How does the left hand know what the right hand is doing?

An investigation of the mechanisms underpinning the intermanual transfer of acquired skilled hand movement as postulated by the Proficiency, Callosal Access and Cross Activation Models.

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Abstract

This thesis proposes that the data conflicts observed in studies of three models of intermanual transfer (the Proficiency Model (Laszlo, Baguley, & Bairstow, 1970), the Callosal Access Model (Taylor & Heilman, 1980) and the Cross Activation Model (Parlow & Kinsbourne, 1989) may be due in part to methodological artefacts such as the nature of the hand skill (task) and types of task-related feedback rather than conceptual or process differences between the models. An in-depth analysis of classical and contemporary research on intermanual transfer of hand skills underpinned the design of the three experimental studies reported in this thesis. The aim of this research was to investigate the role of task type and feedback conditions in intermanual transfer, and to provide evidence that might lead to the refutation of at least one of the three models.

The first study addressed some of the methodological differences in the original studies, in particular, the role of task type (simple/complex motor tasks) and feedback (knowledge of results (KR), visual, auditory) on direction and strength of transfer of hand skills. The second study examined the effect of terminal KR on right hand skill acquisition and includes a more in-depth analysis of the nature of intermanual transfer (motor and spatial representation). The impact of task presentation (overt/covert) on acquisition and transfer of hand skills (motor and spatial representation) was examined in the final study.

The data from these studies support the idea that task type and feedback interact to influence acquisition and transfer of hand skills and thus task type and feedback may have contributed to the conflicts in the observations of earlier researchers. The results provide partial support for the Proficiency Model, in particular, the concept of the standard (STD) which it is proposed is used to indicate to the person the accuracy of their response. The STD comprises both intrinsic and extrinsic feedback. Greater right hand transfer gains (motor representation) following left hand training provides partial support for the Callosal Access Model. The results from the three studies did not provide support for the Cross Activation model.

Declaration of Originality

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Declaration:	I hereby declare that this thesis is the result of my own research and does not contain the work of any other individual. All sources that have been consulted have been identified and acknowledged in the appropriate manner.

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"In the end, though, maybe we must all give up trying to pay back the people in this world who sustain our lives. In the end, maybe it's wiser to surrender before the miraculous scope of human generosity and to just keep saying thank you, forever and sincerely, for as long as we have voices." Elizabeth Gilbert (Eat, Pray, Love)

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Chapter 1

Introduction and Overview

1.1 Background

The study of motor control and learning is concerned with the processes, mechanisms and variables involved in the acquisition and production of movement (motor skills). Skilled hand movements are a subset of the general class of motor skills and are of central importance to humans and other primates. Hands are used for gathering food, creating and manipulating tools and exploring the world we live in. Hands skills are classified as unimanual (e.g. handwriting, throwing a dart, patting a dog) or bimanual (e.g. typing, playing the piano). When engaging in a unimanual task people generally exhibit a consistent preference for either the right or left hand. The dominant hand (preferred hand) is typically faster and more accurate when executing the movement (Corey, Hurley & Foundas, 2001). Intermanual transfer refers to the 'crossing over' of skills from one hand to the other. On occasion people do need to engage the non-dominant hand (non-preferred hand) in activities which would normally be carried out by the dominant hand. This can be a temporary requirement (e.g. the dominant hand is otherwise occupied) or a more permanent condition (e.g. injury or impairment through brain damage). Of central interest to researchers engaged in the study of intermanual transfer are the neural mechanisms involved in the transfer of skill from one hand/hemisphere to the other.

1.2 Research Aims

This thesis examines three models of intermanual transfer: Proficiency, Callosal Access and Cross Activation models. These models provide a different and somewhat incompatible view of the mechanisms involved in the transfer of skill between the hand/hemispheres. These views are not clarified by the results from the studies designed to test the predictions of each model (Laszlo, Bagulay & Bairstow, 1970, Taylor & Heilman, 1980, Parlow &Kinsbourne, 1989). The aim of the current body of work is to re-investigate the predictions and observed data from each model. It is hoped to derive a clearer understanding of the mechanisms involved in intermanual transfer and to shed some light on the efficacy of each model.

1.3 Overview

Chapter 2 begins with a brief outline of the physiology of movement. The development of the theory underpinning motor control and learning set within an information processing paradigm is reviewed. The chapter describes and discusses the debate over the relative importance of the motor program for several models of motor control including open-loop (Keele, 1968) and closed-loop systems (Adams, 1971) and Schema Theory (1975). A final section of this chapter introduces the guidance (Salmoni, Schmidt & Walter, 1984) and ‘specificity of practice’ hypothesis (Tremblay & Proteau, 1998) that discusses the key role played by feedback (intrinsic and extrinsic) in human movement acquisition, production and transfer.

Chapter 3 introduces classic and contemporary research on intermanual transfer. The focus is on three models of intermanual transfer: the Proficiency Model, the Callosal Access Model and the Cross Activation Model. These models offer different accounts of the role played by the motor program and feedback in the transfer of motor skills between the hands/hemispheres. This chapter offers an in-depth analysis of the classical studies undertaken to test the predictions of each model (Laszlo, Bagulay & Bairstow, 1970; Taylor & Heilman, 1980; Parlow & Kinsbourne, 1989). The conclusions drawn as a result of the detailed analysis of the intermanual transfer studies, coupled with the review of contemporary research, provides the basis for the investigations that informed the design of the experiments reported in Chapters 4, 5 & 6. The detailed analysis of the model-specific classical studies highlighted differences in the type of task and feedback used by the models' protagonists. These differences make it impossible to make a direct comparison of the predictions for each of the classical models of intermanual transfer. This issue is explored in Chapter 4.

Chapter 4 describes a study which aimed to clarify the role of task type and feedback conditions in intermanual transfer. The design incorporated a finger tapping and finger sequencing task similar to those used in the original studies by Laszlo et al. and Taylor and Heilman respectively. Four feedback conditions (full feedback and three feedback reductions (terminal KR eliminated, visual feedback eliminated and auditory feedback eliminated)) were included in order to examine the interaction of feedback and task type in motor skills transfer.

Chapter 5 explores the effect of feedback, specifically terminal knowledge of results (KR) on performance levels for the right hand. A more detailed analysis of transfer is conducted through the use of both a spatial and motor representation of the training sequence at the transfer phase.

Chapter 6 addresses the impact of task presentation on motor skills acquisition. A covert presentation of the finger sequence employed in the studies undertaken in Chapters 4 and 5 is used to examine the influence of verbal strategies (a large majority of participants' indicated using one) on other feedback sources such as terminal KR. Spatial and motor transfer are again examined but in this case in relation to a covert task presentation.

Chapter 7 begins by revisiting the motivation for the current body of work. It draws together the results from studies 1, 2 and 3 and summarises these as they pertain firstly to motor acquisition and then intermanual transfer. It highlights areas which may be of interest to future researchers and finishes by offering a position on the relative merits of each model of intermanual transfer.

Chapter 2

Motor Control and Learning

"An oft-cited goal of human movement science is to analyse motor control and learning not only in terms of externally observed variables, but in terms of hypothetical internal variables used by the central nervous system to control movement"

(Kelso, 1997, pg. 453)

2.1 Introduction

Human movement involves a complex interaction between the musculature and sensory information from both the external world and from our bodies (Greer, 1984). Limb and body movements can either be genetically defined e.g., blinking, blushing and patellar reflex, or acquired through learning, practice and experience. Acquired movements are typically called motor skills and include such behaviours as hand-writing (Amazeen, 2002), playing the piano (Pfordresher & Kulpa, 2011), or dancing a waltz (Greer, 1984). Motor skills have been defined as "the ability to achieve a practical goal with spatial success over a limited quantity of time" (Ashworth-Beaumont & Nowicky, 2010, p.181) or as the "ability to bring about some end result with maximum certainty and minimum outlay of energy, or of time and energy" (Guthrie, 1952 as cited in Adams, 1987, p. 42). If we take the example of a professional darts player who can produce a perfect throw on one occasion but not the next, even though that particular throw has been practiced many times, we begin to understand that a number of elements must combine to produce the perfect movement. Motor Control researchers propose that these elements may include a motor program (command from the brain to turn on a sequence of muscle contractions), feedback from the movement which allows the outcome to be checked against a reference system for accuracy, and a correction mechanism when a mismatch occurs (Roy & Marteniuk, 1974). Kelso (1997) asserts that one of the principal goals of research on motor control and learning is to analyse behaviour not only in terms of the elements which can be directly observed (our behaviours) but also in terms of the internal mechanisms which drive movement. One important hypothetical construct is that of the motor program which as Schmidt (1975) argues is "largely a default argument… there is really no direct human evidence of a motor program; centralists reason that there is no other known means of producing the movements; thus programs must be the explanation" (p. 231). Keele (1968) defined the motor program "as a set of muscle commands that are structured before a movement sequence begins, and allows the entire sequence to be carried out uninfluenced by peripheral feedback" (p. 387). For Jeannerod (2006a) the motor program describes the central representation of the parameters of actions (skilled movement sequences) that may or may not be executed. Another important issue for researchers is the role played by feedback in motor control and learning (Anderson, McGill, Sekiya & Ryan, 2005; Guadagnoli & Kohl, 2001; Salmoni, Schmidt & Walter, 1984). Feedback generated by the movement or its effect on the environment can be both intrinsic (kinaesthetic, visual, auditory, proprioception) and extrinsic (knowledge of result (KR) or knowledge of performance (KP)) and plays a critical role in the success or failure of our movements (Russell & Newell, 2007; Van Vliet & Wulf, 2006).

This chapter begins with a brief overview of the physiology of movement control. The importance of cerebral lateralisation to our understanding of human movement and key areas of the brain (motor cortex, corpus callosum, cerebellum, basal ganglia) involved in motor control and learning are described. Theories of movement representation and execution are reviewed. The theories described here are firmly rooted within the information processing model framework (Proctor & Vu, 2006). Within this framework research is driven by argument surrounding the relative importance of the motor program versus feedback in the acquisition and control of movement (Adams, 1971; Laszlo & Manning, 1970; Roy & Marteniuk, 1974; Schmidt, 1975). Section 2.1 will outline the models and research findings which emphasise the relative importance of both. Motor Control theorists who argued that movement is controlled centrally and primarily by the motor program supported an open-loop model of movement control (Keele, 1968; Laszlo & Manning, 1970). In an open-loop model movement once initiated is carried out un-interrupted by feedback until its completion. Those researchers who stressed the critical role played by feedback throughout movement progression (acquisition and production) favoured a closed-loop model of control (Adams, 1971). The motor program in the closed-loop system is relegated to a supporting role (initiating the movement) and the importance of feedback to the creation of a reference system against which movement outcomes can be accessed is emphasised.

Section 2.2.4 describes Schmidt's Schema Theory (1975). Schema theory attempted to overcome limitations of both the open and closed-loop control models and effectively subsumed both. These limitations included the inability of the open-loop control model to account for movements other than over-learned movements of short duration time and the closed loop control model's requirement for checking feedback against a reference system on an on-going basis. The storage capacity needed to hold the large number of motor programs required to produce a variety of movements was a limitation of both. In Schema theory the relative importance of feedback is a function of the stage of learning. As Trembley, Welsh and Elliot (2001) highlight, in the early stages of motor learning feedback is of central importance (closed-loop control) but as learning progresses and as the motor schema develop control moves towards an open-loop control model. Schema theory led to the widely accepted concept of a generalised motor program (GMP). The GMP allowed for the possibility of certain classes of movement being governed by one program (Amazeen, 2002). One GMP would allow for the same movement (e.g. hand writing) to be carried out in various ways; by one effector system (e.g. preferred hand using paper or a blackboard) or by several different effector systems (preferred hand, non-preferred hand, toes, mouth). This in turn lent support to the view that motor skills are transferrable (i.e. effector independent); a view which is central to the concept of intermanual transfer and hence this thesis.

The final section deals with feedback both intrinsic and extrinsic. A wealth of research exists on the relative importance and role of feedback in the acquisition, retention and transfer of motor skills. This section will outline the two principal hypotheses which have directed much of the research on feedback: the guidance hypothesis (Salmoni et al., 1984) and specificity of practice (Tremblay & Proteau, 2001; Tremblay & Proteau, 1998).

2.2 Physiology of Movement Control

Two fundamental principles of brain organisation have been proposed; functional specialisation (specific brain regions are responsible for specific functions, for example, speech production/comprehension or movement) and functional integration (specific functions require the interaction of several specialised areas/regions, for example, hand movements) (Serrien, Ivry & Swinnen, p.160).

Evidence in favour of functional specialisation stems as far back as the nineteenth century to the research work of Paul Broca (1824-1880) and Carl Wernicke (1848-1905). They produced evidence of language impairment associated with damage to particular brain regions (left inferior frontal gyrus and left superior and middle temporal gyri, respectively) (Serrien, Ivry & Swinnen, 2006, p.160). In 1860, John Hughlings Jackson a British clinician described patients with unilateral (one sided) epileptic spasm. He believed that the starting point in the body of epileptic spasm was indicated by the location of the epileptic discharge in the brain. The discharge spread from this point in the brain to adjacent areas which in turn caused spasm in other parts of the body. Following the progression of the spasms Hughlings Jackson was able to map the areas of the brain associated with movement in different parts of the body. He was in effect mapping the motor cortex (Jeannerod, 2006b). The research work of Broca, Wernicke and Hughlings Jackson provided evidence of functional specialisation. Hugo Liepmann's (1863-1925) work on a disorder which became known as apraxia offered further evidence of functional specialisation but also evidence for the superior role of the left hemisphere in motor function. His work demonstrated that the hemispheres were functionally asymmetrical (Serrien, Ivry & Swinnen, 2006). Apraxia is a movement disorder of higher motor cognition which manifests itself in deficits when carrying out purposeful movements with the arms and/or hands. These deficits can include inability to pantomime the use of objects and difficulties manipulating actual objects when the task involves complex sequencing (e.g. making a cup of coffee) (Dovern, Fink & Weiss, 2011, p.1269). Liepmann described three main characteristics of apraxia "misidentification of objects", "loss of comprehension for the use of objects" and "an inability to recognize the usability of seen or palpated objects" (Liepmann, 1900 pp. 185 – 191 in Goldenberg, 2003 p. 516). Liepmann found that patients with left hemisphere lesions suffered both hemiplegia (paralysis) of the right side and apraxia of the left arm. Patients with right lesion damage suffered left side hemiplegia only (Goldenberg, 2003). His interpretation of this finding was that "the left cortical centre was dominant for action representations and sent its commands to the right hemisphere via the corpus callosum" (Jeannerod, 2006b, p. 360). The corpus callosum is a large band of axons which is essential to, and facilities the transfer of information between the hemispheres (interhemispheric transfer) (Cherbuin & Brinkman, 2006). Wyke (1971) studied the effects of brain lesions on the performance of bilaterally synchronous tapping movement. A total of 60 participants **(**40 participants with left- and right-sided hemisphere lesions and 20 participants with intact brain structures) took part in the study. Results indicated that participants with left-sided cortical lesions showed significant impairment in the rapidity of repetitive movements with both arms, whereas participants with right-sided lesions produced impairment of movement in the contralateral (left) arm only. This finding supports Liepmann's hypothesis of the left hemisphere's involvement in left and right hand movement control.

Evidence for specialized functions within the right-hemisphere have also been investigated. Weisenburg and Mc Bride (1935) found that patients with right-hemisphere damage performed particularly badly on tests of spatial awareness. Manipulating geometric shapes, completing puzzles or missing parts of patterns, caused particular difficulty for those with right hemisphere damage. Rhodes (1985) suggested that the right hemisphere is involved in the creation and comparison of facial representation.

Aspects of motor control which increase the involvement of the right-hemisphere was investigated by Woolley, Wenderoth, Heuninckx, Zhang, Callaert, & Swinnen (2010). Using an fMRI study they examined hemispheric lateralisation using a wrist and ankle movement task. This task had two conditions (visual guidance present, visual guidance not present). When visual guidance was given the data showed activity in particular areas of the right-hemisphere (occipital-temporoparietal network and inferior frontal gyrus) which was not present when visual guidance was absent. The research described above provides evidence of both left and right hemispheric specialisation.

Figure 2-1 shows the main areas of the brain involved in movement control (motor cortex, corpus callosum, cerebellum and basal ganglia). Functional integration in movement control is seen in the interaction of four principal regions of the cerebral cortex which are now commonly recognised as contributing directly to the control of hand movements: the primary motor cortex (M1), the supplementary motor area (SMA), premotor area (PMA), and the cingulated motor areas (CMA). Experiments measuring regional cerebral blood flow (rCBF) measured by positron emission tomography (PET) scans showed activation in M1 when subjects performed a simple finger movement, activity in both M1 & SMA when a complex finger movement was performed and activity in SMA only when mental planning of a complex finger movement was carried out (Roland, Larsen, Lassen, & Skinhoj, 1980). Sequential finger movements involve the SMA and CMA (Tyszka, Grafton, Chew, Woods & Coletti, 1994). The basal ganglia which consists of a number of subcortical nuclei (striatum, globus pallidus, sub-thalamic nucleus and substantia nigra) is important for the preservation of learned motor skills (Pendt, Reuler & Muller, 2011; Rothwell, 2011). The cerebellum is involved in movement adaptation when errors in movement are detected through intrinsic feedback.

A key area of research on hemispheric differences in brain functioning is that of hand preference and performance. When most people execute a unimanual (one hand only) movement such as writing they exhibit a consistent preference for either the right or left hand. Handedness is defined in terms of the individuals’ preference to use one hand predominately for unimanual tasks and the ability to perform these tasks more efficiently with one hand (Corey, Hurley & Foundas, 2001). Movement production is controlled by the contralateral hemisphere, i.e., the left hemisphere controls the right hand and the right hemisphere controls the left hand. Thus the dominant hemisphere for right-handers will be the left hemisphere.

