PRACTICE CONDITIONS LEADING TO THE ACQUISITION OF PERCEPTUAL-COGNITIVE-MOTOR PROCESSING

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Contents

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Abstract

In this thesis, specific practice conditions were examined for skill acquisition and transfer of perceptual-cognitive-motor processes underlying dynamic and complex performance. The availability of visual and cognitive processes during practice was modulated to examine contribution of each process to the skill acquisition using a novel computer-based task where participants were required to select and execute decisions to move a cursor to a target whilst avoiding random moving objects. Results demonstrated that practice with necessary information and processes improved the task performance, whereas limiting the underlying processes attenuated skill acquisition. Subsequently, the underlying processes were examined by measuring eye movements and condition-action pairs. Successful skill acquisition was underpinned by the modified visual search and decision making processes through practice. However, limiting necessary sensory information and decoupling cognitive processing during practice developed specific sensorimotor behaviour that did not lead to successful task performance. These results provided an insight of the skill acquisition by suggesting that when a task requires the acquisition of perceptual-cognitive-motor processes to be successful, integration of these processes would be necessary, whereas decoupling of these processes would limit skill acquisition. Moreover, transfer of acquired processes was examined between two tasks. Both tasks required the acquisition of similar perceptual-cognitive processes in order to select successful cursor trajectories, but the main goal differed between tasks. In addition, for both tasks a yoked condition aimed to limit cognitive processes to investigate the role of transfer-appropriate processing in skill acquisition. Results showed positive transfer indicating that practice on another task improved performance on the other task, whereas limiting cognitive processes attenuated the skill acquisition and transfer. Transfer would be maximised when the underlying processes between practice and transfer domain are similar or matched, whereas the transfer would be attenuated when the necessary

processes are decoupled during practice. The overall findings extend the research in perceptual-cognitive-motor processes and have several theoretical and applied implications.

Chapter 1

Review of perceptual-cognitive-motor skill acquisition and conditions of practice

Introduction

Expert and skilled performance is underpinned by the integration of perceptual, cognitive, and motor processes and their acquisition is central to successful performance in many domains, including sports, driving, and law enforcement. These processes enable us to perceive and recognise relevant from irrelevant stimuli, select an appropriate action from more than one available option, and execute the appropriate action under time constraints (Elliott et al. 2010; Wolpert & Kawato, 1998; Yarrow, Brown, & Krakauer, 2009). Expert or skilled performance in any domain is achieved through extensive practice during which these perceptual-cognitive-motor processes are acquired (Ericsson, 2008; Ericsson, Krampe, & Tesch-Römer, 1993). However, little, if any, research has been conducted examining practice conditions required for the acquisition and transfer of these processes of the dynamic and complex tasks found in many domains, particularly cognitive decision making processes. The aim of this thesis was to systematically investigate various conditions of practice to examine the effect on the acquisition and transfer of perceptual-cognitive-motor skills. A novel computer-based task was created that required the acquisition of perceptual-cognitive-motor processes for successful performance. Across seven experiments in this thesis, the task enabled the conditions of practice to be systematically manipulated to examine the acquisition and transfer of skill on the criterion task.

In this introductory chapter, research and theory examining motor behaviour and skill acquisition are reviewed to provide the rationale for the subsequent experimental work. The introduction chapter has five subsections, reviewing skilled behaviour and performance in complex tasks and domains, the role of the central nervous system and sensorimotor systems in this process, the practice conditions required for the acquisition and transfer of these processes, and the aims and hypothesis for the experimental work.

Skilled behaviours and performance

Humans show a remarkable capacity to execute a wide variety of actions to suit different external environments and demands. Through years of experience, our behaviours become skilful. Skill acquisition and learning is defined as the internal processes that make relatively permanent changes in learners' capabilities (Schmidt & Lee, 2011), whereas performance is the observable behaviours (Salmoni, Schmidt, & Walter, 1984). A skilled behaviour is the acquired and learned ability to achieve a desired outcome with certainty, efficiency, and adaptability, with minimum cost or loss (i.e., uncertainty, time, or energy expenditure) (Kording & Wolpert, 2006; Wolpert, Diedrichsen, & Flanagan, 2011). For example, after learning how to ride a bicycle in our childhood, our ability to ride a bicycle will not be diminished, so that we can ride a bicycle even after a long period without the experience of cycling. Additionally, we can ride a bicycle under many variable conditions (i.e. rainy or windy condition, on the flat road, or on the mountain). In some domains and cases, skilled performers can reach expert levels. Expertise is high level skill and knowledge attained from training and experience in a specific domain (Ericsson & Towne, 2010). Recently, the nature of expert performance in domains, such as chess, music and sports, has drawn considerable attention from a number of researchers (e.g., Ericsson & Charness, 1994; Ericsson & Williams, 2007; Williams & Ericsson, 2007). Expert behaviour and performance is predominantly mediated by acquired complex skills, and these acquired skills differentiate experts from novices or less-experienced individuals (Simon & Chase, 1973). The acquired skills consist of three main underlying processes that are *perceptual, cognitive, and motor processes.*

Expert performers have superior *motor skills*, such as more efficient movement patterns, better coordination, and better technique (i.e. throwing, kicking), when compared to novices (Egan, Verheul, & Savelsbergh, 2007; Schorer, Baker, Fath, &

Jaitner, 2007). Coordination is defined as an effective movement pattern when different body parts work together smoothly and efficiently (Newell, 1985). It requires the motor system to regulate multiple degrees of freedom by coordinating all of the different body parts into an action (Nourrit, Delignieres, Caillou, Deschamps, & Lauriot, 2003; Vereijken, van Emmerik, Whiting, & Newell, 1992). Expert movements are more coordinated and have more successful outcomes compared to novices. For example, Egan et al. (2007, see also Schorer et al., 2007) examined soccer kicking ability in experienced and less-experienced players who were required to quickly and accurately kick either a stationary or moving ball at a target. Experienced players were more accurate under both conditions when compared to the less-experienced. In order to increase accuracy when kicking the moving ball, the experienced players adapted their movement pattern by making a smaller range of knee movement and shortening the duration of knee flexion, demonstrating functional variability when coordination patterns needed to be adapted to suit the constraints of the current task. The authors concluded that experts have more established and adaptable movement patters compared to novices, resulting in more successful performance under variable conditions.

Expert performers have superior *perceptual skills*, such as task-specific visual search behaviours, when compared to novices. Visual search behaviours are the ability to direct visual attention to task-relevant information in the external environment (Mann, Williams, Ward, Janelle, 2007; Travassos et al., 2013; Williams, Janelle, & Davids, 2004). The visual search behaviours, and thereby visual attention, of expert performers are quantitatively different from those of novices across many domains, such as sports (e.g., Raab & Johnson, 2007; Savelsbergh, Williams, Van Der Kamp, & Ward, 2002; Vaeyens, Lenoir, Williams, Mazyn, & Philippaerts, 2007) or medicine (e.g., Law, Atkins, Kirkpatrick, Lomax, and Mackenzie, 2004). For example, Savelsbergh et al.

(2002) showed that expert soccer goalkeepers stopped more penalty kicks and used fewer visual fixations of a longer duration to more informative areas of the display, when compared to novices. Furthermore, Law et al. (2004) had expert surgeons and novices perform a one-handed aiming task on a computer-based laparoscopic surgery simulation. Expert surgeons tracked the movement of the tool less and fixated their gaze more on the target when compared to novices, which underpinned their faster and less errorful aiming performance on the task. Experts are better able to constantly perceive the relevant visual information instead of irrelevant stimuli by using task-specific visual search behaviours. They also have the ability to recognise, interpret, understand, and use the visual information for their performance. However, there is little research examining how task-specific visual search behaviours are acquired or developed through practice and experience.

Although rare, there has been some effort to quantify how task-specific visual attention and search behaviours are acquired through practice. For example, a computer-based task was used for this purpose in Sailer, Flanagan, and Johansson (2005). They required participants to move a cursor from a starting position to a target position and measured their visual search behaviours across practice. The eye pursued the cursor in the early stages of practice, whereas in the later stages of practice the eye was shifted towards the space in front of the cursor and there were more goal-directed saccades and fewer saccades in total. These findings were interpreted as evidence for the development of goal-directed visual search behaviours and eye-hand coordination that support the planning and control of simple actions. However, this study was conducted to examine eye-hand coordination in a simple manual-aiming task that did not require decisions to be made regarding the use of various cursor trajectories to the target. There is a lack of research examining the acquisition of visual search and attention in more complex tasks requiring decision making.

Expert performers have superior *cognitive skills*, such as decision making, option generation, and anticipation, when compared to novices. In many domains and tasks, humans make decisions and execute actions in order to achieve a goal or desired outcome in the external environment (Kording & Wolpert, 2006). Decision making is a process that involves selecting an appropriate action to execute from more than one available option, some of which may be more effective than others (Klein, Wolf, Militello, & Zsambok, 1995). Previous research has demonstrated that experts have superior decision making skills when compared to novices in many domains, such as chess (De Groot, 1978; Klein et al., 1995; Simon & Chase, 1973), law enforcement (Suss, Belling, & Ward, 2014; Ward, Suss, Eccles, Williams, & Harris, 2011), nursing (Ward, Torof, Whyte, Eccles, & Harris, 2010), and sports (Raab & Johnson, 2007; Roca, Ford, McRobert, & Williams, 2011; Ward, Ericsson, & Williams, 2013; Williams, Ford, Eccles, & Ward, 2011). For example, De Groot (1978) demonstrated that world-class grandmaster chess players made better decisions of next moves when they were asked to choose the move they would make under certain chessboard configurations, when compared to chess experts. Similarly, Ward et al. (2011) demonstrated that skilled law enforcement officers responded more accurately and faster than less-skilled, when they were required to deal with critical domain-specific situations in a simulated task environment. In addition, Williams and Davids (1998) demonstrated that experienced soccer players made faster and more accurate decisions within both 1 on 1 and 3 on 3 defending scenarios than the less-experienced players. These researches have shown that expert performers make more appropriate and faster decisions under time constraints in their domain, when compared to novices.

A number of researchers have been interested in the underlying mechanisms and the cognitive structures of decision making, as well as the acquisition of these decision making processes. Adaptive Control of Thought (ACT) theory details how human cognitive processes and knowledge are developed and structured as a consequence of skill acquisition (for reviews, see Anderson, 1982; Anderson et al., 2004; Anderson, Fincham, & Douglass, 1997; Neves & Anderson, 1981). ACT involves cognitive architectures, which are formed to model the mental interactions in our mind that occur during the performance of complex tasks. One of the key predictions in ACT is that condition-action units called *productions* are acquired that are used to match environmental, task or individual conditions to actions designed to achieve a goal (Anderson, 1982; Anderson et al., 2004; Anderson et al., 1997; Neves & Anderson, 1981). The cognitive structure contains multiple productions with new or changing conditions leading to the acquisition of newly paired actions. Through experiences, these production systems are expected to be strengthened, resulting in more successful and faster behaviours.

Similar structures and mechanisms of decision making to those in ACT can be found in another decision making model called Recognition-Primed Decision making (RPD). RPD model focuses on the importance of experience in decision making processes, so that acquired processes will minimize lengthy option generation or search by filtering concepts in order to make satisfactory and faster decisions. This model mainly emphasises the generation of options for action in domain-specific task situations. For instance, experienced chess players and skilled law enforcement officers generate task-relevant options and select the best option more frequently compared to lesser-skilled individuals (Klein et al., 1995; Ward et al., 2011). However, experienced and skilled individuals tend to generate relatively few options before making decisions, suggesting they would generate satisfactory options initially, and then stop searching for extensive options before making decisions. These generated options are believed to be organised as the condition-action pairs found in ACT with information encoded around key domain-related concepts and solution procedures (Anderson, 1982; Anderson et al., 2004; Neves & Anderson, 1981), so that the cognitive structure allows rapid and reliable retrieval whenever the stored information is relevant (Ward et al., 2013). This structure is similar to chunking and templates theories (Gobet & Simon 1996). In these theories, when perceptual cues or chunks are recognized, this stimulates experts to think of a next move or strategy based on their previous experiences. These chunks or templates are believed to be acquired through practice and stored in long-term memory (Chase & Simon, 1973; Ericsson & Kintsch, 1995).

Condition-action units have been shown to be more prevalent and selected more appropriately by expert compared to novice performers. Evidence supporting the use of condition-action pairs can be found in the famous work of Simon and Chase (1973). They showed that expert chess players are better able to recognize structured chess board patterns compared to novices, and are better able to use that information to select and execute a more successful decision on their next and subsequent moves. Similarly, McPherson and Thomas (1989) demonstrated that expert tennis players during match-play generated a greater frequency of condition-action pairs that led to better decision making and better performance, when compared to novices. It is hypothesized that the condition-action pairs forming the cognitive structures underpinning decision making are acquired, organised, modified and refined through certain practice and instruction environments (McPherson 1994; McPherson & Kernodle, 2003; McPherson & MacMahon, 2008). However, little, if any, research has been conducted examining how these decision making processes are acquired through practice in the dynamic and complex tasks found in many domains, or how practice should be structured to achieve this outcome.

The role of central nervous system and sensorimotor systems

Researchers have for many years addressed the role of the central nervous and sensorimotor systems in skilled performance. Closed Loop (Adams, 1971) and Schema (Schmidt, 1975) theories detail how the execution, persistence and change of movement behaviour is controlled by centrally-located representations containing the commands for action, known as *motor programs*, and the use of sensory feedback loops that ensure actions are sensitive and can adapt to sudden changes in dynamic environments (Kelso, 1981; Lee, Swinnen, & Serrien, 1994). These representations are believed to contain detailed instructions, such as forces and relative timings of muscular contractions and sensory consequences, to regulate movement behaviour. These motor programs or stored movement representations cooperate with perceptual systems to regulate behaviour. The important factor in these theories was that motor programs are not a priori given, but they have to be rewritten repeatedly through practice and experience (Meijer, 1988). These theories have evolved and developed in recent years (Schmidt, 1991; Schmidt & Lee, 2011; Schmidt & Wrisberg, 2004), although the fundamental ideas and functions of the schema theory have remained relatively stable.

Through practice and experience, learning mainly involves three distinct processes in the central nervous system: *encoding*, *consolidation* and *retrieval* (Kantak & Winstein, 2012). During the encoding phase, the learner would process information related to the task and makes associations between the goal, movement and movement outcome. The consolidation is defined as a set of post-acquisition, time-dependent processes whereby a memory representation for a motor skill becomes more stable across time. Retrieval encompasses multiple processes such as recall, recognition, recollection and relearning that are involved in accessing information from stored memories. Once information is encoded and stored with practice, it must be retrieved in order to be used. Although these encoding, consolidation and retrieval are distinct processes, they are interdependent and may partially overlap in the temporal domain. In particular, encoding processes are thought to dominate primarily during the acquisition or practice phase when the learner practices the motor skill. Over the course of the retention interval, consolidation processes would be engaged to stabilize the acquired motor memory. During later performance, the learner would retrieve the memory necessary to reproduce the motor skill or movement execution.

Skilled and expert performance is thought to be underpinned by the acquisition of these complex integrated internal systems or internal models within the central nervous system (CNS) for the execution, monitoring, planning, and evaluation of performance. Supporting such behaviours are specialised sensorimotor systems that constantly perceive and identify relevant from irrelevant stimuli, as well as providing information about the consequence of our actions (Elliott et al., 2010). The sensory, motor, and cognitive information about our external actions are developed and stored in the CNS as *internal representations* (for reviews, see Elliott et al., 2010; Wolpert & Kawato, 1998). They enable us to select, prepare, initiate, control and evaluate our actions. The term ‘internal representation’ refers to the storage of information learned during practice and provides a medium for translating sensory reafference into motor efference. In addition, the ‘representation’ is continually used during the planning and execution of actions in order to ensure accurate reproduction.

Internal representations are updated and acquired through feedback and feed-forward processes. Feedback is a control process that regulates between desired and actual actions using information about the consequences of our action relative to the environment that is perceived via sensory systems, whereas feed-forward processes are predictions of actions prior to them being executed (Wolpert & Kawato, 1998). Fast and coordinated movements cannot be executed under pure feedback control because biological feedback loops are too slow. Instead, feed-forward processes enable precise actions that are too fast to rely on the inherent delays of sensory feedback, and allow more precise state estimation and delivery of the action execution. Similarly, movements of relatively long duration (i.e., greater than one third of a second) still need to integrate feedback generated during the movement itself to assist in their control and precision, updating feed-forward processes. However, without feed-forward processes, our sensory and motor systems are imperfect, so that the systems provide too noisy information to reproduce a constant and precise movement (Kording & Wolpert, 2004).

Through repeated practice and experience of the associated feed-forward and feedback processes, actions become faster, more accurate, more coordinated, require less conscious control, more sustainable, and more adaptable (Imamizu et al., 2000, Kording & Wolpert, 2004; Todorov, 2004; Wolpert et al., 2011). These repeated experiences of executing an action develop and strengthen its internal representations (Imamizu et al., 2000; Miall & Wolpert, 1996; Wolpert & Kawato, 1998; Wolpert, Miall, & Kawato, 1998). For example, Imamizu et al. (2000) used a computer-based task that required participants to control their cursor by moving a computer mouse to track a moving target on a computer screen. They demonstrated the acquisition of the associated representations based on human cerebellar activities using functional magnetic resonance imagining (fMRI). When the participants became more successful on the task by minimising error, they reduced some cerebellar activities and other cerebellar activities remained, when compared to their baseline activities. The reducing cerebellar activities were associated with error reduction through the learning process, whereas the remaining cerebellar activities reflected the acquired representations of a mapping relationship between the cursor movement on the screen and the mouse movement. Therefore, through practice, the associated representations were acquired and updated, leading to more successful performance.

Researchers have recently demonstrated differences in the structures and functions of brain between experts and novices (Ericsson, 2007; Nielsen & Cohen, 2008; Yarrow et al., 2009). For example, expert string music players who have engaged in many hours of practice had larger representations of the left-hand in the brain compared to non-musicians (Elbert, Pantev, Wienbrunch, Rockstroh, & Taub, 1995). Similarly, expert badminton players sent stronger motor signals to their playing hand compared to lesser-skilled players (Pearce, Thickbroom, Byrnes, & Mastaglia, 2000). In addition, professional soccer players performing ankle movements demonstrated *less* activation in motor regions of the brain when compared to lesser-skilled controls (Naito & Hirose, 2014). Their greater efficiency by largely conserving motor-cortical neural resources to control their foot movements is probably a result of their years of domain-specific activity. These findings in the field of neuroscience are consistent with the view of *neuroplasticity* (for reviews, see Adkins, Boychunk, Remple, & Kleim, 2006; Dayan & Cohen, 2011; Karni, Meyer, Jezzard, Adams, Turner, & Ungerleider, 1995; Yang, 2015) and optimization in sensorimotor system (Kording & Wolpert, 2004; Todorov, 2004; Wolpert et al., 2011). Neuroplasticity and optimization in sensorimotor system refers to structural and functional changes in brain through years of training, practice and experience, leading to a desired action with optimal control minimizing cost or loss (i.e., energy expenditure, time, or signal noise) (Nielsen & Cohen, 2008; Yarrow et al., 2009, Wolpert et al., 2011).

Practice conditions

Practice at a task leads to the acquisition of skilled performance and its underlying internal representations. A number of practice factors have been shown to influence skill acquisition, including the specificity, amount, structure, and difficulty level of practice.

Specificity of practice. Sensorimotor learning and the development of associated internal representations are affected when the availability of relevant sensory information is modulated during practice, such as limiting visual feedback (Proteau & Cournoyer, 1990; Proteau, Marteniuk, Levesque, 1992; Robin, Toussaint, Blandin, & Proteau, 2005) or rescaling kinematic information (Elliott, Chua, Pollock, & Lyons, 1995; Elliott, Lyons, Dyson, 1997). Practice of an action under particular sensory conditions (e.g., vision or no-vision) can lead to the development of specific internal representations that are not immediately generalizable to conditions that contain different sensorimotor information (Proteau, 2005; Proteau & Carnahan, 2001; Proteau & Cournoyer, 1990; Proteau & Isabelle, 2002; Proteau, Marteniuk, Girouard, & Dugas, 1987; Proteau et al., 1992; Robin et al., 2005; Soucy & Proteau, 2001).

Proteau and Cournoyer (1990) had two groups of novice participants perform a manual-aiming task. The full-vision group could observe their arm movement and the target across the whole action. In contrast, the target-vision group could observe the target, but they did not have vision of arm movement. Both groups improved accuracy during practice. In a retention test containing the target-vision only condition, the target-vision group maintained accuracy compared to practice, whereas the full-vision group demonstrated reduced accuracy. Similarly, Proteau et al. (1992) conduced a similar study but found in a retention test containing the full-vision condition, the target-vision practice group had *lower* accuracy compared to practice, whereas the full-vision practice group maintained accuracy between practice and retention. These findings have been interpreted as showing that the internal representations developed during practice are *specific* to the available sensory information present in acquisition. The target-vision only group likely developed internal representations of the mapped relationship between proprioception and kinematics during practice so that they did not rely on visual information to successfully perform the action when it was not available. Furthermore, when vision became available, their performance deteriorated because their internal representation did not incorporate it, even though visual information is salient.

Despite such advances in understanding of internal sensorimotor representations, it is noticeable that the majority of previous research in this area has used perceptual-motor tasks (Imamizu et al., 2000; Kording & Wolpert, 2004; Todorov, 2004; Wolpert et al., 2011). These perceptual-motor tasks do not place a high demand on cognitive processes, especially decision making. In particular, few, if any, researchers have considered the acquisition of dynamic and complex tasks where the performer must decide upon an appropriate action to execute from more than one available option, some of which may be more effective than others (Klein et al., 1995). There is a need to examine the practice conditions required to acquire the perceptual, cognitive and motor processes and internal representations used in the real-world contexts, such as sports, medicine, and law enforcement. Moreover, based on previous findings on sensorimotor learning (e.g., Proteau & Cournoyer, 1990; Proteau et al., 1987; Proteau et al., 1992; Robin et al., 2005), further research should examine the effect on skill acquisition and learning of integrating and segregating these perceptual, cognitive, and motor processes during practice.

Practice amount and structure. Both the amount and underlying structure of practice have been shown to influence skill acquisition. Previous research demonstrates that the amount of time spent in domain-specific practice activities since starting participation in a real-world domain is highly related to the level of skill attained later in that domain (e.g., expert, intermediate, novice), such as in music (Ericsson et al., 1993; Krampe & Ericsson, 1996), chess (Charness, Tuffiash, Krampe, Reingold, & Vasyukova, 2005; De Bruin, Smits, Rikers, & Schmidt, 2008), medicine (Ericsson, 2004; Ericsson, 2007), and sports (Ford et al., 2012; Ford & Williams, 2012; Helsen, Starkes, & Hodges, 1998; Ward, Hodges, Starkes, & Williams, 2007). Large accumulations of hours in domain-specific practice activities across many years of engagement causes physiological adaptations, not least in the brain and sensorimotor internal models, which lead to the aforementioned performance differences between expert performers and novices in complex real-world domains. For example, Ericsson et al. (1993) examined the amount of domain-specific practice that violinists at the West Berlin Music Academy had engaged since starting in the domain. They found that by the age of 18 years the best violinists in the academy and a comparison group of middle-aged professionals from world-class orchestras had accumulated around 7,500 hours of domain-specific practice. In contrast, the good violinists in the academy had accumulated an average of 5,301 hours, whereas the music teachers had accumulated only 3,420 hours. The amount of hours accumulated in domain-specific practice activity was positively related to the level of attainment achieved by the musicians. However, this type of research does not address the underlying structure of practice and its effect on skill acquisition.

Researchers in the area of motor behaviour have examined the effect of practice conditions and structure using movement execution tasks in experimental settings, such as golf putting, dart throwing, balance tasks, sequential movement tasks, or goal-aiming tasks. In this work, the effect of practice conditions has been examined through performance changes across practice, and performance in a retention or transfer-test. They have shown that motor skills become more accurate, quicker, and less cognitively demanding following practice and experience (Crossman, 1959; Li & Wright, 2000; Lin et al., 2009; Tsutsui, Lee, & Hodges, 1998; Wulf, McNevin, & Shea, 2001). In addition, researchers have shown that different types of practice conditions can lead to differing amounts of motor skill acquisition. A number of variables have been used to differentiate practice conditions, such as practice order, distribution of practice, variability of practice, and self-selected practice.

In terms of practice order, comparisons are often made between random and blocked practice. Random practice requires the learner to practice a number of different skills in a randomised order, whereas blocked practice requires the learner to complete a number of trials on one skill before practicing another skill. In one of the first studies to examine practice structure in motor skill learning, Shea and Morgan (1979) examined the influence of random and blocked practice structures on the acquisition of an upper-limb sequential aiming task. They required participants to learn three sequential movement patterns to knock-down barriers. A blocked group completed all trials of practice for one pattern before attempting another pattern. The random group practiced the three different movement patterns in a randomised order with no more than two consecutive attempts at the same movement pattern. Blocked practice led to better performance during acquisition, but random practice led to better learning as evidenced by improved retention and transfer. Similar findings for the learning benefits of random compared to blocked practice have been shown in a number of other studies using various motor behaviour tasks (e.g., Brady, 2004; Brady, 2008; Immink & Wright, 2001; Keetch & Lee, 2007; Lee & Simon, 2004; Li & Wright, 2000). The superiority for learning of the random practice order has been explained by two different cognitive processes that occur in the inter-trial period, which are elaborative comparisons between the trials and action-plan reconstruction for upcoming trials (for details, see Lin, Fisher, Winstein, Wu, & Gordon, 2008). In random practice, these cognitive processes are greater compared to blocked practice, leading to more developed internal representations in memory and the observed learning differences between conditions.

Differences in the rest interval duration during practice also provide conditions that affect motor skill learning. Distributed practice contains rest periods or periods of other activity between trials, and typically leads to better learning compared to massed practice, which contains no or less rest periods between trials (Baddeley & Longman, 1978; Dail & Christina, 2004; Lee, 2012; Lee & Genovese, 1988). In a similar vein, variable practice leads to better learning of motor skill adaptability, whereas constant practice leads to better learning of invariant movement patterns (Lai, Shea, Wulf, & Wright, 2000; Shea, Lai, Wright, Immink, & Black, 2001; Shea & Wulf, 2005). Variable practice requires the participants to parameterise a skill, such as change of velocity or force, whereas the constant practice requires repeat performance of the same parameter of the skill on each trial. Moreover, practice organised and controlled by the learners themselves, termed self-selected practice, can be more effective for learning than practice organised by others (Keetch & Lee, 2007; Lee, 2012; Post, Fairbrother, & Barros, 2011; Wu & Magill, 2004, Wu & Magill, 2011). These findings from the motor skill literature agree that repetitions of trials for a certain task and the practice conditions are crucial in motor skill acquisition and learning. However, despite this large body of research examining practice conditions in motor learning, most has used perceptual-motor tasks, with little, if any, research addressing the acquisition of decision making processes in combination with perceptual-motor skills.

Skill acquisition during practice can also be explained by reinforcement learning principles (Thorndike, 1970; for a review, see Holroyd & Coles, 2002). Reinforcement principles occur when actions that are followed by positive outcomes or successes are more likely to be generated again in the future, whereas actions that are followed by negative outcomes or failures are less likely to reoccur. In reinforcement principles, the two main characteristics are error processing and planning based on action outcomes and feedback. When a failure or error is detected, the performer adjusts the movement on subsequent attempts in order to increase a possibility of success, whereas when success is detected, the performer would not need to change the planning for the next attempt. Lam, Master and Maxwell (2010; see also Trempe, Sabourin, & Proteau, 2012) demonstrated that cognitive demand following errors at golf putting was higher compared to that following successful attempts. They found slower responses to a secondary probe reaction task following errors, suggesting more cognitive resources were allocated to adjust plans for the next trial. It is suggested that reinforcement learning principles, which consist of error processing and planning, require learners to actively reconstruct and update their internal models, resulting in stronger physiological and functional adaptations in the CNS and sensorimotor systems. Although reinforcement learning in human motor tasks has not yet received much attention, repetitions of successful and unsuccessful attempts may also promote the subsequent learning of a skilled behaviour.

A concept that affects the difficulty of practice conditions is the *challenge point hypothesis* (Guadagnoli & Lee, 2004; Lee et al., 1994). In this hypothesis, different conditions of practice provide different challenges for the participants and the key is to provide the optimal challenge point during practice (Guadagnoli & Lee, 2004). The framework contains two types of task difficulty. *Nominal task difficulty* is the difficulty of the task, irrespective of the person performing it. *Functional task difficulty* not only includes the difficulty of the task, but also how challenging it is to the individual who is performing it. Functional task difficulty is directly related to the amount of available information in the task. The greater the functional task difficulty, the more information available and the greater the cognitive demands of the task (Lee et al., 1994). In this framework, if a practice task is too difficult for a performer of certain ability, then too much information is present and either no or minimal learning may occur, whereas the same happens when practice tasks are too easy and not enough information is available. Therefore, the practice task must present the appropriate amount of information and place cognitive demands on the participant at the optimal challenge point so as to promote learning. This idea supports Marteniuk (1976) statement that after a point the amount of information available in practice exceeds the capacity of the individual to process it efficiently, thereby the potential benefit to learning would be diminished.

Transfer of learning

Transfer of learning refers to the ability to transfer or adapt prior experiences to current or future behaviour (Thorndike & Woodworth, 1901). The concept of transfer of learning holds that an individual who acquires successful performance in one task or domain can transfer the successful performance into another task or domain (Duncan, 1953). In regards to skill acquisition, transfer involves the capability to use prior experiences from skilled performance and learning in a particular context and then adapt these experiences to similar or dissimilar contexts (Collard, Oboeuf, & Ahmaidi, 2007).

There has been significant debate in the literature about which theories best explain transfer of learning (Barnett & Ceci, 2002; Rosalie & Muller, 2012). There are three main concepts that attempt to explain transfer and how it occurs. First, identical elements theory (Thorndike & Woodworth, 1901) suggests that in order for transfer to occur, both learning domain and transfer domain must contain similar elements. The identical elements theory implies that the similarities that exist between the learning and transfer domain facilitate transfer of skill learning. Therefore, transfer could be explained due to the similarities between the stimulus characteristics and required response. In support of this theory, transfer between domains with a common classification has been shown, such as in invasion sports (Abernethy, Baker, & Corte, 2005; Causer & Ford, 2014; Smeeton, Ward, & Williams, 2004), martial arts (Rosalie & Muller, 2014), and batting sports (Moore & Muller, 2014). Second, in contrast to the identical elements theory, general principle theory (Judd, 1908) suggests that the general understanding of principles in a domain or task facilitate transfer. This theory focuses on the transfer of principles, rules, or laws that were abstracted during learning in one domain and applied in transfer domains. Therefore, transfer could be explained due to the existence of common principles between the learning and transfer domains. For instance, it has been reported that fundamental overarm throwing skills transferred to sports-specific skills, such as badminton overhead clear and javelin throw (O'Keeffe, Harrison, & Smyth, 2007) and that transfer of perceptual skills, such as pattern recognition, occurred between netball, basketball, and field hockey (Abernethy et al., 2005). While the principle-based theory differs from the identical elements theory suggesting that transfer can occur between relatively dissimilar events so long as the underlying principles match appropriately, both theories imply that transfer increases with learning and acquisition.

Third, *transfer-appropriate processing* hypothesis (Lee, 1988; Morris, Bransford, & Franks, 1977) holds that memory will be enhanced when similar processing occurs between storing and retrieving information. The transfer-appropriate processing view focuses on the overlap in the types of information processing. This hypothesis holds that transfer of learning would be maximized when information processing between the learning and transfer environments are appropriately matched. Therefore, information processing during practice should be similar to that in the retention or transfer test (Lee, 1988). When the processing is similar between practice and retention or transfer tests, the effectiveness of practice would be maximised. However, despite advances in understanding of transfer-appropriate processing hypotheses in memory research (Lockhart, 2002; Roediger, & Butler, 2011; Schendan & Kutas, 2007; Veltre, Cho, Neely, 2014), little research, if any, has been conducted to apply the principles to the acquisition of perceptual-cognitive-motor processes. Support for the transfer-appropriate processing hypothesis has been provided in research using perceptual-motor tasks examining the contextual interference effect (e.g., Lee & Magill, 1983; Shea & Morgan, 1979; Shea & Zimny, 1983; Shea & Zimny, 1988), feedback conditions during practice and transfer (e.g., Lee & Magill, 1985; Sherwood, 1985) and whole and part perceptual-motor practice (e.g., Kurtz & Lee, 2003). Yet, further research needs to be conducted to examine the underlying mechanisms of the transfer of learning in perceptual-cognitive-motor tasks using transfer-tests.

Aim of thesis

The overall aim of this current thesis was to examine the association between practice conditions and the acquisition of perceptual-cognitive-motor processes and their transfer. Specifically, the acquisition and transfer of these processes was examined using a novel computer-based task, along with a yoked-design in order to decouple and segregate the processes. Based on previous learning theories and the transfer-appropriate processing hypothesis, several experiments used this task to investigate the effect of the integration and segregation of perceptual, cognitive, and motor processes during practice on the acquisition and transfer of the dynamic and complex behaviours and subsequent learning. The computer-based task was created because real-world tasks are often too complex to be used as a basis for controlled experimentation (Dicks, Button, & Davids, 2010; Hodges, Huys, & Starkes, 2007; Mann et al., 2007; Williams & Ward, 2007; Williams et al., 2002). Therefore, there was a need to develop a controlled task that requires similar perceptual, cognitive and motor skill to those used in the real-world contexts, such as sports, medicine, and law enforcement.

The task required a cursor to be moved from a home position to an end target while avoiding multiple moving objects. Participants moved a stylus on a digitalising tablet such that it moved a cursor on a computer screen to a target whilst avoiding objects moving in a random order. If the cursor contacted one of the moving objects, then the trial ended and was deemed unsuccessful. Therefore, the task demanded the acquisition and integration of perceptual, cognitive, and motor process in order to distribute and sustain visual attention, select an appropriate action from more than one available option, and execute the appropriate action under time constraints. Compared to the previous tasks used in research (i.e., golf-putting, darts throwing, & single goal-aiming tasks), this task is more dynamic because the background environment is continuously changing, requiring continuous decision making and somewhat complex voluntary movements using different motor constraints/muscle groups (i.e., wrist, elbow, & shoulder joints). Similar perceptual-cognitive-motor processes are required in many situations in everyday settings, such as when crossing a busy street or in sports where a player has to manipulate an object (e.g., ball or puck) while avoiding collision with surrounding teammates and opponents.

