a court each. Three children stood at one end of the guarding the goals, which were outlined by cones on the baseline. The fourth child stood at the other end and was required to drop and hit the ball with the aim of scoring goals. At first, the three children used their hands to catch the ball when attempting to stop the goals. Then racquets were introduced.	See description in Session 1.	Children formed doubles teams. Each doubles pair stood on their respective side of the court. Teams took it in turns being the server. A rally was commenced with an underarm serve, landing over the net and into the other teams space. The other team was required to let the ball to bounce once before being caught and then return the serve. One point was awarded for every rally won. First team to 10 points won.

Practice Session 3

Session Aim: Develop the skills to connect ball and racquet in sequence

Table A3

The activities conducted in session 3

	Activity 1	**Activity 2**	**Activity 3**
Name:	Home run	Throw, bounce and catch	Rally with a partner
Duration:	10 min	10 min	10 min
Description:	See description in Session 2	Children worked in pairs and stood on opposing sides of the net. One child held the cone and the ball while the other child held their racquet. The child with ball threw the ball underarm and the other child hit the ball back. The aim for the child was to catch the ball with their cone.	In pairs, children were required to stand opposite each other with the net in the middle. Children's aim was to rally with each other for as long as possible. Children were given the goal of rallying for more than 2 shots.

Practice Session 4

Session Aim: Learn the backhand

Table A4

The activities conducted in session 4

	Activity 1	**Activity 2**	**Activity 3**
Name:	Backhand game	Backhand game extension	Rally with a partner
Duration:	10 min	10 min	10 min
Description:	Children were divided into three teams. Each team was allocated a court. Children formed a line at the baseline on one side of the court, while the coach stood on the other side. The child standing at the front of the line was required to hit three backhands, progressively moving across the court, with the aim of hitting the ball onto the other side of the court. The team was awarded one point every successful shot. The first team to 20 points won.	A similar game was played, except children's aim was to hit the ball so that it landed in a specific zone on the court (i.e., the left side of the court). Once again, the team was awarded one point for every successful shot, and the first team to 20 points won.	See description in Session 3. However, at first, children threw the ball underarm to each other, with the aim of landing the ball before their partner, whilst their partner attempted to catch the ball. Children then progressed to rallying with their tennis racquets.

Practice Session 5

Session Aim: Re-visit everything from the first four weeks

Table A5

The activities conducted in session 5

	Activity 1	**Activity 2**	**Activity 3**
Name:	Relay races	Bounce the ball on the cone	Rally with a partner
Duration:	10 min	10 min	10 min
Description:	Groups of 5 lined up behind a cone. First children were required to run out to a cone placed 6 m away and back (once each). Then they were required to carry the ball on the racquet to the cone and back (twice each). Then they were required to bounce the ball on the ground continuously to the cone and back (twice each).	Children stood next to a cone with a ball and racquet each. Their goal was to hit the ball in the air so that it landed on the cone. Children were instructed to continuously hit the ball in the air after every bounce until the cone was hit. The activity progressed to children forming pairs, with the aim to hit the ball to each other (2 metres away) so that the ball landed on a cone that was in placed in between the children.	See description in Session 3. Children were also encouraged to use backhands where possible.

Tennis Australia's Fundamental Technique Checklist

The technical points outlined below have been created by expert tennis coaches and are considered the fundamentals of performing tennis strokes.

Forehand

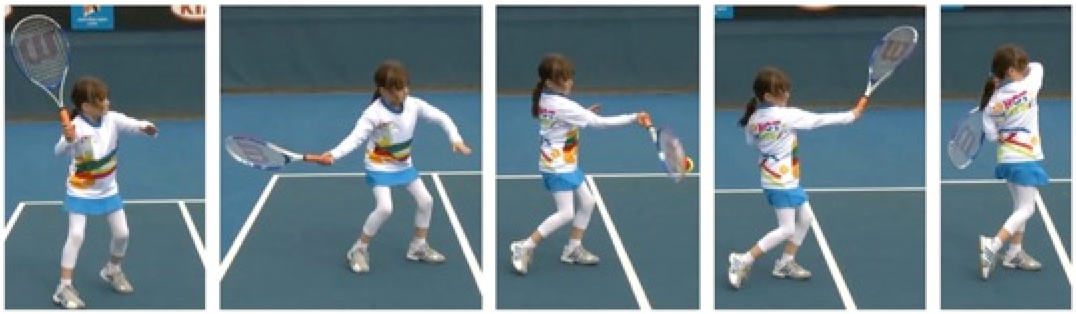


Figure A1. A step-by-step sequence of the forehand [Images extracted from Tennis Australia's ipad/iphone app: 'TA Technique'].

Table A6

Descriptions of the six technical points for the forehand

	Technical Point	*Description*
1.	Grip	Eastern forehand grip to a semi western forehand grip
2.	Circular Swing	A circular-like motion in the backswing with the racquet
3.	Low-to-high Swing	Racquet swung from low to high during the forward swing but with an arc that was more horizontal than vertical
4.	Step Forward	Step forward into the shot with the opposite leg to the hitting hand
5.	Impact	Ball struck in front and to the side of the body
6.	Follow-through	Follow-through considered a natural extension of the swing (i.e., extension and flexion of the elbow)

Backhand

Figure A2. A step-by-step sequence of the backhand [Images extracted from Tennis Australia's ipad/iphone app: 'TA Technique'].

Table A7

Descriptions of the six technical points for the backhand

	Technical Point	*Description*
1.	Grip*	*Single-handed grip* = Eastern backhand grip *Double handed grip* = Bottom hand on grip (right hand is the bottom hand for right-hand players) should be a eastern backhand grip to a continental grip
2.	Circular Swing	A circular-like motion in the backswing with the racquet
3.	Low-to-high Swing	Racquet swung from low to high during the forward swing but with an arc that was more horizontal than vertical
4.	Step Forward	Step forward into the shot with the opposite leg to the hitting hand
5.	Impact	Ball struck in front and to the side of the body
6.	Follow-through	Follow-through considered a natural extension of the swing (i.e., extension and flexion of the elbow)

* children could use either a one-handed or a two-handed grip

Starting a rally (i.e., underarm serve)

Given that these children were 6-8 years of age and beginner tennis players, the underarm serve (i.e., starting a rally with an underarm shot) was measured rather than the overarm serve.

Table A8

Descriptions of the six technical points for the underarm serve

	Technical Point	*Description*
1.	Grip	Eastern forehand grip to a semi western forehand grip
2.	Underarm Swing	Racquet swung in a classical underarm motion
3.	Ball Toss	Ball tossed upwards in the air in a controlled manner
4.	Step Forward	Step forward into the shot with the opposite leg to the hitting hand
5.	Impact	Ball struck in front and to the side of the body
6.	Follow-through	Follow-through considered a natural extension of the swing; although, a large follow-through was not necessary.