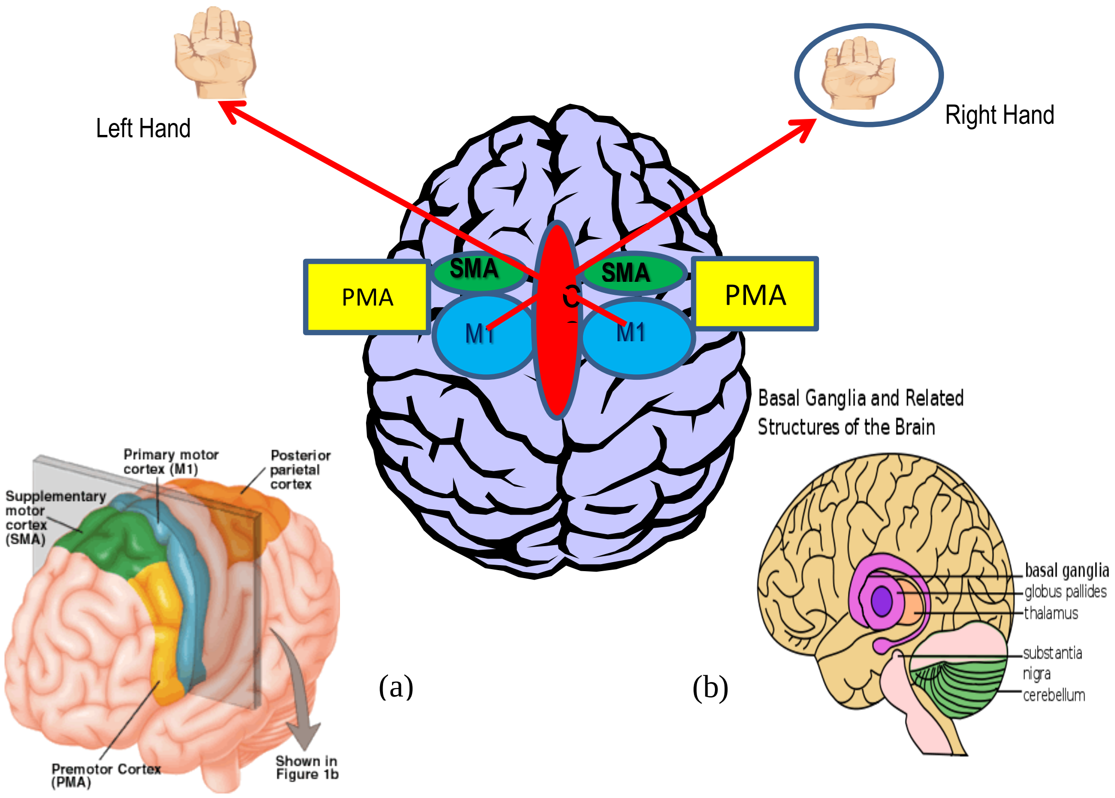

Figure 2-1: Areas of the brain involved in the control of movement. Images (a) & (b) downloaded from https://www.dynamicbrain.ca/brain-anatomy-images.html and http://www.google.ie/imgres?imgurl=https://figures.boundless.com respectively.

2.3 Theories of Motor Control & Learning

Much of the debate surrounding motor skills acquisition has centred on the relative importance of the motor program (open-loop control) versus feedback (closed-loop control) to the successful acquisition and production of movement. In the acquisition phase both types of control systems require feedback (intrinsic and extrinsic), both create some form of reference or standard with which to compare movement outcome and this reference or standard can be used for error detection (Roy & Marteniuk, 1974). The difference between the control systems occurs when a movement has been learned and KR is no longer available. Intrinsic feedback remains a central requirement in the close-loop control model whereas in an open-loop control model intrinsic feedback is not required (Pew, 1966) or cannot be processed during the movement (Keele & Posner, 1968).

2.3.1 Open-loop Control Model

Figure 2-1 outlines the serial nature of movement as hypothesised in the open-loop control model. Movement proceeds sequentially from initiation to completion without interference once it commences. The unidirectional nature of the model is emphasised by the arrows. Feedback does not feature in the model: feedback is available but is not of any benefit at this stage as the movement time is faster than that required to process feedback (Glencross, 1977; Keele, 1968; Schmidt, 1969; Schmidt & Russell, 1972).

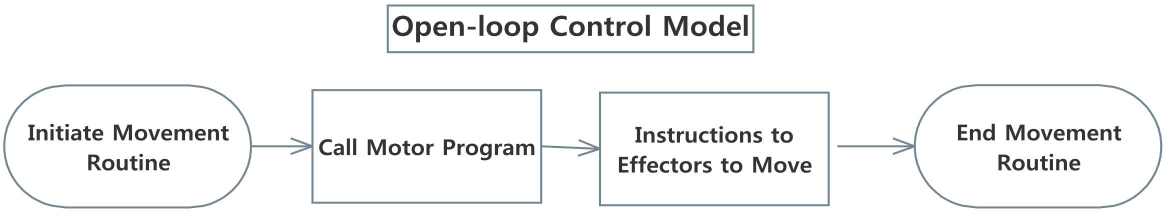

Figure 2-2: Model of Open-Loop Control System.

Two key points against closed loop control advanced by proponents of open loop control are a) the time required to process feedback and b) movement in the absence of feedback. The time taken to process kinaesthetic (Chernikoff & Taylor, 1954; Higgins & Angel, 1970) and visual (Keele & Posner, 1968) feedback is demonstrably too long to be of use in ballistic movement (< 200 ms). For instance Keele and Posner (1968) found that visual feedback did not facilitate accuracy in a target striking task when the movement time was less than 200ms but did facilitate accuracy for movement times greater than 250ms. They estimated that the time required to process visual feedback was in the order of 190 – 260ms, outside the range for ballistic movements. Schmidt and Russell (1972) found that processing of feedback was correlated with movement time rather than movement speed (fast or slow). If the movement time was less than 150ms then the processing of feedback was not facilitated regardless of how fast or slow that movement was. They suggested that the level of movement pre-programming is strongly related to movement time. Schmidt (1969) termed this the *index of pre-programming.*

Reports of patients who could move in the absence of feedback also provided support for an open-loop control model. Evidence in favour of an open-loop control model stems as far back as Lashley (1917): he found that a patient without kinaesthetic feedback from leg movements could reproduce remembered movements, even varying these in length, however he could not perceive or reproduce passive movements of the leg. Rothwell, Taub, Day, Obeso, Thomas & Marsden (1982) reported the case of a human patient who had lost all somatosensory feedback from his limbs, yet was able to perform, even when blindfolded, both simple motor skills, e.g. tapping, to more complex motor tasks such as execution of figure drawing in the air. Pew (1966) demonstrated that for a continuous sequence of movements a change in strategy occurred from a feedback dependent pattern early in practice, to control by a motor program. These observations support the assumption that once a movement sequence had been learned, it could be centrally programmed, stored, and run off without the requirement for either intrinsic or extrinsic feedback.

2.3.2 Refined Open-Loop Control Model

While the open-loop control model described above could explain movements that were already programmed and stored it could not explain how novel movements were acquired. Laszlo and Manning (1970) proposed a refinement to the open-loop model to explain the processes involved in the initial stages of learning a sequence of movements. They postulated that both intrinsic and extrinsic feedback are used in the creation of a standard (STD). The STD is a mechanism that reflects the degree of match/mismatch between desired and achieved goals. The STD involves the following components: demands of the experimental situation, task instructions, the memory traces of the skilled movement, and efference copy (expected outcome of the movement). Intrinsic feedback (visual, auditory, tactile, and kinaesthetic) would also contribute to the development of the STD (Laszlo, Baguley & Bairstow, 1970). In this hypothesis the motor program acts in an "executive manner controlling movement by activating the motor command patterns" (Laszlo et al., 1970, p. 262). The interaction between the motor program and the STD is used to indicate to the person the accuracy of their response (Laszlo et al., 1970; Roy & Marteniuk, 1974). The efferent command elicited by the motor program is compared to the STD to detect any error in the movement. The importance of feedback decreases once the STD has been created and is no longer necessary to facilitate reproduction of the movement (Roy & Marteniuk, 1974).

2.3.3 Closed-Loop Control Model

Those who favoured the closed-loop control model pointed to the fact that certain movements, particularly a complex sequence of movements were degraded once feedback was removed (Adams, Goetz & Marshall, 1972; Roy & Marteniuk, 1974). In real life learners and skilled performers alike will use the available information in the environment (intrinsic and extrinsic), to produce movement (Russell & Newell, 2007). For example, delayed auditory feedback can have a detrimental effect on the performance of a skilled pianist (Pfordresher & Kulpa, 2011). Figure 2-2 outlines the closed-loop control model as postulated by Adams (1971) in which he emphasised the critical role played by feedback. The process of movement is more dynamic here than in the open-loop control model. Movement is initiated by a motor program or memory trace (a) but Adams sees the motor program as having a relatively small part to play and being of very short duration (Adams 1987). Feedback (intrinsic and extrinsic) influences movement at (b): feedback from the movement is checked against a reference system or STD (Adams uses the term perceptual trace) and informs the system about the outcome of the movement. Adams (1987) hypothesised that once a movement was learned and a strong perceptual trace had been developed, extrinsic information in the form of knowledge of results (KR) could be withdrawn. He termed learning without KR as "subjective reinforcement" (p. 59). What is interesting is that the perceptual trace is built up through every movement (good or bad) as evidenced by its location in the model. In theory, a succession of incorrect movements could weaken the perceptual trace – a type of un-learning could occur. This is often seen in real life when athletes perform badly under pressure, commonly referred to as "choking" (Beckmann, Gropel & Ehrlenspiel, 2012). The initial bad performance can be as a result of too much attention being paid to a well learned movement (Baumeister, 1984). However if a lack of confidence ensues and successive errors are made, then this may result in deterioration in the strength of the perceptual trace and hence movement accuracy (Schmidt, 1975).

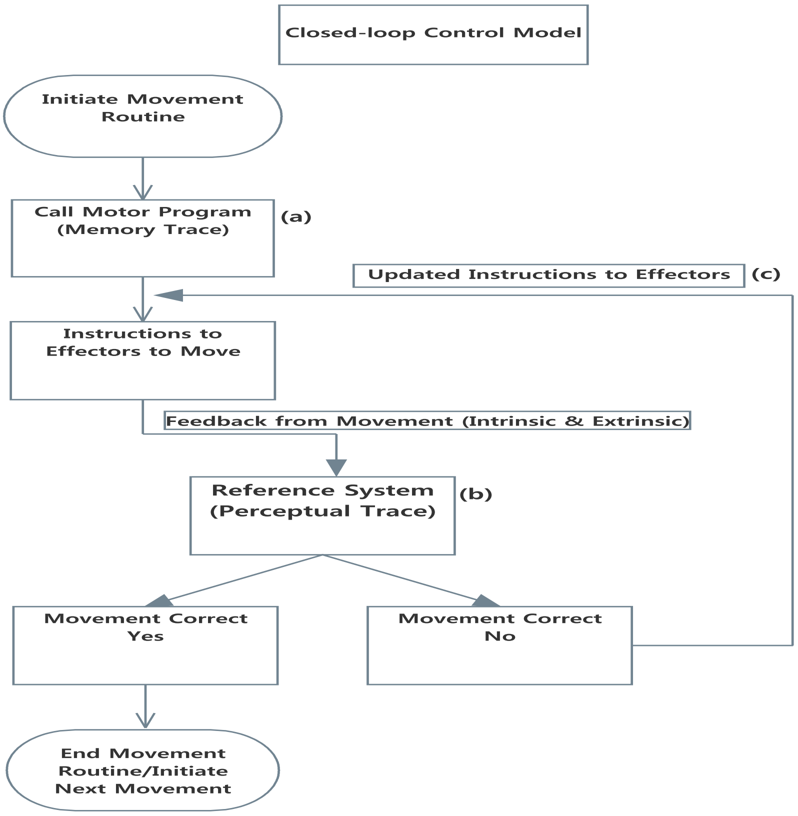

Figure 2-3: The closed-loop model of control incorporating Adams (1971) concept of the memory and perceptual trace.

The closed-loop nature of the model is demonstrated by (c): updated instructions are sent to the effectors when a mismatch occurs between the actual versus the desired outcome. Hence the central construct of Adam's closed-loop model is that of error detection and correction.

This point is re-iterated in Adams (1987) when he states that his closed-loop theory was based on the premise of strengthening the capability to detect and correct errors rather utilising KR to strengthen a habit (p.58). The use of a dual trace (memory and perceptual) is what facilitates the error detection and correction. This is because the memory trace that initiates the movement and the perceptual trace that monitors the movement are separate entities; therefore error detection is possible (Newell, 1991).

2.3.4 Schema Theory

To counteract perceived weaknesses in Adam's closed-loop theory and failings of previous open-loop models Schmidt brought forward his Schema theory (Schmidt, 1975). In a study by Roy and Marteniuk (1974) participants were required to move a cursor along a track (a linear positioning task) at various speeds across trials. The researchers concluded that an open loop model provided a better account of performance for rapid movements but that performance in a slow response condition was best explained by a closed-loop model. They suggested that the type of control utilised (open or closed-loop) was task dependent (fast or slow responses). Therefore neither model alone could account for all movement types, some combination of the two is required. Further support for this argument was provided by Wing (1977). He employed a repetitive finger tapping task with fixed intervals (350, 500 and 650 ms) to investigate which form of control (open or closed-loop) best explained this type of task. Feedback in the form of a brief auditory signal was given to participants after they made their response (touching a small metal plate with their index finger). Visual feedback was eliminated as a screen hid the participant's hand from view. In a number of random trials the auditory feedback was perturbed (increased by 20 or 50 ms or decreased by 10ms). The dependent variable was the interresponse interval (ITI). Wing hypothesised that if repetitive finger tapping was controlled in an open-loop manner then perturbation of the auditory feedback would not have any effect on the ITI but if the movement was under closed-loop control there should be a difference. The findings showed that positive perturbations produce a lengthening of the subsequent ITI, whereas negative perturbations produce a slight shortening of the current interval. He concluded that repetitive finger tapping is normally under open-loop control but participants' do process auditory feedback. When the perturbation to auditory feedback is large participants will respond to the perturbation by "closing the loop" (p. 186). These findings suggest that even within tasks the facility to switch between open and closed loop control is necessary to deal with un-expected events (e.g. perturbations).

At the time that these models were generated the issue of storage capacity of motor memory was of major concern. The models drew heavily from technological analogies (as did the information processing paradigm itself) and the technology of the time was far more constrained when it came to memory capacity; something that is of far less importance in contemporary technologies. Nonetheless the Schema model did propose a very economical storage system for motor memory. Figure 2-3 outlines the Schema Model as hypothesised by Schmidt (1975). According to the Schema model four concepts are stored when an individual produces a movement: (a) the initial conditions (information about limb position, visual and auditory information about the environment), (b) the response specifications (input variables (force, speed)) for the motor program, (c) the sensory consequences of the response produced (afferent feedback), and (d) the outcome of that movement (actual not intended outcome) These four sources of information are stored together after the movement is produced. As more of these movement types are produced, and hence more examples of the four sources of information become available, a schema of the relationship between the four sources of information is abstracted.

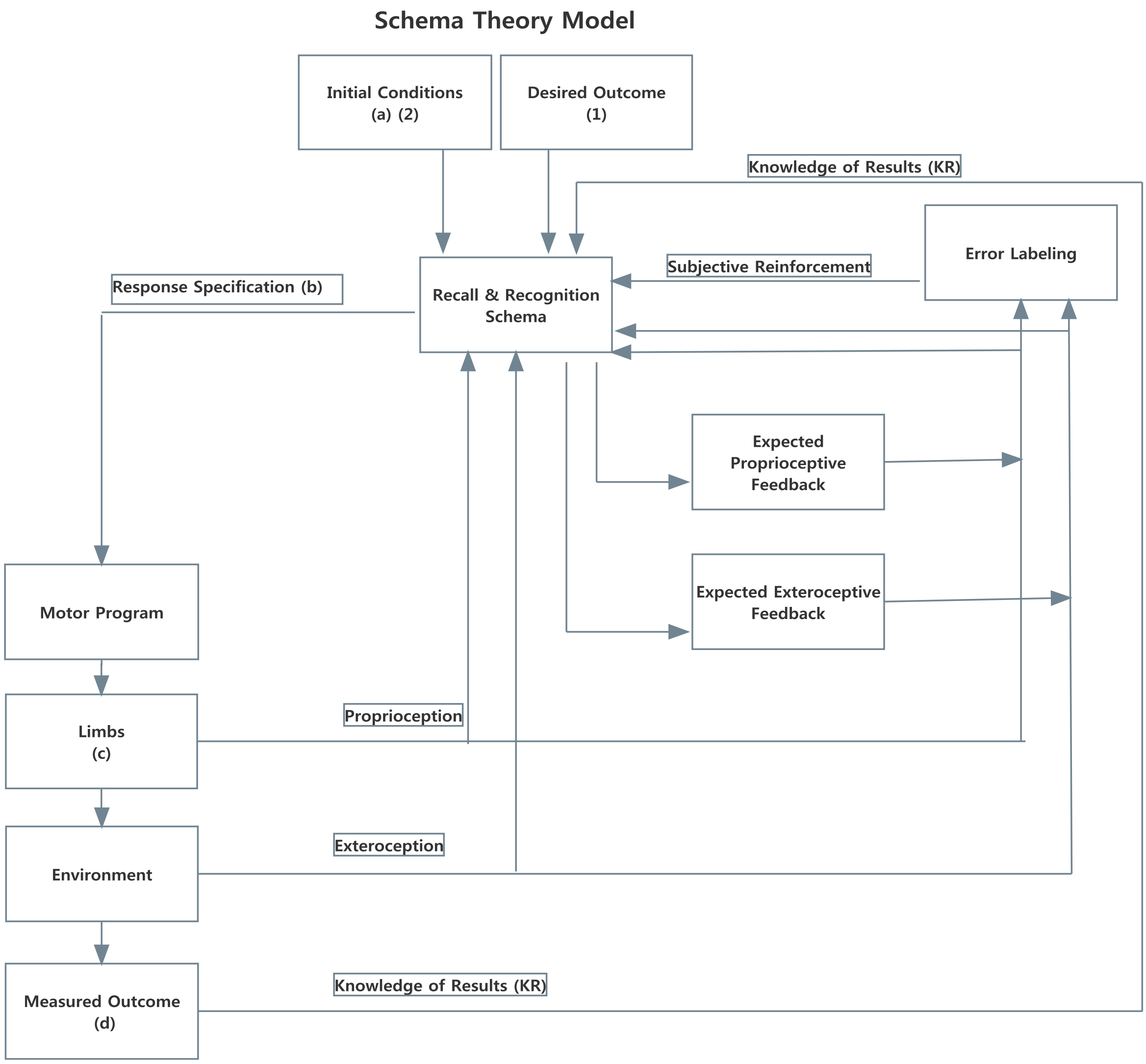

Figure 2-4: The Schema Theory Model adapted from Schmidt (1975) (p. 238).