Chapter 2 was aimed to design and create the computer-based task that would fit these criteria and that could be acquired after a moderate amount of practice. In Experiment 1, task performance during moderate practice was examined. In Experiment 2, acquisition of the computer-based task by a group that practised for a moderate number of trials and a control group that received no practice was examined. No between-group difference was expected at the pre-test, but the practice group was expected to demonstrate more successful performance in the post-test compared to the control group as a function of their engagement in the practice phase.

Chapter 3 examined the underlying mechanisms of successful performance on the task and the contributions of each process by decoupling and segregating perceptual-cognitive-motor processing. In Experiment 3, the underlying processes on successful task performance were examined by measuring visual search behaviours and retrospective reports of cognitive processes. The study design in Experiment 3 was the same as Experiment 2, and thus involved group comparisons. In Experiment 4, to systematically examine the contribution of each perceptual, cognitive, and motor process, a novel protocol was designed so that three groups were yoked during practice in which their acquired processes were modulated. The aim of Experiment 4 was to examine whether limiting the availability of sensory information and constraining decision making processes would influence the acquisition of perceptual-cognitive-motor processes. Due to the modulations to decouple and segregate the underlying processes, the group comparisons were expected to demonstrate the contribution of each process in skill acquisition. It was expected that limiting the availability of sensory information and constraining decision making processes would attenuate skill acquisition.

Chapter 4 examined the transfer of acquired perceptual-cognitive-motor skill. In addition to the aforementioned computer-based task, another similar novel computer-based task was designed that required the acquisition of perceptual-cognitive-motor processes to be successful. The difference between the two tasks was that of task goal, one of which was to move the cursor to the target, whereas the other was to avoid the objects for as long as possible. Three experiments were conducted to examine the transfer effect from the one task to the other task. Furthermore, yoked conditions were used in the similar manner to Experiment 4 to modify and constrain the cognitive processes. It was expected that, when the acquired perceptual-cognitive-motor processing is matched between the two tasks, the transfer effect would be optimized. However, when the underlying processes are not appropriate between the two tasks due to nullifying decision making processing, the transfer effect would be attenuated.

Finally, Chapter 5 collates and synthesises the findings from the thesis to provide a concise summary. Implications of the programme of work are discussed from both a theoretical and applied perspective, with limitations of the current research identified and future research directions outlined.

Chapter 2

Development of a perceptual-cognitive-motor task

2.1. Introduction

Our actions and behaviours demonstrate a remarkable capacity to be successfully executed in different external environments and demands. Internal sensorimotor systems support these actions, as vision and proprioception provide information that is used by feedforward and feedback processes. These sensorimotor systems are involved in the development of *internal representations* (for reviews, see Elliott et al., 2010; Wolpert & Kawato, 1998). Through practice, it is thought that the perceptual-cognitive-motor processes involved in the action are acquired and integrated with the internal representations. These processes enable us to perceive and identify relevant from irrelevant stimuli, plan and select an appropriate action from more than one available option, and execute the action under time constraints. Decisions regarding the upcoming action can be made before and during the movement execution in order to achieve the task goal. The decision making process is fundamental in determining an appropriate motor command to send to our muscles (Kording & Wolpert, 2006). Selecting and planning an action from more than one available option before the actual action execution is thus a part of the initial decision making processes. However, decision making does not stop at initiation and is still required if it is necessary to change the action or plan during the movement execution (e.g., change of directions and speed of an action). Both types of decision making processes are required in many dynamic and complex situations in everyday settings, for example when crossing a busy street, and in dynamic and complex sports/games, such as soccer and American football.

Perceptual-cognitive-motor processes underpin successful performance in domains and tasks in the real world, such as sports, driving, and law enforcement. However, there is an inherent difficulty in measuring the acquisition of these process in real-word tasks, not least because of their complexity and the extended duration required for their acquisition. Therefore, in order to better understand the underlying processes of skilled actions and their acquisition, specific tasks must be designed that require the acquisition and integration of perceptual-cognitive-motor processing in controlled, laboratory conditions (Johnson & Raab, 2003; Klein, 1997).

Researchers in sensorimotor learning have provided insight on how skilled behaviour, and associated internal models, are acquired through practice (Crossman, 1959; Imamizu et al., 2000; Kording & Wolpert, 2004; Li & Wright, 2000; Lin et al., 2009; Robin et al., 2005; Sailer et al., 2005; Todorov, 2004; Tsutsui et al., 1998; Wolpert et al., 2011; Wulf et al., 2001). Still, despite advances in understanding of sensorimotor learning, it is noticeable that the majority of previous research has used *perceptual-motor* tasks with little demand on decision making processes. Since the early experiment by Woodworth (1899), many types of goal aiming tasks have been used to investigate human voluntary movements and internal models associated with the movements (Elliott et al., 2010). In these tasks, participants are required to execute an action and move in a pre-determined manner. Imamizu et al. (2000) used a computer-based task that required participants to control their cursor to track a moving target on the screen. Moreover, Proteau and colleagues (Proteau & Cournoyer, 1990; Proteau et al., 1992) used a manual aiming task that required participants to aim their stylus to a target either with or without visual information, limiting their degrees of freedom and arm movement in the sagittal plane. Kording and Wolpert (2004) used a computer-based task that required participants to move their right index finger to a target on a table without direct view of their arm movement. These tasks required perceptual-motor processes, as well as planning, and strategies for the next trial, but less on-line decision making involved when moving the cursor because a specific movement needed to be executed and the movement trajectory was pre-determined (see Figure 2.1). These previous sensorimotor tasks required one or a few specific cursor trajectories to be acquired through practice (Imamizu et al., 2000; Kording & Wolpert, 2004; Sailer et al., 2005; Todorov, 2004; Wolpert et al., 2011). Furthermore, few tasks would require participants to be engaged in decision making processes before and during the actual movement execution.

In many domains and tasks, humans make decisions and execute actions in order to achieve a desired goal in the environment (Kording & Wolpert, 2006). Decision making and its processes are central to more successful performance in a variety of domains, such as sports (Raab & Johnson, 2007; Roca et al., 2011; Ward et al., 2013; Williams et al., 2011), chess (Klein et al., 1995; Simon & Chase, 1973), and law enforcement (Suss et al., 2014; Ward et al., 2011). In particular, dynamic and complex tasks will require a performer to perceive and identify relevant from irrelevant stimuli, plan and select an appropriate action from more than one available option, and execute the action under time constraints. Few, if any, researchers have considered the acquisition of dynamic and complex tasks where the performer must decide upon an appropriate action to execute from more than one available option, some of which may be more effective than others (Klein et al., 1995). In contrast to the sensorimotor tasks used in the previous research, which did not place a high demand on these cognitive processes, there is a need to develop a controlled task involving cognitive decision making processes. The task in this thesis requires performers to select a successful cursor trajectory to reach a target from a range of potential options (Klein et al., 1995; Kording & Wolpert, 2006). The task has multiple ways to reach the target, replicating a dynamic and complex task in real life situations. It places a demand on and the requirement to acquire cognitive decision making processes.

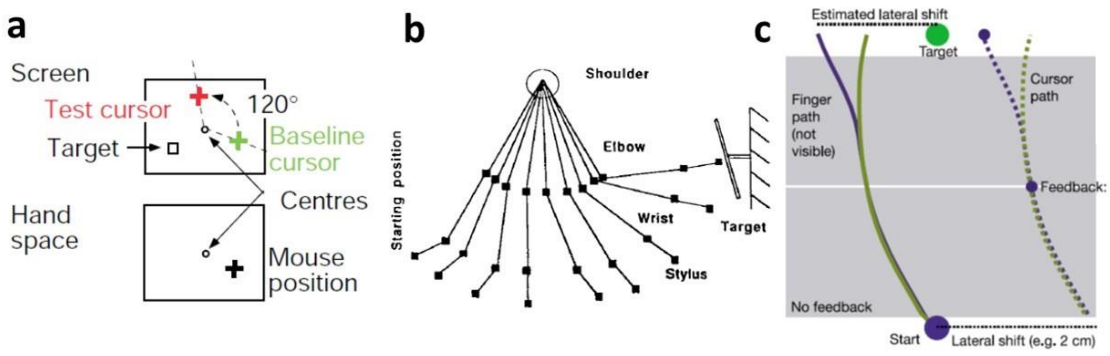

Figure 2.1. The perceptual-motor tasks used in the previous studies, adapted from (a) Imamizu et al. (2000), (b) Proteau, Marteniuk, & Levesque (1992), and (c) Kording & Wolpert (2004).

The aim of the two experiments in this chapter was to develop a novel computer-based task that required the acquisition of perceptual-cognitive-motor processing over a moderate duration of practice. The computer-based task requires participants to move a cursor to a target whilst avoiding random moving objects on the screen, which if touched, ended the trial. Compared to the previous tasks (i.e., golf-putting, darts throwing, & single goal-aiming tasks), this task would be more dynamic changing the background image continuously requiring continuous decision making as well as more complex using different motor constraints/muscle groups based on two different starting positions with spatiotemporal precision avoiding any collision. In Experiment 1, the computer-based task was developed to investigate the acquisition processes required for successful performance on the task. The aim of Experiment 2 was to examine the characteristics of the successful behaviours that differentiate between a practice and control group.

2.2. Experiment 1

The aim of Experiment 1 was to examine changes in task performance during practice on the novel computer-based task. The intention was to determine how successful task performance was acquired from the early to the later stages of practice. Participants were required to complete 96 trials of the computer-based task. According to the previous findings from the sensorimotor learning literature, it was predicted that the participants would have a greater frequency of successful trials towards the later than early stage of practice. More successful performance in the later stage of practice would be associated with less variability, increased movement time, and longer trial durations (i.e., online control, Elliott, Carson, Goodman & Chua, 1991; Elliott et al., 2010; speed-accuracy trade-off, Fitts, 1954; Fitts & Peterson, 1964).

2.2.1. Methods

Participants

Participants were 12 undergraduate students (Male = 9, Female = 3). The characteristics of the participants are shown in Table 2.2. All participants had normal or corrected-to-normal vision and were right–hand dominant. Previous research has demonstrated that there is a positive relationship between computer-game playing experience and perceptual-cognitive skill (Boot, Blakely, & Simons, 2011; Boot, Kramer, Simons, Fabiani, & Gratton, 2008; Green & Bavelier, 2003; Green & Bavelier, 2006). Because the task in this experiment had some similarities to a computer game requiring perceptual-cognitive skill, the amount of hours that participants had spent playing computer games across their life was measured prior to testing using a questionnaire (Ford, Low, McRobert & Williams, 2010). A criterion was determined based on previous research examining the relationship between amount of hours in practice and expertise in a domain (Ericsson et al., 1993). It was considered to be the criterion above which transfer of expertise from computer-game playing would confound the data. Participants were excluded from this experiment when they had accumulated 7,500 or more hours playing computer-games across their life. Participants completed informed consent before taking part in this experiment. All procedures were conducted in accordance with the ethical guidelines of Liverpool John Moores University and the 1964 Declaration of Helsinki.

Table 2.2. The characteristics of the participants in Experiment 1

	Participants
Measures	***M* ± *SD***
Age (years)	20.7 ± 0.9
Computer-game playing experience (hours)	2678.0 ± 1643.0

Apparatus and task

Figure 2.3a shows the experimental set up. The apparatus consisted of an A3 wide digitising tablet and stylus (Wacom Intuos3 PTZ-1231W, Saitama, Japan) and a 22-inch cathode ray tube (CRT) computer monitor (width: 40.6 cm x height: 30.4 cm) (Iiyama MA203DT Vision Master 513, Tokyo, Japan). The monitor operated with a resolution of 1280 x 1024 pixels and a refresh rate of 85 Hz and was connected to a desktop computer (HP Compaq 8000 Elite, California, USA) running Windows XP operating system. The digitising tablet had a spatial resolution of 5000 dpi, sampling rate of 200 Hz and accuracy of ±0.35 mm. The screen and tablet were placed on a desk at a height of 1.0 m. The stylus was held by the participant in their right hand and controlled the cursor location on the computer screen. The participant sat on a computer chair at the desk so they were comfortable when holding and moving the stylus.

A task was created for the experiment that involved visual stimuli shown on the monitor that interfaced with the digitising tablet and stylus. The task was realised using the COGENT toolbox implemented in MATLAB (The Mathworks, Inc., MA, USA) via the computer. Figure 2.3b shows the task. The main aim of the task was for participants on each trial to move the cursor (represented by one white circle on the screen with a diameter of 2.2 cm) from one corner of the computer screen to a red circle target (diameter of 2.2 cm) located in the diagonal corner of the screen. A gain relationship from the stylus movement on the tablet to the cursor movement on the screen was set at a horizontal ratio of 1.0 and a vertical ratio of 1.6. To achieve the aim of the task, the participant had to move the white cursor to the red target while avoiding a number of green objects (n = 20, diameter of 3.1 cm) that were moving around the screen in pseudo-randomised linear trajectories. If the white cursor touched one of the green objects, then the trial ended and was deemed unsuccessful. If the white cursor reached the red target, then the trial ended and was recorded as successful.

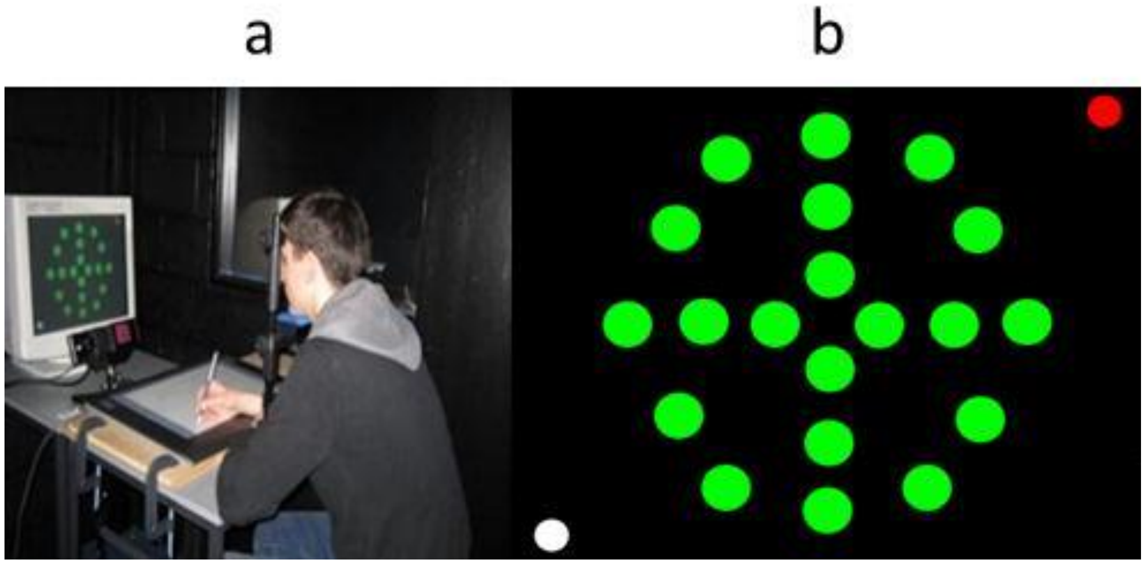

Figure 2.3. (a) The experimental set up and (b) the computer-based task.

Figure 2.4 shows a time-line graphical representation of the various stages of a trial on the task. The white cursor first appeared in either the bottom left or bottom right of the screen at 2.8 cm from the side and 1.9 cm from the bottom of the screen edge. The starting position of the white cursor remained stationary for three seconds. Next, a small black dot (diameter of 0.3 cm) appeared in the centre of the white cursor for two seconds. Participants were instructed to look at the black dot in order to provide a known position of the eye prior to trial onset. Following this, a static image containing the white cursor, red target, and starting position of the green objects was presented for two seconds (see Figure 2.3b). The starting positions of the white cursor changed pseudo-randomly from trial-to-trial, but with an equal number of the two possible starting positions across the experiment. Following the static image, the green objects started their linear movement and participants were allowed to move the white cursor freely on the screen with the goal of reaching the red target. The green objects moved around on the screen with pre-programmed linear trajectories, such that there were four groups of five green objects with speeds of 13.5 cm/s, 13.1 cm/s, 8.3 cm/s, and 7.6 cm/s, respectively. When an object reached the edge of the screen, it rebounded with an angle that was equal to the angle of incidence. However, the objects did not rebound upon collision with each other and instead continued along their trajectory without any change. The constantly moving green objects required participants to navigate the white cursor through them while moving towards the red target. Upon collision between the white cursor and a green object or red target, the trial ended and a blank black screen appeared for 100 ms irrespective of whether participants reached the target successfully or not.

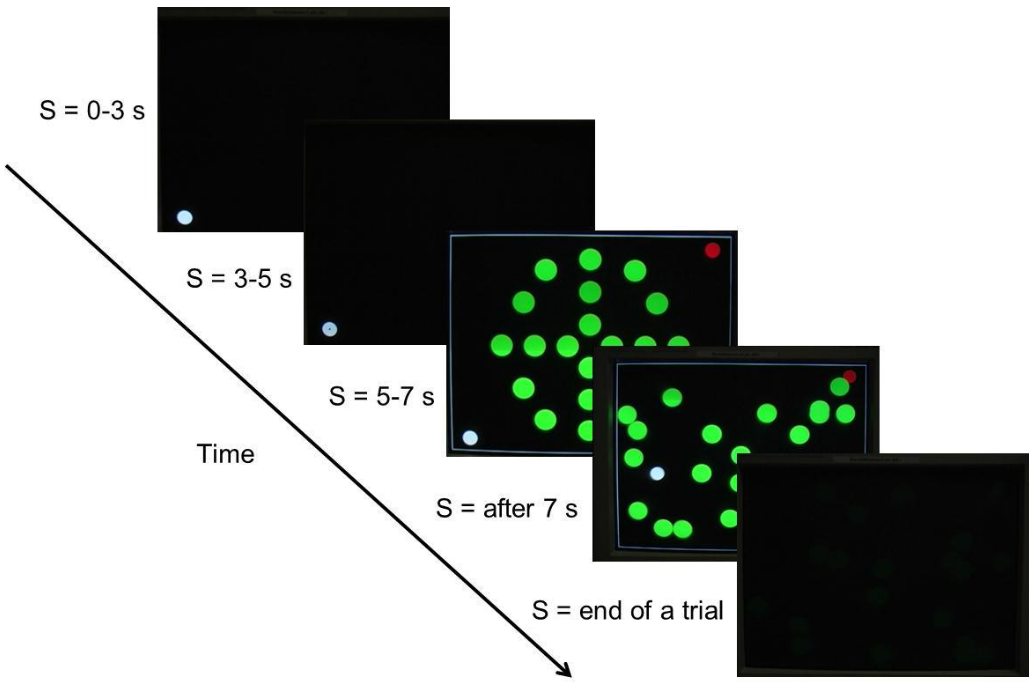

Figure 2.4. Graphical representations of the experimental task elapsing across time.

There were eight different movement patterns that each began with the same start positions for the green objects. The start position had an equal spatial distribution of the green objects across the screen (see Figure 2.3b). A total of 16 movement patterns across the two starting positions were created by mirroring the original eight movement patterns relative to either of the two starting positions of the white cursor, in an attempt to have an equal task difficulty for each starting position.

Procedure

Before the start of this experiment, participants received an illustration of the screen layout (i.e., objects, target and cursor) and pre-scripted instructions regarding the aim of the task. They were instructed to use the stylus on the digitalising tablet to move the white cursor on the screen in order to reach the red target whilst avoiding the green objects. They were unaware of either the gain relationship of the white cursor movement or the amount of different movement patterns of the green objects.

The experiment consisted of a practice phase. During the practice phase, there were six blocks of the 16 trials, with those 16 trials being pseudo-randomly ordered to make a total of 96 trials. Participants were provided with the opportunity of a 60-second break after every two blocks of trials. No augmented feedback was provided to the participants.

Data analysis

Task performance

The primary dependent variable was the frequency of successful trials in which the cursor reached the red target in each block. Absolute error (AE in cm) was calculated as the average absolute deviation between the last location of the white cursor and the location of the red target across a block of the 16 trials, whereas variable error (VE in cm) was calculated to measure the variability of the last location of the cursor across a block of the 16 trials (Schmidt & Lee, 2011). AE measures overall accuracy in the task performance, and VE measures the consistency of the performance. In order to examine the temporal characteristics of task performance, duration of each trial was calculated, which was defined as the time from when the participants were allowed to move the cursor at the start of the trial to the end of the trial. The end of the trial occurred either when the cursor reached the target or when the cursor touched a green object. In addition, preparation time and movement time were analysed. Preparation time was defined as the time participants spent at the starting position after the two-second static image, but before their movement onset. Movement time was defined as the time between movement onset and the end of the trial. All dependent variables were analysed using separate one-way repeated measures ANOVA with block (six blocks of trials) as the repeated measure. For *post-hoc* analysis, Bonferroni pairwise comparisons were used in the event of significant within-participant main effects. This procedure limits the potential inflation of type-1 errors through multiple comparisons by adjusting the alpha level.

Additionally, in order to ensure that the task was set at an optimal level of challenge at which participants could show improvements across practice, any change in the frequency of successful trials for each object movement pattern was subsequently examined to determine whether trials have different levels of difficulty. The frequency of successful trials for each trial difficulty was analysed using separate one-way repeated measures ANOVA with pattern (the original eight object movement patterns) as the repeated measure. The Bonferroni *post-hoc* procedure was used for any significant within-participant main effect. Where violations to sphericity were observed, Greenhouse-Geisser corrections to df were applied. Partial eta squared (η_p^2) was used as a measure of effect size. Statistical significance for all tests was set at p <.05.

2.2.2. Results

Task performance

Figure 2.5 shows the frequency of successful trials in the practice phase. ANOVA revealed a significant main effect of block, $F(3.02, 33.20) = 19.90$, $p < .05$, $\eta_p^2 = .64$. Participants significantly increased the frequency of successful trials from the first block (M = 5 trials, SD = 2) to the second (M = 7 trials, SD = 3), third (M = 9 trials, SD = 2), fourth (M = 10 trials, SD = 3), fifth (M = 10 trials, SD = 2), and sixth block (M = 11 trials, SD = 3), as well as the second block to the fourth, fifth, and sixth block. However, there were no significant differences between the third, fourth, fifth, and sixth block. The frequency of successful trials increased from the early to middle and last stage of practice, but there was no significant difference between the middle and late stage of practice.

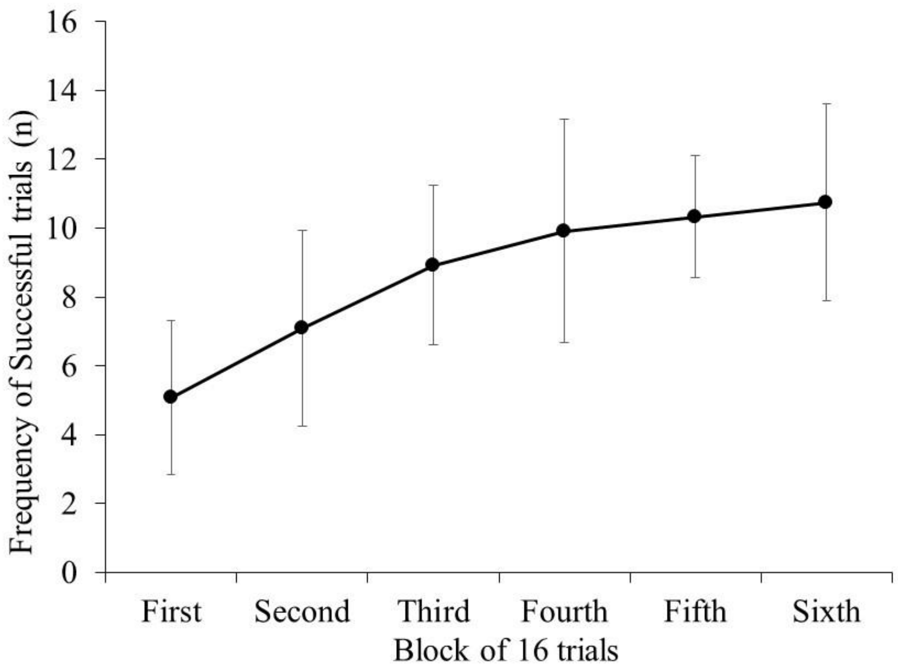

Figure 2.5. Mean (SD) frequency of successful trials in the practice phase.

Figure 2.6a shows AE in the practice phase. ANOVA on AE revealed a significant main effect of block, $F(5, 55) = 19.07$, $p < .05$, $\eta_p^2 = .63$. Participants moved the white cursor significantly closer to the red target from the early to the middle and late stage of practice, but there was no significant difference between the middle and late stage of the practice. Figure 2.6b shows VE in the practice phase. ANOVA on VE revealed a significant main effect of block, $F(2.22, 24.37) = 3.44$, $p < .05$, $\eta_p^2 = .24$. There was a significant difference between the first (M =16.1 cm, SD = 1.0) and fourth block (M = 12.3 cm, SD = 5.8) and between the first and six block (M = 12.1 cm, SD = 4.0). However, there were no significant differences between the second (M = 14.5 cm, SD = 2.2), third (M = 13.9 cm, SD =3.3), fourth, fifth (M = 13.6 cm, SD = 2.4) and sixth block. There was some tendency to improve the consistency of task performance across the practice phase.

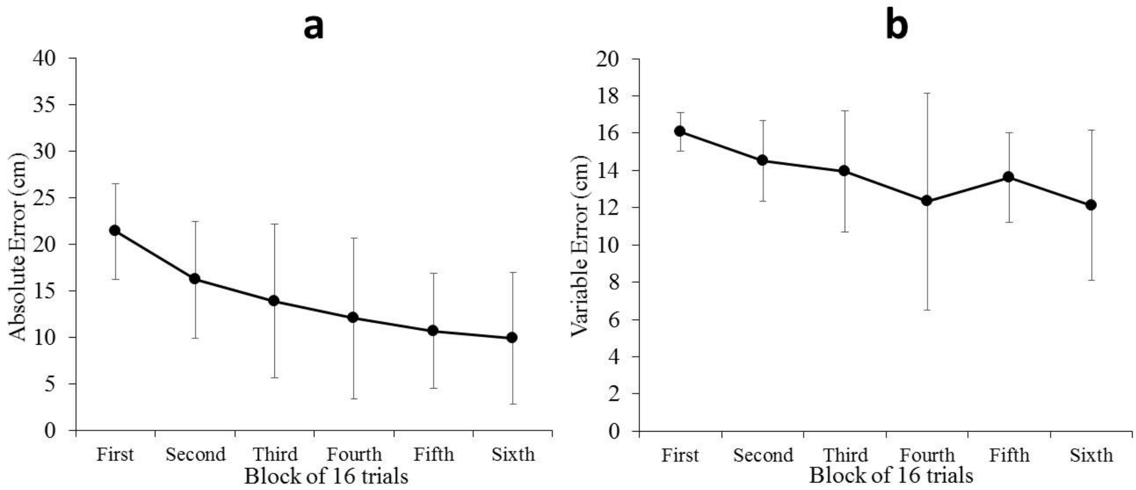

Figure 2.6. Mean (SD) (a) absolute error and (b) variable error in the practice phase.

ANOVA on the trial duration revealed a significant main effect of block, $F(5, 55) = 2.92$, $p < .05$, $\eta_p^2 = .21$. There was a significant difference between the first (M = 3.4 s, SD = 0.5) and third block (M = 4.2 s, SD = 0.9). However, there were no significant differences between the second (M = 3.8 s, SD = 0.8), third, fourth (M = 4.0 s, SD = 1.0), fifth (M = 3.8 s, SD = 0.6), and sixth block (M = 3.9 s, SD = 0.8). Moreover, ANOVA on the preparation time revealed no significant main effect of block, $F(2.89, 31.83) = 1.61$, $p > .05$, $\eta_p^2 = .13$. ANOVA on the movement time revealed a significant main effect of block, $F(5, 55) = 4.95$, $p < .05$, $\eta_p^2 = .31$. Participants significantly increased movement time from the first (*M* = 2.7 s, *SD* = 0.4) to the third (*M* = 3.4 s, *SD* = 0.7), fourth (*M* = 3.3 s, *SD* = 0.7), and sixth block (*M* = 3.3 s, *SD* = 0.8). However, there were no significant differences between the second (*M* = 3.2 s, *SD* = 0.8), third, fourth, fifth (*M* = 3.2 s, *SD* = 0.6), and sixth block.

Trial Difficulty

Figure 2.7 shows the frequency of successful trials for each object movement pattern across the two starting positions of the cursor. ANOVA revealed a significant main effect of pattern, $F(7, 77) = 14.22$, $p < .05$, $\eta_p^2 = .56$. Pattern D (*M* = 3 trials, *SD* = 2) had the lowest frequency of successful trials, whereas Pattern B (*M* = 10 trials, *SD* = 2) had the greatest frequency of successful trials. Based on the frequency of successful trials, Pattern D, F (*M* = 4 trials, *SD* = 3), H (*M* = 5 trials, *SD* = 3), and C (*M* = 7 trials, *SD* = 2) were the more difficult patterns, whereas Pattern B, A (*M* = 8 trials, *SD* = 2), E (*M* = 8 trials, *SD* = 3), and G (*M* = 7 trials, *SD* = 3) were the easier patterns.

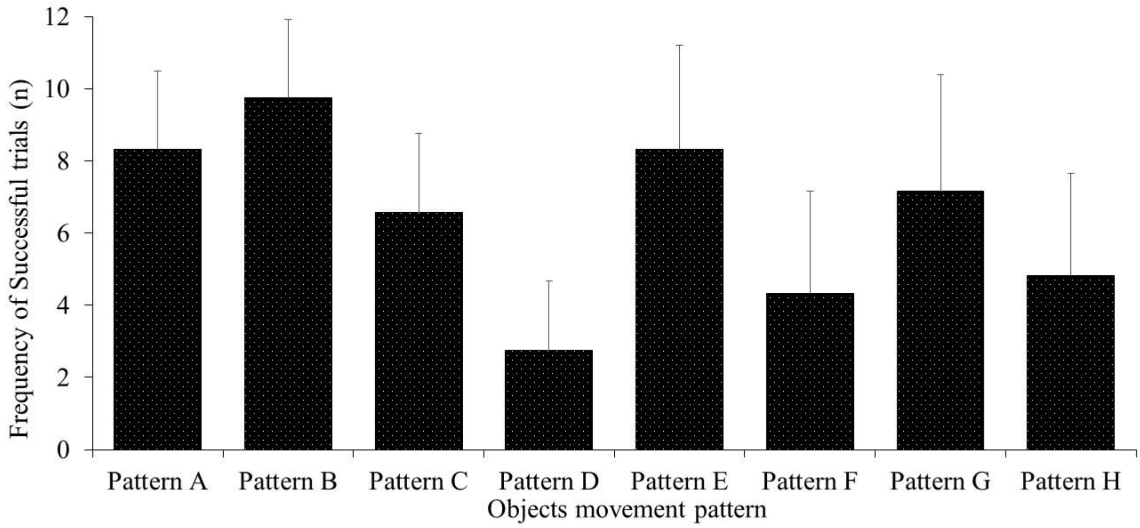

Figure 2.7. Mean (*SD*) frequency of successful trials for each object movement pattern across the right and left cursor starting position.

2.2.3. Discussion

The main aim of the current experiment was to develop a novel computer-based task that required the development of perceptual-cognitive-motor processes across moderate amounts of practice. As expected, participants significantly increased the frequency of successful trials in which the cursor reached the target from the early stage to the later stage of practice. Data shows performance improvement on the task through practice (Crossman, 1959; Fitts, 1964; Newell, Liu, & Mayer-Kress, 2001), consistent with previous sensorimotor skill research (Proteau & Cournoyer, 1990; Proteau et al., 1992). Moreover, as predicted, this improvement on the task performance was associated with a reduction in AE and increased movement time. The AE findings indicate that as practice progressed, participants were moving the cursor closer to the target as they sought to increase the frequency of successful trials, with the result that movement time increased. As predicted, participants reduced VE for the last location of the cursor throughout practice indicating that their performance became more consistent and less variable. Preparation time did not differ across practice, suggesting participants consistently waited for a short duration before initiating their movement. In general, performance became more accurate and successful through repeating and experiencing the task during practice (Li & Wright, 2000; Lin et al., 2009; Sailer et al., 2005; Tsutsui et al., 1998).

Although the results of this experiment showed performance improvement across practice, this might simply be due to task familiarization instead of the practice effect. In order to examine this, a further experiment needs to be conducted including a control group who are familiar with the task, but who do not engage in practice. Any difference between these two groups in favour of the practice group would be interpreted as the practice effect. Additionally, the results revealed differences in the difficulty between object movement patterns, which might influence the learning and practice effect (Guadagnoli & Lee, 2004; Lee et al., 2015). Therefore, the task needs to be set at an optimal level of challenge so that participants can improve task performance across practice (Guadagnoli & Lee, 2004).

2.3. Experiment 2

The aim of this experiment was to examine whether the acquisition of successful performance on the computer-based task was as a function of practice or familiarisation. Participants were randomly allocated into either a practice or control group, with the former performing the computer-based task in a pre-test, practice phase, and post-test, whereas the latter completed only the pre- and post-test. Because the task was novel to both groups, it was expected that in the pre-test there would be no between-group difference in the frequency of successful trials. In the post-test, due to the practice effect, the practice group were expected to exhibit more successful trials when compared to the control group. Furthermore, based on the challenge point hypothesis (Guadagnoli & Lee, 2004), different trial difficulties were expected to influence task performance and skill acquisition. Specifically, participants would not be able to show any improvement on the easy trials (i.e. ceiling effect), whereas the difficult trials were expected to differentiate the practice group from the control group.

2.3.1. Methods

Participants

Participants in this experiment were 24 undergraduate students who did not take part in Experiment 1 (M = 19.9 years of age, SD = 2.3). The experiment exclusion criteria and protocol was the same as Experiment 1. All participants had accumulated less than 7,500 hours of computer game playing experience across their life, in an attempt to control any initial ability at the task. They were assigned to either a practice group (n = 12) or a control group (n = 12). The characteristics of the participants in both groups are shown in Table 2.8. All participants had normal or corrected-to-normal vision and were right–hand dominant. Participants completed informed consent before taking part in this experiment. All procedures were conducted in accordance with the ethical guidelines of Liverpool John Moores University and the 1964 Declaration of Helsinki.

Table 2.8. The characteristics of the participants in both practice and control groups

Group	**Number of subjects**	**Age (years)**	**Computer-game playing experience (hours)**
Practice	12 (Male = 8, Female = 4)	20.4 ± 2.5	2452.5 ± 1806.0
Control	12 (Male = 8, Female = 4)	19.4 ± 2.1	4507.0 ± 2103.0

Apparatus and task

The experimental set up, apparatus and task were the same as in Experiment 1. Based on the findings in Experiment 1, the original eight movement patterns were categorised as four difficult movement patterns and four easy movement patterns, so with 16 trials per block there were eight difficult trials and eight easy trials across the two starting positions.

Procedure

Experiment 2 consisted of a pre-test, practice phase and post-test. There were 16 trials in both pre- and post-tests, which were completed by both the practice and control groups. The order of the 16 trials in the pre- and post-test was randomised and different between tests, but was the same for each participant. The practice group participated in the practice phase, which involved four blocks of 16 trials, with those 16 trials being pseudo-randomly ordered to make a total of 64 trials. Participants were provided with the opportunity of a 60-second break after every two blocks of trials. The control group remained in their seats facing the computer screen for 20 minutes after the pre-test in order to replicate the time it took the practice group to perform their practice phase. No augmented feedback was provided to the participants.

Data analysis

The data analysis was the same as Experiment 1. To quantify performance in the practice phase, dependent variables for the practice group were frequency of successful trials, AE, VE, and temporal characteristics (trial duration, preparation time, and movement time). All of these dependent variables were analysed using separate one-way repeated measures ANOVA with block (first, second, third, fourth block of the practice phase) as a repeated measure. The Bonferroni *post-hoc* procedure was used in the event of significant within-participant main effects. To quantify skill acquisition, the dependent variables were analysed using separate 2 Group (Practice, Control) x 2 Test (Pre-test, Post-test) mixed-factor analysis of variance (ANOVA). The Bonferroni *post-hoc* procedure was used for any significant within-participant main effect, and Tukey HSD *post-hoc* tests were used to determine the origin of any significant interaction. In order to control type-1 and type-2 error rates, the Bonferroni *post-hoc* procedure is more suitable for within-participant main effect because it has more statistical power when the number of comparisons is small, whereas the Tukey HSD *post-hoc* is more appropriate to determine the origin of any significant interaction because this *post-hoc* test has more statistical power when testing large numbers of means. Where violations to sphericity were observed, Greenhouse-Geisser corrections to df were applied. Partial eta squared (η_p^2) was used as a measure of effect size. Statistical significance for all tests was set at p <.05.

2.3.2. Results

Task performance

Figure 2.9 shows the frequency of successful trials for the practice group in the practice phase. ANOVA revealed a significant main effect of block, $F(3, 33) = 4.89$, $p < .05$, $\eta_p^2 = .31$. The practice group significantly increased the frequency of successful trials from the first (M = 7 trials, SD = 2) to the second (M = 9 trials, SD = 2), third (M = 9 trials, SD = 2), or fourth block (M = 9 trials, SD = 2), but there were no significant differences between the second, third, and fourth block.

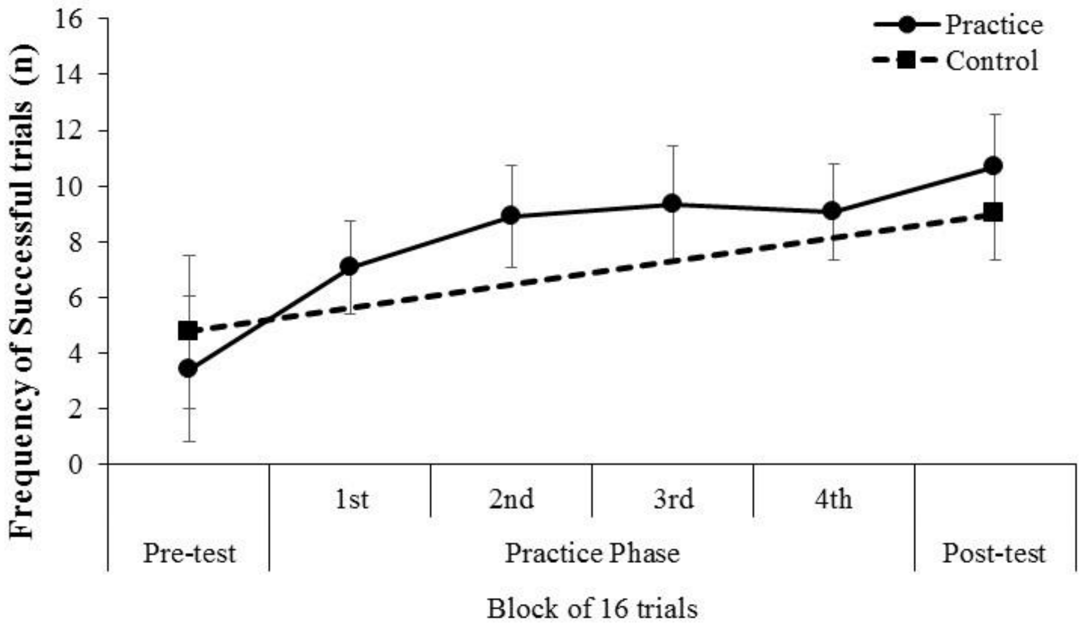

Figure 2.9. Mean (*SD*) frequency of successful trials for the practice and control group at the pre-test, practice phase and post-test.

ANOVA on AE for the practice group revealed a significant main effect of block, $F(3, 33) = 4.95$, $p < .05$, $\eta_p^2 = .31$. The practice group significantly reduced AE from the first (M = 15.1 cm, SD = 3.5) to fourth block (M = 11.1 cm, SD = 3.4), but there were no significant differences between the second (M = 12.2 cm, SD = 4.2), third (M = 11.6 cm, SD = 3.9), and fourth block. Moreover, ANOVA on VE revealed no significant main effect of block, $F(3, 33) = 0.61$, $p > .05$, $\eta_p^2 = .05$, as consistency of task performance did not differ across the practice phase.

Table 2.10 shows the temporal characteristics of the task performance during practice, including trial duration, preparation time and movement time. ANOVA revealed no significant main effect of block for trial duration, $F(3, 33) = 1.23$, $p > .05$, $\eta_p^2 = .10$, preparation time, $F(1.36, 14.95) = 0.08$, $p > .05$, $\eta_p^2 = .01$, or movement time, $F(3, 33) = 1.57$, $p > .05$, $\eta_p^2 = .13$. Results show that the temporal characteristics of the task performance did not differ across the practice phase.

Table 2.10. Mean (*SD*) temporal characteristics (trial duration, preparation time, & movement time) for the practice group in the practice phase.

	Block of 16 trials			
Measures	**First**	**Second**	**Third**	**Fourth**
Trial duration (s)	3.8 (0.8)	4.0 (0.7)	3.9 (1.0)	3.7 (0.4)
Preparation time (s)	0.6 (0.2)	0.7 (0.3)	0.7 (0.4)	0.6 (0.3)
Movement time (s)	3.1 (0.7)	3.3 (0.5)	3.2 (0.7)	3.1 (0.4)

Skill acquisition

Figure 2.9 shows the frequency of successful trials in the pre- and post-test for the practice and control group. ANOVA revealed a significant main effect for test, $F(1, 22) = 86.21$, $p < .05$, $\eta_p^2 = .80$, no effect of group, $F(1, 22) = 0.06$, $p > .05$, $\eta_p^2 = .00$, but a significant interaction, $F(1, 22) = 5.87$, $p < .05$, $\eta_p^2 = .21$. In the pre-test, there was no significant difference for successfully reaching the target between the practice group (M = 3 trials, SD = 3) and the control group (M = 5 trials, SD = 3). Both the practice (M = 11 trials, SD = 2) and control group (M = 9 trials, SD = 2) reached the target in significantly more trials in the post- compared to the pre-test, but there was no between-group difference at the post-test.

ANOVA on AE revealed a significant main effect for test, $F(1, 22) = 106.46$, $p < .05$, $\eta_p^2 = .83$, no effect of group, $F(1, 22) = 0.02$, $p > .05$, $\eta_p^2 = .00$, but a significant interaction, $F(1, 22) = 7.73$, $p < .05$, $\eta_p^2 = .26$. In the pre-test, there was no significant difference in AE between the practice (*M* = 24.4 cm, *SD* = 6.9) and control group (*M* = 20.8 cm, *SD* = 5.0). In the post-test, both the practice (*M* = 8.4 cm, *SD* = 3.5) and control group (*M* = 11.5 cm, *SD* = 2.3) moved the cursor significantly closer to the target when compared to the pre-test, but there was no between-group difference at the post-test. Moreover, ANOVA on VE revealed a significant main effect of group, $F(1, 22) = 8.74$, $p < .05$, $\eta_p^2 = .28$, but no effect of test, $F(1, 22) = 1.79$, $p > .05$, $\eta_p^2 = .08$, and no interaction, $F(1, 22) = 0.06$, $p > .05$, $\eta_p^2 = .00$. The practice group had a significant lower VE (Pre-test *M* = 13.9 cm, *SD* = 3.1; Post-test *M* = 12.8 cm, *SD* = 2.5) when compared to the control group (Pre-test *M* = 15.5 cm, *SD* = 1.7; Post-test *M* = 14.8 cm, *SD* = 1.3).

Table 2.11 shows the trial duration, preparation time, and movement time for both practice and control group in the pre- and post-test, whereas Table 2.12 shows the inferential statistics. There was no significant difference between groups for trial duration, preparation time, and movement time. Moreover, there were longer trial durations, shorter preparation times, and longer movement times in the post- compared to the pre-test. There were no significant interactions between group and test.

Table 2.11. Mean (*SD*) trial duration, preparation time, and movement time for the practice and control group in the pre- and post-test.

Groups	Trial duration (s)		Preparation time (s)		Movement time (s)	
	Pre	Post	Pre	Post	Pre	Post
Practice	3.4 (0.6)	4.0 (0.6)	0.8 (0.3)	0.6 (0.2)	2.6 (0.6)	3.4 (0.5)
Control	3.3 (0.6)	3.8 (0.6)	0.6 (0.3)	0.5 (0.2)	2.7 (0.6)	3.3 (0.6)

Table 2.12. 2x2 ANOVA table for the trial duration, preparation time, and movement time (* p <.05).

Measures	Test			Group			Interaction		
	F	p	η_p^2	F	p	η_p^2	F	p	η_p^2
Trial duration	16.88	.00 *	.43	0.35	.56	.02	0.26	.62	.01
Preparation time	11.17	.00 *	.34	1.70	.21	.07	1.18	.29	.05
Movement time	24.17	.00 *	.52	0.00	.97	.00	0.63	.44	.03

Secondary Analysis

Based on the findings above and those of Experiment 1, a secondary analysis was carried out in order to examine the potential effect of trial difficulty on task performance and skill acquisition. Accordingly, the 16 trials in each block were categorised as eight easy and eight difficult trials. To quantify the influence of the trial difficulty on task performance, the frequency of successful trials for the easy and difficult trials across the practice phase was analysed using separate (easy trials, difficult trials) one-way repeated measures ANOVA with block (first, second, third, fourth block of the practice phase) as a repeated measure. The Bonferroni *post-hoc* procedure was used in the event of significant within-participant main effects. To quantify the effect on skill acquisition, the frequency of successful trials for the easy and difficult trials were analysed separately (easy trials, difficult trials) using 2 Group (Practice, Control) x 2 Test (Pre-test, Post-test) mixed-factor ANOVA. The Bonferroni *post-hoc* procedure was used for any significant within-participant main effect, and Tukey HSD *post-hoc* tests were used to determine the origin of any significant interaction. Partial eta squared (η_p^2) was used as a measure of effect size. Statistical significance for all tests was set at p <.05.

Task performance

For the easy block of trials, ANOVA revealed no significant main effect for block, $F(3, 33) = 2.06$, $p > .05$, $\eta_p^2 = .16$. The practice group did not increase the frequency of successful trials on the easy trials across the practice phase (First block *M* = 5 trials, *SD* = 1; Second block *M* = 6 trials, *SD* = 1; Third block *M* = 6 trials, *SD* = 2; Fourth block *M* = 6 trials, *SD* = 1). Moreover, for the difficult trials, ANOVA revealed no significant main effect for block, $F(3, 33) = 1.96$, $p > .05$, $\eta_p^2 = .15$. The practice group did not increase the frequency of successful trials on the difficult trials across the practice phase (First block *M* = 2 trials, *SD* = 2; Second block *M* = 3 trials, *SD* = 2; Third block *M* = 3 trials, *SD* = 2; Fourth block *M* = 3 trials, *SD* = 2).

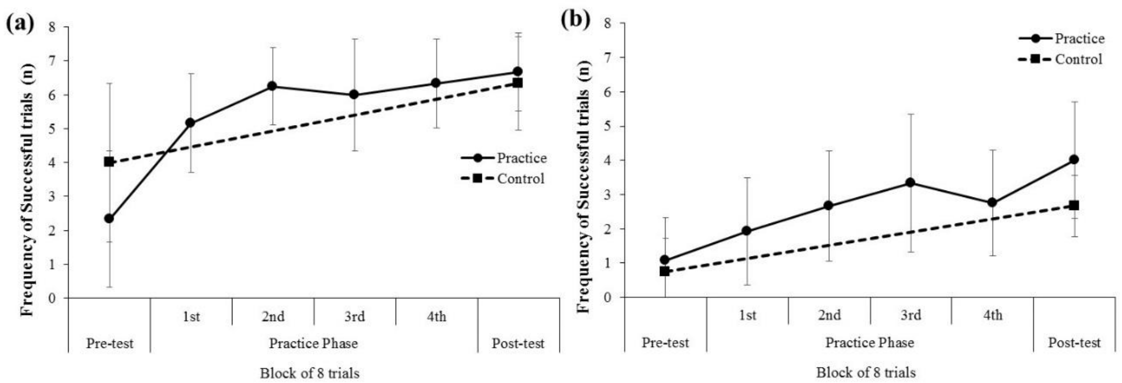

Figure 2.13. Mean (*SD*) frequency of successful trials for the practice and control group at the pre-test, practice phase, and post-test for the: (a) easy and (b) difficult trials.

Skill acquisition

For the easy block of trials, ANOVA revealed a significant main effect for test, $F(1, 22) = 48.35$, $p < .05$, $\eta_p^2 = .69$, no effect of group, $F(1, 22) = 1.48$, $p > .05$, $\eta_p^2 = .06$, and a significant interaction, $F(1, 22) = 4.35$, $p < .05$, $\eta_p^2 = .17$. Both the practice (*M* = 7 trials, *SD* = 1) and control group (*M* = 6 trials, *SD* = 1) reached the target in significantly more trials in the post-test as compared to the pre-test (Practice group *M* = 2 trials, *SD* = 2; Control group *M* = 4 trials, *SD* = 2) on the easy trials, but there was no between-group difference at either the pre- or post-test (see Figure 2.13a). For the difficult trials, ANOVA revealed a significant main effect for test, $F(1, 22) = 49.87$, $p < .05$, $\eta_p^2 = .69$, and group, $F(1, 22) = 4.97$, $p < .05$, $\eta_p^2 = .18$, but no significant interaction, $F(1, 22) = 2.14$, $p > .05$, $\eta_p^2 = .09$. Although there was no interaction, it can be seen in Figure 2.13b that there was some divergence between the practice and control groups. This was confirmed by follow-up independent T-tests, on the pre- and post-test data for the difficult trials. There was no significant between-group difference at the pre-test (Practice group *M* = 1 trials, *SD* = 1; Control group *M* = 1 trials, *SD* = 1), $t(22) = 0.74$, $p > .05$, but the practice group (*M* = 4 trials, *SD* = 2) exhibited superior performance at the post-test as compared to the control group (*M* = 3 trials, *SD* = 1), $t(22) = 2.40$, $p < .05$ (see Figure 2.13b).

2.3.3. Discussion

The aim of this experiment was to examine the acquisition of the computer-based task and whether this was as a function of practice or familiarisation. The novelty of the task and the ability to improve after a moderate number of trials were expected to be shown through a comparison of pre- and post-test behaviour of two groups that either completed a practice phase on the same task, or spent the same amount of time not practicing the task. It was expected that there would be no difference between groups at the pre-test, but that the practice group would have a greater frequency of successful trials, lower AE, lower VE, and longer movement time and trial duration at the post-test when compared to the control group. However, our findings revealed that, both groups increased the frequency of successful trials, reduced AE, and increased movement time and trial duration from pre- to post-test, but there was no significant difference between groups. The main reason for these results was that task difficulty interacted with practice. The practice group demonstrated a greater frequency of successful trials for difficult trials when compared to the control group, but for easy trials there was no between-group difference. Therefore, the difficulty of the easy trials was inappropriate, so that the task did not require a moderate practice to differentiate two groups. The task difficulty needs to be set at the optimal level to challenge learners during practice. Tasks that are too easy or too difficult limit the learning and practice effect (Guadagnoli & Lee, 2004; Lee et al., 2015). The data demonstrated that trial difficulty affected skill acquisition and the practice effect in Experiment 2 and this will need to be addressed in future work.

2.4. General Discussion

The aim of this chapter was to develop a novel computer-based task that required the acquisition of perceptual-cognitive-motor processes for successful performance across moderate amounts of practice. Experiment 1 was conducted to examine successful performance and behavioural changes on the task during practice. Experiment 2 was conducted to investigate skill acquisition and the practice effect on the task. The frequency of successful trials was the key dependent variable to represent performance and skill acquisition on the task, as well as AE, VE, movement time and trial duration were measured to differentiate the practice and control groups. It was expected that when participants became more successful at the task in the later stage of practice or post-test, successful performance would be associated with reaching the target more frequently, less variable error, increased movement time, and longer trial durations.

As expected, in both Experiment 1 and 2 participants became more successful across practice and reduced AE (Soucy & Proteau, 2001; Proteau & Cournoyer, 1990; Proteau et al., 1992; Trempe et al., 2012; Trempe & Proteau; 2010). Experiment 1 revealed that in the last block of 96 trials during practice participants moved the cursor closer to the target, had less variable final locations of the cursor, and increased movement time resulting in longer trial durations, when compared to the early phase. These findings indicated that successful performance is underpinned by the intention to move the cursor closer to the target, as evidenced by less absolute error, less variable error, longer movement times, and trial durations. These results were consistent with the previous research in sensorimotor learning showing that participants became more successful at a goal-directed aiming task with less constant error and less variable error throughout practice (Elliott, Binsted, & Heath, 1999; Elliott et al., 1995; Elliott, Hansen & Grierson, 2009; Elliott et al., 2010; Proteau, 2005). However, the outcomes in Experiment 1 could be interpreted as participants being familiar with the task rather than the practice effect. Performance is defined as the observable behaviours during practice, whereas learning and skill acquisition is defined as a relatively permanent change in performance (Salmoni et al., 1984). Therefore, task performance and skill acquisition needed to be separated to determine the practice effect and account for this performance-learning dichotomy (for a review, see Kantak & Winstein, 2012).

In Experiment 2, the skill acquisition and practice effect on the task was examined by comparing a practice group and control group in a pre- and post-test design. It was expected that the practice group would have a greater frequency of successful trials, lower AE, lower VE, and longer trial duration and movement time at the post-test when compared to the control group, whereas there would be no group difference in these variables at the pre-test. This would indicate findings as skill acquisition, learning and the practice effect. Experiment 2 revealed that both the practice and control group had a greater frequency of successful trials, lower AE, and longer trial duration and movement time at the post- when compared to pre-test. The lack of significant differences in the frequency of successful trials between groups at the post-test contradicted the expected practice effect. Therefore, based on the findings for task difficulty in Experiment 1, further analysis was conducted to examine the potential confounding effect of trial difficulty. Findings showed the practice group had a greater frequency of successful trials on the difficult trials when compared to the control group, whereas there were no between-group differences for the easy trials.

These experiments have led to a number of potential changes to the task for the experiments that follow in this thesis. First, Experiment 1 revealed that there were significant differences in trial difficulty, indicated by the frequency of successful trials. Researchers have suggested that task difficulty influences skill acquisition and the practice effect, with tasks that are too hard or easy limiting their occurrence (Guadagnoli & Lee, 2004; Lee et al., 2015). Hence, the trials were categorized as difficult and easy trials in Experiment 2 based on the findings from Experiment 1. Findings showed that the control group were not differentiated from the practice group for task success on easy trials, but were less successful on difficult trials, suggesting the challenge point for the easy trials was too low. Therefore, in order to examine the acquisition of perceptual-cognitive-motor processes for the forthcoming experiments in the thesis, the difficult trials should be selected and the easy trials removed from the task in order to set an optimal level of the task difficulty for the moderate amounts of practice (Green & Bavelier, 2008; Guadagnoli & Lee, 2004; Keetch & Lee, 2007; Lee et al., 2015; Sidaway, Bates, Occhiogrosso, Schlagenhaufer, & Wilkes, 2012).

Second, participants demonstrated some tendency to become less variable in their performance across 96 trials of practice in Experiment 1, whereas in Experiment 2 there was no change in movement variability across 64 trials of practice. Therefore, 96 trials of practice appears to be the correct amount to lead to behavioural differences between practice and control groups. Third, in Experiment 2, participants were excluded from the experiment when they had accumulated 7,500 or more hours playing computer-games. However, the practice and control group were not matched in terms of computer-game playing experience. The control group accumulated significantly more hours playing computer-games when compared to the practice group, $t(22) = 2.57$, $p < .05$. However, separate independent t-tests revealed no significant difference in the frequency of successful trials between the groups at the pre-test for all trials, $t(22) = 1.21$, $p > .05$, $d = 0.52$, in easy trials, $t(22) = 1.87$, $p > .05$, $d = 0.80$, and in difficult trials, $t(22) = 0.74$, $p > .05$, $d = 0.31$. It remains possible that a positive relationship exists between computer-game experience and performance on the task. The difference in computer-game experience might have led the control group to have some advantage for task performance when compared to the practice group (Boot et al., 2011; Boot et al., 2008; Green & Bavelier, 2003; Green & Bavelier, 2006). Therefore, the amount of hours that participants have spent playing computer games across their life will be matched between groups in future experiments. Together, these methodological changes should create a more suitable task to examine the acquisition of perceptual-cognitive-motor processes underlying performance, including for the first time in the literature the acquisition of visual search behaviours (Mann et al., 2007; Travassos et al., 2013; Williams et al., 2004) and cognitive decision making processes (Ericsson, 2006; Ericsson & Simon, 1993; Fox, Ericsson, & Best, 2011).

In summary, a novel computer-based task was developed requiring the acquisition and integration of perceptual-cognitive-motor skill and processes for successful performance. Previously, researchers have used perceptual-motor tasks that required only perceptual-motor processes, planning, and strategies for the next trial. In contrast to these previous tasks, the current task required the acquisition of perceptual-cognitive-motor processes in the dynamic and complex contexts. Participants needed to move their eyes in order to search, identify and perceive relevant from irrelevant stimuli. Accordingly, cognitive processing was involved to decide and select an appropriate action from more than one available option. Having done so, the motor apparatus had to be controlled in order to execute the action under time constraints. The next chapter in the thesis aims to examine the underlying processes of successful performance on the task (only difficult trials) by using eye movement measurements and retrospective reports of thoughts, and the contributions of each perceptual, cognitive, and motor process by using a yoked-design to decouple and segregate the perceptual-cognitive-motor processing.

Chapter 3

The acquisition of perceptual-cognitive-motor processes underlying complex performance

3.1. Introduction

Sensorimotor learning and the development of associated internal representations are influenced when the availability of relevant sensory information is modified during practice, such as limiting visual feedback or rescaling kinematic information (Elliott et al., 1995; Elliott et al., 1997). Practice of an action under particular sensory conditions (e.g., vision or no vision) can lead to the development of specific internal representations that are not immediately generalizable to conditions that afford different sensorimotor information (Proteau & Cournoyer, 1990; Proteau et al., 1992; Robin et al., 2005). However, despite advances in understanding of sensorimotor learning, the majority of previous research (Imamizu et al., 2000; Kording & Wolpert, 2004; Todorov, 2004; Wolpert et al., 2011) has used perceptual-motor tasks that do not place a high demand on cognitive processes, such as decision making. In particular, there has been little research that has directly examined the acquisition of underlying processes during dynamic and complex tasks where a performer must decide upon appropriate actions to execute from more than one available option, some of which may be more effective than others (Klein et al., 1995).

In many domains and tasks, humans make decisions and execute actions in order to achieve a desired goal in the environment (Kording & Wolpert, 2006). Decision making and its processes are central to more successful performance in a variety of domains, such as chess (Klein et al., 1995; Simon & Chase, 1973) and law enforcement (Suss et al., 2014; Ward et al., 2011). Skilled performers across many domains make more appropriate and faster decisions under specific time constraints when compared to less-skilled. Superiority at decision making is underpinned by experience-based cognitive strategies, processes and knowledge structures. One such cognitive strategy is the generation of options for action in domain-specific task situations. For instance, experienced chess players and skilled law enforcement officers generate more task-relevant options and select the best option more frequently compared to lesser-skilled individuals (Klein et al., 1995; Ward et al., 2011). According to Adaptive Control of Thought (ACT) theory, these options are organised as condition-action pairs that match environmental, task or individual conditions to actions that are designed to achieve a goal (Anderson, 1982; Anderson et al., 2004; Neves & Anderson, 1981). It is suggested that the condition-action pairs forming the cognitive structures underpinning decision making are acquired, organised, modified and refined through certain practice environments (McPherson 1994; McPherson & Kernodle, 2003; McPherson & MacMahon, 2008), although few, if any, researchers have addressed this acquisition process.

An underlying mechanism of decision making is the visual search behaviour used to identify task-relevant information in the environment (Mann et al., 2007; Travassos et al., 2013; Williams et al., 2004). Visual search behaviours, and thereby visual attention, underpin more successful decision making performance across many domains (Charness, Reingold, Pomplun, & Stampe, 2001; Law et al., 2004; Raab & Johnson, 2007; Savelsbergh et al., 2002; Vaeyens et al., 2007). For example, Savelsbergh et al. (2002) showed that skilled soccer goalkeepers stopped more penalty kicks and used fewer visual fixations of a longer duration to more informative areas of the display, when compared to less-skilled goalkeepers. Consistent differences in visual search behaviours between skilled and less-skilled performers across domains and the specificity of the behaviours to domain-specific tasks infer they are an acquired process (for a review, see Mann et al., 2007). In addition to using skilled versus less-skilled protocols, the acquisition of visual search and eye movements has been examined during sensorimotor learning. Sailer et al. (2005) instructed participants to perform a computer-based task so that a cursor was controlled from a starting position to a target. They found that the eye initially pursued the cursor in the early stages of practice, whereas in the later stages of practice the eye was shifted towards the space in front of the cursor, and there were more goal-directed saccades and fewer saccades in total. Although these results are from an upper-limb aiming task where the goal was merely to hit a single target, they suggested that specific and strategic goal-directed visual search and eye-hand coordination behaviours are developed during practice and that these processes support the planning and control of action.

The aim of the current study was to further investigate the acquisition of perceptual-cognitive-motor processes in a novel computer-based task that required the selection of appropriate actions to execute from more than one available option. Findings in Chapter 2 revealed that successful performance on the task is associated with reaching the target more frequently, reduced absolute error and variable error, increased movement time, and longer trial durations. The task required participants to move a cursor to a target whilst avoiding random moving objects. Building upon other studies that examined the development of sensorimotor processes in tasks that had well-structured environments that required one or a few specific cursor trajectories to be acquired through practice (Imamizu et al., 2000; Kording & Wolpert, 2004; Sailer et al., 2005; Todorov, 2004; Wolpert et al., 2011), the present protocol used a dynamic and complex task environment that created a situation where the task goal could be attained in multiple ways. Therefore, by using an environment that simulated those experienced in typical real life settings, such as patterns of play in sport, the current chapter examined the acquisition of sensorimotor and decision making processes in a task where a performer had to select successful cursor trajectories from a range of potential options. To this end, in Experiment 3 the acquisition of the computer-based task was compared in a group that practised for a moderate number of trials and a control group that received no practice. It was expected that the practice group would develop specific cognitive structures for decision making and visual search behaviours leading to more successful performance than the control group. In Experiment 4, two control variations of the computer-based task were added in order to examine the interplay between perceptual-cognitive-motor processes during the development of sensorimotor learning. These variations systematically modulated the availability of the task-specific sensory and decision making information underpinning successful performance. If skilled performance is based on an interplay between specific perceptual-cognitive-motor processes, it was expected that transfer task performance following practice in the two control variations would be limited because the availability of these processes was modulated or constrained during practice.

3.2. Experiment 3

The aim of this experiment was to determine how perceptual-cognitive-motor processes are acquired in a dynamic and complex computer-based task from early to later phases of practice when all relevant sensory information is available. Participants were randomly allocated to a practice or control group. Because the task was novel to both groups, it was expected that in the pre-test there would be no between-group differences in the frequency of successful trials, or visual search behaviours and cognitive processing. In the post-test, due to the practice effect, the practice group was expected to exhibit more successful trials compared to the control group, as well as visual search behaviours containing more goal-directed eye movements. It was also expected that the practice group would exhibit a greater frequency of condition-action pairs in the post-test compared to the pre-test, whereas for the control group there should be no change.

3.2.1. Methods

Participants

Twenty-six participants (*M* = 21.8 years of age, *SD* = 1.8) were assigned to a practice group (*n* = 13) or a control group (*n* = 13). All participants had normal or corrected-to-normal vision and were right–hand dominant. The groups were matched for gender (Male = 9, Female = 4), age (Practice group *M* = 21.4 years of age, *SD* = 2.0; Control group *M* = 20.5 years of age, *SD* = 1.5), and computer-game playing experience (Practice group *M* = 3791.6 hrs, *SD* = 2385.7; Control group *M* = 3152.2 hrs, *SD* = 2167.9). Separate independent *t*-tests on each of these variables showed no between-group differences (all $t < 1.1$). The experiment exclusion criteria and protocol was the same as Experiment 1 (see Chapter 2). Participants completed an informed consent form before taking part in this experiment. All procedures were conducted in accordance with the ethical guidelines of Liverpool John Moores University and the 1964 Declaration of Helsinki.

Apparatus and task

Figure 3.1a shows that the experimental set up and apparatus. A task was used for the experiment that involved visual stimuli being shown on the monitor that interfaced with the digitising tablet and stylus (see Figure 3.1b), and was realised in the same manner as Experiment 1 (see Chapter 2).

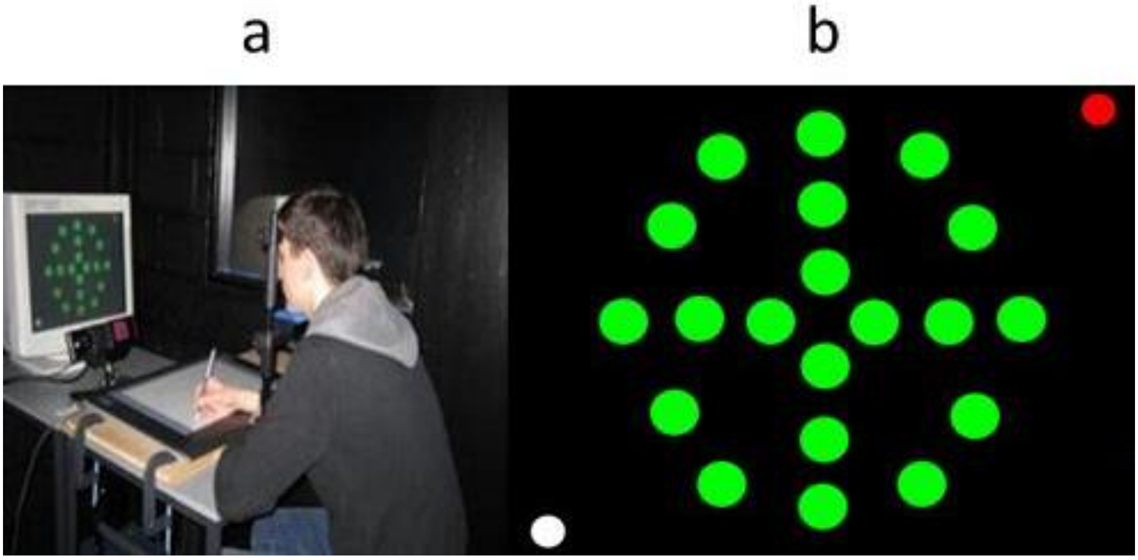

Figure 3.1. (a) The experimental set up, (b) the perceptual-cognitive-motor (PCM) computer-based task.

The goal of this task was for participants on each trial to move the cursor from one corner of the computer screen to a red circle target located in the diagonal corner of the screen while avoiding any collision with number of green objects. If the white cursor touched one of the green objects on the screen during a trial on the task, then the trial ended and was deemed unsuccessful. If the white cursor reached the red target, then the trial ended and was recorded as successful.

The green objects moved around on the screen with pre-programmed linear trajectories, such that there were four groups of five green objects with speeds of 13.5 cm/s, 13.1 cm/s, 8.3 cm/s, and 7.6 cm/s, respectively. Based on the results in Experiment 2 (see Chapter 2), four different movement patterns (four difficult movement patterns in Experiment 2) were used for the green objects so that each began with the same start positions. The start position had an equal spatial distribution of the green objects across the screen (see Figure 3.1b). A total of eight movement patterns across the two starting positions were created by mirroring the original four movement patterns relative to either of the two starting position of the white cursor in an attempt to have an equal task difficulty on each starting position. When an object reached the edge of the screen, it rebounded with an angle that was equal to the angle of incidence. The objects did not rebound upon collision with each other and instead continued along their trajectory without any change. Upon collision between the white cursor and a green object or when participants achieved the target successfully, the trial ended and a blank black screen appeared for 100ms.

Visual search behaviours of both groups were measured using the EyeLink1000 eye movement registration system (SR Research Ltd., Mississauga, Ontario, Canada). Eye gaze locations were sampled at 250 Hz and stored in horizontal and vertical axes for off-line analysis with routines written in MATLAB. A chin and forehead rest was used to minimise head movement, and to ensure that participant eyes were located 89.0

cm perpendicular to the centre of the computer monitor (see Figure 3.1a). At this distance, the green objects subtended a visual angle of 2.0°, whereas the red target and white cursor subtended a visual angle of 1.4°. A nine-point calibration and validation of gaze location accuracy occurred prior to the pre- and post-test.

Procedure

Before the start of the experiment, participants received an illustration of the screen layout for the task and pre-scripted instructions regarding its aim. They were instructed to use the stylus on the digitalising tablet to move the white cursor on the screen such that it reached the red target whilst avoiding the green objects. They were unaware of either the gain relationship of the white cursor movement or the amount of different movement patterns of the green objects.