It is this schema that is stored and not a motor program for every movement. At the onset of a movement two inputs to the model are required: 1) the desired outcome for the movement and 2) the initial conditions. The individual uses their recall schema (the relationship between the past outcomes and response specifications) to specify the desired outcome. The model also contains a relationship between the past outcomes and past sensory consequences (recognition schema). The individual can utilise both recall and recognition schema to generate two types of sensory consequences: the expected proprioceptive feedback (from the muscles, joints and vestibular apparatus) and exteroceptive feedback (from vision and audition about the environment, limb and object position). A comparison is made during and/or after the movement of the actual versus expected sensory consequences (proprioceptive and exteroceptive). If a mismatch (error) occurs between actual versus expected feedback then information (subjective reinforcement) is sent back to the model.

A distinguishing feature for Schmidt of his Schema theory was that it could deal with the issue of actual feedback versus expected feedback for the correct movement (as opposed to the movement that was just performed). He argued that previous theories (Anokhin, 1969; Pew, 1974) did not deal adequately with this issue in that the movement selection and the sensory consequences for that movement progressed serially (movement selection then sensory consequences of that selection) (Schmidt, 1975, p.237). In the Schema theory the independence of both the recall (actual outcomes versus response specifications) and recognition schema (actual outcomes versus sensory consequences) allowed not only for comparison of the sensory consequences of the actual outcome but also the sensory consequences of the desired outcome. This was an improvement on Adams (1971) model which could detect actual versus desired outcome as specified by the perceptual trace but could not distinguish whether the correct movement had been selected in the first place.

The error labelling system (e) is proposed to be another schema, in this case a schema for labelling sensory signals. It is assumed that past sensory signals have been stored along with the actual sensory consequences (based on KR), and a schema rule is built up over time that relates the KR received to the signals received. The error label system (subjective reinforcement) can act as a substitute for KR when KR is not available. However KR is essential in the development of schema for labelling new errors. This error labelling system again is suggested as an improvement to Adam’s model which did not provide adequately for learning in the absence of KR in that the perceptual trace could be weakened by incorrect movements.

2.3.5 Generalised Motor Program

One of the key developments in Schema theory was the idea that a class of movements could be represented by an individual schema (motor equivalence). For example, although we normally write with our preferred hand, when necessary (e.g. through injury) we can use our non-preferred hand. It is also possible to use our feet and mouth to carry out the same skill (Amazeen, 2002). What changes is not the movement representation (schema) but the parameters (e.g. timing, force) required to carry out the movement (Amazeen, 2002; Schmidt, 1975). Amazeen (2002) states that the motor program "must be specific enough to distinguish one class of movements from another (e.g. writing A versus writing B) but general enough to encompass movements that are similar to each other (writing the letter "A" with the preferred and non-preferred hand)" (p.233). This generalisation of the motor presentation gave rise to what is termed the generalised motor program (GMP) (Wulf, Schmidt & Deubel, 1993). Kelso (1997) defined the generalised motor program (GMP) as "an abstract representation stored in the central nervous system that controls 'most importantly' the temporal structure of an upcoming action" (p.454). Schmidt & Lee (2011) described the GMP as containing an abstract code which details the relative timing, structure and force with which events are to be produced (p. 222). The development of the theory describing the GMP mirrored progression in the world of computers where higher level languages (e.g. COBAL, RPG and FORTRAN) were providing an interface between the user and the machine language of ones and noughts(binary code). The advent of modular programming with subroutines called by higher level code with user input of variables dictated how the program would run. This modular approach allowed flexibility which differed from the very structured one dimensional nature of machine code. Typically a higher order program would incorporate an input section (details of the parameters required by the program and a mechanism for inputting these), processing section (code to carry out the action/actions required) and output section (end result). Therefore in order to run the program and produce a specific outcome, input in the form of particular parameters (e.g. dates, transaction numbers) are required. In terms of the GMP it is through an associative process that motor schema and hence the GMP develops; particular parameter values are associated with particular movement outcomes (Trembley et al. 2001). For example, the force required to throw a dart a particular distance, or the angle required to hit a particular location on the board. The parameters (force, amplitude) determine how the movement will be expressed (Schmidt, Young, Swinnen & Shapiro, 1989). Evidence in favour of the associated process was provided by Wulf et al. (1993). They showed using an arm lever movement task that feedback (100% and 63%) had a differential effect on the learning of the GMP and its associated parameterisation (timing and amplitude). In two experiments participants either produced the same movement pattern with different movement durations and amplitude held constant (Experiment 1) or the same movement pattern with different movement amplitudes and movement duration held constant (Experiment 2). While reduced feedback (63%) facilitated the development and retention of the GMP, the facilitation of parameterisation learning was adversely affected. Wulf et al. suggested that there results provide support for the concept of two separate processes in motor learning; the development of a GMP and the development of the parameters associated with that GMP.

2.4 Intrinsic and Extrinsic Feedback

Differences in the conceptualisation of motor control and learning have led to alternative models of control (open-loop, closed-loop, schema theory). Whatever the conceptual differences, any model of motor control must account for the role and use of intrinsic and extrinsic feedback. While feedback may not be required for the production of movements of short duration (Schmidt & Russell, 1972) it is generally regarded as a requirement at the acquisition phase (Laszlo & Manning, 1970; Schmidt, 1975) and for others at the retention phase (Adams, 1971) of movement production. Both the guidance (Salmoni et al., 1984) and the specificity of practice (Tremblay & Proteau, 1998) hypotheses emphasise the important nature of feedback during the acquisition and retention/transfer[1] phases of movement. The specificity of practice hypothesis states that the learner will use whatever feedback is available during acquisition to build up a strong internal representation for that movement and that rather than the feedback becoming redundant, the learner will become reliant on that particular type of feedback as practice with a task continues (Krigolson, Van Gyn, Trembley & Heath, 2006). This is supportive of the closed-loop theories (Adams, 1971) which stresses the on-going importance of intrinsic feedback. It also argues against the idea of a generalised motor program since it emphasises the specific nature of practice with a particular task rather than variability which can be achieved by one schema and different parameters. The role of visual feedback is of particular interest to those investigating the specificity of practice hypothesis.

The guidance hypothesis deals exclusively with extrinsic feedback in the form of knowledge of results (KR) and describes the detrimental effect removal of KR can have to performance if the learner has come to rely upon it. Salmoni, Schmidt and Walter (1984) define KR as the "information provided after a response that tells of the learner's success in meeting the environmental goal" (p. 355). KR is described as augmented (in addition to intrinsic feedback), usually verbal (experimenter tells participant how they have performed) and terminal (it comes at the end of the movement sequence/sequences) (Salmoni et al., 1984). The benefits of KR to the successful acquisition and production of movement have been described as facilitatory (can speed up the learning process), guiding (provides outcome information), and can be both permanent (improvements in responding- hence performance)

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[1] It is important to note that in the guidance hypothesis literature retention tests generally take the form of no-KR tests. Strictly speaking this is a test of transfer as the conditions have changed from the acquisition phase (for a least some of the participants). In the specificity of practice literature the term transfer is used to denote trials following acquisition in which participants will usually transfer to a no-vision condition (Russell & Newell 2007).

and transient (motivational) in nature (Salmoni, Schmidt, & Walter, 1984; Van Vliet & Wulf, 2006). KR is predominantly but not always verbal and can take many forms, for example, it can be minimal (simply telling the participant whether a movement was successful or not) or complex (detail of exact error made). It can be given after each trial (100% KR), after a number of trials (summary KR), or when errors are outside a particular range (bandwidth KR) (Salmoni et al., 1984). One of the objectives of research into the role of KR in movement acquisition and retention is to determine the best frequency with which to give KR in order that the learner will also develop their own internal error detection and correction mechanism (Lee & Carnahan, 1990; Park, Shea & Wright, 2000).

2.4.1 Guidance Hypothesis

The guidance hypothesis postulates that KR given immediately after each trial provides a strong guiding function for an individual in acquiring a new skill. The role of KR is informational in that participants are provided with knowledge/information on how to produce/enhance the required movement (Schmidt, Young, Swinnen & Shapiro, 1989). Therefore in the early stages of movement acquisition KR given after every trial (100% KR) can be very beneficial to successful movement outcomes. Schmidt et al. (1989) found that in the early stages of acquisition in a ballistic aiming task that participants in an immediate KR condition (100% KR) performed better (smaller constant error (CE)) than those in a summary KR (5, 10, 15 trials) condition. Yet the beneficial effect of 100% KR on performance in the acquisition phase was not matched by similar levels of performance on a retention test. Schmidt et al. found that in the delayed no-KR retention test, the summary KR group performed better than the 100% KR group. They suggest that participants given KR after every trial become reliant on KR and thus do not process other available feedback. Those in a summary KR condition may use a different strategy in the absence of KR to learn the task. Hence once KR is eliminated on retention test the participants receiving summary KR fared better. In support of this argument Anderson, McGill, Sekiya and Ryan (2005) found that participants completing an aiming task used intrinsic feedback (e.g. hand position, movement time, movement distance) to a greater extent in a delayed KR condition than participants in a no-delay KR condition. Participants were assigned to either a delay-0 KR condition (KR every trial) or a delay-2 (KR every other trial i.e. KR about trial 1 given after trial 3) and completed a self-paced blind aiming movement with their non-dominant hand. KR was provided visually in two ways: 1) the target location versus their actual end-point position was displayed on a screen 2) the difference in millimetres between the actual target and their end-point position was also displayed. In line with the guidance hypothesis participants in the delayed-KR condition performed better on a retention test. Interestingly performance on the first and last block in the acquisition phase in the delayed-KR condition was poorer than in the no-delay KR condition suggesting that at the initial stages of learning extrinsic feedback may be more valuable than intrinsic feedback in the building of a strong internal representation of the skill. The poorer performance on the last block of trials may be indicative of Salmoni et al's. (1984) concept of the motivational role of KR.

Researchers have manipulated the amount of KR given during movement acquisition in order to facilitate the learner's use of intrinsic feedback. The objective was to discover which frequency and type of KR best facilitates the learners' use of intrinsic feedback (Lee & Carnahan, 1990). KR has been quantified in terms of relative frequency (% number of trials KR is given on) and absolute frequency (actual number of KR trials). Vieira, Ugrinowitsch, Oliveira, Gallo & Benda (2012) investigated the effects of absolute versus relative KR coupled with amount of practice on acquisition and retention in a sequencing task. Participants were assigned to one of 5 groups (100% KR - 30 trials, 66% KR – 30 trials, 33% KR – 30 trials, 66% KR – 45 trials, 33% KR – 90 trials). This led to the amount of trials which KR was given on as 30, 20, 10, 30 and 30 respectively. Participants were required to move 3 tennis balls from 3 starting receptacles to 3 end receptacles in a particular sequence. The dependent variable was time taken to complete the task. The KR provided during the acquisition phase was the difference between target time and performance time. No KR was given in the retention test. The results indicated that the two groups who received the highest (100% KR) and lowest (33% KR – 30 trials) number of KR trials performed worst (highest absolute errors) on the retention task. Vieria et al. say that their results suggest that an error detection and correction mechansim are best faciliated by the processing of intrinsic feedback enhanced but not overpowered by extrinsic feedback (KR). However it should be noted that the target time for the sequence was changed in the retention tests which suggests that this should be considered as a test of transfer rather than of retention.

The effect of internal sources of feedback coupled with KR on task performance was investigated by Guadagnoli and Kohl (2001). They required participants to estimate their errors before providing KR in order to promote the use of error detection using internal sources of feedback. They found that participants in a force production task performed better in a retention test when they had received 100% KR during acquisition but were also required to estimate their level of error before receiving the KR. Those provided with 100% KR but who did not estimate their error fared worst. Two groups (error estimation/no error estimation) who received 20% KR performed at a similar level on the retention test. The results for these two groups suggest that in the absence of large amounts of KR, some form of internal error detection process must have been employed. This internal error detection mechanism be it in the form of error estimation or some other (we do not know what process the no estimation group employed) leads to better performance than receiving 100% KR alone.

The ability of KR to override internal error detection mechanisms is seen in a study carried out by Lee & Carnahan (1990). Three groups were provided KR on a task which had

3 timed segments. The task consisted of moving three barriers positioned at different angles and distances on a table in front of which the participant was standing. KR was given verbally and represented the participant's time for a particular segment. All groups received KR on every trial but the KR referred to only one of the segments not the overall movement time. One group (blocked) received KR on a particular segment consecutively for 20 (1/3) of the trials. One group (random) received KR randomly (each segment received KR 20 times but randomly over the full experiment) and one group (cued) received KR randomly but were cued as to which segment would receive KR before carrying out that trial. A no-KR retention test was performed by each group following the acquisition phase. The results indicated that performance for the blocked group was superior (smaller constant error (CE) – difference between segment goal time and performance time) than the performance of the random and cued groups in the early stages of acquisition, but this was short lived. At the end of the acquisition phase the random group's performance improved and surpassed that of the blocked group, with the cued group also performing better than the blocked group. In the retention test all groups performed at a similar level on the first block of six trials. However, by the end of the retention phase the blocked group's performance had deteriorated. Both the cued and random group's performance had improved suggesting that learning was still taking place. Another interesting point arises: the first segment for which KR was reported in the blocked group continued without KR for 40 trials once KR was switched to another segment. It might be expected that for that particular segment the CE might increase initially but that the CE rate should diminish once the participant began to engage intrinsic feedback to detect errors in this segment timing, but this was not the case. It seems that attention was only given to the segment that was receiving KR and hence the performance in the other two segments deteriorated. This emphasises the powerful nature of KR but also it's limiting effect on the processing of other types of feedback.

Park, Shea and Wright (2000) questioned the strength of the guiding effect of KR on movement acquisition. They cited a number of studies in which performance at acquisition stage was no better for a KR versus reduced KR group (Nicholson & Schmidt, 1991; Winstein & Schmidt, 1990 in Park, Shea & Wright, 2000, p.287). They suggested that concurrent feedback (KR given to the learner during movement acquisition) may be more beneficial than terminal feedback (KR given at the end of each trial). Two groups were given 100% concurrent feedback (visual kinematic feedback indicating force and timing errors) with one of these groups also receiving 100% terminal feedback in the same format as for concurrent feedback. Another two groups were given 100% terminal feedback with one group receiving concurrent feedback on every other trial (50%). They found that the two groups who had received 100% concurrent feedback performed better during the acquisition phase (smaller root-mean-square-error RMSE) but their performance in the retention test (no feedback given) was significantly worse than that of the reduced or no concurrent feedback group. They say that concurrent feedback might produce a better guiding effect than terminal feedback. However Park et al. did not include a control condition (no feedback) in the acquisition phase to assess the relative benefit of terminal or concurrent feedback to a no feedback condition.

What is evident from the studies described above is that augmented feedback (concurrent or terminal) in the form of KR provides a guiding effect during acquisition. If the conditions under which the movement is to be practiced in the retention phase changes then the removal of KR can have a detrimental effect on movement production (Russell & Newell, 2007).

2.4.2 Specificity of Practice

The specificity of practice hypothesis (Proteau, Marteniuk, Girouad & Dugas, 1987; Tremblay & Proteau, 2001; Tremblay & Proteau, 1998) extends the concept of the guidance hypothesis to include the processing of concurrent intrinsic feedback. Researchers suggest that rather than intrinsic feedback becoming redundant with practice as the motor program develops; an individual's reliance on available feedback will increase with practice. A number of studies have investigated the specificity of practice hypothesis using vision/no-vision conditions. For example, Proteau et al. (1987) investigated the accuracy of aiming movements performed for brief (200 trials) or extended (2,000 trials) practice with full visual feedback available (FV) or visual feedback at target only (TO). Participants were assigned to one of four training groups during acquisition but all groups performed a transfer test in the TO condition. The results of the study demonstrated that participants who performed the task with full vision in the acquisition stage suffered the largest decrease in performance (target accuracy) in the transfer test. Furthermore those participants who had received extended practice with full vision in the acquisition stage suffered the largest decrement in performance of all groups. Evidence in support of the specificity of practice hypothesis has been shown for a range of tasks (simple and complex) including simple aiming movements, walking, powerlifting and ball interception (Proteau & Carnahan, 2001; Yoshida, Cauraugh, & Chow, 2004; Proteau, Tremblay, & DeJaeger, 1998; Tremblay & Proteau, 2001).

Which form of afferent feedback (visual or kinaesthetic) is more important as practice continues? Trembley, Welsh and Elliot (2001) found that the use of visual or kinaesthetic feedback may depend upon the distance a target is from its home location: if the target is close to the home position (15cm) then kinaesthetic feedback may be the dominant feedback processed as practice progresses. If the target is a greater distance from the home position (90 cm) then visual feedback may be more relevant. Therefore they consider a modified form of the specificity of practice hypothesis to be more salient: whichever form of afferent information is most beneficial in a given situation will be processed over all others.

A number of researchers have investigated the effects of combining both the guidance and specificity of practice hypothesis (Blandin, Toussaint and Shea; 2008; Maslovat, Brunke, Chua & Franks, 2009). Blandin et al.(2008) conducted two experiments to test for these effects. In their first experiment they employed a flexion-extention task with 4 conditions (vision+ 100%KR, vision+ 33%KR, no-vision+100%KR, no-vision+33% KR). Following the acquisition phase each group moved to a delayed (no-vision+no KR) transfer task. The results from the first experiment supported the specificity of practice hypothesis with the vision+ groups performing worst (largest root-mean-square-error) in the transfer tests. The weakest group was the vision+33%KR. Blandin et al. say that in the absence of KR this group processed the visual feedback more deeply than those in the 100% KR condition, hence their performance suffered more when vision was withdrawn in the transfer test. In a second experiment they employed the same task but visual feedback was available in all conditions at the acquisition phase. What differed was the amount of KR given (33% or 100%) and the length of the acquisition phase (396 trials (extended) versus 54 trials(short)). The findings from experiment 1 were further supported in experiment 2 with those who completed the largest number of trials in the acquisiton phase but only received 33%KR faring worst. The findings from experiment 2 show that as practice increases so too does the reliance on the available feedback which again supports the specificity of practice hypothesis. Blandin et al. further state that the results indicate a " potentially important interaction between the presentation of terminal feedback and the processing of concurrent sensory information" (p. 1000). The less terminal KR that is available the greater the reliance on sensory information, hence the more detrimental its removal in subsequent transfer tests will be.