Both groups completed eight trials in each of a pre-test and post-test. The order of the eight trials differed in the pre- compared to post-test, but was the same for all participants. Between the pre- and post-tests, the practice group completed 12 blocks of the same eight trials. These were arranged in a pseudo-random order, which was the same for all participants. Participants in the practice group were provided with the opportunity of a 60-second break after every four blocks of trials. The control group remained in their seats facing the blank computer screen for 30 minutes after the pre-test in order to closely replicate the time it took the practice group to perform their practice trials. The current experiment was conducted to examine the effect of encoding and processing activities during practice on the skill acquisition and performance at the post-test. Therefore, this experiment did not contain retention or transfer-tests, which are used to determine learning and performance-learning dichotomy (Kantak & Winstein, 2012). No augmented feedback was provided to the participants.

Retrospective reports of the underlying cognitive thought processes and strategies used by the participants were collected. The retrospective reports have been shown to be a valid method to examine cognitive thoughts in various tasks (Ericsson, 2006; Ericsson & Simon, 1993; Fox et al., 2011). Prior to the experiment, participants were trained on how to provide their reports (Raab, 2003; Ward et al., 2011). During the experiment, participants were required to write down all of the strategies, tactics and thought processes that they used to complete the task in separate condition-action formatted statements (Anderson, 1982; McPherson & Kernodle, 2007; Raab, 2003). A pre-printed paper sheet contained prompts and space for participants to write their condition-action statements. Condition-action statements contain information on a specific situation occurring in the task (i.e., condition where IF was used as the prompt) and the specific action or options for actions executed in that situation (i.e., action where THEN was used as the prompt). Condition-action statements were collected at the end of the last trial in the pre- and post-test.

Data analysis

Task performance

The primary dependent variable was the frequency of successful trials in which the cursor reached the red target in the pre- and post-test, and in the practice phase for the practice group only. Practice phase data was divided into early, middle, and late phases, each of which contained 32 trials.

Visual search

Eye gaze locations were low-pass filtered using a zero-phase digital filter (autoregressive; forward and backward filter; cut-off frequency, 35 Hz). Eye velocity and acceleration were then derived from eye position data using a two-point central difference algorithm. Next, saccades were identified and removed from the smooth response using a technique similar to that described in previous research (Bennett & Barnes, 2003). Saccades were identified as points in the acceleration trace exceeding a threshold of 750°/s^2. When the threshold criteria were exceeded, the complete saccade trajectory was identified by finding the peak and trough of acceleration. On the rare occasions when the use of the acceleration threshold failed to identify a saccade, a second pass was made in which a maximum amplitude threshold (Horizontal 25.7°, Vertical 19.4°, i.e., the size of the monitor) and minimum amplitude threshold of 0.3° was applied. By using these criteria, saccades of 0.3° or more were reliably detected and differentiated from blinks and other noise. Saccades were generally of small amplitude and brief duration, so linear interpolation was used as a simple and adequate method of waveform restoration. Data on the saccades during a presentation were stored for later analysis. To obtain desaccaded smooth eye velocity, data points equivalent to 12ms at the beginning and end of the identified saccade trajectory were excluded to ensure that no saccadic element remained when applying subsequent interpolation. A linear interpolation routine was used to bridge the gaps produced by removal of saccades from the eye velocity trajectory. The desaccaded eye velocity data were then filtered at 35 Hz with a low-pass, zero-phase filter.

In both horizontal and vertical axes, saccades were labelled *goal-directed* when their velocity peak in the acceleration phase was directed toward the target location, whereas in all other instances they were labelled as *reversed*. The total frequency of saccades during each trial in both horizontal and vertical axes was extracted, as well as the frequency of goal-directed and reversed saccades. The total contribution of saccadic eye displacement (SAD) during each trial was obtained by summing the absolute amplitude of all the saccades. Smooth eye displacement (SED) during the trial was obtained by multiplying the interpolated smooth eye velocity (obtained by linear interpolation) by its duration. The total eye displacement during the trial (TED) was calculated by adding SAD and SED. The frequency of saccades and TED was normalised by trial duration in order to minimise the possibility that any differences in visual search behaviours were related to more or less time on task. In order to examine the characteristics of visual search behaviours, the contribution of goal-directed saccades (%) and reversed saccades (%) was calculated by dividing with the frequency of saccades. The contribution of SAD (%) and SED (%) was calculated by being divided by TED.

Cognitive processes

The frequency of condition-action statements was calculated as a function of group for the two tests. In addition, condition-action statements were coded for each participant using the protocol analysis technique described by Ericsson and Simon (1993). The statements were classified into different concept categories according to the information present in the statements, as per McPherson and colleagues (McPherson, 1994; 1999; McPherson & Kernodle, 2003; McPherson & Kernodle, 2007; McPherson & MacMahon, 2008), as well as Ericsson and Simon (1993). A condition-action statement could contain one to several concept categories. The five major concept categories include: (a) *condition concepts* specify under what conditions or when to apply an action or patterns of actions; (b) *action concepts* specify an action selected or patterns of actions selected which may produce goal-related changes in the context of the computer-based task; (c) *goal concepts* reflect the goal structure of the task or anticipated situation, and the purpose of an action selected or specifying a condition; (d) *evaluation concepts* reflect some form of comparison, assessment, or appraisal of task events that are situation, task, performance, or context relevant; and (e) *do concepts* specify how to perform an action selected or patterns of actions selected (see more details in Table 3.2). Other statements (e.g. emotional concepts or concentration) were classified and coded as *uncategorized concepts*. The frequency of units of information was calculated in each concept category for each participant, as well as the sum of the five major concepts generated, as a function of the two tests.

Table 3.2. Definitions and classifications of concepts of the condition-action statements

Concept: A concept is defined as a unit of information about response selection in the context of the computer-based task. Each unit of information will be classified as a condition, action, goal, do, and evaluation concept.
Condition concept: A unit of information that specifies under what conditions or when the action or patterns of actions are to be applied to achieve the task aim or sub-aims. Condition concepts may refer to an individual's consideration of the task situation and their cursor location. Overall, condition concepts specify under what conditions or when to apply an action or patterns of actions.
Action concept: A unit of information that refers to an action selected or patterns of actions selected which may produce goal-related changes in the context of the computer-based task. Actions might be characterised by motor responses (e.g., action itself or cursor movement) or visual responses (e.g., watch or look at certain cues). They may also include characteristics of the type of action (e.g., direction, placement, and speed).
Goal concept: A unit of information that reflects the goal structure of the task or anticipated situation, and the purpose of an action selected or specifying a condition.
Do concept: A unit of information specifying how to perform an action selected or patterns of actions selected (e.g., technical or mechanical statements of how to perform an action).
Evaluation concept: A unit of information which reflects some form of comparison, assessment, or appraisal of task events that are situation, task, performance, or context relevant.
Uncategorized concept: A unit of information which indicates other than those five main concept categories. The concepts might include emotional comments (i.e., I feel relaxed, I keep calm, be aggressive, be patient, & be careful) and concentration (i.e., I try hard, I need to focus, & I need to pay attention).

Reliability of the coding system

The primary investigator trained an independent investigator on the coding instrument. The independent investigator was unfamiliar with the research at the start of the training and coding. Both investigators coded eight randomly selected participants (four participants from each group). Altogether, just over 20.0% of the data were analyzed for reliability using the procedures recommended by Thomas, Nelson, and Silverman (2005). Inter-rater and intra-rater reliability were estimated using the equation: number of agreements / (number of agreements + disagreements) × 100 = percentage for all coded categories for each participant. Additionally, both inverstigators were blinded to group membership during all phases of the coding process. Mean reliability estimates for inter-rater reliability were 92.6%. To determine intra-rater reliability, both investigators coded the same participants two weeks later. Mean reliability estimates for intra-rater reliability were 96.3%. Following this reliability procedure, the primary imvestigator coded the remaining statements.

Inferential statistics

To quantify task performance in the practice phase, frequency of successful trials was analysed using one-way ANOVA with phase (early, middle, late phase of the practice) as a repeated measure. The Bonferroni *post-hoc* procedure was used in the event of significant within-participant main effects. To quantify acquisition on the task, dependent variables of task performance, visual search, and cognitive processes were analysed using separate 2 Group (Practice, Control) x 2 Test (Pre-test, Post-test) mixed-factor analysis of variance (ANOVA). The Bonferroni *post-hoc* procedure was used for any significant within-participant main effect, and Tukey HSD *post-hoc* tests were used to determine the origin of any significant interaction. Partial eta squared (η_p^2) was used as a measure of effect size. Statistical significance for all tests was set at p <.05.

3.2.2. Results

Practice

A main effect of phase $F(2, 24) = 9.22$, $p < .05$, $\eta_p^2 = .44$, indicated the practice group significantly increased the frequency of successful trials from the early ($M = 11$ trials, $SD = 5$) to the middle ($M = 14$ trials, $SD = 5$) phase of practice, but no further significant increase was observed between middle and late phases ($M = 16$ trials, $SD = 4$).

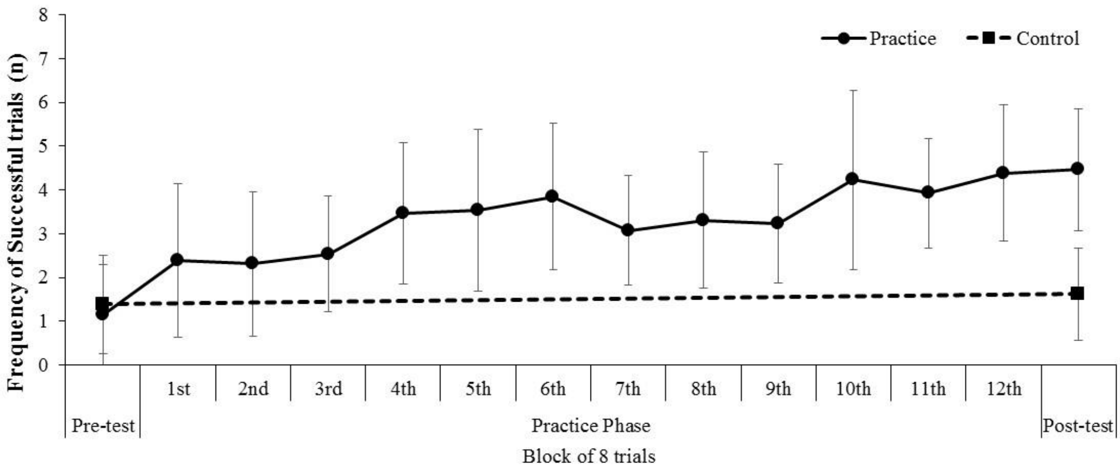

Figure 3.3. Mean (SD) frequency of successful trials for the practice and control group at the pre-test, practice phase and post-test.

Skill acquisition

Task performance

Figure 3.3 shows the frequency of successful trials in the pre- and post-test for the practice and control group. ANOVA revealed a main effect for test, $F(1, 24) = 30.01$, $p < .05$, $\eta_p^2 = .56$, group, $F(1, 24) = 15.45$, $p < .05$, $\eta_p^2 = .39$, and a group x test interaction, $F(1, 24) = 22.70$, $p < .05$, $\eta_p^2 = .49$. In the pre-test there was no significant difference in successful trials between the practice group ($M = 1$ trials, $SD = 1$) and the control group ($M = 1$ trials, $SD = 1$), whereas in the post-test the practice group ($M = 5$

trials, *SD* = 1) reached the target in significantly more trials than the control group (*M* = 2 trials, *SD* = 1).

Visual search behaviours

Descriptive (Table 3.4) and inferential (Table 3.5) statistics are presented for the time-normalised frequency of saccades, as well as the proportion of goal-directed and reversed saccades, for the two groups in pre- and post-test. There was no significant difference between groups in the frequency of saccades in the pre-test in either the horizontal or vertical direction. In the post-test, the practice group had a significantly lower frequency of saccades in the horizontal and vertical direction than the control group. In terms of the characteristics of the saccades, there was no significant group difference at pre-test in the contribution of goal-directed saccades in both horizontal and vertical directions. This had changed by the post-test, with the practice group exhibiting a significantly higher proportion of goal-directed saccades than the control group. While there was no difference between groups in the proportion of reversed saccades at pre-test, the practice group had a significantly lower proportion of reversed saccades compared to the control group in the post-test.

Table 3.6 shows the time-normalised TED and the proportion of SAD and SED for the two groups in the pre- and post-test. Table 3.7 shows the inferential statistics for the aforementioned dependent variables. In both horizontal and vertical directions, there was no significant difference between groups in TED in the pre-test. In the post-test, the practice group had significantly reduced TED compared to the pre-test, whereas there was no significant change in the control group. There was no significant difference between groups in the contribution of SAD or SED in the pre-test in either the horizontal or vertical direction. In the post-test, the practice group had a significantly lower proportion of SAD in the horizontal direction compared to their pre-test, whereas the control group exhibited no significant change. In the vertical direction, the proportion of SAD was lower in the post- compared to the pre-test, whereas the proportion of SED was greater in the post- compared to the pre-test.

Cognitive processes

The frequency of condition-action statements revealed no effect of group, $F(1, 24) = 3.35$, $p < .1$, $\eta_p^2 = .12$, but a significant main effect of test, $F(1, 24) = 19.84$, $p < .05$, $\eta_p^2 = .45$ and a group x test interaction, $F(1, 24) = 23.44$, $p < .05$, $\eta_p^2 = .49$. While there was no significant difference in frequency of condition-action statements between the practice (M = 2 statements, SD = 1) and control group (M = 2 statements, SD = 1) in the pre-test, the practice group (M = 4 statements, SD = 2) made significantly more statements than the control group (M = 2 statements, SD = 1) in the post-test.

Descriptive (Table 3.8) and inferential (Table 3.9) statistics are presented for the concept categories from the condition-action statements in the pre- and post-test. At the pre-test, there was no significant difference between groups for the sum of five major concepts. The practice group significantly increased the sum of the major concepts from the pre-test to post-test, whereas the control group did not increase the sum between tests. The frequency of statements containing information about the concepts of evaluation, do, and unrecognised was zero, so these categories were removed from further analysis. However, the practice group significantly increased the frequency of condition and action concepts from the pre-test to post-test, whereas there was no difference between groups in the frequency of these concepts at pre-test, and the control group did not increase the frequency of these two concepts between tests.

Table 3.4. Mean (*SD*) time-normalised frequency of saccades, proportion of goal-directed saccades, and proportion of reversed-saccades for the practice and control group in the pre- and post-test (Tukey HSD *post-hoc* test: * *p* <.05).

	Frequency of Saccades (n)				**Goal-directed Saccades (%)**				**Reversed Saccades (%)**			
	Horizontal		**Vertical**		**Horizontal**		**Vertical**		**Horizontal**		**Vertical**	
Groups	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**
Practice	3.4 (0.6)	2.3 * (0.4)	3.2 (0.7)	2.3 * (0.6)	59.0 (6.0)	70.9 * (6.1)	64.0 (8.8)	81.6 * (7.1)	41.0 (6.0)	29.1 * (6.1)	36.0 (8.8)	18.4 * (7.1)
Control	3.5 (1.0)	3.4 (0.9)	2.8 (1.0)	3.0 (1.1)	59.6 (6.0)	64.1 (5.9)	65.7 (8.1)	70.1 (6.8)	40.4 (6.0)	35.9 (5.9)	34.3 (8.1)	29.9 (6.8)

Table 3.5. 2x2 ANOVA table for the time-normalised frequency of saccades, proportion of goal-directed saccades, and proportion of reversed-saccades (* *p* <.05).

		Test			**Group**			**Interaction**		
Measures		F	p	η_p^2	F	P	η_p^2	F	p	η_p^2
Time-normalised frequency of Saccades	**Horizontal**	15.37	.00 *	.39	4.91	.04 *	.17	11.05	.00 *	.32
	Vertical	2.73	.11	.10	0.37	.55	.02	9.03	.01 *	.27
Goal-directed Saccades	**Horizontal**	23.90	.00 *	.50	3.57	.07	.13	4.96	.04 *	.17
	Vertical	30.64	.00 *	.56	4.66	.04 *	.16	10.95	.00 *	.31
Reversed Saccades	**Horizontal**	23.90	.00 *	.50	3.57	.07	.13	4.96	.04 *	.17
	Vertical	30.64	.00 *	.56	4.66	.04 *	.16	10.95	.00 *	.31

Table 3.6. Mean (*SD*) time-normalised total eye displacement (TED), proportion of saccadic eye displacement (SAD), and proportion of smooth eye displacement (SED) for both groups in the pre-test and post-test (Tukey HSD *post-hoc* test: * *p* <.05).

	TED (°)				SAD (%)				SED (%)			
	Horizontal		Vertical		Horizontal		Vertical		Horizontal		Vertical	
Groups	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**
Practice	14.7 (3.4)	9.0 * (2.0)	13.1 (3.6)	9.0 * (3.7)	77.9 (5.8)	69.3 * (6.4)	73.4 (10.5)	63.9 (10.4)	22.1 (5.8)	30.7 * (6.4)	26.6 (10.5)	36.1 (10.4)
Control	14.1 (5.0)	13.0 (4.7)	11.0 (4.2)	11.8 (4.5)	78.7 (6.6)	75.8 (5.1)	63.2 (14.4)	60.5 (12.4)	21.3 (6.6)	24.2 (5.1)	36.8 (14.4)	39.5 (12.4)

Table 3.7. 2x2 ANOVA table for the time-normalised total eye displacement (TED), proportion of saccadic eye displacement (SAD), and proportion of smooth eye displacement (SED) (* *p* <.05).

		Test			Group			Interaction		
Measures		F	p	η_p^2	F	P	η_p^2	F	p	η_p^2
Time-normalised TED	**Horizontal**	16.17	.00 *	.40	1.65	.21	.06	7.30	.01 *	.23
	Vertical	3.53	.07	.13	0.06	.81	.00	7.46	.01 *	.24
SAD	**Horizontal**	19.19	.00 *	.44	3.59	.07	.13	4.79	.04 *	.17
	Vertical	12.52	.00 *	.34	2.35	.14	.09	3.90	.06	.14
SED	**Horizontal**	19.19	.00 *	.44	3.59	.07	.13	4.79	.04 *	.17
	Vertical	12.52	.00 *	.34	2.35	.14	.09	3.90	.06	.14

Table 3.8. Mean (*SD*) frequency for the concept categories from the condition-action statements for the practice and control group in the pre- and post-test (Tukey HSD post-hoc test: * p <.05).

	Sum		**Condition**		**Action**		**Goal**		**Evaluation**		**Do**		**Uncategorized**	
Groups	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**
Practice	6 (3)	10 (4) *	2 (1)	4 (2) *	3 (1)	5 (2) *	1 (1)	1 (1)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Control	6 (3)	6 (4)	2 (1)	2 (1)	3 (1)	3 (2)	1 (1)	1 (1)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)

Table 3.9. 2x2 ANOVA table for the frequency for the concept categories from condition-action statements for the practice and control group in the pre- and post-test (* p <.05).

	Test			**Group**			**Interaction**		
Measures	F	p	η_p^2	F	P	η_p^2	F	p	η_p^2
Sum	13.20	.00 *	.36	1.96	.17	.08	11.38	.00 *	.32
Condition	19.59	.00 *	.45	4.26	.05	.15	16.70	.00 *	.41
Action	11.35	.00 *	.32	2.69	.11	.10	7.26	.01 *	.23
Goal	0.13	.72	.01	0.63	.44	.03	1.17	.29	.05

3.2.3. Discussion

The current experiment examined perceptual-cognitive-motor processes involved in the acquisition of a dynamic, complex and novel computer-based task. Compared to the control group, the practice group increased the frequency of successful trials from pre-test to post-test by four trials. Using the difficult trials only based on findings in Experiment 2, the practice group achieved five successful trials (*SD* = 1) after 96 trials of practice, as compared to those in Experiment 2 who had four successful trials (*SD* = 2) for the difficult trials after its 32 trials during practice, demonstrating more successful and consistent performance at the post-test. The overall change in skill acquisition most likely occurred during the perceptual-cognitive-motor adaptation operating between the early to middle phase of practice, although a gradual increase of success can be seen from the middle to last phase of practice. The change in outcome performance was underpinned by a reduction in the frequency of saccades, more goal-directed saccades, reduced TED, increased smooth pursuit, and an increased frequency of condition-action pairs. Taken together, these performance and eye movement behaviours support the primary aim of Experiment 3 by describing the nature of the acquired perceptual-motor processes that develop during moderate practice at a task that requires a performer to determine visuomotor solutions akin to complex environments.

As predicted, the practice group significantly increased the frequency of condition-action statements from the pre- to post-test, whereas the control group did not modify the number between the pre- and post-test. The significant increase in condition-action pairs for the practice group between the pre- and post-test is a key finding because it indicates that in addition to the expected changes in motor outcome performance and eye behaviour, active task experience led to the development of cognitive decision making processes. Finding suggests the improvement in task performance for the practice group was facilitated in part by the generation of cognitive task solutions in the practice phase. Further protocol analysis revealed that the statements of the practice group at the post-test contained more condition and action concepts when compared to the pre-test and the control group. These findings were consistent with the previous predictions that these cognitive processes would be developed and refined in certain practice environments (McPherson 1994; McPherson & Kermode, 2003; McPherson & MacMahon, 2008), resulting in significant differences between skilled and lesser-skilled individuals in a variety of domains (Klein et al., 1995; Ward et al., 2011; Suss et al., 2014). The findings here confirm for the first time that practice involving active decision making leads to the acquisition of cognitive processes alongside the typical perceptual-motor processes shown elsewhere. These active decision making processes during practice allow participants to select and execute their action/s from two or more options based on the movements of background objects, actively engaging in searching for successful cursor trajectories. This active processes and engagement resulted in greater frequency of condition-action pairs consisting of more concepts about conditions and actions, leading to better performance in the dynamic and complex task.

The acquisition of perceptual-cognitive-motor processes is crucial for the execution of many everyday tasks. These tasks require the continuous perception and identification of relevant from irrelevant stimuli, the planning and selection of appropriate action/s from more than one available option, and action execution under time constraints. Therefore, across practice it is likely these combined processes are integrated and represented so that successful performance can be attained in dynamic and complex tasks. To examine this interplay and integration of these processes, the purpose of Experiment 4 was to systematically examine the contribution of these processes during acquisition.

3.3. Experiment 4

To systematically examine the contribution of perceptual, cognitive, and motor processes, a novel protocol was designed in which access to these processes was differentially modulated. In the pre- and post-test, all participants completed the computer-based task from Experiment 3 that was shown to require the acquisition of perceptual-cognitive-motor processes. In the practice phase, the first group practised the same task, and therefore had the opportunity to acquire perceptual-cognitive-motor processing (PCM group) by engaging in active decision making processes in order to avoid moving objects and choose successful cursor trajectories from a range of potential options. To modulate access to these processes two yoked groups practised a variation of the task where acquisition conditions were limited to perceptual-motor processes (PM group) or motor processes (M group). To modulate the active decision making component of skill acquisition, practice amended by instructing PM and M groups to control a cursor so that it remained within a circle that was presented on the screen. Importantly, the circle followed the path generated by a yoked-participant from the PCM group when actively engaged in the task and, therefore, provided the exact same trajectories towards the target. To modulate the perceptual information during practice, the PM group performed the task with the moving objects presented on the screen, whereas the objects were removed for the M group. Additionally, the demand on cognitive decision making processes in the PM task was minimised by nullifying the effect of the moving objects, thus the PM and M groups were not actively engaged to make any decision to avoid collisions. Therefore, the PM and M group were required to select and execute only pre-determined cursor trajectories during practice. They were required to follow the yellow circle without actively being engaged in selecting and executing their action/s from two or more options based on the movements of background objects.

It was hypothesised that there should be no between-group differences in the pre-test. If successful performance at this task requires the active interplay of perceptual-cognitive-motor processes, it was expected that the PCM group would reach the target in more trials in the post-test than the PM and M groups because the latter experienced a decoupling between the perceptual and/or decision making processes during practice. Moreover, the PCM and PM groups were expected to have more goal-directed eye movement in the post- compared to the pre-test because they had the similar visual information available during practice, whereas the M group would not change their visual search behaviours because they had no information about the moving objects. The PCM group were expected to have a higher frequency of condition-action pairs, when compared to the PM and M groups, because of greater engagement in decision making processes during practice.

3.3.1. Methods

Participants

Thirty-nine participants (M = 21.6 years of age, SD = 1.9) who were novel to the task and procedure volunteered to participate. The experiment exclusion criteria and protocol was the same as Experiment 3. All participants were assigned to one of three practice groups defined as: perceptual-cognitive-motor processing (PCM) (n = 13); perceptual-motor processing (PM) (n = 13); or motor processing (M) (n = 13). The three groups were matched for gender (Male = 11, Female = 2), age (PCM M = 21.0 years of age, SD = 2.3; PM M = 21.6 years of age, SD = 1.1; M M = 22.1 years of age, SD = 2.1), and computer-game playing experience (PCM M = 3616.7 hrs, SD = 1946.4; PM M = 4006.1 hrs, SD = 2775.1; M M = 3570.3 hrs, SD = 1731.2). Separate one-way ANOVAs on each of these variables showed no between-group differences (all F < 1.1). All participants had normal or corrected-to-normal vision and were right handed. They completed an informed consent form before taking part in this experiment. All procedures were conducted in accordance to the ethical guidelines of Liverpool John Moores University and the 1964 Declaration of Helsinki.

Apparatus and task

The experimental set up and apparatus was the same as Experiment 3, as was the task for the perceptual-cognitive-motor (PCM) group (see Figure 3.10a). The two other groups practised variations of the PCM task, namely the perceptual-motor (PM) task and motor (M) task represented in Figure 3.10b and 3.10c, respectively. The main aim of the PM and M task was for participants on each trial to move the white cursor (circle diameter of 2.1 cm) from a corner of the computer screen and keep it within a yellow circle (diameter of 6.4 cm) as it automatically moved across the screen towards the red target in the diagonal corner (see Figure 3.10b & 3.10c). In order to ensure that the white cursor movements of the three groups during the practice phase would be the same or similar, participants in the PM and M group were yoked with a partner participant in the PCM group. The white cursor movements of the PCM participant from their practice trials were converted into the yellow circle movements for the practice trials of their yoked partner in the PM and M group. The participants in the PM and M group were required to keep their own cursor within the yellow experimental circle during their practice. The demand on cognitive decision making processes in the PM task was minimised by reducing the effect of the moving objects. That is, the trial did not end when the white cursor touched a green object, so the task did not involve making decisions related to avoidance. The M task reduced the demand on both perceptual and cognitive processing by showing only the white cursor, red target, and the yellow circle. The M task did not contain moving green objects, so that there was no need to select or execute decisions to avoid them. Therefore, the PCM and PM task contained essentially the similar perceptual information, whereas the M task contained only perceptual information related to cursor movement (see Figure 3.10).

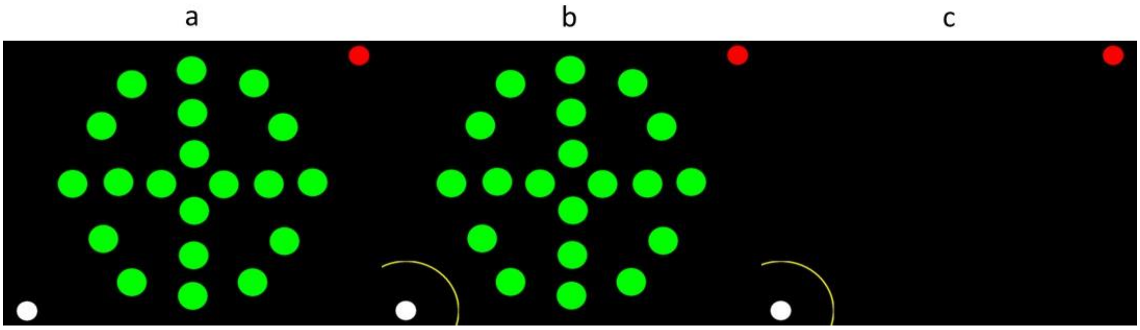

Figure 3.10. (a) The perceptual-cognitive-motor (PCM) computer-based task, (b) the perceptual-motor (PM) computer-based task, and (c) the motor (M) computer-based task.

Procedure

Experiment 4 consisted of a pre-test, practice phase and post-test. All participants completed eight trials of the PCM task in the pre-test. Next, the PM and M group received an illustration and pre-scripted instructions regarding their respective tasks. No additional explanation or instructions were given to the PCM group. In the practice phase, each group completed 96 practice trials of their task, organised as 12 blocks of eight trials. After the practice phase, all participants completed eight trials of the PCM task in the post-test. The current experiment was conducted to examine the effect of encoding and processing activities during practice on the skill acquisition and performance at the post-test. Therefore, this experiment did not contain retention or transfer-tests, which are used to determine learning and performance-learning dichotomy (Kantak & Winstein, 2012). Eye-movements and retrospective reports of cognition were collected using the same procedures as in Experiment 3.

Data analysis

The data analysis was the same as Experiment 3. The reliability of the coding system for the condition-action statements was established using the intra-observer (95.2%) and inter-observer (87.8%) agreement methods as in Experiment 3. Additionally, in order to quantify how well both PM and M groups had tracked the white cursor movements of their yoked partner in the PCM group during the practice phase, successful trial duration (s) was calculated by measuring the time duration the white cursor was inside of the yellow circle across each trial. The proportion of successful movement duration (%) was calculated by dividing the successful trial duration the white cursor was inside of the yellow circle by the trial duration. These can refer to the ability to replicate the cursor movements of their yoked partner temporally and spatially during practice. To quantify task performance in the practice phase, dependent variables for the three groups, which were the frequency of successful trials for the PCM group, and the successful trial duration and proportion of successful movement duration for both PM and M groups, were analysed using separate one-way ANOVAs, with phase (early, middle, and late phase of the practice) as a repeated measure. The Bonferroni *post-hoc* procedure was used in the event of significant within-participant main effects. Furthermore, to quantify the skill acquisition, dependent variables were analysed using 3 Group (PCM, PM, M) x 2 Test (Pre-, Post-test) analysis of variance (ANOVA) with repeated measures on the test factor. The Bonferroni *post-hoc* procedure was used for any significant within-participant main effect, and Tukey HSD *post-hoc* tests were used to determine the origin of any significant interaction. Partial eta squared (η_p^2) was used as a measure of effect size. Statistical significance for all tests was set at p <.05.

3.3.2. Results

Practice

A main effect of phase, $F(2, 24) = 12.62$, $p < .05$, $\eta_p^2 = 51$, indicated the PCM group significantly increased the frequency of successful trials from the early ($M = 12$ trials, $SD = 4$) to the middle phase ($M = 16$ trials, $SD = 4$), but there was no further significant increase between the middle and late phase ($M = 18$ trials, $SD = 4$).

ANOVAs for the PM group revealed a significant main effect of phase for successful trial duration, $F(2, 24) = 17.53$, $p < .05$, $\eta_p^2 = .59$, and the proportion of successful movement duration, $F(2, 24) = 4.01$, $p < .05$, $\eta_p^2 = .25$. The PM group significantly increased successful trial duration from the early ($M = 3.0$ s, $SD = 0.7$) through the middle ($M = 3.4$ s, $SD = 0.9$) to the late phase ($M = 3.8$ s, $SD = 0.9$). In addition, there was no significant difference between the early ($M = 84.2$ %, $SD = 8.9$) and middle phase ($M = 84.1$ %, $SD = 7.7$), but the proportion of successful movement duration was increased from the middle to the late phase ($M = 87.1$ %, $SD = 5.9$). ANOVAs for the M group revealed a significant main effect of phase on successful trial duration, $F(2, 24) = 14.79$, $p < .05$, $\eta_p^2 = .55$, and the proportion of successful movement duration, $F\ (2, 24) = 3.39$, $p = .05$, $\eta_p^2 = .22$. The M group significantly increased successful trial duration from the early ($M = 3.0$ s, $SD = 0.8$) through the middle ($M = 3.4$ s, $SD = 1.0$) to the late phase ($M = 3.8$ s, $SD = 0.9$). In addition, there was no significant difference between the early ($M = 85.7$ %, $SD = 8.6$) and middle phase ($M = 84.9$ %, $SD = 8.7$), but again the proportion of successful movement duration was greater in the late ($M = 87.2$ %, $SD = 8.1$) compared to the middle phase. Both PM and M groups significantly improved the task performance on their own task during practice, and kept the white cursor inside the yellow circle for more than 80 % of the trial duration throughout the practice phase. Therefore, their cursor movements were similar to the cursor movements of their yoked partner in the PCM group.

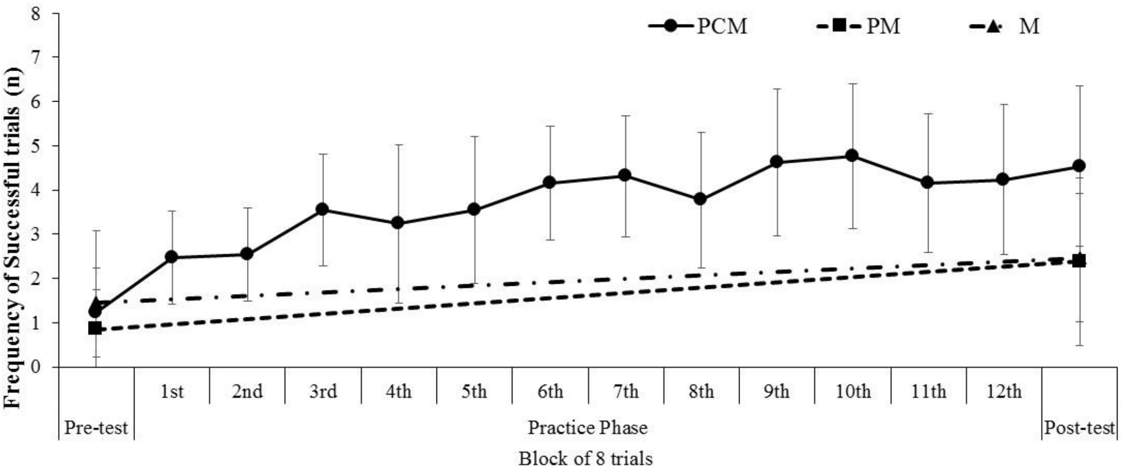

Figure 3.11. Mean (SD) frequency of successful trials for the perceptual-cognitive-motor processing (PCM), perceptual-motor processing (PM), and motor processing (M) group at the pre-test, practice phase, and post-test.

Skill acquisition

Task performance

Figure 3.11 shows the frequency of successful trials in the pre- and post-test for the PCM, PM and M group. ANOVA revealed a significant main effect of test, $F(1, 36) = 41.65$, $p < .05$, $\eta_p^2 = .54$, group, $F(2, 36) = 4.16$, $p < .05$, $\eta_p^2 = .19$, and a group x test interaction, $F(2, 36) = 5.33$, $p < .05$, $\eta_p^2 = .23$. In the pre-test, there was no significant difference in successful trials between the PCM (M = 1 trials, SD = 1), PM (M = 1 trials, SD = 1), and M group (M = 1 trials, SD = 2). In the post-test the PCM group (M = 5 trials, SD = 2) reached the target in significantly more trials than the PM (M = 2 trials, SD = 2) and M group (M = 2 trials, SD = 1). There was no significant difference between the PM and M groups in the post-test.

Visual search behaviours

Descriptive (Table 3.12) and inferential (Table 3.13) statistics are shown for the time-normalised frequency of saccades, as well as the proportion of goal-directed and reversed saccades. In the pre-test, there were no differences between groups in the frequency of saccades in either the horizontal and vertical direction. In the post-test, the frequency of saccades in the horizontal direction was significantly lower compared to the pre-test for all groups. In the vertical direction, only the PCM and PM group had a lower frequency of saccades in the post- compared to pre-test. In terms of the characteristics of saccades in the pre-test, there were no differences between groups in the proportion of goal-directed saccades in either the horizontal and vertical direction. However, the proportion of goal-directed saccades in the horizontal direction was significantly greater in the post-test compared to the pre-test for all groups. In the vertical direction, the PCM and PM group had a greater proportion of goal-directed saccades in the post-test compared to pre-test.

Table 3.14 shows the time-normalised TED, and the proportion of SAD and SED for the three groups in the pre- and post-test. Table 3.15 shows the inferential statistics for these dependent variables. In both horizontal and vertical directions, there were no significant differences between groups in TED in either the pre- or post-test. In the post-test, TED was significantly lower compared to the pre-test for all groups. There were no differences between groups in the proportion of SAD and SED in both horizontal and vertical directions in either the pre- or the post-test. In the post-test, the proportion of SAD was significantly lower compared to the pre-test for all groups, whereas the proportion of SED was significantly greater in the post-test compared to the pre-test for all groups.

Table 3.12. Mean (*SD*) time-normalised frequency of saccades, proportion of goal-directed saccades, and proportion of reversed-saccades for the three groups in the pre-test and post-test (Tukey HSD *post-hoc* test: * p <.05).

	Frequency of Saccades (n)				**Goal-directed Saccades (%)**				**Reversed Saccades (%)**			
	Horizontal		**Vertical**		**Horizontal**		**Vertical**		**Horizontal**		**Vertical**	
Groups	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**
PCM	3.6 (1.1)	2.8 (0.8)	3.2 (1.0)	2.4 * (0.7)	63.1 (5.9)	70.8 (5.3)	67.0 (7.5)	77.3 * (6.5)	36.9 (5.9)	29.2 (5.3)	33.0 (7.5)	22.7 * (6.5)
PM	4.3 (0.9)	3.4 (0.7)	3.8 (0.9)	3.0 * (0.6)	59.5 (5.3)	70.2 (5.5)	64.2 (10.6)	75.3 * (7.2)	40.5 (5.3)	29.8 (5.5)	35.8 (10.6)	24.7 * (7.2)
M	3.7 (0.6)	3.6 (1.3)	3.2 (0.8)	3.3 (1.2)	59.6 (8.2)	65.8 (7.8)	67.6 (7.1)	72.1 (7.5)	40.4 (8.2)	34.2 (7.8)	32.4 (7.1)	27.9 (7.5)

Table 3.13. 3x2 ANOVA table for the time-normalised frequency of saccades, proportion of goal-directed saccades, and proportion of reversed-saccades (* p <.05).

		Test			**Group**			**Interaction**		
Measures		F	p	η_p^2	F	P	η_p^2	F	p	η_p^2
Time-normalised frequency of Saccades	**Horizontal**	12.81	.00 *	.26	2.54	.09	.12	2.50	.10	.12
	Vertical	11.27	.00 *	.24	2.65	.08	.13	3.92	.03 *	.18
Goal-directed Saccades	**Horizontal**	61.69	.00 *	.63	1.87	.17	.09	1.64	.21	.08
	Vertical	73.51	.00 *	.67	0.47	.63	.03	4.17	.02 *	.19
Reversed Saccades	**Horizontal**	61.69	.00 *	.63	1.87	.17	.09	1.64	.21	.08
	Vertical	73.51	.00 *	.67	0.47	.63	.03	4.17	.02 *	.19

Table 3.14. Mean (*SD*) time-normalised total eye displacement (TED), proportion of saccadic eye displacement (SAD), and proportion of smooth eye displacement (SED) for the three groups in the pre-test and post-test (Tukey HSD *post-hoc* test: * p <.05).

	TED (°)				**SAD (%)**				**SED (%)**			
	Horizontal		**Vertical**		**Horizontal**		**Vertical**		**Horizontal**		**Vertical**	
Groups	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**
PCM	13.3 (4.4)	9.7 (2.6)	11.7 (4.8)	8.1 (2.2)	77.2 (4.0)	73.1 (7.5)	69.7 (8.3)	62.2 (11.4)	22.8 (4.0)	26.9 (7.5)	30.3 (8.3)	37.8 (11.4)
PM	15.8 (5.1)	10.6 (2.7)	13.3 (5.1)	9.8 (2.9)	79.6 (5.2)	74.7 (6.4)	71.5 (9.2)	64.8 (10.7)	20.4 (5.2)	25.3 (6.4)	28.5 (9.2)	35.2 (10.7)
M	15.0 (4.8)	14.5 (6.4)	12.4 (4.6)	11.4 (5.7)	78.5 (6.0)	77.5 (7.6)	70.7 (8.0)	68.7 (9.7)	21.5 (6.0)	22.5 (7.6)	29.3 (8.0)	31.3 (9.7)

Table 3.15. 3x2 ANOVA table for the time-normalised total eye displacement (TED) and the proportion of saccadic eye displacement (SAD), and proportion of smooth eye displacement (SED) (* p <.05).

		Test			**Group**			**Interaction**		
Measures		F	P	η_p^2	F	P	η_p^2	F	p	η_p^2
Time-normalised TED	**Horizontal**	16.02	.00 *	.31	2.35	.11	.12	2.94	.07	.14
	Vertical	20.68	.00 *	.37	0.95	.40	.05	1.92	.16	.10
SAD	**Horizontal**	10.52	.00 *	.23	0.96	.39	.05	1.35	.27	.07
	Vertical	11.80	.00 *	.25	0.67	.52	.04	1.19	.32	.06
SED	**Horizontal**	10.52	.00 *	.23	0.96	.39	.05	1.35	.27	.07
	Vertical	11.80	.00 *	.25	0.67	.52	.04	1.19	.32	.06

Cognitive processes

Figure 3.16 shows the frequency of condition-action pairs in the pre- and post-test for the PCM, PM and M group. ANOVA on the statements revealed a significant main effect of test, $F(1, 36) = 4.87$, $p < .05$, $\eta_p^2 = .12$, no effect of group, $F(2, 36) = 3.18$, $p < .1$, $\eta_p^2 = .15$, but a significant group x test interaction, $F(2, 36) = 7.71$, $p < .05$, $\eta_p^2 = .30$. In the pre-test, there were no significant differences in the frequency of condition-action statements between the three groups (PCM $M = 3$ statements, $SD = 1$; PM $M = 3$ statements, $SD = 1$; M $M = 3$ statements, $SD = 1$). In the post-test, the PCM group had a higher frequency of condition-action statements compared to the pre-test ($M = 4$ statements, $SD = 2$), whereas there was no significant difference for the other two groups between the pre- and the post-test (PM $M = 2$ statements, $SD = 1$; M $M = 3$ statements, $SD = 1$).

Descriptive (Table 3.17) and inferential (Table 3.18) statistics are presented for the concept categories from the condition-action statements in the pre- and post-test. At the pre-test, there was no significant difference between groups for the sum of five major concepts. At the post-test, the PCM group had a significantly greater sum of the major concepts when compared to the PM and M group, whereas both PM and M groups did not increase the sum between tests. Moreover, the frequency of statements containing information about the concepts of do and unrecognised was zero, so these categories were removed from further analysis. There was no significant difference between groups in the frequency of condition and action concepts at pre-test. However, the PCM group significantly increased the frequency of these two concepts from the pre-test to post-test, while the PM and M group did not increase the frequency of these concepts between tests.

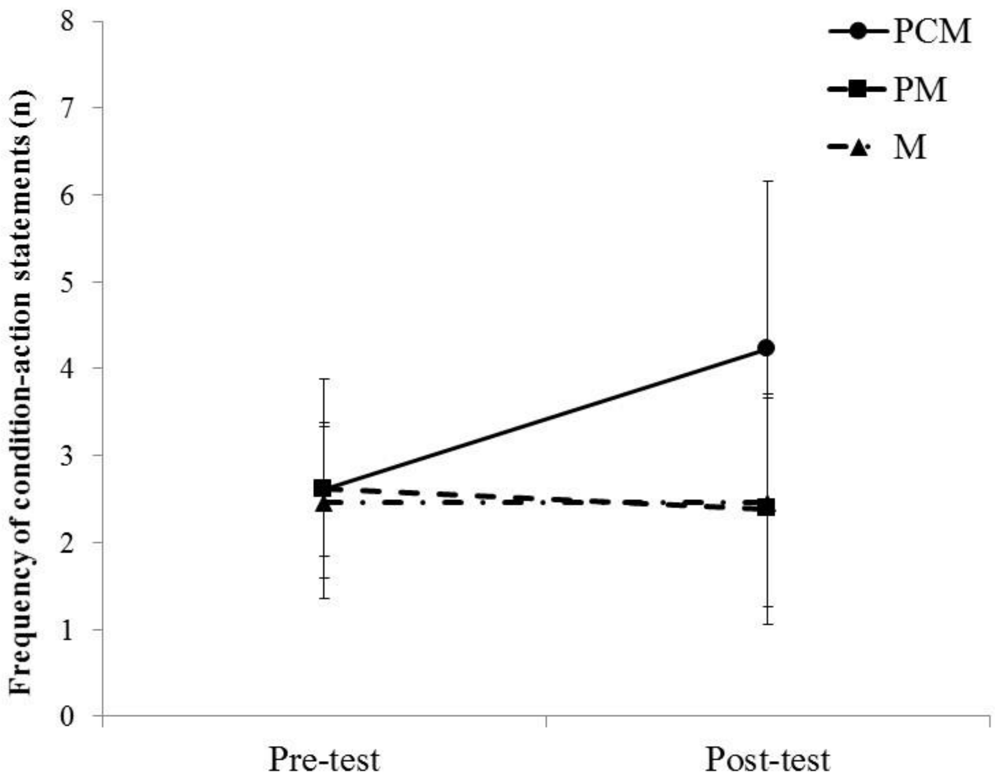

Figure 3.16. Mean (SD) frequency of condition-action statements for the perceptual-cognitive-motor processing (PCM), perceptual-motor processing (PM), and motor processing (M) group in the pre-test and post-test.

Table 3.17. Mean (*SD*) frequency for the concept categories from the condition-action statements for the three groups in the pre- and post-test (Tukey HSD *post-hoc* test: ***** *p* <.05).

	Sum		**Condition**		**Action**		**Goal**		**Evaluation**		**Do**		**Uncategorized**	
Groups	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**
PCM	6 (3)	11 (5) *	3 (1)	4 (2) *	3 (2)	5 (3) *	0 (1)	1 (1)	0 (0)	1 (2)	0 (0)	0 (0)	0 (0)	0 (1)
PM	6 (2)	5 (3)	3 (1)	2 (1)	3 (1)	2 (2)	0 (0)	0 (0)	0 (1)	0 (1)	0 (0)	0 (0)	0 (1)	0 (1)
M	6 (3)	6 (3)	2 (1)	3 (1)	3 (1)	3 (1)	1 (1)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)

Table 3.18. 3x2 ANOVA table for frequency for the concept categories from the condition-action statements for the three groups in the pre- and post-test (***** *p* <.05).

	Test			**Group**			**Interaction**		
Measures	F	p	η_p^2	F	P	η_p^2	F	p	η_p^2
Sum	9.00	.01 *	.20	4.77	.02 *	.21	9.91	.00 *	.36
Condition	3.98	.05	.10	2.52	.10	.12	4.90	.01 *	.21
Action	7.68	.01 *	.18	4.71	.02 *	.21	7.78	.00 *	.30
Goal	0.70	.41	.02	1.81	.18	.09	5.56	.01 *	.24
Evaluation	1.89	.18	.05	0.76	.47	.04	0.63	.54	.03

3.3.3. Discussion

The aim of this experiment was to systematically examine the contribution of perceptual, cognitive, and motor processes during skill acquisition. As expected, there were no between-group differences in the frequency of successful trials in the pre-test. In the post-test, the PCM group reached the target in significantly more trials compared to the pre-test, as well as compared to the post-test of the PM and M groups. These between-group differences were found, even though all groups improved the performance on their own task and were exposed to similar cursor movement patterns in the practice phase. With respect to the underlying mechanisms, there were no between-group differences in pre-test in visual search behaviours and cognitive processes. In the post-test the PCM and PM groups demonstrated similar visual search behaviours characterised by a lower frequency of saccades and more goal-directed saccades. In contrast, the M group did not change their visual search behaviours from the pre- to post-test. The PCM group also acquired a higher frequency of condition-action pairs and concepts in the post-test compared to the pre-test, whereas the PM and M group exhibited no change. These findings are consistent with the suggestion that practice leads to the development of perceptual-cognitive-motor processes that need to be integrated through practice, and moreover that modulating the availability of visual information and constraining cognitive decision making leads to no or less skill acquisition. When a task requires the integration of perceptual-cognitive-motor processes for successful performance, these processes must be integrated during practice for skill acquisition, whereas decoupling and limiting of these processes during practice limits skill acquisition.

3.4. General discussion

Much is known about sensorimotor learning in perceptual-motor tasks that demand a coordinated contribution from feedback and feedforward processes to continually monitor and update behaviour (Elliott et al., 2010; Wolpert & Kawato, 1998). However, there has been little consideration of dynamic and complex tasks where the performer must make decisions to select an appropriate action to execute from more than one available option. Therefore, the current study examined the acquisition of perceptual-cognitive-motor processes required for successful performance on a novel computer-based task that did not demand or facilitate responding with a single movement path. Across two experiments, findings demonstrate that practice with the availability of task specific sensory information and cognitive processes enabled participants to significantly improve the frequency of successful trials. The pre- and post-test comparisons between groups in Experiment 3 showed that the practice group demonstrated superior task performance when compared to the control group as a function of practice rather than task familiarization. The practice group modified their visual search behaviours such that they exhibited more goal-directed saccades and a greater contribution from smooth pursuit in the post-test. These findings are consistent with sensorimotor research that has shown changes in task performance and underlying perceptual-motor processes as a function of practice (Imamizu et al., 2000; Kording & Wolpert, 2004; Sailer et al., 2005; Todorov, 2004; Wolpert et al., 2011). As predicted, practice led to the development of cognitive processes in the form of a greater number of reported condition-action pairs, and thus an increased contribution from decision making processes for the practice group compared to the control group (Anderson, 1982; Anderson et al., 2004; Neves & Anderson, 1981).

Next, pre- and post-test data in Experiment 4 was compared to determine whether constraining the underlying processes influences skill acquisition. Firstly, the

PCM group experienced the same conditions as the practice group in Experiment 3 and thus had the opportunity to acquire perceptual-cognitive-motor processing during practice. They exhibited differences between pre- and post-test showing that they increased task success and modified visual search behaviours and cognitive decision making processes. Specifically, visual search behaviours in the post-test consisted of lower TED, a lower frequency of saccades, more goal-directed saccades, and more smooth pursuit compared to the pre-test. These acquired visual search behaviours are consistent with those reported by Sailer et al. (2005), who showed practice of a manual aiming task led to fewer saccades overall and reduced TED, as well as increased saccades that shifted visual attention towards desired cursor locations (i.e., goal-directed). In addition, here it was shown that there was an increased reliance on smooth pursuit eye movements (i.e., greater proportion of SED from the pre- to post-test), which could be functional in this task as it keeps visual attention near to the moving cursor and maintains awareness of the immediately surrounding moving objects.

Keeping visual attention near to surrounding objects is most likely a developed strategy that ensures visuo-spatial awareness required for making decisions to attain task success. This is consistent with the finding of an increased number of condition-action pairs and concepts in the post- compared to pre-test for the PCM group. The development of cognitive decision making processes is consistent with ACT theory, and the proposal that modulating processes underpinning skill acquisition will lead to both changes in experience-dependent perceptual-motor ability, and cognition (Anderson, 1982; Anderson et al., 2004; Neves & Anderson, 1981). Specifically, the development of these condition-action pairs and concepts in the PCM group most likely contributed to successful performance by providing rule-governed processes used to match certain task conditions with the appropriate visual and/or motor actions (McPherson & Thomas, 1989). Further protocol analysis suggested that the active decision making processes during practice enabled participants to develop knowledge based and domain-related strategies (i.e., action plan profile & current event profile) along-side typically found perceptual-motor processes, particularly increasing the frequency of condition and action concepts (McPherson & Kernodle, 2003). In the present task, therefore, these processes would include strategies to monitor current conditions (e.g., cursor position; object/s location) with respect to previous successful or unsuccessful attempts at attaining the desired goal and selecting and executing action/s from two or more options based on the movements of the background objects (McPherson & Thomas, 1989; McPherson & MacMahon, 2008; McPherson & Kernodle, 2003).

Secondly, comparisons between pre- and post-test for the PM and M group indicated no increase in the frequency of successful trials, and confirmed that performance was significantly less accurate to the PCM group at post-test. Therefore, practice in the PM and M conditions led to specific sensorimotor behaviour that was not immediately transferable to the PCM condition, which required different sensorimotor processes to be engaged in order to be successful (see also Proteau & Cournoyer, 1990; Proteau et al., 1992; Robin et al., 2005). Transfer-appropriate processing following task specific practice was further evident in the eye movement and decision making data. The PM group, who had the similar visual information during practice as the PCM group, reduced the frequency of saccades and used more goal-directed saccades from the pre- to post-test in a similar manner to the PCM group. Although participants in the PM group did not have to avoid the objects, it is likely that they would have noticed that the yellow circle was dodging the objects as it moved towards the target. Therefore, participants may have found it useful to direct overt visual attention, and thus eye movements towards the moving objects in order to help anticipate where the yellow circle would be heading. In contrast, the visual search behaviours of the M group, who were not presented with the moving objects during practice, did not differ between pre-and post-test. Moreover, both the PM and M group did not have to make decisions during practice to avoid the moving objects and select successful cursor trajectories, and subsequently did not increase the amount of condition-action pairs and concepts from pre- to post-test. The PM and M group were required to select and execute only pre-determined options during practice, following the yellow circle without actively being engaged in selecting and executing their action/s from two or more options based on the movements of background objects.

Together, these findings show for the first time that the acquisition of visual search behaviours and cognitive processes in the form of condition-action pairs and concepts was specific to the available sensory information and processing required during practice. So, although the PM group may have acquired similar visual processing to the PCM group, the decoupling of such processing for cognitive decision making during practice did not facilitate successful skill acquisition for the post-test. In fact, post-test performance of the PM group was not different to the M group, thus showing that active decision making, active action generation, and perception-action coupling during practice (i.e., PCM group) was a key element to successful behaviour in this task, rather than following of the cursor. Systematically limiting and constraining necessary underlying processes of task performance, particularly visual sensory information and decision making processes, attenuated skill acquisition for the PM and M group, even though these groups improved performance on their own task during practice and were exposed to the similar motor process of the cursor movement to their yoked partners in the PCM group. It is suggested that, when a task requires the acquisition of perceptual-cognitive-motor processes to be successful, as in many real-word tasks and domains, integration of these processes during practice would be necessary for skill acquisition, whereas decoupling of these processes during practice would limit skill acquisition.

In summary, the findings presented in this chapter demonstrate that the novel complex aiming task was better acquired and transferred under conditions that facilitated of the necessary perceptual-cognitive-motor processes. While this might not always be possible to practice a task under the conditions that simulate latter demands on perceptual-cognitive-motor processes, it should be recognised that limiting necessary sensory information and decoupling cognitive processing could attenuate skill acquisition. Future research could investigate whether the integrated underlying processes would be specific to a task or transferrable to a different task, which would require the integration of the same processes but differs in the task goal or intention, thereby demonstrating transfer of learning effect.

Chapter 4

Transfer of perceptual-cognitive-motor processes underlying complex performance

4.1. Introduction

The ability to successfully apply and adapt acquired skills and previous experiences to new contexts is key to all human activities. For example, while driving a car, constraints such as changing traffic flow or weather conditions require the driver to use previous driving experiences and transfer these experiences to the present situation in order to manoeuvre the vehicle successfully (Underwood, 2007). This phenomenon is known as *transfer of learning*, and refers to the ability to transfer or adapt prior experiences to current or future contexts (Thorndike & Woodworth, 1901).

The concept of transfer of learning holds that an individual who acquires successful performance in one task or domain can transfer it into another task, context or domain (Duncan 1953). It involves the capability to use and adapt prior experiences from performance and learning in one context to similar or dissimilar contexts (Collard et al., 2007). A theory based on memory research that attempt to explain transfer and how it occurs, is *transfer-appropriate processing.* This theory holds that transfer of learning will occur when information processing between the learning and transfer domain is similar (Morris, Bransford, & Franks, 1977; Lee, 1988). Researchers examining the contextual interference effect (e.g., Shea & Morgan, 1979; Shea & Zimny, 1983; Shea & Zimny, 1988) have provided some support for the transfer-appropriate processing hypothesis. For example, Shea and Morgan (1979) examined the influence of random and blocked practice structures on the acquisition of an upper-limb sequential aiming task. They required participants to learn three sequential movement patterns to knock-down barriers. A blocked group completed all trials of practice for one pattern before attempting another pattern. The random group practiced the three different movement patterns in a randomised order with no more than two consecutive attempts at the same movement pattern. At transfer-tests, one half of the participants in each group performed the same sequential task in a random order, while the remaining half in each group completed a blocked order. Under the random transfer-condition, the random group performed the task better than the blocked group. More importantly, under the blocked transfer-condition, the random group was also superior compared to the blocked group. Based on the notion of elaborative processing or action-plan reconstruction, the suggestion was that processing activities during the random practice were more similar and/or appropriate to those required in the transfer-conditions.

There is a lot of research that has examined transfer of learning and how this would occur based on the notion of identical elements (Abernethy et al., 2005; Causer & Ford, 2014; Moore & Muller, 2014; Rosalie & Muller, 2014; Smeeton et al., 2004) and general principles (O'keeffe et al., 2007; Rienhoff et al., 2013). However, there has been little, if any, empirical work to systematically examine the role of information processing during practice for the transfer of perceptual-motor tasks that require decision making processes in a dynamic and complex task where the performer must decide upon an appropriate action to execute from more than one available option (Klein et al., 1995). Therefore, the aim of the current study was to investigate the transfer of processes acquired following practice of two novel computer-based tasks. Findings in Chapter 3 revealed that when a task requires the acquisition of perceptual-cognitive-motor processes to be successful, integration of these processes during practice is necessary for effective skill acquisition, whereas decoupling of these processes during practice results in limited skill acquisition. Yet, Chapter 3 did not include a transfer-test to examine the transfer of acquired processes to a different task. Here, then, participants were required to move a cursor across the screen in order to reach a target whilst avoiding random moving objects, or to move a cursor around the screen in order to avoid random moving objects for as long as possible. Although the goal differed between tasks, both required the acquisition of similar perceptual-cognitive-motor processes in order to select and complete successful cursor trajectories from multiple potential options. In addition, a yoked version of both tasks was included with the intention of limiting cognitive decision making processes by externally guiding a cursor trajectory and nullifying the effect of moving objects. Three experiments were conducted to examine the transfer effect between the first and second task, as well as the effect on transfer of limiting cognitive processing during acquisition. Based on the transfer-appropriate processing hypothesis, it was expected that, when the acquired perceptual-cognitive-motor processing during practice was similar between the two tasks, there would be a positive transfer effect which leads to a better task performance on a different task. However, when the acquired perceptual-motor processing was similar, but there was limited cognitive processing in the form of decision making, it was expected that there would be little or no positive transfer effect between the tasks.

4.2. Experiment 5

4.2.1. Methods

Participants

Participants were 24 undergraduate students (*M* = 19.9 years of age, *SD* = 0.8), and were pseudo-randomly assigned to two groups ($n = 12$). The two groups were matched for gender (Male = 11, Female = 1), age (*M* = 19.6 years of age, *SD* = 0.7; *M* = 20.3 years of age, *SD* = 0.9), and computer-game playing experience (*M* = 4200.6 hrs, *SD* = 1664.0; *M* = 4713.9 hrs, *SD* = 2177.6). Separate independent *t*-tests on each of these variables showed no between-group differences (all $t < 1.5$). All participants had normal or corrected-to-normal vision and were right-handed. The experiment exclusion criteria and protocol was the same as Experiment 1 (see Chapter 2). Participants completed an informed consent form before taking part in this experiment. All procedures were conducted in accordance to the ethical guidelines of Liverpool John Moores University and the 1964 Declaration of Helsinki.

Apparatus and task

The experimental set up and apparatus was the same as Experiment 1 (see Chapter 2). Two main tasks were used for the experiment that involved visual stimuli being shown on the monitor that interfaced with the digitising tablet and stylus (see Figure 4.1). Both tasks were realised in the same manner as Experiment 1 (see Chapter 2). One of the tasks was the same as Experiment 3 (see Chapter 3). The goal of this task was for participants on each trial to move the cursor from one corner of the computer screen to a red circle target located in the diagonal corner of the screen while avoiding any collision with number of green objects (see Figure 4.1a). It was termed the *target task*. The goal of the second task was for participants on a trial to move the white cursor (represented by one white circle on the screen with the diameter of 2.1 cm), which was controlled by movement of the stylus on the digitising tablet, to avoid for as long as possible up to 10 seconds all of 20 green objects (diameter of 3.1 cm) that were moving around the screen in pseudo-randomised linear trajectories (see Figure 4.1c). This was termed the *no target task*. If the white cursor touched one of the green objects on the screen during a trial on either task, the trial ended and was deemed unsuccessful. If the white cursor reached the red target on the target task, or if the white cursor did not contact any green object for 10s on the no target task, the trial ended and was recorded as successful. Although one main difference between both tasks was whether a task had a particular directional goal, the characteristics of moving stimuli (i.e. sizes, trajectories, and numbers of the objects) were identical between the target and no target task.

In addition, in the same manner as Experiment 4 (see Chapter 3), a variation of the target task was created designed to limit, modify or constrain cognitive processing, such as the decision making that was occurring in the target task. This was termed the *target-yoked task,* and the main aim was for participants on each trial to move the white cursor from a corner of the computer screen and keep it within a yellow circle as it automatically moved across the screen towards the red target (see Figure 4.1b). In this task, the trajectory of the yellow circle was yoked to the cursor trajectories of a participant in the target group. The demand on cognitive decision making processes in the yoked task was minimised by nullifying the effect of the moving objects. That is, the trial did not end when the white cursor touched a green object, so the task did not involve making decisions related to avoidance. Therefore, the target-yoked task contained essentially the same perceptual and motor processing, but limited cognitive decision making processing as there was no requirement to select successful cursor trajectories from a range of potential options (see Figure 4.1).

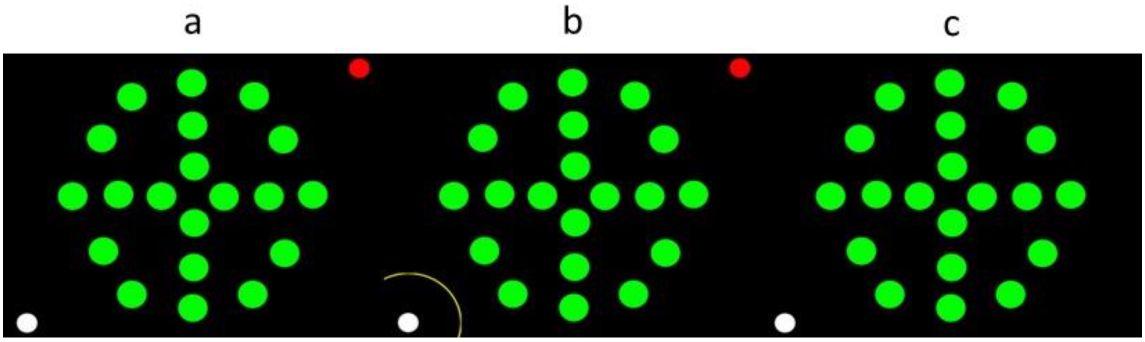

Figure 4.1. (a) The target task, (b) the target-yoked task, and (c) the no target task.

Procedure

The experiment consisted of two pre-tests, a practice phase, two post-tests, and a transfer-test. The pre- and post-tests each contained two counterbalanced blocks of trials in the target (n=8) and target-yoked (n=8) task. The order of the eight trials differed in the pre- compared to post-test, but was the same for all participants. During the practice phase, one group engaged in the target task and the other group engaged in the target-yoked task. Each group completed 96 practice trials of their task, organized as 12 blocks of eight trials. Participants had a 60-second break after every four blocks of trials. Participants in the second group were yoked with a partner participant in the target group to ensure that the white cursor movements of two groups during the practice phase would be the same or similar. The white cursor movements of each participant in the target group from their practice trials were converted into the yellow circle movements for the practice trials of their yoked partner in the other group. For the pre- and post-test, the target-yoked task was created by converting the white cursor movements of the lead experimenter into yellow circle movements, so that all participants experienced identical conditions. The target-yoked task in both the pre- and post-test were included in an attempt to reduce the importance of and interfere with the knowledge the target-yoked group might acquire in the pre-test about the main target task, as well as to reduce any effect of task switching from one to another task (see Chapter 3). Following the post-tests, all groups completed eight trials of the no target task in the transfer-test. No augmented feedback was provided to the participants. Eye-movements and retrospective reports of cognition were collected using the same procedures as in Experiment 3 (see Chapter 3).

Before the pre-test and transfer-test, participants received an illustration of the screen layout for the target and target-yoked task (i.e., objects, target, cursor, and task goal) and pre-scripted instructions regarding the goal of the tasks. They were unaware of either the gain relationship of the white cursor movement or the amount of different movement patterns of the green objects. Additionally, they were unaware of the task used as a transfer-test until they completed the post-tests.

Data analysis

Task performance

The primary dependent variable of the target and no target task was the frequency of successful trials in which the cursor reached the red target (target task) or in which the cursor did not contact an object for 10s (no target task). In addition, mean trial duration was recorded for the no target task. It was defined as the time from when the participants were allowed to move the cursor at the start of the trial to the end of the trial. In order to quantify task performance on the yoked task, successful trial duration (s) was calculated by measuring the time duration the white cursor was inside of the yellow circle across each trial, and the proportion of successful movement duration (%) was calculated by dividing the successful trial duration by the trial duration which the yoked partner in the target group spent each trial, with higher scores indicating greater success. The practice phase data was divided into early, middle, and late phases, each of which contained 32 trials.

Visual search and cognitive processes

The data analysis of visual search and cognitive processes was the same as Experiment 3 (see Chapter 3) with one exception. In both horizontal and vertical axes, saccades were labelled *goal-directed* on the target task when their velocity peak was directed toward the target location or *forward-directed* on the no target task when their velocity peak was the opposite from the starting location, whereas in all other instances they were labelled as *reversed*. The characteristics of the goal-directed and forward-directed saccades were identical. The data reliability of the coding system of the condition-action statements was established using the intra-observer (95.9%) and inter-observer (89.9%) agreement methods as in Experiment 3. Additionally, in order to reduce any effect of expectations and interfere with the knowledge of the primary and yoked task, eye-movements and condition-action pairs were collected for all participants at the pre-test and post-test of the yoked task. However, these data were not included in the data analysis because this was simply to minimise Hawthorne and placebo effects. Accordingly, it was anticipated that any difference between groups would not be due to Hawthorne and/or placebo effects.

Inferential statistics

To quantify task performance in the practice phase, the frequency of successful trials for the target group and proportion of successful time for the target-yoked group were analysed using separate one-way ANOVA with phase (early, middle, late phases of the practice) as a repeated measure. Where violations to sphericity were observed, Greenhouse-Geisser corrections to df were applied. The Bonferroni *post-hoc* procedure was used in the event of significant within-participant main effects. To quantify skill acquisition on the target task and target-yoked task, dependent variables were analysed using separate 2 Group (target, target-yoked) x 2 Test (Pre-test, Post-test) mixed-factor analysis of variance (ANOVA). The Bonferroni *post-hoc* procedure was used for any significant within-participant main effect, and Tukey HSD *post-hoc* tests were used to determine the origin of any significant interaction. In addition, all dependent variables for the no target task in the transfer-test were analysed using separate independent t-tests. The effect sizes were calculated using partial eta squared (η_p^2) and Cohen's *d* as appropriate. Statistical significance for all tests was set at p <.05.

4.2.2. Results

Task performance

ANOVA on the practice data of the target group revealed a significant main effect of phase, $F(1.32, 14.52) = 11.08$, p <.05, $\eta_p^2 = .50$. There was no significant difference between the early (M = 15 trials, SD = 5) and middle phase of practice (M = 17 trials, SD = 3), but the target group reached the target in significantly more trials in the late (M = 21 trials, SD = 3) compared to the middle phase. ANOVAs for the target-yoked group revealed a significant main effect of the phase on the successful trial duration, $F(2, 22) = 9.49$, p <.05, $\eta_p^2 = .46$, but no significant main effect on the proportion of successful movement duration, $F(2, 22) = 1.37$, p >.05, $\eta_p^2 = .11$. The target-yoked group significantly increased the successful trial duration, for which the white cursor remained in the yellow circle, from the early (*M* = 3.0 s, *SD* = 0.6) through the middle (*M* = 3.1 s, *SD* = 0.7) to the late phase (*M* = 3.4 s, *SD* = 0.8). In addition, there was no significant difference in the proportion of successful movement duration between the early (*M* = 76.6%, *SD* = 8.4), middle (*M* = 77.2%, *SD* = 10.8), and late phase (*M* = 78.7%, *SD* = 8.9). The target-yoked group significantly improved the task performance during practice, and kept the white cursor inside the yellow circle for more than 75% of the trial duration throughout the practice. Therefore, their cursor movements during practice were similar to the cursor movements of their yoked partner in the target group.