The results from research on both the guidance and specificity of practice hypotheses indicate that the conditions under which a task will normally be carried out might suggest what type of feedback is more relavant at the acquistion stage. It appears from the research that both concurrent and terminal feedback delivered during acquisition aid performance. If the conditions remained the same i.e. the skill is to be retained rather than performed under different conditions(transfer), then the more feedback available the better the performance.

2.5 Summary

This chapter has given a brief introduction to some of the main areas of research on motor control and learning as envisaged by information processing theorists. These theories/hypotheses relate to the hypothetical internal mechanisms that may control how we move and operate within our daily lives. The issues discussed focussed on different types of movement (short/long duration and novel/well practiced) we produce on a daily basis. The original open loop models (Keele, 1968) tended to deal only with movements of short duration that were already well practiced by the individual. They produced evidence to show that these movements could operate in the absence of feedback (e.g. de-afferentation studies). But these open-loop theories did not explain how novel movements or movements of longer duration are learned. Through refinements to the open-loop theory (Laszo and Manning, 1970) and through the work of Adams (1971) and Schmidt (1975) it has been generally accepted that new movements require feedback to create a STD or reference system against which all subsequent movements of this type can be judged. However differences exist between those who believe that feedback is required even after the STD has been set down (Adams, 1971) and those who believe that it is no longer necessary (Schmidt, 1975). Research on the role of feedback would suggest that movements performed in the absence of feedback, particularly if that feedback was present during acquisition, is detrimental to movement production (Salmoni et al., 1984; Trembley et al., 2001). Therefore those who favour the specificity of practice hypothesis (Proteau et al., 1987) would argue that a skill develops through practice under one set of conditions only and if these conditions change then performance deteriorates. In conflict with this viewpoint is that of the generalised motor program. It offered an explanation as to why we might be able to carry out the same action with a number of different effector systems; that transfer of skill to other limbs was possible under the guidance of one program using different parameters. These issues form the basis for the arguments set out by intermanual transfer researchers and will be examined in more detail in Chapter 3 .

Chapter 3

Analysis of the Three Main Models of Intermanual Transfer

3.1 Introduction

Intermanual transfer of skill refers to the ‘crossing over’ of skills from one hand to the other. It is our ability to transfer and perform a skill learned with one hand (e.g. texting) to the opposite hand if the preferred or dominant hand for that task is otherwise occupied, injured, or impaired through brain damage. Birbaumer (2007) states of intermanual transfer that “it is critical for our survival in a world which requires rapid modification of skills learned with one limb only” (p. 1024). A number of key concerns for intermanual transfer researchers centre on a) the hemispheric location of the motor program (MP) for a skill learned with one hand, b) whether movement goals and parameters (standard - STD) can be shared between the hemispheres thereby facilitating the learning of that skill by the other untrained hand and c) predicting the direction of transfer (right-hand to left-hand, left-hand to right-hand, or symmetrical). The current chapter reviews the three models of intermanual transfer as outlined by Schulze, Luders and Jancke (2002). They are the Proficiency Model (Laszlo, Bagulay & Bairstow, 1970), Callosal Access Model (Taylor & Heilman, 1980) and the Cross Activation Model (Parlow & Kinsbourne, 1989). Section 3.2 will outline the background to each of the models and their predictions with regard to the key concerns outlined above. Three sections follow which describe the methods used to test the predictions of each model. A description of the methodology and results for each model are given. The results from each experiment have been extracted from figures and tables in the original articles to provide a graphical account of their findings. The penultimate section provides a comparison of the results from each model. Differences in methodologies are explored and the examination of these provides the platform for the three experimental chapters to come. A final section reports on current research on intermanual transfer and examine some of the findings in relation to the findings from the three models.

3.2 Overview of the Models

The Proficiency model (Laszlo et al., 1970) has its origins in the open-loop control theories of motor control as discussed in Chapter 2. Laszlo et al. drew on the work of Laszlo and Manning (1970) in which they described a refinement to the open-loop control model. This refined version of the model provided an explanation for the processes involved in motor skill acquisition. Central to this refined version of the open-loop control model is the inter-connection of two units, the motor program (MP) and the standard (STD). The STD is built up from both intrinsic and extrinsic feedback and includes any or all of the following components: situational and task demands, the memory traces of the skilled movement, efference copy, visual, auditory, tactile, and kinaesthetic feedback (Laszlo et al., 1970). The STD as proposed by Laszlo and Manning (1970) is similar to the perceptual trace as envisaged by Adams (1971). Similarly the STD may be compared to the recall and recognition schema described in Schmidt's Schema theory (1975). Recall and recognition schema allow for the generation of two types of sensory feedback (exteroceptive and proprioceptive) which can be used to monitor the success of the movement. In essence the STD, perceptual trace and recall and recognition schema may be thought of as error detection mechanisms. Laszlo et al. explain the difference in performance level of the dominant and non-dominant hand in terms of the benefit that each can derive from the STD. They suggest that the dominant hand can use more elements of the STD, it's superior performance (tapping rate) "could be due to a finer definition of the STD" (Laszlo et al., 1970, p.269). Hence the dominant hand is more proficient at utilising elements of the STD. An analogy might be that of having MS Word 2010 on one PC (dominant hemisphere) and MS Word 2007 on another (non-dominant hemisphere). You can in theory access and work on the same document on both versions provided that the document has been stored in MS 2007 format (non-dominant hemisphere STD), in so doing you lose the extra functionality that was available in MS Word 2010 version (dominant hemisphere STD). Training of the dominant hand benefits the non-dominant hand. Training of the non-dominant hand does not lead to the same degree of transfer of information to the dominant hemisphere. This is because according to the proficiency model the STD created by the non-dominant hand is not as comprehensive as that created by the dominant hand. The model predicts that direction of most transfer will be from the dominant hand/hemisphere to non-dominant hand/hemisphere (right-hand to left-hand).

The Callosal Access Model (Taylor & Heilman, 1980) proposes that the motor programs for skilled hand movement are held in the dominant hemisphere (usually the left hemisphere) irrespective of the hand used for hand skills training. Taylor and Heilman drew on their work with patients suffering from apraxia to advance their Callosal Access model of intermanual transfer. As described in Chapter 2 apraxia is a movement disorder which "leads to an inability to perform skilled purposeful movements due to loss of knowledge of how to perform these movements" (Stamenova, Black & Roy, 2011, p.954). The seminal research work of Hugo Liepmann (1863-1925) with patients with lesions of either the left or right hemisphere showed that patients with left hemisphere lesions displayed apraxia of the left arm/hand in 50% of cases whereas none of his patients with right hemisphere lesions were apraxic (Zwinkels, Geusgens, Van de Sande & Van Heugten, 2004). Liepmann concluded that left hemisphere was dominant for motor control and sent commands to the right hemisphere (left hand) via the corpus callosum (Jeannerod, 2006b, Zwinkels et al., 2004). Taylor and Heilman (1980) drawing on the work of Liepmann and others on apraxia (e.g. Dee, Benton and Van Allen, 1970; Kimura, 1977) concluded that the left hemisphere is responsible for movement control in both the dominant and non-dominant hand. The motor program must reside in the left hemisphere. The dominant hand has direct access to the motor programs whereas the non-dominant hand has indirect access presumably via the corpus callosum. If the non-dominant hand is trained, the dominant hand will have direct access to the motor programs as they are stored in the dominant hemisphere. It follows that the dominant hand benefits from non-dominant hand training. The non-dominant hand does not benefit as much (e.g. speed) from dominant hand training because it is limited to indirect access to the motor programs via the corpus callosum. This indirect access requires interhemispheric communication resulting in additional processing time (interhemispheric transfer time – IHTT) before the non-dominant hand can perform the required action (Baynard, Gosselin, Manon & Lassonde, 2004). This may result in the non-dominant hand being slower on a given task than the dominant hand. The model predicts that transfer will be from non-dominant to the dominant hand (left-hand to right-hand).

Parlow and Kinsbourne’s (1989) original objective was to discover whether the Proficiency or Callosal Access Model best described the processes involved in intermanual transfer. The results from their studies provided partial support for the Proficiency model. However Parlow and Kinsbourne felt that a third explanation (Cross Activation) best described the mechanisms involved in intermanual transfer. They concluded that if the dominant hand was trained then a copy of the motor program was sent to the non-dominant hemisphere (Cross Activation), but if the non-dominant hand were trained then the motor program was stored in the non-dominant hemisphere only. The model predicts that transfer will be from dominant hand/hemisphere to non-dominant hand/hemisphere (right-hand to left-hand) only.

3.3 Testing the Proficiency Model

Laszlo et al. (1970) used a fast tapping task under two conditions (Experiment 1 - reduced feedback (FB-) and Experiment 2 – full feedback (FB+)) to investigate the differences in the control of movement in the dominant and non-dominant hand. They chose fast tapping with the index finger because of its "relatively low perceptual loading" (p. 262). Laszlo et al. hypothesised that using transfer between different muscle groups (tapping with the index finger of the dominant and non-dominant hand) as the main variable, it might be shown that STD and MP effects on transfer could be separated. This would provide a) evidence for the existence of the two functional units (MP and STD) and b) expose differences in the dominant and non-dominant hands ability to exploit elements of the STD.

3.3.1 Experiment 1 (FB-)

In the FB- condition visual, auditory and kinaesthetic feedback were eliminated using a blindfold, earphones connected to white noise generator and a nerve compression block. Thirty six participants[2] were randomly assigned to one of three groups (dominant hand (RH), non-dominant hand (LH), and an alternating group). Results from the alternating group are not included: the participants in this condition alternated from trial to trial between RH and LH and took part in experiment 1 only. Each participant completed eight trials (30 sec duration) with the RH or LH in the training phase (pre-shift) followed by eight trials with the opposite un-trained hand in the transfer phase (post-shift). The eight post-shift trials were competed one week after the pre-shift trials because nerve block compression could not be applied more frequently than this. A concave Morse key was used to record tapping performance (pressure and key-movement). The threshold for a correct tap was either 2.5mm

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[2] Sixty participants in total took part in Experiment 1 and 2, this included seventeen females. Laszlo et al. do not tell us the breakdown of females in each Experiment.

free movement or 200gm pressure or both. The dependent variable was number of taps per trial.

The results from experiment 1 showed that the RH and LH performed at a similar level over the eight pre-shift trials although a significantly more rapid improvement was made by the LH (see figure 3-1). The results of a Friedman 2-way analysis of variance confirmed the significant nature of the LH's performance gain over the eight trials. The improvement of the RH was non-significant. Laszlo et al. suggest that the similar performance of both hands in the pre-shift phase is reflective of the fact that the STD under reduced feedback (FB-) remains at a "rudimentary level" (p. 269). The LH appears able to make better use of this rudimentary STD than the RH. In the post-shift trials positive transfer occurred for the RH only. Transfer was measured by a trial by trial comparison for the RH (Group 1 pre-shift with Group 2 post-shift) and LH (Group 2 pre-shift with Group 1 post-shift).

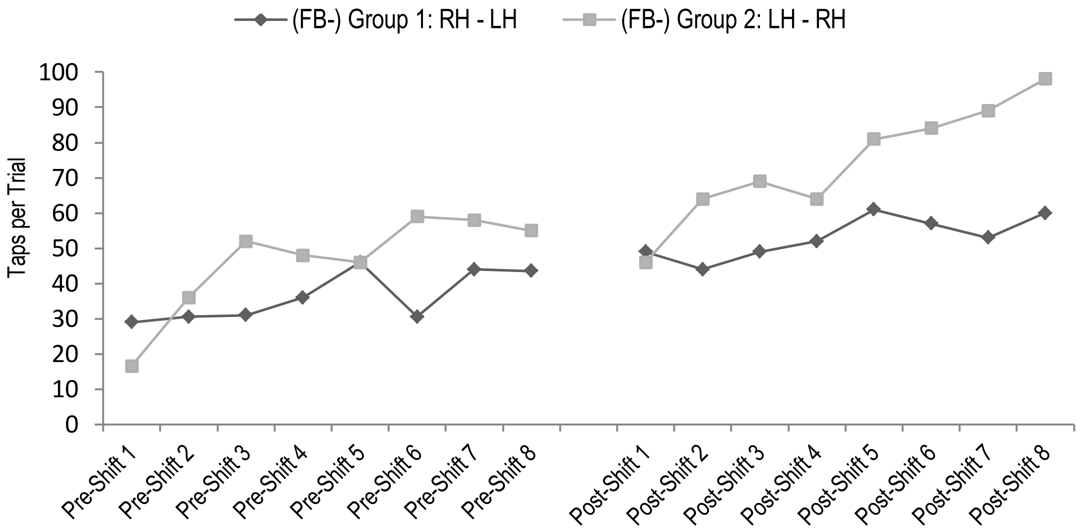


Figure 3-1: Results from Experiment 1 in which visual, auditory and kinaesthetic feedback were eliminated. The number of taps per trial at pre-shift and post shift are shown for each transfer group (Group 1 - RH to LH, Group 2 - LH to RH). The data was extracted from figure 1 in the original article (Laszlo et al., 1970 p. 265).

A Kolmogorov-Smirnov test revealed that each trial by trial comparison for the RH yielded a significant result (except trial 5) indicating a positive transfer gain for the RH after LH training. Similar testing for the LH revealed non-significant results (except trial 1) which indicated that the LH did not benefit from RH training. For Laszlo et al. this indicates that the LH can trigger the motor program with less information from the STD, which in the post shift trials the RH could use to its advantage. The results indicate that right hand's greater proficiency is lost when feedback is eliminated.

3.3.2 Experiment 2 (FB+)

In the FB+ (full feedback available) condition twenty four participants were randomly assigned to one of two groups (dominant hand (RH), non-dominant hand (LH)) Each participant completed eight trials (10 sec duration + 120sec rest period) with the RH or LH in the training phase (pre-shift) followed by eight trials with the opposite un-trained hand in the transfer phase (post-shift). The eight post-shift trials were completed 2 minutes after the pre-shift trials. The equipment used to record the dependent variable (number of taps per trial) was the same as for experiment 1.

In the pre-shift trials the RH performance (number of taps per trial) increased significantly from trial 1 to trial 8 as confirmed by analysis of variance testing. The performance for the LH did not improve significantly over the eight trials. The results are displayed graphically in figure 3-2.

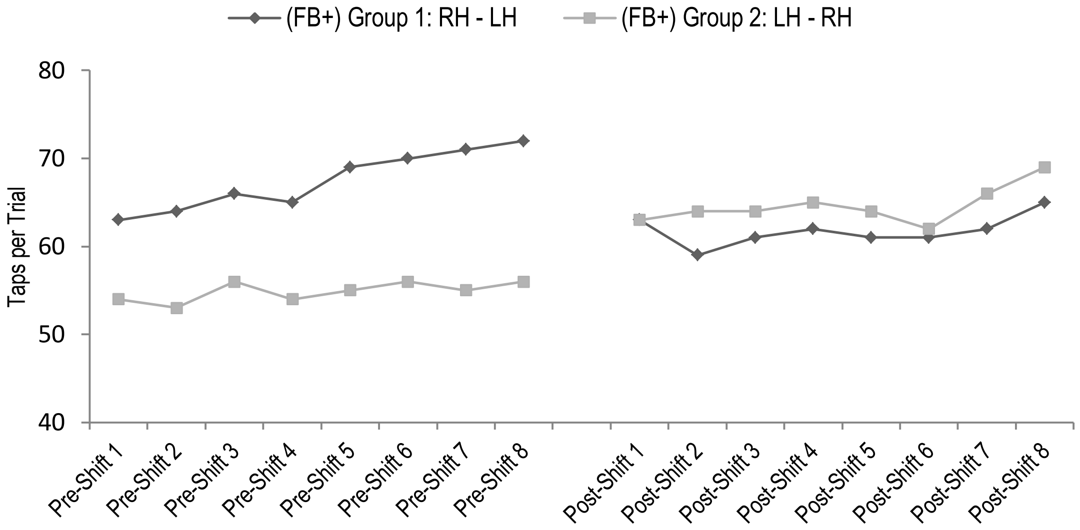


Figure 3-2: The results for Experiment 2 in which full feedback was available are displayed here. The number of taps per trial for each group (Group 1- RH to LH and Group 2- LH to RH) are shown at pre and post-shift Phases. The data was extracted from figure 2 in the original article (Laszlo et al. 1970, p. 267).

Laszlo and colleagues argue that this may be due to a “finer definition of the STD” used by the right hand (p. 269). In the post-shift trials positive transfer occurred only for the LH (confirmed using analysis of variance). Laszlo et al. interpreted this finding as the LH making use of the STD created by the RH in the pre-shift phase. The right hand could not make as much use of the STD created by the LH. These findings support their hypothesis that the right hand is more proficient at exploiting elements of the STD than is the left hand.

Overall the findings of the two experiments reveal a different pattern of results when feedback is available or unavailable. These results are summarised in Table 3-1. In the full feedback condition the RH appears to be able to make greater use of the available feedback to create a better STD as evidence by the RH’s superior performance in the pre-shift phase. In keeping with their hypothesis the LH performs better in the post-shift phase because it has access to this superior STD.

Table 3-1 ***A summary of the results for each condition are compared to the hypothesis and support is indicated (Yes/No).***

Experimental Condition*	Result	Support for Hypothesis *(The right hand is more proficient at exploiting elements of the STD than is the left hand)* (Yes/No)
Right-Hand (FB-)	Post-shift performance greater than Pre-shift performance	No
Right-Hand (FB+)	Pre-shift performance greater than Post-shift Performance	Yes
Left-Hand (FB-)	Pre-shift performance greater than Post-shift performance	No
Left Hand (FB+)	Post-shift performance greater than Pre-shift performance	Yes

*Note: FB- refers to the reduced feedback condition (visual, auditory and kinesthetic feedback removed). FB+ refers to the full feedback condition

The results for the reduced feedback condition showed that the LH performance was similar to that of the RH in the pre-shift phase. This does not support Laszlo et al.'s hypothesis of the RH's ability to make greater use of available feedback than the left hand. Laszlo et al. say that these result reflect the LH's ability to operate more proficiently when less feedback is available than the RH. Their findings and interpretation of same suggests that the RH is more reliant on visual, auditory and kinaesthetic feedback than the LH.

3.4 Testing the Callosal Access Model

Taylor & Heilman (1980) used a complex key-pressing task under two conditions (full feedback (FB+) and reduced feedback (FB-)) to examine acquisition and transfer levels. They chose a complex key pressing task because participants would not be familiar with it and so it was hoped that it would avoid conferring an initial advantage to the right hand (no prior experience or practice with the task). Taylor and Heilman hypothesised that the new skill (correct movement sequences completed) would be acquired more rapidly by the right (dominant) hand, as it has direct access to the motor program, whereas the left (non-dominant) hand has indirect access via the corpus callosum (H_1). They also hypothesised that the right hand would benefit more from left hand training, as again, the right hand would have direct access to the motor program stored in the left hemisphere (H_2).

3.4.1 Experiment 1 (FB-)

Thirty two right-handed participants (16 females) took part in the experiment. Participants were split by gender into two groups: right hand trained (RH) and left hand trained (LH). Handedness was confirmed using the Neurosensory Centre Handedness Questionnaire (Varney & Benton, 1975 in Taylor & Heilman, 1980 p. 589). Visual feedback was eliminated in the reduced feedback condition (placing the participant's hand behind a screen). Taylor and Heilman's rationale for the removal of visual feedback was to prevent "engagement of both hemispheres in the task through the visual modality" (p. 590). Concurrent extrinsic feedback was given during each trial as participants were informed (a warning tone sounded) when they made an error in the sequence. They were then required to re-start that sequence. This provided information about errors made but conversely also informed participants when they completed a correct sequence (no tone). A flat keyboard with 10 keys (3 x 3, + one additional key at the bottom) was used to complete the task. Only the two outside keys in each of the three rows were used in the task. Each participant rested their forearm on a wooden platform and pressed the keys from top to bottom (using the middle, ring and baby finger) for the top, middle and bottom rows respectively. Key pressing progressed from the key closest to the thumb to the key farthest away from the thumb (the movements of the two hands mirrored each other). All participants were shown the sequence to be completed and were allowed to familiarise themselves with the sequence, however they were not allow to press the keys during familiarisation. Participants were tested at pre-training (1 trial with each hand), training (25 trials with training hand) and at transfer (1 trial) with each hand immediately after training and at a one week interval. Each trial lasted for 30 seconds with a 15 second rest period between trials and a 60 second rest period between trial blocks (5 trials). The dependant variable measured was average number of sequences (correct and incorrect) completed per trial block.

Results – Overall Groups

The average number of correct sequences completed at pre-training for the RH and LH were very similar: (RH = 4.63, LH = 4.38). The 25 training trials were averaged over 5 trial blocks and the result for each group by block is displayed in figure 3-3. The performance (average number of correct sequences) of each group increased significantly over the 5 trial blocks. This was confirmed using analysis of variance testing. The lack of a significant difference in performance between the groups at the training phase indicated that the performance rate for each hand was similar. Transfer gain was calculated as the difference between the pre-shift trial performance for each hand and the immediate and delayed transfer performance. There was very little difference in performance for each untrained hand following opposite hand training indicating that transfer was symmetrical. Taylor and Heilman suggest that the overall results provide some support H_1 (although they are not significant). The results do not support H_2. A subsequent analysis by gender was carried out by Taylor and Heilman as there was no significant difference in performance between the overall groups at either training or transfer phases.

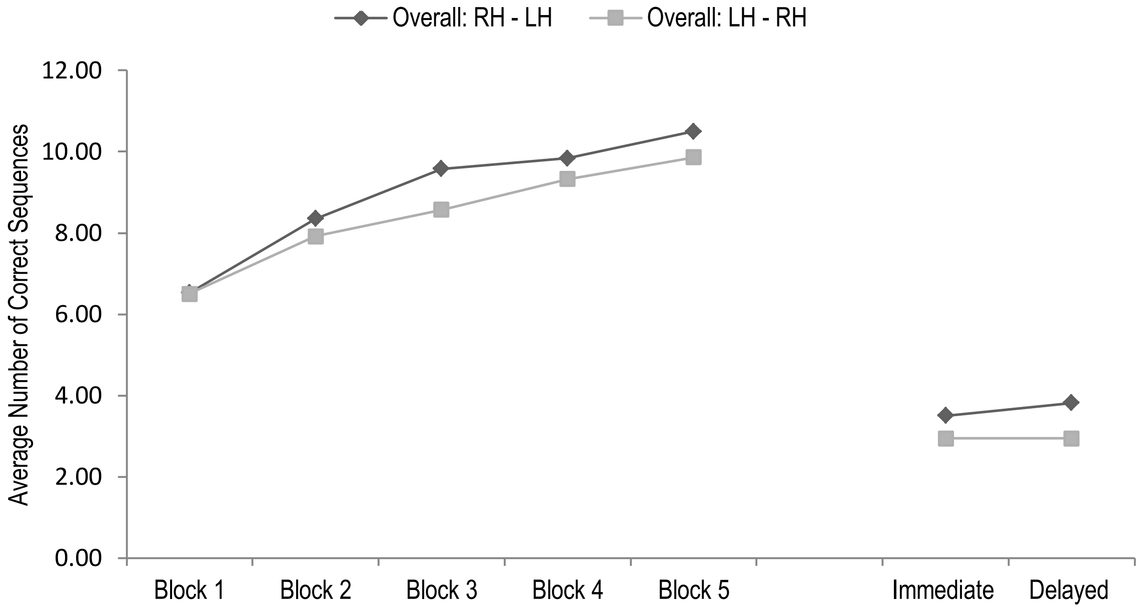


Figure 3-3: The Average Number of Correct Sequences completed by the overall groups (RH - LH, LH - RH) at training and transfer phases. Transfer was calculated as the difference between performance at pre-training and transfer phases and was recorded immediately following training and at a one week interval. The data is extracted from Table I & II in the original article (Taylor & Heilman, 1980, p.590 & p.593).

Results: Male Participants

The performance of both the RH and LH trained males improved significantly over the 5 training blocks. There was a linear improvement for both hands across the 5 blocks with the RH making a more rapid improvement. The LH outperformed those trained with their RH on the first 3 blocks but the performance of the RH trained group improved (blocks 4 & 5) and was equal to that of the LH trained group by block 5 (see figure 3-4). Taylor and Heilman concluded that these results are consistent with H_1 in that the right hand had a faster acquisition rate. They seem to ignore the fact that the LH performance was better than that of the RH. This would seem to contradict H_1 which suggests that the RH should acquire the new skill more rapidly than the LH but Taylor and Heilman appear to make a distinction here between acquisition rate and performance. Taylor and Heilman argue that the initial greater performance (more correct sequences completed) of the left hand is supportive of earlier work by Kimura & Vanderwolf (1970) in which they demonstrated superior left hand performance on a finger flexion task (in Taylor & Heilman 1980, p.592). Taylor and Heilman suggest that if enough trials had been completed the RH may have surpassed the LH.

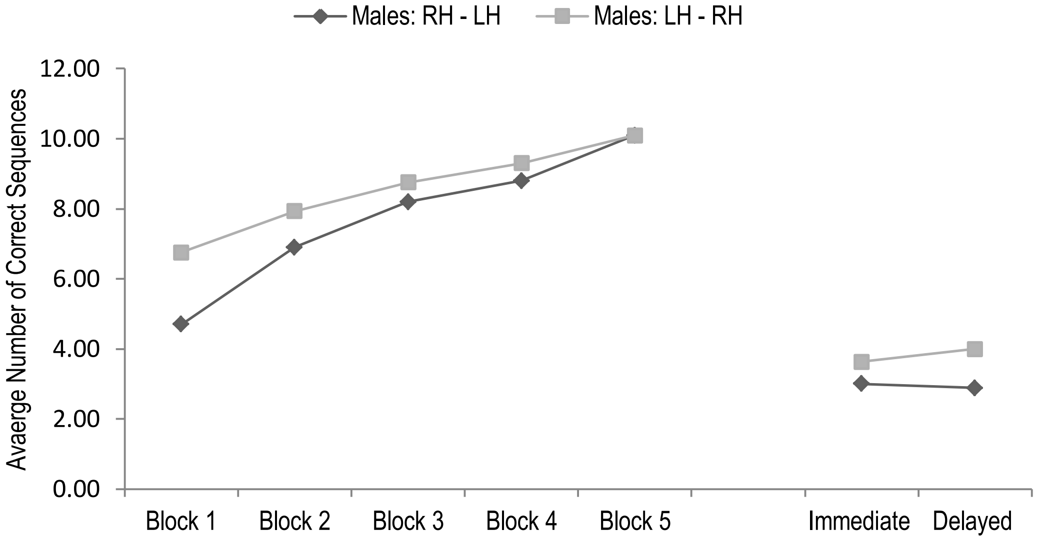


Figure 3-4: The average number of correct sequences recorded for males in the reduced feedback condition. The data was extracted from Table I & II in the original article (Taylor & Heilman, 1980, p. 591 & p. 593).

To test H_2 the pre-trial performance (figure not reported by gender) of each hand was subtracted from the immediate and delayed transfer results to provide a figure for transfer gain. The results for the males showed that transfer gain was greater for the RH than the LH. Although the data are consistent with H_2 in that the RH gain increased from the immediate to the delayed transfer test, they did not reach significance.

Results: Female Participants

Results from analysis of variance testing indicated a significant improvement across the training blocks for both hands. Females trained with their RH outperformed those trained with their LH for all trial blocks. Again this would seem to support H_1 but if viewed in terms of acquisition rates as Taylor and Heilman see it then the result does not support H_1.

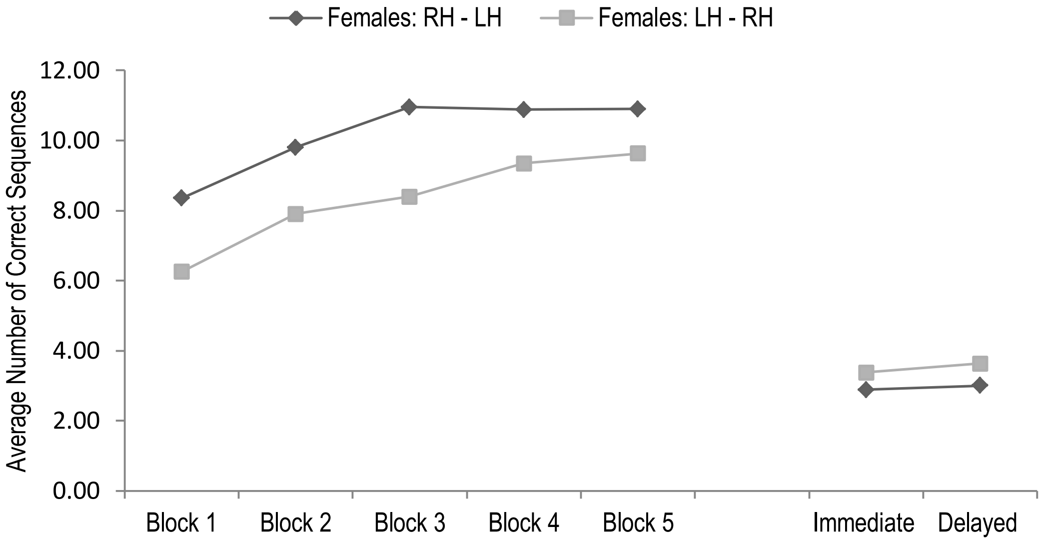


Figure 3-5: The average number of correct sequences recorded for females in the reduced feedback condition (visual feedback eliminated). The data is extracted from the original article (Taylor & Heilman, 1980, p. 591 & p.593).

There was little difference in transfer gain between the RH and LH in the immediate and delayed transfer phases for the female group. This suggests that transfer was symmetrical rather than asymmetrical, therefore inconsistent with H_2. Taylor and Heilman suggested that females may have engaged in some form of verbal strategy to help remember the sequence. A left hemisphere verbal strategy may have interfered with left hemisphere motor processing, which could have affected the outcome. They point to several studies which suggest that fine motor performance in the right hand is affected to a greater extent by verbal strategies than the left hand (Bowers, Heilman, Satz & Altman, 1970; Lomas & Kimura, 1976 in Taylor & Heilman, 1980, p. 595). However it is difficult to reconcile the assertion that the use of verbal strategies affected performance at the transfer phase when the performance of the RH in females was superior at all points during the training phase. The fact that only females were affected by verbal strategies raises some doubt about Taylor and Heilman's rationalisation for female performance. Research has shown that verbal interference with performance of motor tasks occurs in both males and females, for example McGowan and Duka (2000) found no gender differences in tapping interference using a manual (finger tapping) – verbal (visual memory) task combination. Lomas and Kimura

(1976) found a decrease in performance in a dowel balancing task when changing from a silent to a speaking condition to be greater in males than females. Why verbal strategies should have affected the performance of female participants to a greater extent than males has not been fully explained.

Analysis of Errors

An analysis of overall group errors showed that RH trained participants made more errors (mean = 1.64) than LH trained participants (mean = 0.65). A breakdown by gender was not given – therefore it is not possible to identify which gender made more errors. If we assume that the figures are representative of each gender then for males these figures could account for the poorer performance of the RH trained participants (when an error was made the sequence had to be restarted), this would also imply that females were even faster with their RH than LH. Furthermore, there was not a significant reduction in errors across trials. This implies that speed and accuracy are transferred differently. The results of the analysis of errors indicates that the removal of visual feedback may be more detrimental to the RH than the LH.

Taylor and Heilman conclude that the results from Experiment 1 provide evidence of left-hemisphere dominance. They draw this conclusion even though it is clear that the asymmetrical results in the transfer phase for male participants do not reach significance. They explain the symmetrical transfer found in females in terms of verbal strategies that may have interfered with left hemisphere processing. There is no suggestion that participants were asked to confirm if they had used any strategy to remember the sequence. In order to further test their hypothesis and to try to avoid the necessity for females to engage in verbal strategies they conducted the same experiment with visual feedback available. The experiment was also extended from 25 to 40 trials in the training phase. The rationale here is that extending the amount of practice might elicit the right hand superior performance that was not found for males in the training phase of experiment 1.

3.4.2 Experiment 2 (FB+)

An additional thirty two right-handed participants (16 females) were recruited for experiment 2. Participants were again split by gender into two groups: right hand trained (RH) and left hand trained (LH). Handedness was confirmed using the Neurosensory Centre Handedness Questionnaire (Varney & Benton, 1975 in Taylor & Heilman, 1980 , p.589). Some changes were made to the procedure. Experiment 2 was run over two days: day 1 pre-training (1 trial with both hands) and 4 blocks x 5 trials in the training phase (training hand only). On Day 2, 4 blocks were again completed with the training hand and an immediate transfer trial (1 trial with each hand) followed. They delayed transfer test was not performed due to the fact that the results for Experiment 1 (immediate to delayed transfer) were not significant.

Results: Overall Groups

Almost twice as many sequences were completed by both hands during the pre-trial test (8.50 RH, 8.13 LH) compared to the FB- condition, suggesting that visual feedback made the task easier. As was the case in experiment 1 overall both groups performed at a similar level at both training and transfer phases. While each groups performance increased significantly across trial blocks. The between group analysis as might be expected from viewing the graphical representation of the data presented in figure 3-6 was not significant.

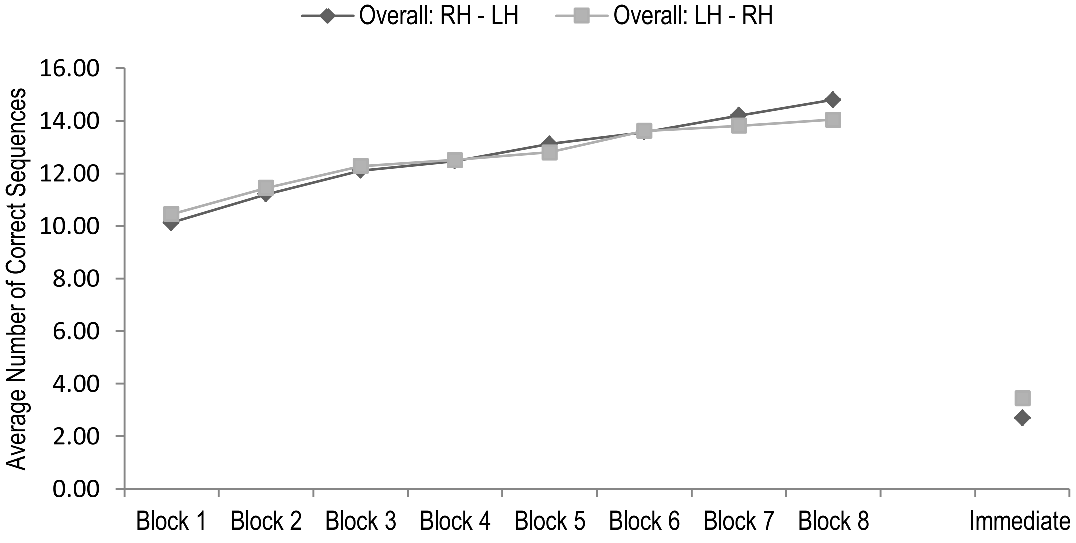


Figure 3-6: The average numbers of correct sequences from Experiment 2 (full feedback available) are shown here. The data was extracted from Table III & IV in the original article (Taylor & Heilman, 1980, p. 597 & p. 598).

However Taylor and Heilman say that the more rapid acquisition of the task by the RH is supportive of H_1. H_2 which stated that the right hand would benefit more from left hand training, as the right hand would have direct access to the motor program stored in the left hemisphere, is not supported as transfer gain was symmetrical in nature.