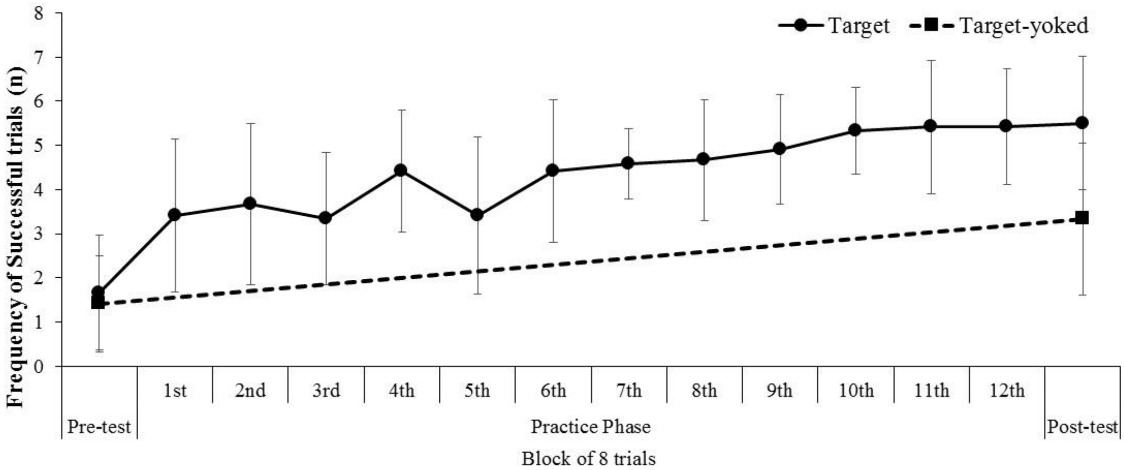

Figure 4.2. Mean (*SD*) frequency of successful trials on the target task for the target group and target-yoked group at the pre-test, practice phase, and post-test.

Skill acquisition on target task

Figure 4.2 shows the frequency of successful trials on the target task in the pre- and post-test for the target and target-yoked group. ANOVA revealed a significant main effect for test, $F(1, 22) = 65.55$, $p < .05$, $\eta_p^2 = .75$, group, $F(1, 22) = 6.89$, $p < .05$, $\eta_p^2 = .24$, and a significant interaction, $F(1, 22) = 7.28$, $p < .05$, $\eta_p^2 = .25$. In the pre-test, the frequency of successful trials did not differentiate between the target (*M* = 2 trials, *SD* = 1) and target-yoked group (*M* = 1 trials, *SD* = 1). However, in the post-test, the target group (*M* = 6 trials, *SD* = 2) reached the target in significantly more trials than the target-yoked group (*M* = 3 trials, *SD* = 2), although both groups increased the frequency of successful trials from the pre- to post-test.

Visual search behaviours

Descriptive (Table 4.3) and inferential (Table 4.4) statistics are presented for the time-normalised frequency of saccades, as well as the proportion of goal-directed and reversed saccades, for the two groups in pre- and post-test. Table 4.5 shows the time-normalised TED and the proportion of SAD and SED for the two groups in the pre- and post-test. Table 4.6 shows the inferential statistics from the related ANOVAs. There were no between-group differences and no significant interactions, whereas both groups reduced the frequency of saccades, increased the proportion of goal-directed, reduced the proportion of reversed saccades, and reduced TED significantly from the pre-test to the post-test.

Cognitive processes

ANOVA on the frequency of condition-action statements revealed a significant main effect of group, $F(1, 22) = 6.87$, $p < .05$, $\eta_p^2 = .24$, test, $F(1, 22) = 8.17$, $p < .05$, $\eta_p^2 = .27$, but no interaction, $F(1, 22) = 0.61$, $p > .05$, $\eta_p^2 = .03$. The target group had a greater frequency of condition-action statements compared to the target-yoked group. The frequency of condition-action statements was lower in the pre- (target *M* = 3 statements, *SD* = 1; target-yoked *M* = 2 statements, *SD* = 1) compared to post-test (target *M* = 4 statements, *SD* = 2; target-yoked *M* = 2 statements, *SD* = 2).

Descriptive (Table 4.7) and inferential (Table 4.8) statistics are presented for the concept categories from the condition-action statements in the pre- and post-test. The frequency of statements containing information about the concepts of evaluation, do, and unrecognised was zero, so these categories were removed from further analysis. Although there was no significant interaction between groups and tests in the sum of the major concepts, both target and target-yoked groups significantly increased the sum from the pre-test to post-test, and the target group had a significantly greater sum as compared to the target-yoked group. Specifically, both groups significantly increased the frequency of condition and action concepts from the pre-test to post-test, and the target group had a significantly greater frequency of these concepts as compared to the target-yoked group.

Skill acquisition on target-yoked task

ANOVA on the proportion of successful movement duration in the target-yoked task revealed a significant main effect of test, $F(1, 22) = 81.61$, $p <.05$, $\eta_p^2 = .79$, but not group, $F(1, 22) = 0.00$, $p >.05$, $\eta_p^2 = .00$, and no significant interaction, $F(1, 22) = 0.66$, $p >.05$, $\eta_p^2 = .03$. Both groups increased the proportion of successful movement duration from the pre- (target $M = 61.6$ %, $SD = 6.4$; target-yoked $M = 60.9$ %, $SD = 7.0$) to post-test (target $M = 68.1$ %, $SD = 6.5$; target-yoked $M = 68.7$ %, $SD = 7.2$), whereas there was no significant difference between groups.

Table 4.3. Mean (*SD*) time-normalised frequency of saccades, proportion of goal-directed saccades, and proportion of reversed-saccades on the target task for the target and target-yoked group in the pre- and post-test (Tukey HSD *post-hoc* test: * p <.05).

	Frequency of Saccades (n)				**Goal-directed Saccades (%)**				**Reversed Saccades (%)**			
	Horizontal		**Vertical**		**Horizontal**		**Vertical**		**Horizontal**		**Vertical**	
Groups	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**
Target	3.8 (0.8)	3.1 (0.5)	3.4 (0.6)	2.8 (0.5)	62.6 (6.2)	74.3 (4.3)	70.4 (6.6)	80.1 (4.0)	37.4 (6.2)	25.7 (4.3)	29.6 (6.6)	19.9 (4.0)
Target-yoked	4.0 (0.8)	3.4 (0.3)	3.3 (0.8)	3.0 (0.3)	61.1 (6.9)	69.2 (7.7)	65.6 (7.8)	75.0 (10.3)	38.9 (6.9)	30.8 (7.7)	34.4 (7.8)	25.0 (10.3)

Table 4.4. 2x2 ANOVA table for the time-normalised frequency of saccades, proportion of goal-directed saccades, and proportion of reversed-saccades of the target task (* p <.05).

		Test			**Group**			**Interaction**		
Measures		F	p	η_p^2	F	P	η_p^2	F	p	η_p^2
Frequency of Saccades	**Horizontal**	21.39	.00 *	.49	1.30	.27	.06	0.04	.85	.00
	Vertical	11.82	.00 *	.35	0.10	.75	.01	0.82	.38	.04
Goal-directed Saccades	**Horizontal**	46.86	.00 *	.68	2.33	.14	.10	1.52	.23	.06
	Vertical	56.98	.00 *	.72	3.12	.09	.12	0.01	.94	.00
Reversed Saccades	**Horizontal**	46.86	.00 *	.68	2.33	.14	.10	1.52	.23	.06
	Vertical	56.98	.00 *	.72	3.12	.09	.12	0.01	.94	.00

Table 4.5. Mean (*SD*) time-normalised total eye displacement (TED), proportion of saccadic eye displacement (SAD), and proportion of smooth eye displacement (SED) on the target task for both target and target-yoked groups in the pre-test and post-test (Tukey HSD *post-hoc* test: * *p* <.05).

	TED (°)				SAD (%)				SED (%)			
	Horizontal		Vertical		Horizontal		Vertical		Horizontal		Vertical	
Groups	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**
Target	14.8 (4.7)	11.1 (2.4)	13.2 (6.5)	9.9 (3.8)	76.4 (6.5)	76.0 (5.3)	67.9 (10.2)	65.6 (8.3)	23.6 (6.5)	24.0 (5.3)	32.1 (10.2)	34.4 (8.3)
Target-yoked	15.3 (4.1)	11.2 (1.6)	12.4 (3.4)	9.7 (1.4)	77.5 (6.2)	74.5 (5.4)	66.4 (12.7)	63.2 (9.2)	22.5 (6.2)	25.5 (5.4)	33.6 (12.7)	36.8 (9.2)

Table 4.6. 2x2 ANOVA table for the time-normalised total eye displacement (TED), proportion of saccadic eye displacement (SAD), and proportion of smooth eye displacement (SED) of the target task (* *p* <.05).

		Test			Group			Interaction		
Measures		***F***	***p***	η_p^2	***F***	***P***	η_p^2	***F***	***p***	η_p^2
TED	**Horizontal**	25.08	.00 *	.53	0.07	.80	.00	0.05	.83	.00
	Vertical	14.85	.00 *	.40	0.13	.72	.01	0.16	.70	.01
SAD	**Horizontal**	2.34	.14	.10	0.01	.91	.00	1.42	.25	.06
	Vertical	3.10	.09	.12	0.25	.62	.01	0.07	.79	.00
SED	**Horizontal**	2.34	.14	.10	0.01	.91	.00	1.42	.25	.06
	Vertical	3.10	.09	.12	0.25	.62	.01	0.07	.79	.00

Table 4.7. Mean (*SD*) frequency for the concept categories from the condition-action statements on the target task for the target and target-yoked group in the pre- and post-test (Tukey HSD post-hoc test: * *p* <.05).

	Sum		Condition		Action		Goal		Evaluation		Do		Uncategorized	
Groups	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**
Target	6 (2)	9 (5)	3 (1)	4 (2)	3 (1)	4 (3)	1 (1)	1 (1)	0 (0)	0 (1)	0 (0)	0 (0)	0 (0)	0 (1)
Target-yoked	4 (2)	5 (3)	2 (1)	2 (2)	2 (1)	3 (2)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)

Table 4.8. 2x2 ANOVA table for the frequency for the concept categories from the condition-action statements on the target task for the target and target-yoked group in the pre- and post-test (* *p* <.05).

	Test			Group			Interaction		
Measures	F	p	η_p^2	F	P	η_p^2	F	p	η_p^2
Sum	8.05	.01 *	.27	11.55	.00 *	.34	0.50	.49	.02
Condition	6.13	.02 *	.22	7.34	.01 *	.25	0.46	.51	.02
Action	7.18	.01 *	.25	7.19	.01 *	.25	0.38	.54	.02
Goal	0.63	.44	.03	3.71	.07	.14	0.16	.70	.01

Transfer-test task performance

An independent t-test on the frequency of successful trials on the no target task indicated that the target group (*M* = 3 trials, *SD* = 1) successfully reached the end of the 10s trial more frequently compared to the target-yoked group (*M* = 2 trials, *SD* = 1), $t(22) = 2.30$, $p < .05$, $d = 0.98$. Moreover, the target group (*M* = 6.8 s, *SD* = 0.9) had a significantly longer mean trial duration in the transfer-test compared to the target-yoked group (*M* = 5.6 s, *SD* = 0.9), $t(22) = 3.36$, $p < .05$, $d = 1.43$.

Visual search behaviours in transfer-test

Descriptive (Table 4.9) and inferential (Table 4.11) statistics are presented for the time-normalised frequency of saccades, as well as the proportion of forward-directed and reversed saccades, for the two groups at the transfer-test. Table 4.10 shows the time-normalised TED and the proportion of SAD and SED for the two groups in the transfer-test. Table 4.11 shows the inferential statistics from the related independent t-tests. The target group had significantly fewer saccades in the vertical direction compared to the target-yoked group, whereas there was no between group difference in the horizontal direction. There was no significant difference between groups in the proportion of forward-directed and reversed saccades, TED, and the proportion of SAD and SED in both directions.

Cognitive processes in transfer test

An independent t-test on the frequency of condition-action statements at the transfer-test revealed no significant difference between the target (*M* = 3 statements, *SD* = 2) and target-yoked group (*M* = 3 statements, *SD* = 1), $t(22) = 1.43$, $p > .05$, $d = 0.61$. Descriptive (Table 4.12) and inferential (Table 4.13) statistics are presented for the concept categories from the condition-action statements in the transfer-test. There was no significant difference between groups in the concepts of the statements.

Table 4.9. Mean (*SD*) time-normalised frequency of saccades, proportion of forward-directed saccades, and proportion of reversed-saccades on the no target task for the target and target-yoked group in the transfer-test (***** *p* <.05).

Groups	Frequency of Saccades (n)		Forward-directed Saccades (%)		Reversed Saccades (%)	
	Horizontal	Vertical	Horizontal	Vertical	Horizontal	Vertical
Target	2.8 (0.4)	2.2 (0.2) *	53.3 (2.7)	65.2 (4.7)	46.7 (2.7)	34.8 (4.7)
Target-yoked	2.9 (0.4)	2.6 (0.5)	54.9 (3.9)	64.8 (7.6)	45.1 (3.9)	35.2 (7.6)

Table 4.10. Mean (*SD*) time-normalised total eye displacement (TED), proportion of saccadic eye displacement (SAD), and proportion of smooth eye displacement (SED) of the no target task for the target and target-yoked group in the transfer-test (***** *p* <.05).

Groups	TED (°)		SAD (%)		SED (%)	
	Horizontal	Vertical	Horizontal	Vertical	Horizontal	Vertical
Target	9.1 (0.7)	7.9 (2.2)	70.3 (6.3)	61.4 (8.8)	29.7 (6.3)	38.6 (8.8)
Target-yoked	9.3 (2.1)	8.5 (2.5)	69.2 (4.0)	61.5 (6.9)	30.8 (4.0)	38.5 (6.9)

Table 4.11. Independent t-tests table for the visual search behaviours of the no target task for the target and target-yoked group in the transfer-test (* p <.05).

Measures		**Group** *t*	*P*	*d*
Frequency of Saccades	**Horizontal**	0.58	.57	0.25
	Vertical	2.25	.04 *	0.96
Forward-directed Saccades	**Horizontal**	1.18	.25	0.50
	Vertical	0.15	.88	0.06
Reversed Saccades	**Horizontal**	1.18	.25	0.50
	Vertical	0.15	.88	0.06
TED	**Horizontal**	0.28	.78	0.12
	Vertical	0.61	.55	0.26
SAD	**Horizontal**	0.47	.64	0.20
	Vertical	0.03	.98	0.01
SED	**Horizontal**	0.47	.64	0.20
	Vertical	0.03	.98	0.01

Table 4.12. Mean (*SD*) frequency for the concept categories from the condition-action statements on the no target task for the target and target-yoked group at the transfer-test (***** *p* <.05).

	Sum	**Condition**	**Action**	**Goal**	**Evaluation**	**Do**	**Uncategorized**
Groups	**Transfer**	**Transfer**	**Transfer**	**Transfer**	**Transfer**	**Transfer**	**Transfer**
Target	8 (4)	3 (2)	3 (2)	1 (1)	0 (0)	0 (0)	0 (1)
Target-yoked	6 (3)	3 (1)	3 (2)	1 (1)	0 (1)	0 (0)	0 (0)

Table 4.13. Independent t-tests table for the frequency for the concept categories from the condition-action statements on the no target task for the target and target-yoked group at the transfer-test (***** *p* <.05).

	Test		
Measures	***t***	***P***	***d***
Sum	1.09	.29	.46
Condition	1.26	.22	.54
Action	0.88	.39	.38
Goal	0.30	.76	.13

4.2.3. Discussion

The aim of this experiment was to examine the transfer of perceptual-cognitive-motor processes from one novel computer-based task (target task) to another (no target task), both of which required the acquisition of these processes for successful performance. First, it was hypothesised that, as a function of practice, the target group would demonstrate skill acquisition on the target task, whereas the target-yoked group would exhibit no or less skill acquisition on the target task. In the pre-test, there was no between-group difference in the frequency of successful trials on the target task. In the post-test, the target group reached the target in significantly more trials compared to their pre-test, as well as compared to the post-test of the target-yoked group. This difference was found, even though two groups improved the performance on their own task, and were exposed to similar cursor movement patterns and perceptual information during practice. With respect to the underlying mechanisms, there was no between-group difference in their visual search behaviours, whereas the target group had a greater frequency of condition-action pairs containing more condition and action concepts as compared to the target-yoked group. These findings were consistent with Experiment 4 (see Chapter 3), suggesting that practice leads to the integration of perceptual-cognitive-motor processes, and that limiting the involvement of cognitive decision making processes leads to no or less skill acquisition in the target-yoked group.

Second, the target group was expected to demonstrate superior task performance on the no target task in the transfer-test, as compared to the target-yoked group. As predicted, the target group had a greater frequency of successful trials and longer trial duration in the transfer-test than the target-yoked group, indicating that positive transfer of their acquired skills and processes occurred between the two tasks. These findings were obtained even when both groups had their first attempt on the no target task *after* their post-test on the target task. At the transfer-test, the target group used different visual search behaviours, indicated by fewer saccades in the vertical direction when compared to the target-yoked group, albeit there was no between-group difference in the frequency and concepts of condition-action pairs. Together, the findings provided the empirical work to systematically examine the role of information processing during practice for the transfer of perceptual-cognitive-motor processes to a different task. The positive transfer from one task to the other task suggests that transfer of skill acquisition would be maximized when the processing activities between two tasks are similar, whereas the transfer is no or less when these processes are decoupled or limited during practice (Proteau & Cournoyer, 1990; Proteau et al., 1992; Robin et al., 2005), supporting the transfer-appropriate processing hypothesis (Lee, 1988).

A limitation in this experiment was that there was no baseline task performance recorded for the no target task for either group, raising the possibility that the target group were superior on the no target task from the beginning when compared to the target-yoked group. Therefore, a further experiment was conducted with the same study design as Experiment 5, but assessing the transfer from the no target to the target task. It was hypothesised that positive transfer would occur for the no target practice group, whereas in comparison the yoked group would have lesser task performance in the transfer-test.

4.3. Experiment 6

4.3.1. Methods

Participants

Participants were 24 undergraduate students (*M* = 20.1 years of age, *SD* = 2.5) who did not take part in Experiment 5. Participants were pseudo-randomly assigned to two groups (*n* = 12). The two groups were matched for gender (Male = 11, Female = 1), age (*M* = 20.3 years of age, *SD* = 2.5; *M* = 19.9 years of age, *SD* = 2.6), and computer-game playing experience (*M* = 3441.2 hrs, *SD* = 1623.2; *M* = 3703.4 hrs, *SD* = 1575.3).

Separate independent *t*-tests on each of these variables showed no between-group differences (all $t < 1.2$). All participants had normal or corrected-to-normal vision and were right-handed. The experiment exclusion criteria and protocol was the same as Experiment 5. Participants completed an informed consent form before taking part in this experiment. All procedures were conducted in accordance to the ethical guidelines of Liverpool John Moores University and the 1964 Declaration of Helsinki.

Procedure

The experimental design, procedure and measures were the same as Experiment 5. However, one group engaged in the no target task during practice (see Figure 4.14a), whereas the other group engaged in a no target yoked task during practice by being yoked to participants in the first group (see Figure 4.14b). The main difference between the target-yoked and no target yoked task was whether a red target was presented on the screen, but otherwise the stimulus characteristics of the task (i.e. white cursor, green objects, yellow circle) were identical between the tasks (see Figure 4.14b). Following the post-tests, all groups completed eight trials of the target task as the transfer-test (see Figure 4.14c).

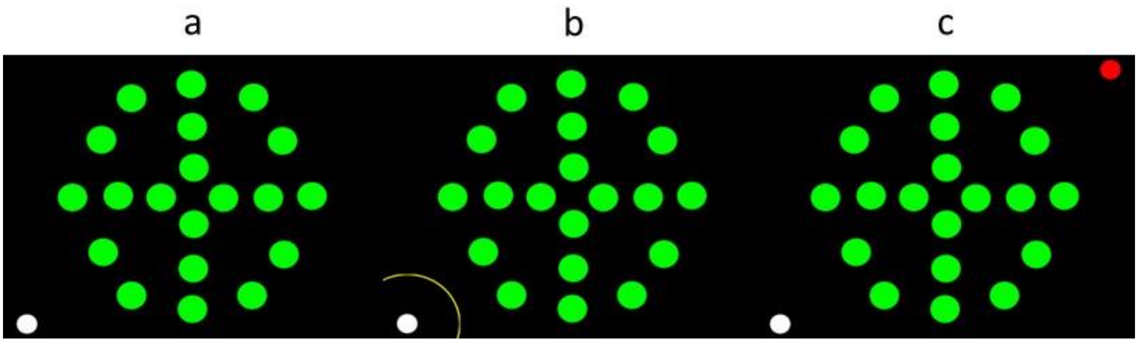

Figure 4.14. (a) The no target task, (b) the no target yoked task, and (c) the target task.

Data analysis

One of the main dependent variables on the no target task was trial duration, whereas the dependent variables on the no target yoked task were the successful trial duration (s) and proportion of successful movement duration (%) (see Experiment 5). Although these dependent variables represent a temporal measure of performance, they are not identical and thus could not be compared in the same statistical test. Trial duration represented the time from when participants were allowed to move the cursor at the start of the trial to the end of the trial, whereas both successful trial duration and proportion of successful movement duration revealed the time for which the white cursor was inside the yellow circle in each trial. Accordingly, the data was analysed in the same as Experiment 5 with separate repeated measures and mixed-effects ANOVA. The data reliability of the coding system of the condition-action statements was established using the intra-observer (97.1%) and inter-observer (92.6%) agreement methods as in Experiment 3.

4.3.2. Results

Task performance

One-way ANOVA on the frequency of successful trials in the practice phase by the no target group revealed a significant main effect of phase, $F(2, 22) = 7.06$, $p <.05$, $\eta_p^2 = .39$. There was no significant difference between the early (M = 10 trials, SD = 4) and middle phase of practice (M = 12 trials, SD = 5), but the no target group kept the cursor active for 10s in significantly more trials in the late phase (M = 13 trials, SD = 5) compared to the early phase. One-way ANOVA on the trial duration during practice revealed a significant main effect of phase, $F(2, 22) = 7.26$, $p <.05$, $\eta_p^2 = .40$. There was no difference between the early (M = 5.8 s, SD = 1.0) and middle phase of the practice

(M = 6.1 s, SD = 1.2), but the no target group significantly increased the trial duration from the middle to the late phase (M = 6.6 s, SD = 1.2).

One-way ANOVAs for the no target yoked group during practice revealed a significant main effect of the phase on the successful trial duration, $F(2, 22) = 9.59$, $p < .05$, $\eta_p^2 = .47$, but no significant main effect on the proportion of successful movement duration, $F(2, 22) = 2.79$, $p > .05$, $\eta_p^2 = .20$. The no target yoked group significantly increased the successful trial duration, for which the white cursor remained in the yellow circle, from the early (M = 4.5 s, SD = 1.0) through the middle (M = 4.8 s, SD = 1.3) to the late phase (M = 5.4 s, SD = 1.4). In addition, there was no significant difference in the successful movement duration between the early (M = 77.6%, SD = 9.3), middle (M = 78.6%, SD = 10.1), and late phase (M = 80.6%, SD = 9.6). The no target yoked group significantly improved the task performance during practice, and kept the white cursor inside the yellow circle for more than 75% of the trial duration throughout the practice. Therefore, their cursor movements during practice were similar to the cursor movements of their yoked partner in the no target group.

Skill acquisition on no target task

Figure 4.15a shows the frequency of successful trials on the no target task in the pre- and post-test for the two groups, whereas Figure 4.15b shows the trial duration of the no target task as a function of group and test. A 2 Group (no target, no target yoked) x 2 Test (Pre-test, Post-test) ANOVA revealed a significant main effect for test, $F(1, 22) = 9.72$, $p < .05$, $\eta_p^2 = .31$, but not group, $F(1, 22) = 3.63$, $p > .05$, $\eta_p^2 = .14$, and no significant interaction, $F(1, 22) = 0.46$, $p > .05$, $\eta_p^2 = .02$. Both groups increased the frequency of successful trials from the pre- (no target M = 2 trials, SD = 1; no target yoked M = 1 trials, SD = 1) to post-test (no target M = 3 trials, SD = 2; no target yoked M = 2 trials, SD = 1). Moreover, ANOVA on the trial duration revealed a significant main effect for test, $F(1, 22) = 11.11$, $p <.05$, $\eta_p^2 = .34$, group, $F(1, 22) = 6.41$, $p <.05$, $\eta_p^2 = .23$, but no significant interaction, $F(1, 22) = 0.48$, $p >.05$, $\eta_p^2 = .02$. Both groups increased the trial duration from the pre- (no target $M = 5.0$ s, $SD = 1.3$; no target yoked $M = 4.3$ s, $SD = 1.3$) to post-test (no target $M = 6.4$ s, $SD = 1.3$; no target yoked $M = 5.2$ s, $SD = 1.1$), whereas the no target group had a longer mean trial duration than the no target yoked group.

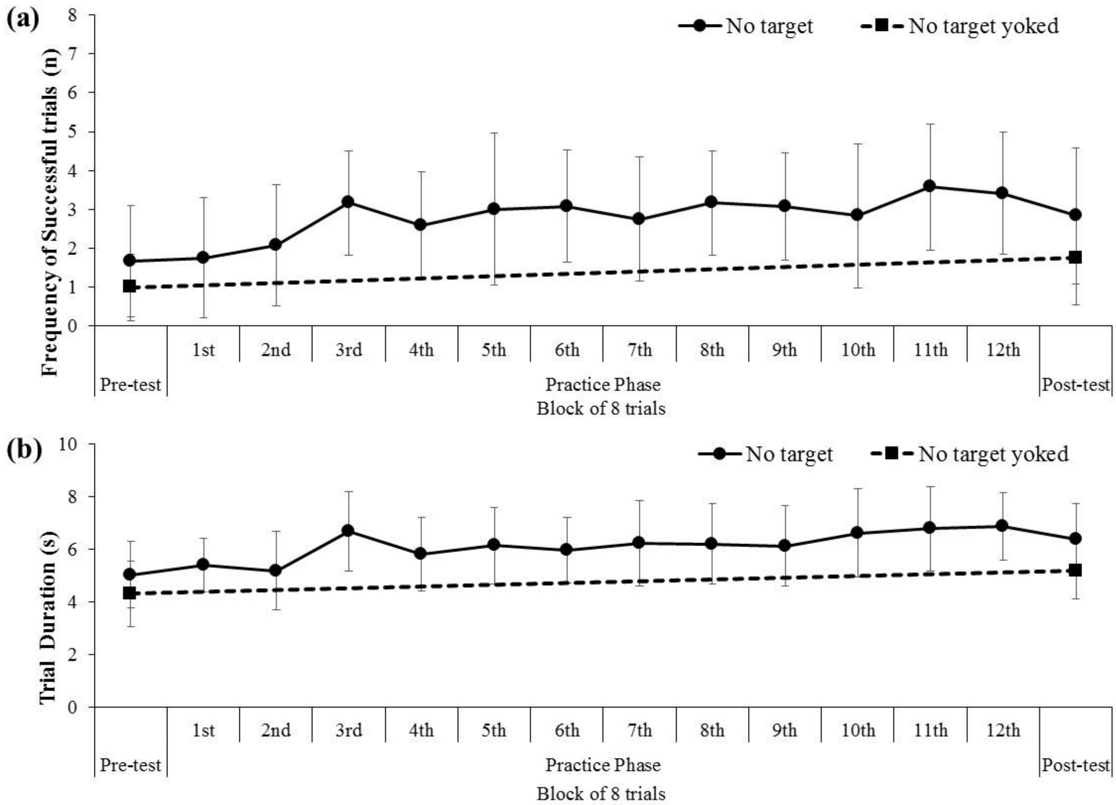

Figure 4.15. Mean (*SD*) (a) frequency of successful trials and (b) trial duration on the no target task as a function of group at the pre-test, practice phase, and post-test.

Visual search behaviours

Tables 4.16 and 4.17 show descriptive and inferential statistics for time-normalised frequency of saccades, and proportion of forward-directed and reversed saccades. Tables 4.18 and 4.19 shows the descriptive and inferential statistics for time-normalised TED and proportion of SAD and SED. The no target group reduced SAD and increased SED from the pre- to post-test, whereas the no target yoked group did not exhibit any change in SAD and SED between tests. All other measures of visual search except for the proportion of SAD and SED were significantly different in the post-compared to the pre-test, whereas there were no between-group differences and no significant interaction.

Cognitive processes

ANOVA on the frequency of condition-action statements revealed no main effect of test, $F(1, 22) = 1.41$, $p > .05$, $\eta_p^2 = .06$, group, $F(1, 22) = 0.76$, $p > .05$, $\eta_p^2 = .03$, and no interaction, $F(1, 22) = 0.72$, $p > .05$, $\eta_p^2 = .03$. Participants made three condition-action statements on average across tests and groups. Furthermore, descriptive (Table 4.20) and inferential (Table 4.21) statistics are presented for the concept content of the condition-action statements in the pre-test and post-test. The frequency of statements containing information about the concepts of do and unrecognised was zero, so these categories were removed from further analysis. There were no significant differences between groups in the measures of the concept content of the condition-action statements between the pre-test and post-test.

Table 4.16. Mean (*SD*) time-normalised frequency of saccades, proportion of forward-directed saccades, and proportion of reversed-saccades of the no target task for the no target and no target yoked group in the pre- and post-test (Tukey HSD *post-hoc* test: * p <.05).

	Frequency of Saccades (n)				**Forward-directed Saccades (%)**				**Reversed Saccades (%)**			
	Horizontal		**Vertical**		**Horizontal**		**Vertical**		**Horizontal**		**Vertical**	
Groups	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**
No target	3.2 (0.8)	2.6 (0.5)	2.8 (0.7)	2.3 (0.6)	54.2 (5.1)	55.3 (5.5)	64.1 (8.2)	70.1 (9.8)	45.8 (5.1)	44.7 (5.5)	35.9 (8.2)	29.9 (9.8)
No target yoked	3.4 (0.7)	3.1 (0.6)	3.0 (0.8)	2.8 (0.7)	53.0 (3.4)	55.8 (3.2)	61.0 (6.3)	63.9 (5.2)	47.0 (3.4)	44.2 (3.2)	39.0 (6.3)	36.1 (5.2)

Table 4.17. 2x2 ANOVA table for the time-normalised frequency of saccades, proportion of forward-directed saccades, and proportion of reversed-saccades of the no target task (* p <.05).

		Test			**Group**			**Interaction**		
Measures		F	p	η_p^2	F	P	η_p^2	F	p	η_p^2
Frequency of Saccades	**Horizontal**	11.80	.00 *	.35	2.16	.16	.09	0.45	.51	.02
	Vertical	8.00	.01 *	.27	1.97	.18	.08	0.67	.42	.03
Forward-directed Saccades	**Horizontal**	5.89	.02 *	.21	0.05	.82	.00	1.04	.32	.05
	Vertical	17.90	.00 *	.45	2.56	.12	.10	2.24	.15	.09
Reversed Saccades	**Horizontal**	5.89	.02 *	.21	0.05	.82	.00	1.04	.32	.05
	Vertical	17.90	.00 *	.45	2.56	.12	.10	2.24	.15	.09

Table 4.18. Mean (*SD*) time-normalised total eye displacement (TED), proportion of saccadic eye displacement (SAD), and proportion of smooth eye displacement (SED) of the no target task for both no target and no target yoked groups in the pre-test and post-test (Tukey HSD *post-hoc* test: * *p* <.05).

	TED (°)				SAD (%)				SED (%)			
	Horizontal		Vertical		Horizontal		Vertical		Horizontal		Vertical	
Groups	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**
No target	11.3 (2.9)	8.7 (2.2)	9.6 (2.1)	7.8 (1.9)	73.5 (6.2)	66.9 * (8.9)	65.3 (9.1)	57.5 (7.9)	26.5 (6.2)	33.1 * (8.9)	34.7 (9.1)	42.5 (7.9)
No target yoked	12.5 (4.0)	10.2 (1.8)	10.8 (4.0)	9.3 (2.6)	72.7 (9.3)	71.2 (7.2)	68.0 (8.1)	65.2 (7.2)	27.3 (9.3)	28.8 (7.2)	32.0 (8.1)	34.8 (7.2)

Table 4.19. 2x2 ANOVA table for the time-normalised total eye displacement (TED), proportion of saccadic eye displacement (SAD), and proportion of smooth eye displacement (SED) of the no target task (* *p* <.05).

		Test			Group			Interaction		
Measures		***F***	***p***	η_p^2	***F***	***P***	η_p^2	***F***	***p***	η_p^2
TED	**Horizontal**	11.58	.00 *	.35	2.14	.16	.09	0.07	.79	.00
	Vertical	14.61	.00 *	.40	1.60	.22	.07	0.08	.79	.00
SAD	**Horizontal**	14.57	.00 *	.40	0.33	.57	.02	5.56	.03 *	.20
	Vertical	17.02	.00 *	.44	2.93	.10	.12	3.62	.07	.14
SED	**Horizontal**	14.57	.00 *	.40	0.33	.57	.02	5.56	.03 *	.20
	Vertical	17.02	.00 *	.44	2.93	.10	.12	3.62	.07	.14

Table 4.20. Mean (*SD*) frequency for the concept categories from the condition-action statements on the no target task for the no target and no target yoked group in the pre- and post-test (Tukey HSD post-hoc test: * p <.05).

	Sum		**Condition**		**Action**		**Goal**		**Evaluation**		**Do**		**Uncategorized**	
Groups	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**
No target	7 (4)	6 (3)	3 (1)	3 (2)	3 (2)	3 (2)	1 (1)	0 (0)	1 (1)	0 (1)	0 (0)	0 (0)	0 (1)	0 (0)
No target yoked	7 (3)	5 (2)	3 (1)	2 (1)	3 (1)	2 (1)	1 (1)	0 (1)	0 (0)	0 (1)	0 (0)	0 (0)	0 (0)	0 (1)

Table 4.21. 2x2 ANOVA table for the frequency for the concept categories from the condition-action statements on the no target task for the no target and no target yoked group in the pre- and post-test (* p <.05).

	Test			**Group**			**Interaction**		
Measures	F	p	η_p^2	F	P	η_p^2	F	p	η_p^2
Sum	3.27	.08	.13	0.25	.62	.01	0.71	.41	.03
Condition	3.48	.08	.14	0.39	.54	.02	1.41	.25	.06
Action	1.83	.19	.08	0.01	.93	.00	1.23	.28	.05
Goal	2.73	.11	.11	0.53	.48	.02	0.30	.59	.01
Evaluation	0.00	1.00	.00	2.94	.10	.12	2.64	.12	.11

Skill acquisition on no target yoked task

ANOVA on the proportion of successful movement duration in the no target yoked task revealed a significant main effect of test, $F(1, 22) = 12.81$, $p <.05$, $\eta_p^2 = .37$, but not group, $F(1, 22) = 1.66$, $p >.05$, $\eta_p^2 = .07$, and no significant interaction, $F(1, 22) = 0.59$, $p >.05$, $\eta_p^2 = .03$. Both groups increased the proportion of successful movement duration from the pre- (no target *M* = 61.7 %, *SD* = 10.3; no target yoked *M* = 58.9 %, *SD* = 7.9) to post-test (no target *M* = 67.6 %, *SD* = 5.1; no target yoked *M* = 62.8 %, *SD* = 7.9).