Results: Male Participants

The results for male participants showed that both the RH and LH group's performance increased significantly across the training blocks. As was the case in experiment 1 the LH trained group outperformed the RH trained group (See figure 3-7), but this difference was not significant. Taylor and Heilman still insist that performance of the RH would probably have surpassed that of the LH if training had continued. They argue that this is evidence of left-hemisphere dominance although not supportive of H_1 because the acquisition rate is not faster in this instance for the RH. They cite a sampling error as the cause of the differences in performance between the RH and LH training groups in experiment 2. The pre-training results for RH trained males (mean = 6.63) was significantly below that of LH trained males (8.94). But such a sampling error is not forwarded as a reason for the difference seen in experiment 1.

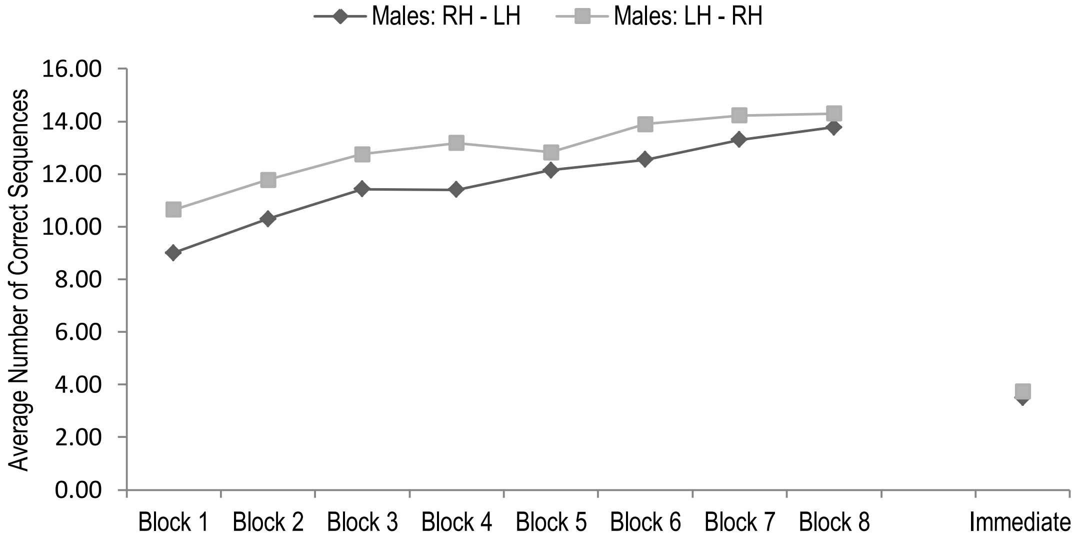


Figure 3-7: The average number of correct sequences for males in the full feedback condition. The data was extracted from Table III & IV in the original article (Taylor & Heilman, 1980, p. 597 & p. 598).

Taylor & Heilman seem to ignore this point and say that "the difference between hand-trained groups across blocks may be best described as one in which the right hand group tends to lag behind initially but eventually equals and then surpasses the left hand group" (p. 597). The transfer gain for both the RH and LH groups is symmetrical. This result does not support H_2.

Results: Female Participants

As was the case in the first experiment the RH trained females performed more correct sequences than the LH trained group (See Figure 3-8). The number of correct sequences completed in the full feedback condition increased for both hand trained groups, but the increase did not diminish the superiority of the RH performance compared to the LH. The RH performance of females at the end of the training phase (mean = 15.83) was greater than that of the male group (mean = 14.30) further emphasising the superior performance of the RH. Taylor and Heilman argue that their results are consistent with previous observations of greater laterality of motor functions in females (Annett, 1970; Hicks, 1974).

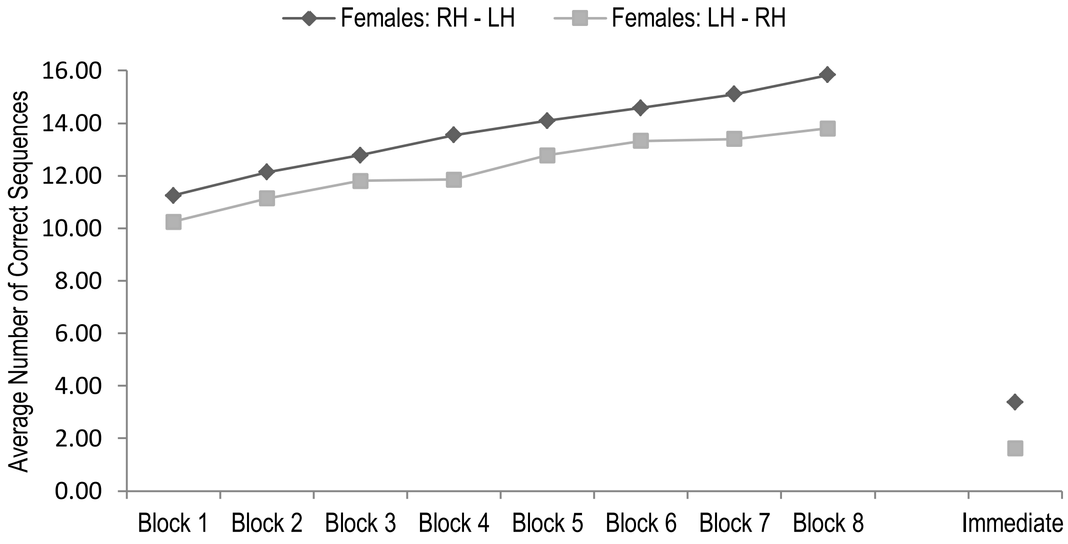


Figure 3-8: the average number of correct sequences for females in the full feedback condition is shown here. The data was extracted from Table III & IV in the original article (Taylor & Heilman, 1980, p. 597 & p. 598).

However, the LH performed more sequences than the RH at post training which did not support H_2. The results would suggest that visual feedback has a more detrimental effect on left hemisphere motor dominance than does the use of left hemisphere verbal strategies, at least for females. If females do show greater laterality than males as is suggested by Annett (1970) & Hicks (1974) then it may follow that the visual element of the present experiment may have interrupted the transfer of skill to the RH more than in the case of males who show less laterality.

Analysis of Errors

In experiment 1 a larger number of errors was made by the RH (mean = 1.64) than the LH (mean = .67) during the training phase which could be attributed to the RH's greater reliance on visual feedback than the LH. This notion is supported by the fact that in experiment 2 the same numbers of errors were made by both hands (approx. 1 per trial) which could indicate that visual feedback levelled the playing pitch for both hands.

Overall Taylor and Heilman report that their findings are "supportive of Liepmann's concept of left-hemisphere dominance for motor programming in right-handers" (p. 599). This is based on the fact that RH acquisition was faster than LH acquisition (Overall and Males) and that transfer was greater from LH to RH (Males) in Experiment 1 (FB-) (see table 3-2). The contradictory results for females are explained in terms of verbal strategizing on the part of females. The results for Experiment 2 (FB+) which do not not provide much support for Taylor and Heilman's hypotheses are explained in terms of visual feedback which may have engaged both hemispheres to a greater extent and in the process may have made it more difficult to elicit asymmetries in both males and females.

Table 3-2: A summary by each condition and group of support for H_1 (hypothesis 1) and H_2 (hypothesis 2).

Experimental Condition*	Group	Support for H_1 (Yes/No)	Support for H_2 (Yes/No)
		The new skill (correct movement sequences completed) would be acquired more rapidly by the right (dominant) hand, as it has direct access to the motor program, whereas the left (non-dominant) hand has indirect access via the Corpus Callosum.	*The right hand would benefit more from left hand training, as again, the right hand would have direct access to the motor program stored in the left hemisphere*
FB -	Overall	Yes	No
FB -	Males	Yes	Yes
FB -	Females	No	No
FB +	Overall	Yes	No
FB +	Males	No	No
FB +	Females	Yes	No

* Note: FB- = Visual Feedback Eliminated, FB+ = Visual Feedback Available

3.5 Testing the Cross Activation Model

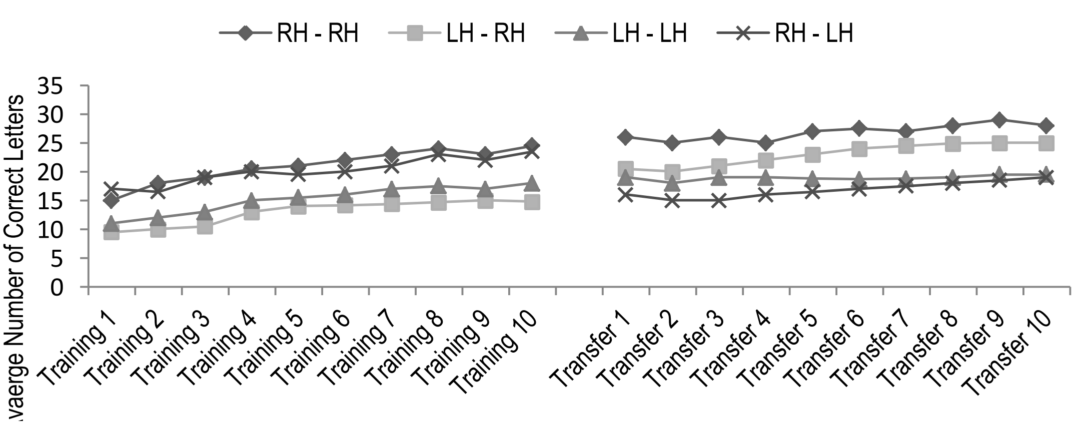
Parlow & Kinsbourne, 1989 stated that the purpose of their experiment was to examine the contrasting views of intermanual transfer provided by the Callosal Access and the Proficiency models. They utilised an inverted-reversed printing task in two experiments to investigate whether the Callosal Access or Proficiency model best described intermanual transfer. Experiment 1 (males only) is described here. The rationale for this is that Experiment 2 was conducted with children and does not provide a direct analysis (adults versus children) with the experiments undertaken by Laszlo et al. and Taylor and Heilman. Parlow and Kinsbourne hypothesised that if the Callosal Access model provides the most accurate account of intermanual transfer then lateral transfer should favour the right hand (in right-handed subjects) (H_1). Performance should correlate more highly in the right to left transfer condition than the reverse (H_2). If the Proficiency model provides the most accurate account of intermanual transfer then the left hand should benefit more than the right hand from opposite hand training (H_3). Correlations should differ in direction also (H_4) (pgs. 99 – 100).

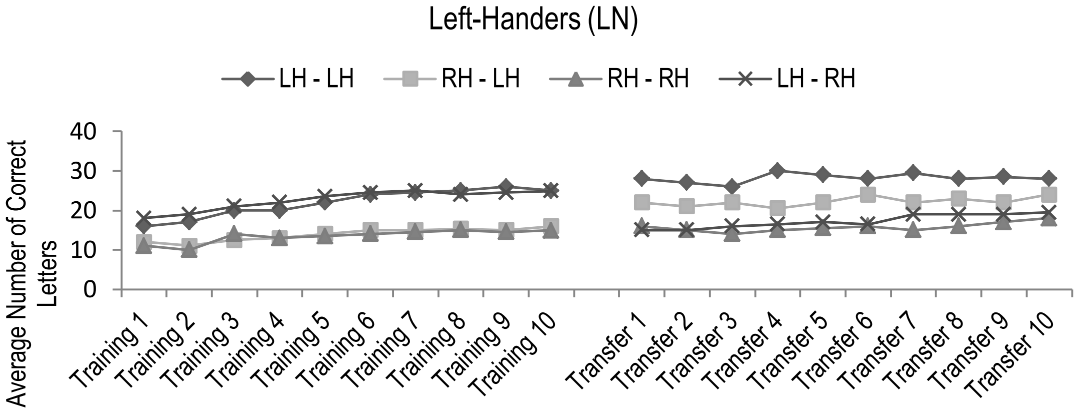
3.5.1 Experiment 1

Ninety six male undergraduate students (48 right-handers, 48 left-handers) were trained in an inverted-reversed printing task with either the right or the left hand. They used only male participants to minimise the number of variables in the design. The experiment was a 3 x 4 between groups design. The first independent variable was handedness group (right (R), Left Normal (LN), Left Inverted (LI). Left inverters were those participants who wrote with the nib of the pen pointing towards the body with the hand cupped so that it was above the writing line. This is a writing position often favoured by left-handers in order to be able to see what they have written and to avoid smudging the ink. The second independent variable was training direction (RH-RH, RH-LH, LH-RH, LH-LH). The dependant variable was the number of letters printed in the correct orientation (inverted and reversed). Each participant received two wide-ruled, legal size sheets of paper and a pencil. Electronic timers, timed at 10 & 15 seconds respectively, with audible signal were used. Terminal extrinsic feedback was provided by allowing participants to check their own work for errors after each trial. The training phase consisted of 10 trials (30 seconds duration) with a 15 second rest between trials. The transfer phase consisted of a further 10 trials which began two minutes after the training phase. One to four participants were tested at a time and were required to print the uppercase letters of the alphabet in inverted-reversed orientation as rapidly as possible. The letters were printed from the lower right hand corner of the page to the left and from the bottom of the page to the top. A tone indicated the beginning and end of each trial. Participants marked the completion of each trial with two lines. Participants were then permitted to turn the page to check for errors (terminal feedback). The next trial began on the same line with the next letter of the alphabet.

Analysis of Results

Initial investigations by Parlow and Kinsbourne established that hand posture (Left Inverted (LI) or Left Normal (LN)) had not influenced the performance of left-handers during the training trials. Therefore on the basis of this finding the data was analysed by hand (RH vs. LH). An ANOVA was performed to assess the effects of handedness (right or left), hand used (dominant or non-dominant), type of training (same vs. opposite) and trials (training (1-10) and transfer (11 – 20)). A main effect for hand, type of training and trials was found but not for handedness. The dominant hand (RH or LH) was superior to the non-dominant hand; same hand training was superior to opposite-hand training and performance improved across trials. The data for each group is represented graphically in figure 3-9.





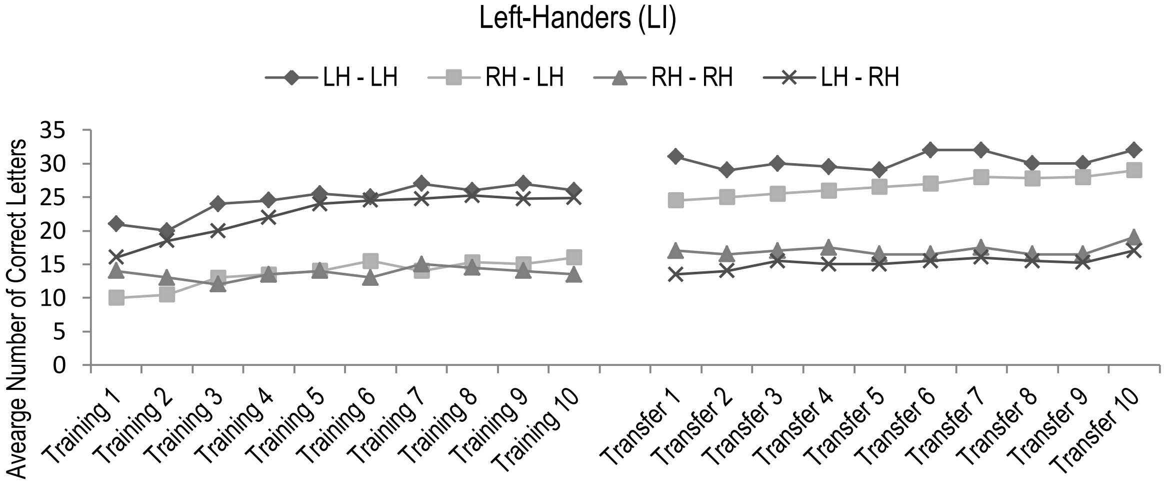


Figure 3-9: the average number of correct letters for both right- handers and left-handers in the 4 conditions. The results are shown for both the training and transfer phase. The data is extracted from Figure 1 in the original article (Parlow & Kinsbourne, 1989, p. 102).

Parlow and Kinsbourne found that the two factors of primary interest in the transfer phase– hand x type of training and hand x type of training x trial interactions were not significant. Parlow and Kinsbourne explain this by proposing that after trial 11 practice and learning are taking place which may obscure transfer effects. It is for this reason that they limit their analysis to an average of trials 11 to 13 to investigate transfer effects. No baseline pre-training trial was conducted by Parlow and Kinsbourne. In order then to quantify the transfer gain for the opposite hand trained groups (RH-LH and LH-RH) the difference between their transfer test score (averaged across trials 11-13) and the average score trial 1 for that hand obtained by participants who received same hand training was calculated. This score was then expressed as a percentage of the actual gain scores calculated for participants in same-hand training groups. Gain scores for RH and LN participants using the dominant hand after opposite-hand training averaged 49.7% & 50.5% respectively of the gains expected after same-hand training, compared with 94.2% & 72.7% for the non-dominant hand. Thus non-dominant hand to dominant hand transfer was more detrimental to transfer gain than dominant to non-dominant hand transfer. This finding lends support to the Proficiency model. One exception to the above finding was the LI group. Very little transfer was found in either direction for this group.

Parlow and Kinsbourne explored inter-trial correlations between trials 10 & 11in order to ascertain whether there was covariation between the trained and transfer hands. The authors propose that strict interpretation of the Proficiency model would lead to the conclusion that the highest gain scores in transfer would be associated with the highest levels of correlation between the hands. This was not the case. The groups with the lowest transfer gain (RH: LH – RH and LI: LH- RH) had the highest inter-trial correlations (.86 & .89 respectively). These figures are shown in table 3-3. This result according to Parlow and Kinsbourne does not support the idea of the dominant hand being able to share the better STD created by it during acquisition with the opposite un-trained hand.

Table 3-3: Inter-Trial Correlations (Trial 10 & 11) for each handedness group. The data was extracted from Table 1 in the original article (Parlow & Kinsbourne, 1989, p.105).

Handedness Group*	Dominant To Dominant	Non-Dominant To Dominant	Dominant To Non-Dominant	Non-Dominant To Non-Dominant
RH	.84	.86	.21	.94
LN	.89	.60	.02	.90
LI	.79	.46	.89	.95

***Note: RH = Right Hand Group, LN = Left Non-Inverters, LI = Left Inverters.**

In summary Parlow and Kinsbourne conclude that opposite-hand training in the inverted-reversed printing task typically benefits the non-dominant hand more than the dominant hand. They found this to this to be true for both left and right- handers. Upon re-examination of the Hicks (1974) data (inverted-reversed printing) which favoured the Callosal Access model, they state that the results are obscured by the learning that occurs during later trials in the transfer phase. Examination of the 1st trial of the transfer phase was more consistent with the Proficiency Model than the Callosal Access Model in that it showed a similar pattern of results as the Parlow and Kinsbourne experiment, thus providing support for the Proficiency rather than Callosal Access model. Parlow and Kinsbourne conclude that "the between-hand correlational data showed that greater transfer occurred when there was poor correlation between the hands; this suggests dissimilar underlying processes. Poor transfer was associated with large correlations between the hands, suggesting similar underlying processes" (p. 111). They propose that when the dominant-hand is trained "dual engrams" are formed, one in each hemisphere. When the non-dominant hand is trained, a "single engram" may be formed (p. 111). They hypothesise that the non-dominant hemisphere is kept in "a state of readiness" (p. 111). When the dominant-hemisphere learns a new skill then learning occurs in parallel in the non-dominant hemisphere. However non-dominant hemisphere learning does not facilitate parallel learning in the dominant hemisphere.

3.6 Comparative Analysis of the Three Models

It is difficult to compare the results of the studies undertaken by the proponents of each model due to the large number of design and methodological differences between each. The tasks employed, feedback conditions, gender and handedness groups, number and type of trials (pre-training, training, transfer) and measures of training (correct/incorrect movement) and transfer differed in each study. The rationale for the choice of tasks used was as follows:

Laszlo et al. favoured a finger tapping task because of its low perceptual load, Taylor and Heilman utilised a novel finger sequencing task so that an initial advantage would not be provided to the right-hand and Parlow and Kinsbourne chose (although not expressed directly) the inverted reversed printing task presumably as this was used in the Hick's (1974) study. It is interesting to note that Taylor and Heilman disputed the validity of the use of an inverted reversed printing task to examine motor dominance for a number of reasons: they felt that the task may have involved verbal processing, the right hand is already more proficient at the writing component of the task and the letters are written in the same direction with both hands and so may have provided an advantage to one hand over the other.

Another key issue arising from the three models was the type of feedback available. While Laszlo et al. (1970) sought to eliminate all feedback (kinaesthetic, visual auditory, KR), Taylor & Heilman (1980) eliminated only visual feedback and provided concurrent KR in the form of an auditory cue when the sequence was not performed correctly. The visual nature of the reversed inverted printing task and the need to manipulate a pen meant that it would have been difficult to eliminate visual and kinaesthetic feedback from the Parlow & Kinsbourne (1989) experiment. Terminal KR was also provided by allowing participants to check how many correct letters they had printed after each trial. Laszlo et al. found a different pattern of results when feedback was eliminated (the right hand appeared to benefit from left hand training) but we do not know which element/elements of the feedback may have caused this reversal in performance for the right and left hand. The all or nothing nature of the feedback in the Laszlo et al. study does not provide any detail on the effect of each component of feedback on performance. The elimination of visual feedback in the Taylor and Heilman experiment did allow for an examination of a vision/non-vision condition but it would also be useful to examine other forms of feedback (auditory, knowledge of results).

The gender and handedness profile of participants different across each experiment. Laszlo et al. (1970) used only right-handers with less than 20% of their participants being female. Taylor and Heilman (1980) employed right-handers only with equal numbers of males and females. Parlow and Kinsbourne (1989) recruited males only but included an equal number of right and left-handers.

Taylor and Heilman recorded both correct and incorrect sequences which provided a fuller picture of acquisition rates for each hand. They found that in the reduced feedback condition the right-hand made more errors than the left-hand. Both hands made an equal and lesser amount of errors in the full feedback condition. This finding suggests that the right hand benefits more from visual feedback than the left-hand in terms of levels of accuracy at any rate. While Laszlo et al. specified the threshold (force and distance) for a correct tap they did not report the occurrence of mis-taps. Likewise in Parlow and Kinsbourne's experiment 1 the rate of incorrectly printed letters was not given. In experiment 2 in which they used children to test their hypothesis they did report errors and suggested that speed and accuracy transferred independently. This supports the finding of Taylor and Heilman in the reduced feedback but not in the full feedback condition.

Transfer was calculated differently: Laszlo et al. and Parlow and Kinsbourne did not use a pre-training trial to gather base rates for each group. Transfer was calculated based on differences between same hand trained and opposite hand trained groups (between groups). Taylor and Heilman calculated their transfer gains on the difference between pre-training trials and transfer trials after opposite hand training (within groups). Another issue arises with the number of trials utilised by each study in the transfer phase. Laszlo et al. based their findings on the use of all eight trials in the transfer phase, Taylor and Heilman recorded only one transfer trial and Parlow and Kinsbourne used an average of the first three transfer trials. The major differences in methodology are summarised in Table 3-4.

Table 3-4: A summary of the tasks used and feedback conditions used to test the predications of the three models of intermanual transfer.

Model	Task Employed	Feedback Type	Participant Profile
Proficiency	Finger Tapping	- Visual - Auditory -Kinaesthetic	Males (72)% Females (18%) RH (100%)
Callosal Access	Finger Sequencing	- Vision + Concurrent Knowledge of Results (KR)	Males (50%) Females (50%) RH (100%)
Cross Activation	Inverted Reversed Printing Task	+ Terminal Knowledge of Results (KR)	Males (100%) RH (50%) LH (50%)

In order to undertake a very basic comparison of the models the following results were included: results from the right-handed groups (Parlow and Kinsbourne), normal feedback conditions only (Taylor & Heilman, Laszlo et al.) and the first trial in the transfer phase. The results from this basic comparison are displayed in figure 3-10. The large disparity between the training and transfer figures for Taylor and Heilman are the result of transfer gains rather than the actual number of correctly completed sequences being recorded. What can be seen from figure 3–10 is that transfer amounts/gain favour the left hand in both the Laszlo et al. and Parlow and Kinsbourne studies. In the Taylor and Heilman study transfer appears to be symmetrical. These initial observations suggest that type of task does impact upon the amount and direction of transfer. This basic comparison seems to support a Proficiency or Cross Activation model of transfer. What is interesting is that the finger tapping task, described as requiring low perceptual loading appears to elicit the largest asymmetry in performance in the training phase when full feedback was available.

Asymmetry of performance is also found for the inversed-reversed printing task.

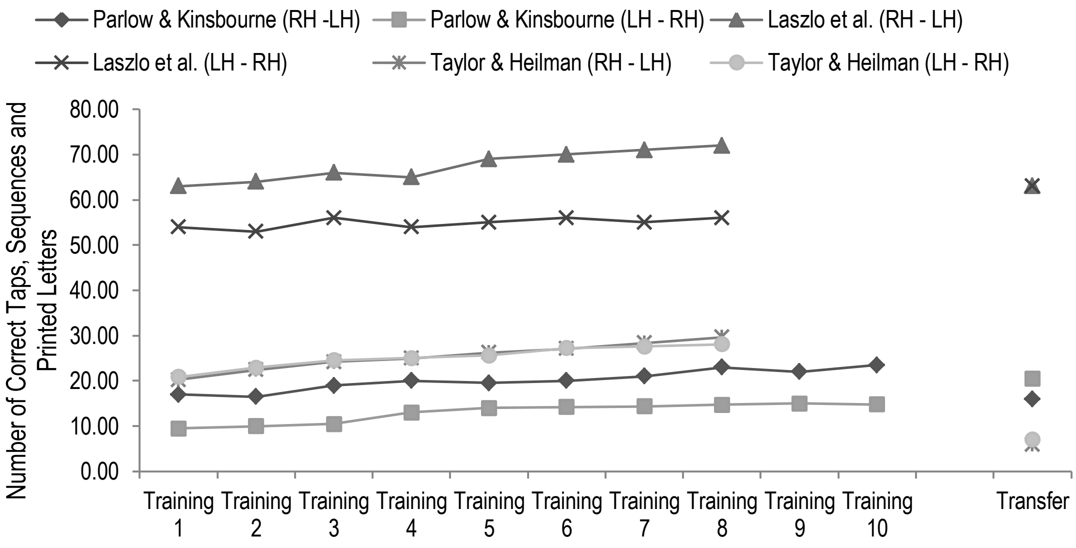


Figure 3-10: A comparison of data from the three studies including full feedback conditions only and results for right handed groups. The Y axis represents the number of correct taps (Laszlo et al.), correct sequences (Taylor & Heilman) and correctly printed letters (Parlow & Kinsbourne).

This might be explained in part by the right hand's prior proficiency in producing normally orientated letters. It seems in the finger sequencing task that both hands can perform at a similar level when full feedback is available. Taylor and Heilman suggest that this may be because visual feedback engages both hemispheres and so asymmetry of performance is difficult to elicit. It may also be due in part to the use of verbal strategies to remember the sequence. It may be that in the finger sequencing task that there is a large cognitive loading involved in remembering the sequence and through the use of rehearsal. In the inverse printing task the letters are already known so the emphasis in this task may be placed on spatial abilities in reversing and inverting what is already known.

In summary the three models utilised very different tasks, feedback and methodologies to test their predictions. Table 3-5 lists the hypotheses tested by each model and whether support was found for these. The data derived from the above studies do not offer unequivocal support for any of the three models of intermanual transfer described in this chapter. This ambiguity may be attributable to the variation in tasks, feedback and methodologies employed by the researchers.

Table 3-5: Summary of the level of experimental support generated by the researchers who proposed each of the three models of intermanual transfer.

Research	Hypothesis	Supported	
Laszlo et al., 1970: Bilateral transfer in tapping skill in the absence of peripheral information.	"Using transfer between different muscle groups (tapping with the index finger of the right & left hands) as the central variable, it was hoped to show that STD and MP effects on transfer could be separated. It was proposed that differential movement control for the two hands could be investigated by comparing bilateral transfer under reduced feedback (-FB) and normal feedback (+FB)" (p.263).	FB + Yes	FB – No
Taylor & Heilman (1980): Left hemisphere motor dominance in right-handers.	H1: "New skills will be acquired more rapidly by the right hand than the left hand there being direct input from the right-hand to the left hemisphere but only indirect input, presumable across the callosum, form the left hand to the left hemisphere."	FB+ ♂ No ♀ Yes O/all: Yes	FB - ♂ Yes ♀ No O/all Yes
	H2: "The right hand will have direct access to skills learned by the left hand (and stored in the left hemisphere) whereas the left hand will have only indirect access, across the callosum, to skills learned by the right hand and also stored in the left hemisphere). As a result there will be greater transfer of skill from the left hand to the right than vice versa" (p.588).	♂ No ♀ No O/all No	♂ Yes ♀ No O/all No
Parlow & Kinsbourne (1989): Asymmetrical transfer of training between hands: Implications for interhemispheric communication in normal brain.	H1: " If the Callosal access model holds true then lateral transfer should favour the right hand (in right-handed subjects)"	FB+ No	
	H2: "Performance should correlate more highly in the right to left transfer condition than the reverse"	No	
	H3: "If the Proficiency model holds true then the left hand should benefit more than the right hand from opposite hand training"	Yes	
	H4: Correlations should differ in direction also. (pgs. 99 -100).	No	

Note ♂= Male Groups, ♀= Female Groups O/all – males and females groups combined

3.7 Review of more Contemporary Research

Results from other studies of intermanual transfer are equivocal with respect to the direction of transfer. Thut, Cook, Regard, Leenders, Halsbrand & Landis (1996) used a meaningless-figure drawing task to investigate intermanual transfer. Original learning (OL) was compared to transfer learning (TL) with half the participants receiving OL with their right hand and the other half with their left hand. Their findings provided some support for the Proficiency and Cross Activation models with a right-to-left hand benefit in terms of speed in completing the figures; however, in terms of precision in figure drawing the transfer effect showed a left-to-right hand benefit. These results support the concept of different components of a task being transferred independently. Thut et al. suggested that transfer effects might differ depending on the muscle group involved (proximal or distal). They found that there was a slowing of transfer speed effects for the distal musculature.

Differential transfer of task components is further supported by Sainburg and Wang (2002). They hypothesised that the pattern of intermanual transfer for a particular task variable is determined by the proficiency of the controller for specifiying that variable. They used a centre-out reaching task with a 30 degree counterclockwise rotation. Participants were seated facing a horizontally oriented projection screen, with either the right or left hand (training hand) supported over a table top. A start circle, target (8 in all, presented pseudorandomly), and cursor representing finger position were projected onto a screen positioned above the arm. A mirror was used to give the illusion that the display was in the same horizontal plane as the fingertip. In session 1 (no visual rotation): participants were instructed to bring their index finger to a complete rest within the starting circle and then to move the finger to the indicated target using a single, rapid movement. Participants completed 2 blocks of 192 trials (24 x 8 targets). In Session 2 (30^0 counterclockwise rotation of the cursor position): Each participant performed the session first with the trained hand and then with the opposite hand. The variables measured were: hand-path direction error at peak tangential hand accelation (A_{max}), hand-path direction error at peak tangential hand velocity (V_{max}), and final position error. Hand direction error was calcuated as the angular difference between the target vector and hand-path position vector (hand-path movement position at movement start and hand-path position at V_{max} or A_{max}). Final position error was calculated as the distance between the index finger at movement end and the location of the centre of the target. Sainburg and Wang found that initial movement direction transferred from non-dominant to dominant arm. Final position accuracy transferred from dominant to non-dominant arm. These findings support the notion of the dominant arm controller as more proficient for trajectory information whereas the non-dominant arm controller is more proficient for final position information (Sainburg & Wang 2002; Wang & Sainburg 2006). Wang and Sainburg (2006) explored the degree to which the various models of intermanual transfer of learning **(**Proficiency, Callosal Access Model, Cross Activation**)** could account for their findings. Wang & Sainburg (2006) consider the models to be inadequate in their ability to account for two major features of interlimb transfer as it pertains to visuomotor adaptations. Firstly, different features of task performance, directional accuracy and final position accuracy, transfer in different directions. Secondly, task performance of the two arms show signs of symmetric adaptation to visuomotor rotations (both arms adapted equally well to visuomotor rotations). Symmetric adaptation is inconsistent with the unidirectional transfer predictions of the three models.

Criscimagna-Hemminger, Donchin, Gazzaniga and Shadmehr (2003) found transfer to be asymmetrical (dominant to non-dominant arm) in their reaching task in which force was manipulated. They suggest that transfer is not mediated by interhemispheric transfer via the corpus callosum but may be facilitated at a corticospinal level. They found dominant to non-dominant hand transfer also in a commissurotomy (split brain- corpus callosum severed) patient (JW) suggesting that perhaps the dominant (left) hemisphere can influence movement in both the contralateral (right) and ipsilateral (left) hand through these corticospinal connections. Malfait & Ostry (2004) suggest that the transfer found by Criscimagna-Hemminger et al. may have been due to a higher order cognitive strategy for dealing with large perturbations in force rather than any form of interhemispheric transfer. To test their hypothesis participants were subjected to either an abrupt perturbation (sudden increase in load) or a gradual perturbation (gradual almost undetectable increase in load) when completing an arm reaching task. The results showed transfer occurred from dominant to non-dominant arm in the abrupt condition but no transfer occurred in the gradual condition. Malfait and Ostry suggest that the "interlimb transfer reported by Criscimagna-Hemminger et al. (2003) might rely substantially on the use of high-level information about the effects of the force field. This kind of information may be mostly independent of that which underlies predictive changes observed in patterns of muscle activity that are developed by a trained arm" (p. 8088). The results from the studies by Sainburg & Wang (2002), Criscimagna-Hemminger et al. 2003 and Malfait and Ostry (2004) indicate the varied nature of the predictions and results with regard to intermanual transfer. These results provide a valuable insight into the on-going debate into the processes involved in interhemispheric/intermanual transfer. However because of the particular nature of the task (arm reaching) and manipulations involved (load, visual rotation) the findings may not be applicable to such tasks as repetitive finger tapping or complex finger sequencing action.

Intermanual transfer has been investigated in tasks as varied as a finger opposition with the middle finger, finger tapping, peg placing and anticipatory timing, (Karni, Meyer, Rey-Hipolilo, Jezzerd, Adams, Turner, & et al., 1998; Koeneke, Battista, Jancke, & Peters, 2009; Schulze, Luders & Jancke, 2002; Teixiera, 2000). The results from each of the studies support a view of intermanual transfer as being dependent on a number of factors (e.g. task type, hand trained, and duration of training). For instance Karni et al. (1998) found that a few minutes of daily practice on a sequential finger opposition task induced large incremental performance gains over a few weeks of training. Participants in the study learned a sequence in which each finger touched the thumb in a particular order. The training was carried out with the non-dominant hand. Speed and accuracy were recorded for the task which took place over a three week period. Karni et al. found that gains in speed and accuracy did not generalise to the opposite hand (intermanual transfer) or to a matched sequence of identical component movements (intralimb transfer). This suggested a lateralised representation of the learned sequence of movements. Unfortunately, the design of this study (only the non-dominant hand received training) limits its contribution to our understanding of intermanual transfer of skill. Both Koeneke et al. (2009) and Schultz et al. (2002) found transfer to be symmetrical in their finger tapping (2 week trial) and pegboard task (4 week trial). Symmetrical transfer was also found by Teixeira (2000) in an anticipatory timing task. Participants, who were asked to predict the onset of the last light in a line of light emitting diodes (LED) by pressing a button, demonstrated improved accuracy in both the trained and untrained hand. Further research led Teixeira to propose that symmetry of intermanual transfer may be influenced by the nature of the skilled movement. If the task requires use of a refined movement control then the dominant hand will have an advantage over the non-dominant hand and so transfer could be expected to be asymmetrical (dominant to non-dominant hand). However if the task requires the use of a more general purpose motor program for movement control (e.g. anticipatory time task) then both hands could benefit equally from training and transfer could be expected to be symmetrical. In a second experiment, in which participants were required to propel a cursor along a pathway by manipulating forces exerted in a wrist flick (refined movement control), the intermanual transfer was asymmetrical and from the dominant to non-dominant hand.