Transfer-test task performance

Independent t-test on the frequency of successful trials on the target task indicated that the no target group (*M* = 5 trials, *SD* = 2) successfully reached the target on more trials in the transfer-test compared to the no target yoked group (*M* = 3 trials, *SD* = 2), $t(22) = 2.53$, $p <.05$. $d = 1.08$.

Visual search behaviours in transfer-test

Descriptive (Table 4.22) and inferential (Table 4.24) statistics are presented for the time-normalised frequency of saccades, as well as the proportion of goal-directed and reversed saccades, for the two groups at the transfer-test. Table 4.23 shows the time-normalised TED and the proportion of SAD and SED for the two groups in the transfer-test. Table 4.24 shows the inferential statistics from the related independent t-tests. The no target group used more goal-directed saccades and fewer reversed saccades in both horizontal and vertical directions at the transfer-test, when compared to the no target yoked group. There was no significant difference between groups in the frequency of saccades, TED, and the proportion of SAD and SED in both directions.

Cognitive processes in transfer-test

Independent t-test on the frequency of condition-action statements at the transfer-test revealed no significant difference between the no target (*M* = 2 statements, *SD* = 1) and no target yoked group (*M* = 2 statements, *SD* = 1), $t(22) = 0.33$, $p > .05$, $d = 0.14$. Furthermore, descriptive (Table 4.25) and inferential (Table 4.26) statistics are presented for the concept content of the condition-action statements in the transfer-test. The frequency of statements containing information about the concepts of do and unrecognised was zero, so these categories were removed from further analysis. There was no significant difference between groups in the measures of the concept content of the condition-action statements at the transfer-test.

Table 4.22. Mean (*SD*) time-normalised frequency of saccades, proportion of goal-directed saccades, and proportion of reversed-saccades on the target task for the no target and no target yoked group in the transfer-test (* *p* <.05).

	Frequency of Saccades (n)		**Goal-directed Saccades (%)**		**Reversed Saccades (%)**	
Groups	**Horizontal**	**Vertical**	**Horizontal**	**Vertical**	**Horizontal**	**Vertical**
No target	3.1 (0.5)	2.8 (0.4)	71.5 (4.8) *	79.8 (7.4) *	28.5 (4.8) *	20.2 (7.4) *
No target yoked	3.4 (0.7)	3.1 (0.7)	65.8 (4.8)	72.4 (5.2)	34.2 (4.8)	27.6 (5.2)

Table 4.23. Mean (*SD*) time-normalised total eye displacement (TED), proportion of saccadic eye displacement (SAD), and proportion of smooth eye displacement (SED) on the target task for the no target and no target yoked group in the transfer-test (* *p* <.05).

	TED (°)		**SAD (%)**		**SED (%)**	
Groups	**Horizontal**	**Vertical**	**Horizontal**	**Vertical**	**Horizontal**	**Vertical**
No target	11.3 (2.9)	9.0 (1.7)	76.8 (7.3)	68.9 (8.3)	23.2 (7.3)	31.1 (8.3)
No target yoked	13.1 (3.3)	10.7 (3.2)	78.9 (6.1)	73.3 (6.9)	21.1 (6.1)	26.7 (6.9)

Table 4.24. Independent t-tests table for the visual search behaviours of the target task for the no target and no target yoked group in the transfer-test (* p <.05).

Measures		**Group**		
		t	***P***	***d***
Frequency of Saccades	**Horizontal**	1.43	.17	0.61
	Vertical	1.31	.21	0.56
Goal-directed Saccades	**Horizontal**	2.89	.01 *	1.23
	Vertical	2.86	.01 *	1.22
Reversed Saccades	**Horizontal**	2.89	.01 *	1.23
	Vertical	2.86	.01 *	1.22
TED	**Horizontal**	1.42	.17	0.61
	Vertical	1.65	.11	0.70
SAD	**Horizontal**	0.75	.46	0.32
	Vertical	1.41	.17	0.60
SED	**Horizontal**	0.75	.46	0.32
	Vertical	1.41	.17	0.60

Table 4.25. Mean (*SD*) frequency for the concept categories from the condition-action statements on the target task for the no target and no target yoked group at the transfer-test (***** *p* <.05).

	Sum	**Condition**	**Action**	**Goal**	**Evaluation**	**Do**	**Uncategorized**
Groups	**Transfer**	**Transfer**	**Transfer**	**Transfer**	**Transfer**	**Transfer**	**Transfer**
No target	6 (4)	2 (1)	3 (2)	1 (1)	0 (1)	0 (0)	0 (1)
No target yoked	6 (3)	2 (1)	3 (1)	0 (1)	1 (2)	0 (0)	0 (1)

Table 4.26. Independent t-tests table for the frequency for the concept categories from the condition-action statements on the target task for the no target and no target yoked group at the transfer-test (***** *p* <.05).

	Test		
Measures	***t***	***P***	***d***
Sum	0.55	.59	.23
Condition	0.49	.63	.21
Action	0.82	.42	.35
Goal	0.48	.64	.21
Evaluation	0.35	.73	.15

4.3.3. Discussion

The aim of this experiment was to further examine the transfer effect and the underlying processes involved during skill acquisition. First, it was hypothesised that, as a function of practice, the no target group would demonstrate skill acquisition on the no target task, whereas the no target yoked group would show no or less skill acquisition. However, both the no target and no target yoked group increased the frequency of successful trials from the pre- to post-test, and moreover there was no group effect and no interaction. Both groups also increased trial duration from the pre- to post-test, but the no target group had a longer trial duration when compared to the no target yoked group. These findings failed to differentiate two groups as a function of practice. With respect to the perceptual-cognitive-motor processes, the no target group had different visual search behaviours indicated by the reduction of SAD and increase of SED in the post- compared to pre-test, whereas the no target yoked group did not exhibit any change in SAD and SED. There was no between-group difference in the frequency and concepts of condition-action pairs.

Second, the no target group was expected to demonstrate superior task performance on the target task in the transfer-test, when compared to the no target yoked group. As predicted, the no target group had a greater frequency of successful trials in the transfer-test compared to the no target yoked group, indicating that positive transfer of their acquired skills and processes occurred between the two tasks. The transfer findings were consistent with Experiment 5, and were obtained when both groups had their first attempt on the target task after their post-test on the no target task. At the transfer-test, the no target group had different visual search behaviours in the transfer-test, demonstrated by more goal-directed saccades and fewer reversed saccades in both horizontal and vertical directions, when compared to the no target yoked group. There was no between-group difference in the frequency and concepts of condition-action pairs. Findings were consistent with Experiment 5, revealing that acquired visual search behaviours might underlie the positive transfer from one task to another similar task, both of which required the acquisition of perceptual-cognitive-motor processes. Additionally, the positive transfer from one task to the other and vice versa confirmed that transfer of skill acquisition was maximized when the processing activities between two tasks were similar, supporting the transfer-appropriate processing hypothesis (Lee, 1988).

The previous two experiments in this chapter did not contain baseline task performance for each transfer-test. Therefore, they did not examine whether skill acquisition in one task benefited skill acquisition in another task (transfer) above and beyond practice on that other task (specificity). Therefore, another experiment was conducted combining the data from the two experiments enabling comparisons between the pre-test performance of each task (target task, no target task) to the post- and transfer-test data of each task. Based on the transfer of learning concept (Abernethy et al., 2005; Causer & Ford, 2014; Collard et al., 2007), it was expected that transfer performance would be superior when compared to pre-test performance on the same task. In addition, based on specificity of practice (Proteau & Cournoyer, 1990; Proteau et al., 1992; Robin et al., 2005) and especial skills (Breslin, Hodges, Kennedy, Hanlon, & Williams, 2010; Breslin, Hodges, Steenson, & Williams, 2012; Keetch, Lee, & Schmidt, 2008; Keetch, Schmidt, Lee, & Young, 2005), post-test performance was expected to be superior when compared to transfer-test performance.

4.4. Experiment 7

The aim of this experiment was to examine whether skill acquisition in one task would benefit skill acquisition in another task (transfer) when compared to practice on that other task (specificity). First, in order to quantify and consolidate the transfer effects from one task to the other task, task performance between the pre- and transfer-test data on either the target or no target task were compared for the four groups, as per Whiting & Savelsbergh (1992). Given the novelty of the tasks, the observed pre-test scores were not expected to be different to other participants from the population, enabling their comparison to transfer-test data for the same task. Performance on the target task from the pre-test of the target group and target-yoked group, and the transfer-test data of the no target group and no target yoked group, were compared (Table 4.27). Frequency of successful trials on the target task was analysed using one-way ANOVA with Group as the between-subject variable (Target, Target-yoked, No target, No target yoked). The same comparison occurred for the no target task using the pre-test of the no target group and no target yoked group, and the transfer-test data of the target group and target-yoked group (Table 4.27). Frequency of successful trials and trial duration on the no target task were analysed using separate one-way ANOVA with Group (No target, No target yoked, Target, Target-yoked) as the between-subject variable (Whiting & Savelsbergh, 1992).

Table 4.27. Tasks used at the pre-, post- or transfer-test for four groups.

Groups	**Pre-test**	**Post-test**	**Transfer-test**
Target	Target task	Target task	No target task
Target-yoked	Target task	Target task	No target task
No target	No target task	No target task	Target task
No target yoked	No target task	No target task	Target task

Second, in order to examine the transfer versus specificity hypothesis, task performance between the post- and transfer-test data on either the target or no target task were collated for the four groups. Performance for the target task from the post-test of the target group and target-yoked group, and from the transfer-test data of the no target group and no target yoked group were compared (Table 4.27). Frequency of successful trials on the target task was analysed using one-way ANOVA with 4 Group (Target, Target-yoked, No target, No target yoked) as the between subject factor. The same comparison occurred for the no target task using the post-test of the no target group and no target yoked group and the transfer-test data of the target group and target-yoked group (Table 4.27). Frequency of successful trials and trial duration on the no target task were analysed using separate one-way ANOVA with Group (No target, No target yoked, Target, Target-yoked) as the between subject factor. Tukey's HSD tests were used to determine the origin of any main effect of group. Partial eta squared (η_p^2) was used as a measure of effect size. Statistical significance for all tests was set at p <.05.

4.4.1. Results

Transfer

Figure 4.28 shows the frequency of successful trials on the target task for the target and target-yoked group in the pre-test, and the no target and no target yoked group in the transfer-test. ANOVA revealed a significant main effect of group, $F(3, 44) = 12.17$, $p < .05$, $\eta_p^2 = .45$. The transfer-test score of the no target group (M = 5 trials, SD = 2) was greater compared to the pre-test score of the target (M = 2 trials, SD = 1) and target-yoked group (M = 1 trials, SD = 1), and the transfer-test score of the no target yoked group (M = 3 trials, SD = 2). There were no significant differences between the target, target-yoked, and no target yoked groups. Therefore, practice on the no target task significantly improved performance on the target task beyond novice levels.

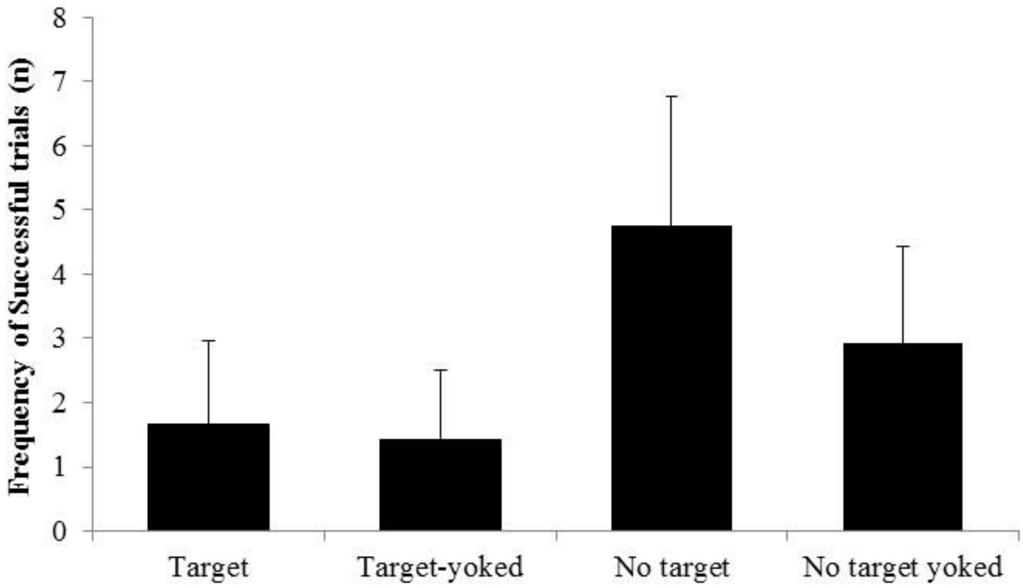

Figure 4.28. Mean (*SD*) frequency of successful trials on the target task for the target and target-yoked group in the pre-test, and the no target and no target yoked group in the transfer-test.

Figure 4.29 shows the frequency of successful trials on the no target task for the no target and no target yoked group in the pre-test, and the target and target-yoked group in the transfer-test. ANOVA revealed a significant main effect of group, $F(3, 44) = 9.45$, $p < .05$, $\eta_p^2 = .39$. For the no target task, the transfer-test score of the target group (M = 3 trials, SD = 1) was greater than the pre-test score of the no target (M = 2 trials, SD = 1) and no target yoked group (M = 1 trials, SD = 1). The transfer-test score of the target and target-yoked (M = 2 trials, SD = 1) did not differ, even though the independent t-test in Experiment 5 demonstrated a significant between-group difference in favour of the target group. Furthermore, ANOVA on trial duration revealed a significant main effect of group, $F(3, 44) = 11.61$, $p < .05$, $\eta_p^2 = .44$. Trial duration was greater for the transfer-test score of the target group (M = 6.8 s, SD = 0.9) compared to the pre-test score of the no target (M = 5.0 s, SD = 1.3) and no target yoked group (M = 4.3 s, SD = 1.3), and the transfer-test score of the target-yoked group (M = 5.6 s, SD = 0.9). Trial duration for the target-yoked group was longer compared to the no target yoked, whereas the no target and target-yoked group did not differ. In summary, practice on the target task significantly improved performance on the no target task beyond novice levels.

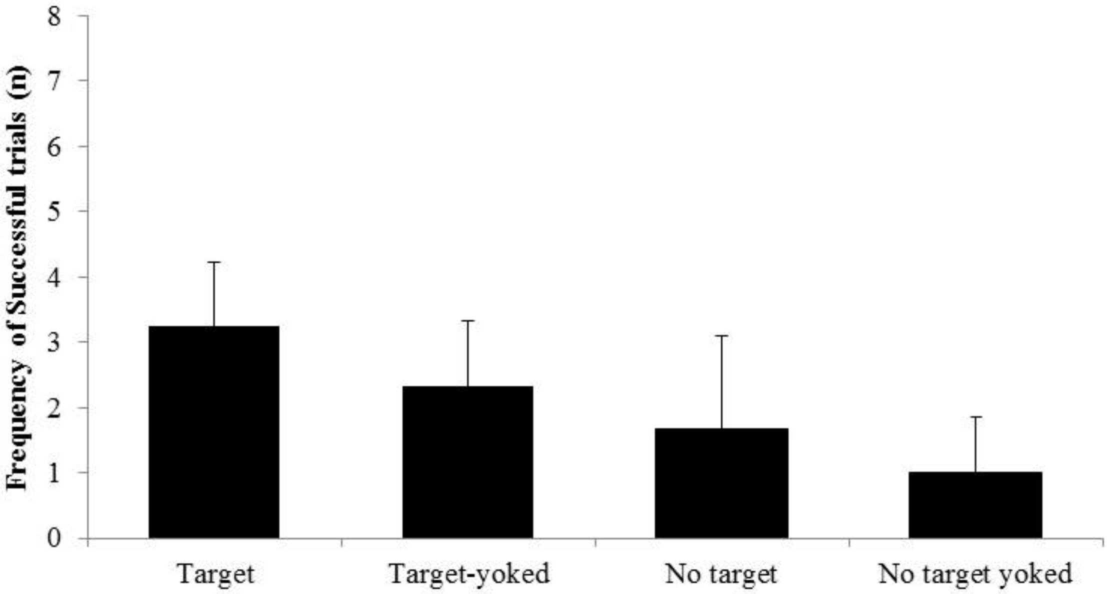

Figure 4.29. Mean (*SD*) frequency of successful trials on the no target task for the no target and no target yoked group in the pre-test and the target and target-yoked group in the transfer-test.

Specificity versus transfer

Figure 4.30 shows the frequency of successful trials on the target task for the target and target-yoked group in the post-test, and the no target and no target yoked group in the transfer-test. ANOVA revealed a significant main effect of group, $F(3, 44) = 6.06$, $p < .05$, $\eta_p^2 = .29$. Frequency of successful trials did not differ between the post-test score of the target group ($M = 6$ trials, $SD = 2$) and the transfer-test score of the no target group ($M = 5$ trials, $SD = 2$). However, there were more successful trials for the target group compared to the no target yoked ($M = 3$ trials, $SD = 2$) and target-yoked group ($M = 3$ trials, $SD = 2$). There were no significant differences between the no target, no target yoked, and target-yoked group, although the independent t-test in

Experiment 6 demonstrated a significant difference between the no target and no target yoked group. In summary, practice on the no target task improved performance on the target task to a level that did not differ to practice on the target task. Moreover, active engagement of decision making rather than passively following the cursor movement was also beneficial in skill acquisition.

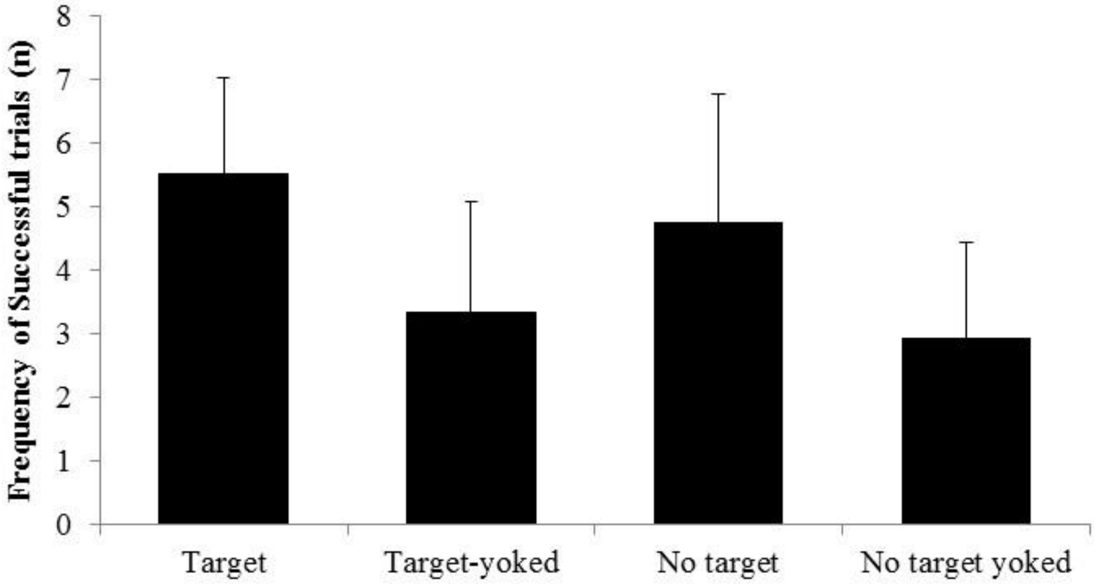

Figure 4.30. Mean (*SD*) frequency of successful trials on the target task for the target and target-yoked group in the post-test and the no target and no target yoked group in the transfer-test.

Figure 4.31 shows the frequency of successful trials on the no target task for the no target and no target yoked group in the post-test, and the target and target-yoked group in the transfer-test. ANOVA revealed a significant main effect of group, $F(3, 44) = 3.12$, $p <.05$, $\eta_p^2 = .18$. There was no significant difference between the target ($M = 3$ trials, $SD = 1$) and the no target group ($M = 3$ trials, $SD = 2$). However, there were more successful trials for the target group compared to the no target yoked group ($M = 2$ trials, $SD = 1$), whereas the target and target-yoked group ($M = 2$ trials, $SD = 1$) did not differ, even though the independent t-test in Experiment 5 demonstrated a significant difference in favour of the target group. There were no significant differences between the no target, no target yoked, and target-yoked group.

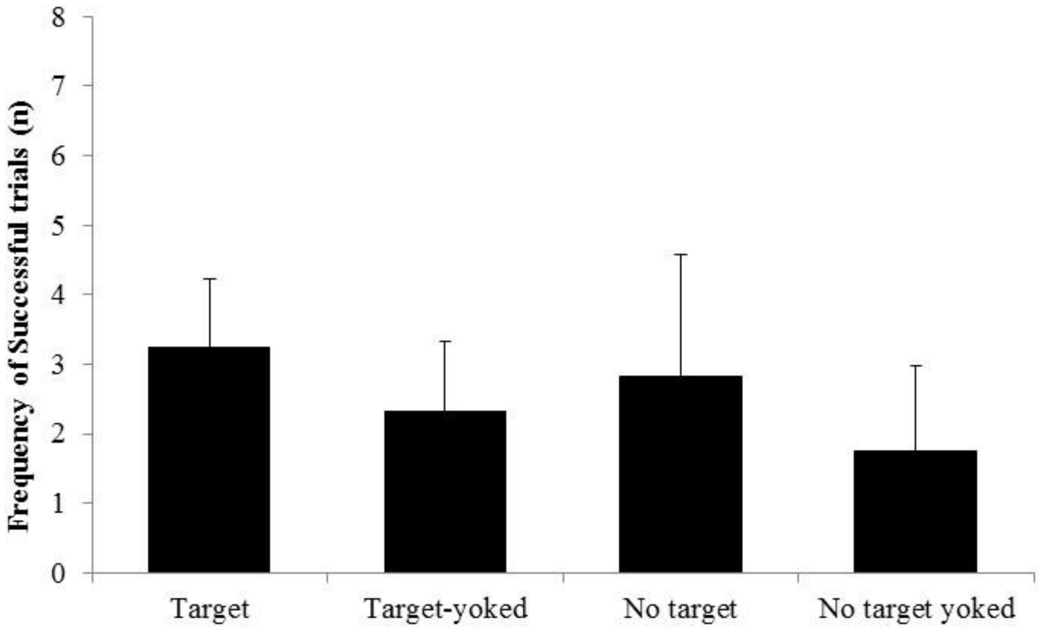

Figure 4.31. Mean (*SD*) frequency of successful trials on the no target task for the no target and no target yoked group in the post-test and the target and target-yoked group in the transfer-test.

Furthermore, ANOVA on trial duration revealed a significant main effect of group, $F(3, 44) = 5.80$, $p < .05$, $\eta_p^2 = .28$. There was no difference in trial duration on the no target task between the target ($M = 6.8$ s, $SD = 0.9$) and no target group ($M = 6.4$ s, $SD = 1.3$). The target group exhibited a longer trial duration compared to the target-yoked ($M = 5.6$ s, $SD = 0.9$) and no target yoked group ($M = 5.2$ s, $SD = 1.1$). In contrast, there were no differences between the target-yoked, no target, and no target yoked group. In summary, practice on the target task improved performance on the no target task to a level that did not differ to practice on the no target task.

4.4.2. Discussion

The aim of this experiment was to examine whether there would be evidence for specificity or transfer effect in the acquisition of perceptual-cognitive-motor processes in dynamic and complex tasks, as well as to quantify and confirm the transfer effects from one task to the other task as per Whiting & Savelsbergh (1992). It was hypothesised that, for the no target task, the transfer-test performance of the target group would be superior when compared to the pre-test performance of the no target and no target yoked group and the transfer-test performance of the target-yoked group. Moreover, for the target task, the transfer-test performance of the no target group would be superior when compared to the pre-test performance of the target and target-yoked group and the transfer-test performance of the no target yoked group.

As predicted, the target group had a greater frequency of successful trials and longer trial duration in the transfer test on the no target task when compared to the pre-test of the no target and no target yoked group. Moreover, as predicted, the no target group had a greater frequency of successful trials on the target task when compared to the pre-test performance of the target and target-yoked group, and the transfer-test performance of the no target yoked group. Together, these findings demonstrate that practice on one task significantly improved performance on the other task beyond novice levels. Data confirmed that when the underlying processes between two tasks were matched appropriately, successful transfer occurred, supporting the transfer-appropriate processing hypothesis (Lee, 1988). Additionally, limiting and decoupling those underlying processes during the practice exhibited no or less skill acquisition in one task and attenuated the transfer effect to the other task.

Based on the specificity of practice hypothesis (Proteau & Cournoyer, 1990; Proteau et al., 1992; Robin et al., 2005) and especial skills findings (Breslin et al., 2010; Breslin et al., 2012; Keetch et al., 2008; Keetch et al., 2005), it was expected that, on the no target task, the post-test performance of the no target group would be superior when compared to the transfer-test performance of the target and target-yoked group. Moreover, the post-test performance of the target group would be superior on the target task when compared to the transfer-test performance of the no target and no target yoked group. However, there was no difference in the frequency of successful trials and trial duration on the no target task between the post-test performance of the no target group and the transfer-test performance of the target group. Similarly, there was no difference in the frequency of successful trials on the target task between the post-test performance of the target group and the transfer-test performance of the no target group. Consequently, the comparisons between practice and yoked groups suggested that during practice, active engagement of decision making rather than passively following the cursor movement would be more beneficial in the acquisition of perceptual-cognitive-motor processes in dynamic and complex tasks. Findings together demonstrate that practice on one task improved performance on the other task to a level that did not differ to practice on that task, indicating that there was no significant advantage of specific practice over the transfer effect for the primary task. These data contradict previous findings on specificity of practice and especial skills (Breslin et al., 2010; Breslin et al., 2012; Keetch et al., 2008; Keetch et al., 2005; Proteau & Cournoyer, 1990; Proteau et al., 1992; Robin et al., 2005).

4.5. General Discussion

The aim of the three experiments was to examine the transfer of perceptual-cognitive-motor processes between two novel computer-based tasks. The target task required participants to move a cursor across the computer screen in order to reach a target whilst avoiding random moving objects. The no target task required them to move a cursor around the screen in order to avoid random moving objects for as long as possible. In addition, yoked version of both tasks were included with the aim of limiting decision making, to investigate the hypothesis that transfer is improved when cognitive processing during practice is similar to that in the retention or transfer-test (Morris et al. 1977; Lee, 1988). It was expected that when the acquired *perceptual-cognitive-motor* processing was similar between the two tasks during practice, the positive transfer would occur. However, when the *perceptual-motor* processing was similar during practice, but cognitive processing was limited, transfer would be limited.

As predicted, across three experiments, positive transfer occurred when cognitive processing during practice was similar to that in the transfer test, whereas it was limited when cognitive processing was constrained during practice. Findings in Experiment 5 showed superior performance for the target practice group in the transfer-test involving the no target task due to the similarity in perceptual-cognitive-motor processing between the two tasks and phases, when compared to the target-yoked group whose demand for cognitive processing was limited during practice. Similarly, in Experiment 6, the no target practice group had superior performance at the transfer-test in the target task when compared to the no target yoked group. Findings were supported in Experiment 7, where pre-test scores were significantly lower compared to transfer-test scores on the same task, despite practice of the different task. Moreover, practice on one task significantly improved performance on the other task beyond novice levels when the cognitive processing during practice was similar to that in the transfer test. Limiting the demand for cognitive processing during practice led to no or less skill acquisition on one task and transfer to the other task. Across the three experiments, findings support the concept of transfer of learning in that successful performance in a similar task or domain can transfer to another task, context or domain (Duncan 1953). However, in order for this to occur in tasks requiring perceptual-cognitive-motor processing, it was found that information processing between the learning and transfer had to be matched or similar (Morris et al. 1977; Lee, 1988). The transfer effect was limited when the cognitive processes were decoupled or constrained during practice (Proteau & Cournoyer, 1990; Proteau et al., 1992; Robin et al., 2005).

Across these experiments, the underlying mechanisms of the transfer effect were examined by measuring visual search behaviours and cognitive processing in the form of condition-action pairs. When the cognitive processing was similar between the practice condition and transfer test, it was expected that the visual search behaviours and cognitive decision making processes would transfer between one task and the other task, and underpin the transfer in performance. As predicted, in Experiment 5 the target group demonstrated fewer saccades in the vertical direction in the transfer-test on the no target task when compared to the target-yoked group. Similarly, in Experiment 6 the no target group exhibited more goal-directed visual search behaviours in the transfer-test when compared to the no target yoked group. In both experiments, there was no difference between groups in these visual search behaviours in the pre-test. These findings suggest that acquired visual search behaviours from one task could underpin the transfer in performance on the other task. However, acquired visual search behaviours were not used in exactly the same manner in the post-test on one task compared to the transfer test of the other task. In Experiment 5, visual-search behaviours were not different between groups in the target task post-test. In Experiment 6, the no target group had lower SAD and greater SED in the post-test when compared to the yoked group, as opposed to more goal-directed visual search behaviours found in the transfer-test. It appears that through practice on the primary task, the acquired visual search behaviours might have become flexible and adaptable, enabling the positive transfer from one task to the other. Alternatively, task-specific differences in visual search behaviours between the two tasks might have led to the observed adaptability for the practice groups. The target task appears to be underpinned by goal-directed saccades, which were greater for the no target compared to no target yoked group in the transfer test and for the target and target-yoked groups in the post-test compared to pre-test. For the no target task, a reduction in measures of saccades differentiated the no target group from the yoked group in the post-test and the target group from the yoked group in the transfer test. It is suggested that practice on either the target or no target task required experimenting with various visual search behaviours to maximise performance, increasing their flexibility and adaptability, which underpins the transfer effect.

It was expected that the perceptual-cognitive-motor practice groups (e.g., target or no target group) would exhibit greater cognitive decision making processes during the transfer-test when compared to their yoked group (i.e. target-yoked or no-target yoked group). Findings contradict this hypothesis, as there were no differences between groups on either task for the frequency and concepts of condition-action pairs in the transfer-test. In the transfer-test, the practice groups had different visual search behaviours compared to the yoked groups. It may be that the acquisition of visual search behaviours precedes the development of advanced cognitive decision making processes. For example, it has been suggested that reducing the time spent fixating on task-irrelevant information results in increased cognitive processing efficiency, which possibly led to the lack of between-group differences in condition-action pairs found during the transfer-test (Haider & Frensch, 1999; Lee & Anderson, 2001; Sohn, Douglass, Chen, Anderson, 2005). Alternatively, some of the condition-action pairs acquired during practice may have been specific to that task and not transferable to the other task, leading to the lack of between-group differences in the transfer-test. In previous research, the acquisition of condition-action pairs has been shown on a single specific task (e.g., McPherson 1993; McPherson 1994; McPherson, 1999; McPherson &

Thomas, 1989; Raab et al., 2009), and few, if any, researchers have compared this to performance on a transfer task.

Based upon findings on specificity of learning (Proteau & Cournoyer, 1990; Proteau et al., 1987; Proteau et al., 1992; Robin et al., 2005) and especial skills (Breslin et al., 2010; Breslin et al., 2012; Keetch et al., 2008; Keetch et al., 2005), it was expected that specific practice would be more beneficial than practice which involves similar but not exactly the same processing. It was predicted that the post-test performance of the target group would be superior compared to the transfer-test performance of the no target group, whereas the post-test performance of the no target group would be greater on the no target task when compared to the transfer-test performance of the target group. Although practice on the primary task improved performance significantly from the pre- to post-test, in Experiment 7 there was no difference between the post-test performance of the practice groups and transfer-test performance of transferring groups. Practice on the primary task improved task performance to a level that did not differ from the positive transfer that occurred from the other task. These findings contradict those of previous work on specificity of learning (Proteau & Cournoyer, 1990; Proteau et al., 1987; Proteau et al., 1992; Robin et al., 2005) and especial skills (Breslin et al., 2010; Breslin et al., 2012; Keetch et al., 2008; Keetch et al., 2005). Notably, Experiment 5 and 6 employed only 96 practice trials, which might be far below the number of trials required to exhibit advantage of the specific practice and especial skills on the current tasks. Indeed, previous studies demonstrated the specificity effect from moderate (i.e. 150 trials) to extensive practice (i.e. 2,000 trials) using simple aiming tasks (Proteau & Cournoyer, 1990; Proteau et al., 1987; Proteau et al., 1992; Robin et al., 2005), whereas the especial skills emerged with large amounts of practice (Breslin et al., 2010; Breslin et al., 2012; Keetch et al., 2008; Keetch et al., 2005). Consistently, the tasks used in the current thesis are more complex and dynamic than simple aiming tasks, and reasonably would be expected to require more extensive practice to demonstrate the effect of specific practice and especial skills.

In summary, the findings show that acquired perceptual-cognitive-motor processes transfer to different tasks and conditions, which require the integration of the same processes, but differ in the task goal or intention. Limiting and decoupling cognitive decision making processes attenuated skill acquisition and transfer. These data are consistent with the notion of transfer-appropriate processing (Morris et al. 1977; Lee, 1988).

Chapter 5

Epilogue

5.1. Aim of the thesis

The aim of the current thesis was to investigate the effect of various practice conditions on the acquisition and transfer of perceptual-cognitive-motor processes. Perceptual-cognitive-motor processes enable us to continuously perceive and identify relevant from irrelevant stimuli, select and plan an appropriate action, and execute the action under time constraints (Elliott et al. 2010; Wolpert & Kawato, 1998; Yarrow et al., 2009). However, previous *perceptual-motor* research demonstrated little consideration of dynamic and complex tasks where the performer must use perceptual-cognitive processes to make decisions and select an appropriate action to execute from more than one available option (Imamizu et al., 2000; Kording & Wolpert, 2004; Todorov, 2004; Wolpert et al., 2011). Researchers are yet to examine the practice conditions required for the acquisition of the perceptual-cognitive-motor processes underpinning decision making and required for successful performance on dynamic and complex tasks.

In the current thesis, a novel computer-based task was created in which participants were required to select and execute decisions to move a cursor to a target whilst avoiding random moving objects. It required the acquisition and integration of perceptual-cognitive-motor processes for successful performance in this dynamic and complex context. Compared to previous tasks (i.e., golf-putting, darts throwing, single goal-aiming tasks), this task is more dynamic because the background objects move continuously requiring continuous decision making to avoid them, as well as somewhat complex voluntary movements using different motor constraints/muscle groups (i.e., wrist, elbow, & shoulder joints). Similar perceptual-cognitive-motor processes are required in many situations in everyday settings, for example when crossing a busy street, and in sports where a player has to manipulate an object (e.g., ball or puck) while avoiding collisions with surrounding teammates and opponents. Based on learning theories and the transfer-appropriate processing hypothesis, the current thesis examined these principles from both a theoretical and applied perspective. The experimental work systematically investigated the effect of integration and segregation of perceptual, cognitive, and motor processes during practice on the acquisition and transfer of dynamic and complex behaviours.

The aim of the experiments in Chapter 2 was to investigate performance and behavioural changes across practice on the task (Experiment 1) and skill acquisition by comparing a practice and control group in a pre- and post-test design (Experiment 2). Subsequently, Chapter 3 investigated the acquisition of perceptual-cognitive-motor processes (Experiment 3) and the contribution of these processes to skill acquisition (Experiment 4). The aim of Experiment 3 was to quantify the underlying processes of task performance in a group that practised for moderate amounts of trials and a control group that received no practice. In Experiment 3, the underlying processes measured were eye movements for visual search behaviours and condition-action pairs and concepts for cognitive decision making processes. It was expected that practice would lead to participants exhibiting visual search behaviours containing more goal-directed eye movements and a greater frequency of condition-action pairs and concepts, as well as more successful performance. In Experiment 4, the contribution of perceptual-cognitive-motor processes to skill acquisition was examined by applying a novel protocol in which access to these processes was differentially modulated during practice as a function of three yoked groups. One group (M) practiced the task with limited visual information (perceptual) and decision making (cognitive), whereas another group (PM) practiced with limited decision making (cognitive), and a final group (PCM) practiced with all of these processes available. It was hypothesised that the integration of these processes during practice would be necessary for skill acquisition, whereas decoupling of any processes during practice would limit skill acquisition.

Finally, Chapter 4 investigated the transfer of acquired processes between the computer-based task and a related version of the task that had a different goal. Both tasks required the acquisition of similar perceptual-cognitive processes in order to select successful cursor trajectories from multiple potential options, but the main goal differed between tasks (target, no target). In addition, for both tasks, a yoked condition aimed to limit cognitive decision making processes to investigate the role of transfer-appropriate processing in skill acquisition. The aim of Experiments 5, 6 and 7 was to examine the transfer effect between the two tasks, as well as the effect on transfer of limiting cognitive processing during practice. The transfer-appropriate processing hypothesis predicts that transfer of learning would be optimised when information processing between practice and transfer environments is similar or matched, whereas the transfer would be limited when the information processing during practice is limited and decoupled.

5.2. Summary of key findings

Across the experiments in this thesis, moderate amounts of practice led to the acquisition of successful performance on the novel computer-based task. In Experiment 2 (Chapter 2) and 3 (Chapter 3), the practice groups demonstrated superior task performance at the post-test when compared to the control groups and pre-test, whereas there were no significant between-group differences at pre-test. Consistent findings were found in Experiment 4 (Chapter 3) and Experiment 5 (Chapter 4), demonstrating that practice in a condition that required perceptual-cognitive-motor processing led to a greater frequency of successful trials in the post-test compared with pre-test. In Experiment 3 (Chapter 3), the practice group modified their visual search behaviours and decision making processes across practice, demonstrating the underlying processes of successful performance on the task. Across practice, they reduced the frequency of saccades, increased goal-directed saccades, reduced TED, increased smooth pursuit, and increased the frequency of condition-action pairs containing more condition and action concepts, when compared to the control group who did not exhibit any change in visual search behaviours and decision making processes.

In Experiment 4 (Chapter 3), limiting or constraining the underlying visual and/or decision making processes during practice led to no increase in the frequency of successful trials between pre- and post-test, even though both PM and M groups improved performance on their own task during practice and were exposed to the similar motor process of cursor movement to their yoked partners in the PCM group. This finding confirms the importance of having access to relevant underlying processes during practice. The PM group had similar visual information available during practice when compared to the PCM group. They reduced the frequency of saccades and used more goal-directed saccades between the pre- and post-test, in a similar manner to the PCM group. In contrast, the M group had key visual information missing during practice and, as a consequence, their visual search behaviours did not differ between pre- and post-test. In addition, both the PM and M group had no requirement to make decisions to avoid the moving objects and select successful cursor trajectories during practice and, subsequently, did not increase the amount of condition-action pairs or concepts from pre- to post-test. Experiment 5 (Chapter 4) replicated the findings from Experiment 4. Decoupling cognitive decision making process during practice attenuated skill acquisition. Moreover, the PM practice condition enabled participants to acquire similar visual search behaviours to the PCM practice condition. Together, these findings across experiments show that the acquisition of visual search behaviours and cognitive processes was specific to the available information and processing required during practice.

The transfer effect was shown in Experiment 5 and 6 (Chapter 4). In Experiment 5, the target practice group demonstrated superior task performance in the transfer-test of the *no target task* when compared to the target-yoked group. In Experiment 6, the no target practice group demonstrated superior task performance in the transfer-test of the *target task* when compared to the no target yoked group. The positive transfer effect was shown again in Experiment 7 where the transfer-test performance of the target group on the no target task was greater than the pre-test performance of the other groups on the same task, despite being the first attempt on the task by each group. Similarly, the transfer-test performance of the no target group on the target task was superior when compared to the pre-test performance of the other groups on that task. Together, findings in Chapter 4 demonstrated that practice on one of the two tasks significantly improved performance on the other task beyond novice levels, thus showing evidence for the transfer effect.

In Experiment 5 and 6 (Chapter 4), the underlying mechanisms of the transfer effect were examined by measuring visual search behaviours and cognitive processes. In Experiment 5, the target group demonstrated fewer saccades in the vertical direction in the transfer-test on the no target task when compared to the target-yoked group. Similarly, in Experiment 6, the no target group exhibited more goal-directed visual search behaviours in the transfer-test on the target task when compared to the no target yoked group. Findings demonstrate that acquired visual search behaviours from one task underpinned the transfer in performance on the other task. However, in both experiments, there were no significant differences between groups for the frequency of condition-action pairs in the transfer-test, although decoupling the cognitive decision making process during practice *did not* lead to successful transfer. One interpretation for the lack of between-group differences in cognitive decision making processing is that it might not underpin successful transfer between tasks, as the rule-governed processes for decision making are specific to the task practiced.

Further evidence for the transfer effect was shown in Experiment 7. There was no difference between the post-test performance of the target group and transfer-test performance of the no target group on the target task. Additionally, there was no difference between the post-test performance of the no target group and transfer-test performance of the target group on the no target task. Findings show that practice on the primary task improved performance on that task from pre- to post-test, but did not differ to transfer effect from the other task.

5.3. Theoretical implications

The previous section identified and summarised the key findings from Chapter 2, 3, and 4. The subsequent sections will provide the theoretical and practical implications of these findings, as well as the potential limitations of this research and future directions. In doing so, it is important to recognise that from a theoretical perspective, this thesis investigated the development of internal models, and transfer of learning in skill acquisition.

Development of internal models

Internal models or representations are central to learning theories (Adam, 1971; Schmidt, 1975; Solso, 1995). Closed Loop (Adams, 1971) and Schema (Schmidt, 1975) theories both detail how the execution, persistence and change of movement behaviour is controlled by centrally-located representations containing the commands for action, known as *motor programs*, and the use of sensory feedback loops that ensure actions are sensitive and can adapt to sudden changes in dynamic environments (Kelso, 1981; Lee, Swinnen, & Serrien, 1994). These representations are believed to contain detailed instructions, such as forces and relative timings of muscular contractions and sensory consequences, to regulate movement behaviour. Practice leads to the acquisition and refinement of these representations, mainly involving three distinct processes in the central nervous system: encoding, consolidation and retrieval (Kantak & Winstein, 2012). Once information is encoded and stored following practice, it must be retrieved in order to be used for performance. These internal representations are used for the planning, execution, monitoring, and evaluation of skilled performance (Elliott et al., 2010; Wolpert & Kawato, 1998). The integration of perceptual, cognitive, and motor processes within these representations is thought to mediate skilled behaviours and performance in many domains, including sports, driving, and law enforcement.

Experiment 3 and 4 (Chapter 3) demonstrated that improved performance on the task was linked to acquired visual search behaviours and cognitive decision making processes. Following practice, visual search behaviours exhibited more goal-directed saccades and a greater contribution from smooth pursuit (Sailer et al., 2005), whereas decision making processes were governed by a greater number of rules and knowledge in the form of condition-action pairs and concepts (Anderson, 1982; Anderson et al., 2004; Neves & Anderson, 1981). It is suggested that these processes became integrated into an internal representation that was used to support performance as detailed in previous research and theory (Adam, 1971; Elliott et al., 2010; Schmidt, 1975). In this thesis, practice in specific conditions that contained information requiring these processes likely led to their integration in an internal representation, whereas conditions that did not contain key information likely led to limited internal representations. Due to the different requirements of motor constraints/muscle groups (i.e., wrist, elbow, & shoulder joints), specific representations were expected to be developed and acquired based on each starting position, but the constant increase in the frequency of successful trials during practice suggests that each specific representation would be used to speed up the acquisition and learning process while organizing and refining the modularity in multiple paired forward and inverse models (see reviews Wolpert & Kawato, 1998; Wolpert et al., 1998). Overall, the current thesis shows support for the development of internal representations and adds to the ever-growing literature base surrounding the concept (Imamizu et al., 2000; Miall & Wolpert, 1996; Nielsen & Cohen, 2008; Wolpert et al., 2011; Wolpert & Kawato, 1998; Wolpert et al., 1998; Yarrow et al., 2009).

The acquisition of cognitive decision making processes in Chapter 3 is consistent with ACT theory and its proposal that modulating processes during skill acquisition will lead to changes in both experience-dependent perceptual-motor ability and cognition (Anderson, 1982; Anderson et al., 2004; Neves & Anderson, 1981). ACT involves cognitive architectures that are formed to model the mental interactions that occur during the performance of complex tasks. One of the key predictions of ACT is that condition-action units, called *productions,* are acquired and used to match environmental, task or individual conditions to actions designed to achieve a goal. Findings across the experiments reported in this thesis support the prediction that these production systems are acquired and accumulated in the form of condition-action pairs and concepts through practice involving active decision making, resulting in more successful performance. In addition, findings in these experiments show that when there was no or less active decision making during practice, as in the yoked PM and M conditions, the acquisition of these productions was attenuated.

Moreover, the acquired condition-action pairs shown in Experiment 3 and 4 support the concept of action plan and current event profiles, which are rule-governed memory processes that match task conditions with appropriate visual and/or motor actions (McPherson & Thomas, 1989). These profiles include strategies to monitor current conditions (e.g., cursor position; object/s location) with respect to previous successful (or unsuccessful) attempts at attaining the desired goal (McPherson & Kernodle, 2003; McPherson & McMahon, 2008; McPherson & Thomas, 1989). In McPherson and colleagues work, it is suggested that the condition-action pairs forming the cognitive structures underpinning decision making are acquired, organised, modified and refined through certain practice and instruction environments, but these conditions are not specified (McPherson 1994; McPherson & Kernodle, 2003; McPherson & MacMahon, 2008). Findings in Experiment 3 and 4 demonstrate the specific practice conditions required for the acquisition of these action plan and current event profiles, revealing that active decision making (PCM) increased the frequency of condition-action pairs and concepts from the pre- to post-test, whereas conditions involving no or less active decision making during practice (PM, M) did not exhibit any change in these pairs between tests. These findings were consistent with the previous research demonstrating significant differences in the cognitive processes between skilled versus lesser-skilled individuals in a variety of domains (Klein et al., 1995; McPherson 1994; McPherson & Kermode, 2003; McPherson & MacMahon, 2008; Suss et al., 2014; Ward et al., 2011). The current thesis confirms for the first time that active decision making processes are developed along-side typical perceptual-motor processes.

Sensorimotor learning and the development of associated internal representations are affected when the availability of relevant sensory information is modulated during practice, such as limiting visual feedback (Proteau & Cournoyer, 1990; Proteau et al., 1992; Robin et al., 2005) or rescaling kinematic information (Elliott et al., 1995; Elliott et al., 1997). Experiment 4 (Chapter 3) systematically investigated the contribution of perceptual, cognitive, and motor processes to skill acquisition by manipulating the availability of underlying visual and/or cognitive processes during practice. Findings in Experiment 4 demonstrated that the PM and M group had limited skill acquisition on the primary task at the post-test, even though both groups improved performance on their own task during practice and were exposed to similar motor process of the cursor movement to their yoked partners in the PCM group. In addition, the PM group acquired similar visual search behaviours from pre- to post-test when compared to the PCM group. In contrast, the visual search behaviours of the M group did not differ between pre- and post-test. Findings extend the work of Sailer et al. (2005) who demonstrated the acquisition through practice of task-specific visual search behaviours and eye-hand coordination that support the planning and control of simple actions. However, they did not indicate the specific practice conditions that enable or limit the acquisition of task-specific visual search behaviours. The current experiments consistently revealed significance differences between the pre- and post-test for the PCM and PM group, whereas there were few significant differences for the control and M groups. The changes in eye movements for the control group in Experiment 3 and M group in Experiment 4 appeared to mirror the changes for the PCM group, suggesting task familiarisation or exposure through the pre- and post-test could have led to these changes, rather than any specific practice effect. Therefore, overall findings for visual search behaviours suggest that the visual information available during practice (PCM, PM) enables the development of task-specific visual search behaviours, or not (M). In addition, practice conditions with active decision making (PCM) enable participants to acquire the visual search behaviours that underpin performance on the task *and* the underlying cognitive processes.

Furthermore, in Experiment 4 both the PM and M group did not increase the amount of condition-action pairs and concepts from pre- to post-test, whereas the PCM group accumulated more of these pairs and concepts. Therefore, practice in the PM and M conditions led to *specific* sensorimotor behaviour that was not immediately transferable to the PCM condition, which required different sensorimotor processes and cognitive processing to be engaged in order to be successful (Proteau & Cournoyer, 1990; Proteau et al., 1992; Robin et al., 2005). Findings indicate that active decision making processes or the active interplay of perceptual-cognitive-motor processes are key elements to successful behaviour in dynamic and complex tasks, even though both PM and M groups improved the performance on their own task during practice and were exposed to similar movement processes of the cursor to the yoked partners in the PCM group. It is suggested that, when a task requires the acquisition of perceptual-cognitive-motor processes to be successful, integration of these processes is necessary for skill acquisition, whereas decoupling of any of these processes would attenuate skill acquisition. Moreover, practice conditions with active decision making (PCM) would enable participants to integrate perceptual, cognitive, and motor adaptations rather than each adaptation separately. This process probably results in physiological and functional adaptations in the CNS and sensorimotor systems through connecting neurons and synapses, which can allow neurons to communicate much faster and more efficiently, resulting in better performance in the dynamic and complex tasks (Gold & Shadlen, 2007; Miller & Cohen, 2001; Pesaran, Nelson, & Andersen, 2008; Yarrow et al., 2009).

Transfer of learning

The concept of transfer of learning holds that an individual who acquires successful performance in one task or domain can transfer the successful performance into another task or domain (Duncan, 1953). In regards to skill acquisition, transfer involves the capability to use prior experiences from skilled performance and learning in a particular context and then adapt these experiences to similar or dissimilar contexts or events (Collard et al., 2007). Previously, researchers have examined the transfer of learning by requiring expert or skilled participants in one domain to perform some task either in a similar or dissimilar domain. Although motor skill transfer has been examined many times (e.g., Kantak, & Winstein, 2012; Kwon, Zelaznik, Chiu, & Pizlo, 2010; Shea & Morgan, 1979), few studies have been conducted to examine the transfer effect in a learning study design where participants were required to acquire performance in a dynamic and complex task that involves cognitive decision making processes. Chapter 4 demonstrated the transfer effect between two similar computer-based tasks. In Experiment 5 (Chapter 4), the perceptual-cognitive-motor practice group (target group) demonstrated superior task performance at the transfer-test when compared to the yoked group (target-yoked group). In Experiment 6 (Chapter 4), the other perceptual-cognitive-motor practice group (no target group) demonstrated superior task performance at the transfer-test when compared to the yoked group (no target yoked group). In Experiment 7 (Chapter 4), these findings were supported by demonstrating that task performance on one task after practice on the other task was greater when compared to that completed by the participants for their first attempts on that task. Practice on one task significantly improved performance on the other task beyond novice levels, when the acquired processes during practice were similar to that in the transfer-test. Overall, findings support the concept of transfer of learning between tasks with similar elements and the transfer appropriate processing hypothesis.

The underlying mechanisms of the transfer effect were examined by measuring visual search behaviours and cognitive processing in Experiment 5 and 6 (Chapter 4). In Experiment 5, the target group demonstrated fewer saccades in the vertical direction in the transfer-test on the no target task when compared to the target-yoked group. Similarly, in Experiment 6, the no target group exhibited more goal-directed visual search behaviours in the transfer-test when compared to the no target yoked group. The perceptual-cognitive-motor practice groups (target, no target group) exhibited different visual search behaviours at the transfer-test when compared to the yoked groups (target-yoked, no target yoked group), although each group completed the transfer-test as their first attempt. It is suggested that acquired visual search behaviours from one task underpin the positive transfer in performance on the other task. However, the acquired visual search behaviours were not used in exactly the same manner in the post-test on one task compared to the transfer test of the other task. It appears that through practice on the primary task, the acquired visual search behaviours might have become flexible and adaptable, enabling the positive transfer from one task to the other. In a similar manner, motor skills become more flexible and adaptable to suit different demands and movement parameters (i.e., speed, size, muscle group/effector) during variable practice where participants parameterise their movement under differing conditions (Lai et al., 2000; Shea et al., 2001; Shea & Wulf, 2005). It is suggested that practice on either the target or no target task required experimenting with various visual search behaviours to maximise performance, increasing their flexibility and adaptability, which underpins the transfer effect.

Additionally, the mechanisms of transfer of learning are outlined in the transfer-appropriate processing hypothesis (Lee, 1988; Morris et al., 1977), which predicts that the transfer effect would occur when information processing is similar between practice and transfer-test. Chapter 4 investigated the role of transfer-appropriate processing in skill acquisition by limiting the underlying decision making processes of task performance for the yoked groups during practice. In Chapter 4, the yoked groups demonstrated no or less skill acquisition on the primary task and on the other task at the transfer-test when compared to the perceptual-cognitive-motor practice groups. In Experiment 7 (Chapter 4), these findings were supported by comparing the first attempts on each task (Whiting & Savelsbergh, 1992), revealing that there were mainly no differences between the transfer-test performance of the yoked groups and pre-test performance of the practice groups. Findings support and extend the transfer-appropriate processing hypothesis as the effect was no or little when the underlying decision making processes between practice condition and transfer-test were *not* similar or matched (Lee, 1988; Morris et al., 1977), although groups improved the performance on their own task, and were exposed to similar motor commands and perceptual information during practice. It is suggested that transfer of skill acquisition in a dynamic and complex task occurs when the underlying processes between practice condition and transfer domain are similar or matched (Lee, 1988; Morris et al., 1977), whereas the transfer is no or less when these processes are decoupled or limited during practice (Proteau & Cournoyer, 1990; Proteau et al., 1992; Robin et al., 2005).

5.4. Limitations and future research

The current thesis explored various conditions of practice leading to the acquisition of perceptual-cognitive-motor processes, and thus extended research in the areas of motor learning and skill acquisition. As with all research, answers to specific hypotheses were established, but with some limitations, which are outlined in this section along with suggestions for future research.

The development of internal models

The current thesis demonstrated that specific visual search behaviours and condition-action pairs underpinned successful task performance. The integration of perceptual-cognitive-motor processes into internal representations was suggested as being related to successful performance on the dynamic and complex task. Elsewhere it has been suggested that the hierarchy of integration or acquisition of these processes might be sequential in the order of perception, cognition, and motor, possibly with parallel processing (Anderson et al., 2004; Lee & Anderson, 2001; Smith, 1968). Alternatively, these three processes might have multi-directional interaction so that they influence each other (Miller & Cohen, 2001; Nielsen & Cohen, 2008; Yarrow et al., 2009). However, the current experiments were not designed to determine the interaction and/or hierarchy of these processes during and following acquisition. Moreover, the neurophysiological adaptations accompanying skill acquisition from the various practice conditions were not examined in this thesis. Future research could incorporate neuroimaging techniques, such as functional magnetic resonance image (fMRI), to investigate activations on specific regions of the brain or neural network systems during practice (Imamizu et al., 2000). Researchers have recently used these techniques to demonstrate differences in brain structures and functions between experts and novices (Ericsson, 2007; Nielsen & Cohen, 2008; Yarrow et al., 2009). For example, expert string music players who have engaged in many hours of practice had larger representations of the left-hand in the brain compared to non-musicians (Elbert et al., 1995; see also Pearce et al., 2000; Naito & Hirose, 2014). These findings are consistent with the view of neuroplasticity and consolidation (Adkins et al., 2006; Dayan & Cohen, 2011; Karni et al., 1995) for optimization in sensorimotor systems (Kording & Wolpert, 2004; Todorov, 2004; Wolpert et al., 2011). Neuroplasticity refers to structural and functional changes in the brain through years of training, practice and experience. Consolidation is the processes of stabilizing a memory trace after initial acquisition, which includes the process of information encoding and storage, leading to a desired action with optimal control that minimizes cost or loss (i.e., energy expenditure, time, or signal noise) (Nielsen & Cohen, 2008; Wolpert et al., 2011; Yarrow et al., 2009).

As the current task attempted to replicate the dynamic and complex characteristics seen in many real life domains, future research could incorporate neuroimaging techniques, such as fMRI, to investigate activations on specific regions of the brain or neural network systems during practice of the task by limiting degrees of freedom (i.e. joystick control). Specifically, frontal and parietal regions would be expected to increase their activation through practice because they appear to play an important role for decision making and action selection (Gold & Shadlen, 2007; Miller

& Cohen, 2001; Pesaran et al., 2008; Yarrow et al., 2009). Furthermore, by using fMRI on the task, the integration of perceptual-cognitive-motor processes could be identified at a neural level by detecting changes associated with blood flow in the brain demonstrating certain neural activation patterns underlying neural network systems and connections, which can allow neurons to communicate much faster and more efficiently (Li, Mayhew, & Kourtzi, 2009; Mayhew, Li, & Kourtzi, 2012; Zhang & Kourtzi, 2010), resulting in better performance in the dynamic and complex task (Nielsen & Cohen, 2008; Wolpert et al., 2011; Yarrow et al., 2009). Neuroimaging techniques could provide some insight into the acquisition of processes during practice (Imamizu et al., 2000), including neuroplasticity and consolidation, perhaps by employing a delayed retention test (i.e. 24 hours later or 1 week later) and control of sleep before the delayed retention. Future research can use brain imagining techniques in order to determine neural adaptations during learning and to examine neural functions and network systems corresponding to the integration of visual attention, decision making, and action execution during skill acquisition.

A limitation in the current thesis is that the role of successful and error experiences was not considered and controlled for in the yoked conditions. Despite using the yoked practice conditions to manipulate sensory information and decision making processes, the yoked groups did not actively generate successful or unsuccessful trials during practice as per their partners in the PCM groups. That is, PCM practice conditions allowed participants to easily recognise their success and failure, whereas both PM and M practice conditions might be harder to identify such experiences during the attempt to stay in the yellow circle. It is suggested that error processing and successful experiences are key for skill acquisition via active engagement in decision making and searching for successful solutions on the task (Kording & Wolpert, 2006; Todorov, 2004; Wolpert et al., 2011). It is also suggested that error processing and correction would require learners to actively reconstruct and update their internal models (Imamizu et al., 2000). Therefore, it may be that the errors made in the PCM condition led to the between-group differences at the post-test, rather than the processes associated with or presence of active decision making or not. Otherwise, the errors might have been used in combination with active decision making. Future research should be conducted to examine the role of error processing and successful experiences in skill acquisition of perceptual-cognitive-motor processes.

Another potential limitation in this thesis is that the possibility of Type II errors ("false negatives") exists for the characteristics of the participants in terms of their initial abilities and skills on the computer-based task. Participants' perceptual-cognitive-motor abilities (i.e., simple reaction time, go/no go task, eye-hand coordination, multiple object tracking task) and neural functions were not assessed and matched before the start of the experiments, suggesting this possibility. Counter to this argument, no between-group differences were found in any of the dependent variables (perceptual, cognitive, motor), in the pre-test across all experiments. In addition, a computer game history questionnaire was used in this thesis in an attempt to control transfer of initial abilities and skills from these tasks to the experimental task (Boot et al, 2011; Boot et al., 2008; Green & Bavelier, 2003; Green & Bavelier, 2006). A criteria of less than 7,500 hours of computer game playing experience would be expected to be reasonable to control any initial ability of the novice participants for the computer-based task, minimising any confounding. In order to minimise this confounding factor in future studies, screening could occur of some perceptual-cognitive-motor abilities (i.e., simple reaction time, go/no go task, eye-hand coordination, multiple object tracking task) (Alves et al., 2013; Faubert, 2013; Mangine et al., 2014; Poltavski & Biberdolf, 2015) to match groups on these abilities before the experiments start.

Underlying mechanisms of the acquisition and transfer of perceptual-cognitive-motor processes

The underlying mechanisms of the acquisition and transfer between the two tasks were examined by measuring eye movements. Findings suggested that practice on either task led to the acquisition of task-specific visual search behaviours that underpinned superior performance, as well as increasing their flexibility and adaptability, which underpinned transfer to the other task. Eye movement registration systems do not directly measure visual attention, which is thought to play an important role in successful performance in a dynamic and complex task (Abernethy, 1990; Nougier & Rossi, 1999). In order to select relevant from irrelevant visual information, visual attention has two characteristics: overt and covert visual attention (Corbetta & Shulman, 2002; Itti & Koch, 2000; Orquin & Loose, 2013). Overt visual attention directs visual attention to the task-relevant information with movement of eyes (i.e., eye movement, visual search behaviours), whereas covert visual attention is a shift of attention without eye movements. It is suggested that both overt and covert visual attention will be improved through experiences and practice (Inhoff, Pollatsek, Posner, & Rayner, 1989; Itti & Koch, 2001; Underwood, 2007). This view is partially consistent with the findings of the visual search behaviours in the thesis, even though covert attention was not measured. Based on this view, it is expected that covert attention, which would cover areas of the parafoveal and peripheral retina, would also be acquired through practice to select relevant from irrelevant visual information during the task and should be considered in future research using gaze-contingency (i.e. moving window or moving mask) or similar paradigms (e.g., McConkie & Rayner, 1975; Rayner, 1975; Ryu, Abernethy, Mann, Poolton, & Gorman, 2013).

In addition, it is suggested that a shift from explicit (i.e. deliberate) to implicit (i.e. intuitive or automatic) decision making processes occurs across practice (Chase &

Simon, 1973; Gobet & Simon, 1996; Moxley, Ericsson, Charness, & Krampe, 2012; Thomson, Lebiere, Anderson, & Staszewski, 2014). Intuitive decision making is fast and underpinned by unconscious processing between a perceived situation and a course of action, whereas deliberative decision making is reflective of a conscious and effortful rational choice (Dane & Pratt, 2007; Kahneman & Klein, 2009; Raab & Laborde, 2011). Other researchers have shown that implicit motor skill learning occurs in the early stages of learning with no switch from explicit to implicit knowledge (Maxwell, Masters, & Eves, 2000). Chapter 4 demonstrated that there was no between-group difference in the frequency of condition-action pairs at the post-test and transfer-test on each task, indicating that groups accumulated similar amounts of rule-governed knowledge. However, the frequency of condition-action pairs might not necessarily imply that the cognitive processes of both groups were the same or similar. The cognitive processing of the perceptual-cognitive-motor practice groups might have shifted to more intuitive, fast, and somewhat automatic processing, when compared to the yoked groups (Moxley et al., 2012). Intuitive, fast, and somewhat automatic processing is often not open to explicit verbalisation (Anderson, 1982; Anderson et al., 2004; Neves & Anderson, 1981; Thomson et al., 2014), which may have led to the lack of between-group differences in the frequency of condition-action pairs in Chapter 4.

Future research could make use of the secondary task paradigm to measure implicit cognitive decision making processes. The secondary-task paradigm involves performance of two tasks simultaneously (Abernethy, Maxwell, Masters, van der Kamp, & Jackson, 2007), such as a probe reaction time task (PRT) in which participants respond to an auditory tone whilst performing the primary task (Abernethy et al., 2007). With this method, the greater the cognitive demands of the primary task at any given moment, the slower the reaction time on the secondary task (Goh, Gordon, Sullivan, & Winstein, 2014). Therefore, if a shift from explicit to implicit cognitive processes occurs across practice, the perceptual-cognitive-motor practice groups could be expected to respond faster on the secondary task when compared to the yoked groups because there is less explicit cognitive processing (Glockner & Witteman, 2010; Moxley et al., 2012).

Specificity versus transfer/generality

Based upon findings on specificity of learning (Proteau & Cournoyer, 1990; Proteau et al., 1987; Proteau et al., 1992; Robin et al., 2005) and especial skills (Breslin et al., 2010; Breslin et al., 2012; Keetch et al., 2008; Keetch et al., 2005), it was hypothesised that specific practice groups would demonstrate greater performance on the practiced task when compared to the other group who practiced a different task. Our findings contradicted the hypothesis, demonstrating that practice on a primary task improved task performance from pre-test to post-test, but did not differ to transfer from the other task. That is, there was no advantage of practiced task over positive transfer for skill acquisition. Findings contradicted those on specificity of learning (Proteau & Cournoyer, 1990; Proteau et al., 1987; Proteau et al., 1992; Robin et al., 2005) and especial skills (Breslin et al., 2010; Breslin et al., 2012; Keetch et al., 2008; Keetch et al., 2005). Keetch et al., (2005) revealed that extensive practice on one skill or one situation (i.e. free throw in basketball, pitching distance in baseball) led to superior task performance, suggesting a specificity effect embedded within generality in skill acquisition. Moreover, Proteau et al. (1987) found that 2,000 trials of practice on the aiming task led to better performance when compared to 200 trials of practice. Both previous findings supported the idea of specificity, suggesting that extensive practice will generate an advantage over lower amounts or practice on other tasks. The experiments in the current thesis employed 96 trials of practice, which was less than the number in these previous studies and which might be a reason for the lack of a specificity effect or advantage on the primary task. Moreover, previous studies demonstrated the specificity effect from moderate (i.e. 150 trials) to extensive practice (i.e. 2,000 trials) using simple aiming tasks (Proteau & Cournoyer, 1990; Proteau et al., 1987; Proteau et al., 1992; Robin et al., 2005), whereas the especial skills emerged with large amounts of practice (Breslin et al., 2010; Breslin et al., 2012; Keetch et al., 2008; Keetch et al., 2005). Consistently, the tasks used in the current thesis are more complex and dynamic than simple aiming tasks, and reasonably would be expected to require more extensive practice to demonstrate the effect of specific practice and especial skills. If participants had extensive practice on the primary task (e.g., 2,000 trials), it may be that they would have better performance in the post-test when compared to the transfer-test. Further research examining the role of specificity and generality in skill acquisition needs to be conducted using a relatively high number of trials.

5.5. Practical implications

From an applied perspective, the thesis confirms the negative or detrimental effect on skill acquisition in many domains when the information processing between practice conditions and transfer domain is not similar or matched (Lee, 1988; Morris et al., 1977). When practice conditions limit or decouple the underlying mechanisms of perceptual-cognitive-motor processes, the effectiveness of practice is lessened and often results in no or less positive transfer to activities requiring the integration of these processes. In sport, the transfer of acquired skill to competition from practice activities is a key measure of their effectiveness (Cushion, Ford, & Williams, 2012; Ford, Yates, & Williams, 2010). An example of complex sports is soccer, which requires players to combine perceptual, cognitive, and motor skills to perform successfully during match-play. Expert soccer players have task specific visual search behaviours (Jordet, 2013; Savelsbergh et al., 2002; Vaeyens et al., 2007), cognitive processes (e.g., Roca, Ford, McRobert, & Williams, 2013), make more accurate and quicker decisions (Roca et al., 2011; Williams & Davids, 1998), and more effective and efficient movement patterns and technique (Egan et al., 2007; Naito & Hirose, 2014), when compared to less skilled or novices. When practicing movement patterns or technique without decision making processes in the form of technical/part-practice in soccer, the practice effect might not be maximised. In this case, performance during match-play would not be enhanced because of the decoupling of perceptual-cognitive-motor processes, limiting their integration. The thesis suggests that the effectiveness of practice would be maximised when the processing is similar or matched between practice conditions and match-play. Furthermore, findings could indicate that perceptual-cognitive-motor processes need to be acquired under conditions that facilitate integration in order to optimize performance on dynamic and complex tasks that simulates many real-life situations. While this might not always be possible, it should be recognised that limiting necessary sensory information and decoupling cognitive processing could attenuate skill acquisition. The empirical evidence supporting these implications was found using a computer-based task in a controlled environment in the laboratory. For example, in surgery, training with a computer-based laparoscopic surgery simulation has demonstrated a positive learning effect for novice surgeons (Grantcharov et al., 2004; Sroka et al., 2010). This type of training could provide an opportunity to integrate the perceptual and motor processes during practice, supporting the findings in this thesis. There is still a need to examine if findings transfer to a more dynamic and complex applied setting, such as sports, driving, and law enforcement. In soccer, future applied research could be conducted to examine the effect of decoupling perceptual, cognitive and motor processes during practice and the influence on skill acquisition and behaviour.

5.6. Concluding remarks

In conclusion, this thesis provided an in-depth assessment of the various conditions of practice involved in the acquisition and transfer of perceptual-cognitive-motor processes in a dynamic and complex task. The current thesis extends previous research from the perceptual-motor learning literature that has failed to consider the role of cognitive processes, such as decision making, in the development of internal models and transfer of learning. The thesis provides empirical support for the transfer-appropriate processing hypothesis to explain skill acquisition and transfer of skill in a dynamic and complex perceptual-cognitive-motor task. That is, acquisition and transfer of successful performance was enhanced when the processes between practice and the transfer domain were similar or matched, but was lessen when they were not. Overall, the findings in this thesis have corroborated and extended the literature surrounding skill acquisition and conditions of practice required for effective learning. The thesis will act as a foundation for future research in several different areas from both a theoretical and practical perspective.

Chapter 6

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