3.8 Summary

The research discussed in this chapter on the impact of dominant or non-dominant hand training on intermanual transfer of skill, indicates a level of ambiguity and conflict that is inconsistent with a single or unified model of intermanual transfer of motor skill such as that proposed by the Proficiency, Callosal Access or Cross Activation models. The ambiguities in the results may be in part due to design artefacts inherent in earlier research; specifically confounding factors resulting from task type, feedback conditions, and hand trained. This is evidenced in the varied and conflicting findings of studies investigating the three models of intermanual transfer described in Sections 3.3, 3.4 and 3.5. Results from more recent research also raise questions with regard to the task and feedback types utilised to investigate intermanual transfer. Koeneke et al. (2009) and Karni et al. (1998) used tasks which did not have a visuomotor component: finger tapping and finger opposition tasks are not reliant on visual feedback. Thut et al. (1996), Schulze et al. (2002), and Teixeira (2000) used tasks which do have a visuomotor component: the figure drawing, pegboard task, anticipatory timing task and cursor propelling task involve the use of visual feedback to aid in completing the figures (drawing task) placing the pegs (pegboard task) and watching a series of lights for a cue (anticipatory task). What had been perceived by Teixeira (2000) and Schulze (2002) as symmetrical transfer of skill may in fact be learning acquired in a completely different way. Thut et al. (1996) suggested that transfer of speed may be mediated by the left hemisphere and so may benefit a right-to-left transfer; precision of movement may be mediated by the right hemisphere and so may benefit a left-to-right transfer. Precision of movement may engage the visual system more than speed. Sainburg and Wang (2002) support the concept of each hemisphere being dominant for particular aspects of movement. What is evident from investigation of the three models and from the varied results from more recent research is that our understanding of the mechanisms involved in intermanual transfer are far from complete. A more systematic approach to an exploration of the contribution of methodological differences to the results of previous studies of intermanual transfer would at least facilitate explanation of the observed inconsistencies and at most further advance our understanding of these mechanisms.

The three experimental chapters which follow will attempt to investigate more precisely the role of task type and feedback conditions in intermanual transfer of acquired hand skill. In Chapter 4 both a finger tapping and finger sequencing task similar to those used by Laszlo et al. (1970) and Taylor & Heilman (1980) are employed. Participants (all right handers in each experiment) are tested under four reducing feedback conditions (full feedback, terminal KR eliminated, vision eliminated, auditory feedback eliminated). Finger sequencing is again investigated in Chapter 5 using the same finger sequencing task as in Chapter 4. Mirror and spatial transfer are examined in two feedback conditions (terminal KR given/terminal KR withheld). An emphasis is placed in Chapter 5 on examining the role of terminal KR in right hand acquisition hence the use of 4 right hand (RH) trained groups. The left hand (LH) trained group is used for comparison purposes. In Chapter 6 a covert version of the finger sequencing task employed in Chapters 4 and 5 is used with mirror and spatial transfer again being examined. In this experiment KR (concurrent & terminal) is of a visual nature. The RH and LH hand training groups were balanced here as in Chapter 4. Table 3-6 provides a summary of the experimental designs employed.

Table 3-6: Summary of experimental designs employed in the 3 experimental chapters that follow.

Chapter/ Study	**Task**	**Transfer**	**Feedback**	Hand Trained
Chapter 4 Study 1	Finger Tapping Finger Sequencing	Mirror	KR+ (Auditory) KR- Vision- Auditory -	RH 4 groups LH 4 groups
Chapter 5 Study 2	Finger Sequencing	Mirror & Spatial	KR+ (Auditory) KR-	RH 4 groups LH 1 group
Chapter 6 Study 3	Finger Sequencing (Covert)	Mirror & Spatial	KR+ (Visual)	RH 2 groups LH 2 groups

Chapter 4

Study 1: Re-investigating the Models of Intermanual Transfer using a Reducing Feedback Paradigm

4.1 Introduction

This first study re-examines the methodologies employed to test the logic that underpins the three models of intermanual transfer described in Chapter 3. The Proficiency Model (Laszlo, Bagulay & Bairstow, 1970) asserts that the direction of greatest transfer is from right to left hand; the Cross Activation Model (Parlow & Kinsbourne, 1989) proposes that direction of transfer is solely from right to left hand, and the Callosal Access Model (Taylor & Heilman, 1980) suggests that the direction of greatest transfer is from left to right hand.

The Proficiency and Cross Activation Models agree in principle on direction of transfer (right-hand to left-hand) but the logic behind this assertion is quite different. The Proficiency Model proposes that when the dominant (more proficient) hand is trained it can make greater use of the available information (intrinsic & extrinsic) to form a better standard (STD). A copy of this motor program and STD are then sent to the opposite hemisphere for use by the non-dominant hand. Training of the dominant hand thus benefits the non-dominant hand (right to left-hand transfer). The Cross Activation Model (Parlow & Kinsbourne, 1989) submits that when the dominant hand is trained two motor programs are generated (one located in each hemisphere). These programs act in a coupled manner: when learning occurs with the dominant hand a copy of the updated motor program is sent to the opposite hemisphere. Training of the dominant hand thus benefits the non-dominant hand (right to left-hand transfer). The Proficiency and Cross Activation model agree that the direction of transfer will be from right to left hand when the dominant hand is trained. But the logic underpinning the two models differs when accounting for the consequences of non-dominant hand training. The Proficiency model proposes that when full feedback is available the STD created by the non-dominant hand is of little benefit to the dominant hand. This is because the dominant hemisphere already has more information available to it to create a better STD than can be acquired from the STD created by the non-dominant hand/hemisphere. There is little to be gained by the dominant hand from non-dominant hand training when full feedback is available. The Proficiency model does not rule out the possibility that transfer could occur from left-to-right hand. The results from the study carried out by Laszlo et al. (1970) to test the predictions of the Proficiency Model found that the direction of most transfer was from left to right hand when feedback was removed (visual, auditory and kinaesthetic). Laszlo et al. stated that the left hand appeared to be able to activate the motor program with a poorer STD and to a greater extent than the right hand in their reduced feedback condition. Therefore in the absence of visual, auditory and kinaesthetic feedback the right hand benefited from left hand training. The Cross Activation Model holds that if learning occurs with the non-dominant hand then an updated copy of the motor program is not sent to the opposite hemisphere, therefore non-dominant hand training does not benefit the dominant hand. The Cross Activation model argues that communication between the hemispheres occurs in one direction only, from dominant to non-dominant hemisphere. Parlow and Kinsbourne (1989) found that the dominant hand did not benefit from non-dominant hand training in an inversed reversed printing task with full feedback available. The model was not tested using a reduced feedback condition. We do not know then if the assertions of the model hold true when full feedback is not available.

The Callosal Access Model (Taylor & Heilman, 1980) suggests that the motor programs for skilled hand movement are held in one hemisphere only (dominant hemisphere) irrespective of the hand used for hand skills training. The dominant hand has direct access to the motor program whereas the non-dominant hand has indirect access via the corpus callosum. The dominant hand benefits from non-dominant hand training, but the non-dominant hand does not benefit as much from dominant hand training because some elements of performance (speed, accuracy) are lost through this circuitous access to the motor program via the corpus callosum. The results from the finger sequencing task used to test the predictions of the model were very mixed. Support for the hypothesis was found for male participants but only in the reduced feedback condition (visual feedback removed). Transfer was symmetrical in males when full feedback was available. Transfer was symmetrical for female participants in both full and reduced feedback conditions. These conflicting results cast some doubt on the assertions of the model.

A number of issues arise with the methodologies used to explore the logic underpinning each model. The tasks used (finger tapping, finger sequencing, inversed reversed printing task) and the feedback conditions employed (full feedback, reduced feedback) varied greatly in each study. The tasks used to test the predictions of each model differed in terms of the cognitive and motor processes required. Laszlo et al. (Proficiency Model) engaged a finger tapping task because of its low perceptual load. This task involved movement of the index finger only. Taylor and Heilman (Callosal Access Model) employed a novel finger sequencing task. Their intention was to avoid giving an initial advantage to the dominant hand. Participants were required to remember (cognitive process) and produce (motor process) a finger sequence. The sequence involved the use of the middle, ring and baby finger. Parlow & Kinsbourne (Cross Activation Model) used an inverted reversed printing task. This task required the use of the musculature of the whole hand and involved a number of processes: recalling (cognitive), inverting and reversing (spatial) and producing (motor) the required letters of the alphabet. The differences in both the cognitive and motor processes required for each task may have influenced the type of transfer (asymmetrical/symmetrical). Evidence supporting the concept of transfer being task dependent was found in studies conducted by Teixiera (2000). He reported transfer to be asymmetrical (dominant to non-dominant hand) in a cursor propelling task but to be symmetrical in an anticipatory timing task. Teixiera proposed that when a refined movement is required (e.g. wrist flick – cursor propelling task) the non-dominant hand may benefit from dominant hand training. In a general purpose movement (e.g. button pressing – anticipatory timing task) both hands may benefit equally from training of the other. Wang & Sainburg (2006) propose that direction of transfer is determined not at the task level but at the sub-task level of task components. They hypothesise that the pattern of intermanual transfer for a particular task component is determined by the proficiency of the hemispheric controller for specifiying that variable. For instance they found that the non-dominant hemisphere was more proficient in specifiying initial movement direction. Final position accuracy transferred from dominant to non-dominant arm. Their findings endorse the notion that the dominant arm controller is more proficient for trajectory information whereas the non-dominant arm controller is more proficient for final position information (Sainburg & Wang 2002; Wang & Sainburg 2006). It is likely then that the tasks used in the original studies by Laszlo et al., Taylor and Heilman, and Parolw and Kinsbourne may have influenced the type of transfer observed in their experiments.

Available feedback was another key issue arising from the different methodologies employed by each study. Laszlo et al. (1970) sought to eliminate kinaesthetic, visual and auditory feedback. Taylor and Heilman (1980) eliminated visual feedback only and provided concurrent knowledge of results (KR) in the form of an auditory cue when the sequence was performed incorrectly. In the Parlow and Kinsbourne experiment full feedback was available with terminal KR provided by allowing participants to check how many correct letters they had printed following each trial. Both the guidance (Salmoni, Schmidt & Walter, 1984) and 'specificity of practice' (Tremblay & Proteau, 1998) hypotheses described in Chapter 2 emphasise the importance of feedback both at acquisition and transfer stages of motor control. The specificity of practice hypothesis proposes that rather than intrinsic feedback becoming redundant with practice as the motor program develops; an individual's reliance on available feedback will increase with practice. The learner will decide early on which form of concurrent intrinsic information is most useful and will process this above all others (Krigolson, Van Gyn, Trembley & Heath, 2006). The important role played by visual feedback in skills acquisition has been shown in a number of studies: the results of these studies revealed a significant deterioration in performance once visual feedback was removed (Proteau, Marteniuk, Girouad & Dugas, 1987; Tremblay & Proteau, 2001; Tremblay & Proteau, 1998). In the Taylor and Heilman study the inclusion of visual feedback in the 2nd experiment was associated with improved performance for both hands reflected in a) an increase in the number of correct sequences completed and b) a decrease in errors. Transfer was *symmetrical* in the presence of visual feedback suggesting that the superiority of the dominant hand for this particular task is lost when visual feedback is available. Symmetrical transfer has also been observed in peg-board and button press tasks (Schulze, Luders & Jancke, 2002; Texiera, 2000). Laszlo et al. eliminated visual, auditory and kinaesthetic feedback so it cannot be determined which form of feedback affected the results of the finger tapping task to the greatest extent. The results did show that the right hand's performance was affected to a greater degree than the left hand in the reduced feedback condition. When full feedback was available the right hand showed superior performance (number of taps) over the left hand and transfer was asymmetrical (right to left hand). These results differ from those found for the finger sequencing task where the introduction of full feedback resulted in symmetrical transfer. Parlow and Kinsbourne used a full feedback condition so it is not possible to analyse or explore the relative effect of feedback. Both Taylor and Heilman, and Parlow and Kinsbourne included KR in their experimental design. The guidance hypothesis stresses the importance of knowledge of results (KR) which provides information to the learner about the movement outcome (Salmoni et al., 1984). Taylor and Heilman provided concurrent KR in the form of an auditory tone when participants made an error. Parlow and Kinsbourne provided terminal KR by allowing participants to check their errors at the end of each trial. Both types of feedback have been found to be associated with improved rates of learning in the acquisition phase for a skill (Park, Shea and Wright, 2000; Schmidt, Young, Swinnen & Shapiro, 1989). We cannot ascertain from the studies of Parlow and Kinsbourne or Taylor and Heilman how beneficial both types of feedback were in terms of skill acquisition and transfer as a no-KR condition was not included in their design. It is difficult to remove concurrent feedback in a finger sequencing task if the purpose is for the participant to learn the correct sequence. It is possible however to perform a KR/no-KR comparison with terminal KR.

The purpose of my first study was to address the issue of heterogeneous task type and feedback conditions used in the original studies. As was discussed in Chapter 3 the heterogeneous nature of the designs used to test the predictions of each model did not allow for a like with like comparison. Hence differences in the results of the studies driven by each model may be as a result of the methodologies employed rather than being attributable to the underlying logic (Schultz, Jancke & Luders, 2002). A finger tapping and finger sequencing task similar to those used by Laszlo et al. and Taylor and Heilman were employed in order to investigate the role of task type in intermanual transfer. The design includes 4 feedback conditions (full feedback available plus three successive feedback reductions, terminal KR eliminated, visual feedback eliminated and auditory feedback eliminated) in order to examine the interaction of feedback and task type in intermanual transfer. The aim of the study was to better understand the role of task type and feedback conditions in intermanual transfer. It was hoped to provide evidence which might lead to the rejection of at least one of the three models of intermanual transfer. It was hypothesised that the interaction of task type and feedback given would have a direct impact on the amount of transfer (number of taps/ sequences completed) and direction of transfer (right to left, left to right, symmetrical).

4.2 Methodology

Participants

Eighty right-handed participants (60 female) took part in this study, which was conducted in the Psychology Laboratory at Mary Immaculate College. Handedness was determined using the Edinburgh Handedness Inventory (Oldfield, 1971) (see appendix A). Participants who scored between +40 and +100 (defined as right handed) on the inventory were included in the study. Participants were required to be free from hand or arm injuries/disability and visual/auditory problems. Participants ranged in age from 18- 65 and were recruited through convenience sampling as the majority came from within the college community. The participants received an information sheet (see appendix B) and instruction sheet (see appendix C) outlining the study. Written consent was obtained from each participant (see appendix D). Ethical clearance was received from the Mary Immaculate College Ethics Committee (MIREC).

Design

A 2 x 4 independent groups design was used to conduct the study. The 1st independent variable was the hand trained (dominant hand (right hand), non-dominant hand (left hand)). The 2nd independent variable was feedback condition (KR+, KR-, Vision-, Auditory-):

KR+:	Full feedback available including terminal extrinsic KR. The finger sequencing task included concurrent KR.
KR- :	Terminal KR eliminated
Vision - :	KR & Visual Feedback eliminated
Auditory-:	KR, Visual & Auditory feedback eliminated

Participants were informed of the number of taps and number of correct sequences completed (terminal KR) at the end of each trial. In the finger sequencing task participants were also informed when the made an error during execution of the sequence (concurrent KR). Concurrent KR was provided in a similar manner by Taylor & Heilman (1980) in their study. Terminal feedback was presented in the form of number of taps/no of correct sequences completed. This type of terminal KR was considered the most appropriate indication for participants of the success of their movements (time was held constant in each trial and whole movements (taps, keypresses) were measured). The dependant variables measured were number of taps per trial (task 1) and the number of correct/incorrect sequences (task 2).

Materials & Equipment

Participants completed two questionnaires: The ten item Edinburgh Handedness Inventory (Oldfield, 1971) and a short closing questionnaire created by the experimenter. The closing questionnaire included a question asking whether participants engaged in any type of strategy to remember the finger sequence (task 2). They were also asked if they played a musical instrument, had taken formal typing lessons and if they played video games. A copy of the closing questionnaire is contained in appendix (E).

Task 1: Finger Tapping Task

An MLA92 Push-Button Switch connected via an ADI Powerlab unit to a laptop (running Labchart Software) recorded finger flexion movement (taps). Each depress of the push-button switch (red button in figure 4-1) produced an auditory feedback (click) and marked one tap. The push-button was attached to a vise grip which was anchored to the desk to provide stability. This allowed participants to place their hand on the arm of the vise grip in a manner that allowed for movement of the index finger only during testing. An elbow pad provided support for the participant's elbow. Participants in the Vision- condition (terminal KR + visual feedback eliminated) were required to wear blackout goggles. In Auditory- condition (terminal KR + vision + auditory feedback eliminated) participants also wore headphones through which white noise was played. Wideband white noise software (employed in the relief of the symptoms of tinnitus) was used to generate the white noise as this was deemed to be a safe method of doing so. The software (CD format) was purchased from www. tinnitusmasker.com.

Figure 4-1: Vise Grip with MLA92 push-button attached. The push-button produced auditory feedback when fully depressed.

Task 2: Key sequencing task

A Cedrus RB 830 series response pad with eight keys (2 unused) connected to a laptop (running Superlab 4.0 stimulus presentation software) recorded index, middle and ring finger flexion movements (keypresses) for a nine digit sequence. The keys produced auditory feedback when fully depressed. The keys to be used were marked as 1, 2 & 3. The sequence was as follows: (1 2 3 2 3 1 3 1 2).

Figure 4-2: Cedrus RB 830 response pad. The keys produced auditory feedback when fully depressed.

Participants used their index (1), middle (2) and ring (3) finger of each hand to complete the sequence.

Participants in the Vision- condition were required to wear blackout goggles. In addition to the blackout goggles participants in Auditory- condition were required to wear headphones through which white noise was played. Participants were provided with a wrist pad for comfort purposes.

4.3 Procedure

Testing was carried out on a one-to-one basis in a quiet room in the Psychology Department Laboratory Suite at Mary Immaculate College. Participants were given the information and instructions sheets to read which explained the nature of the tasks to be undertaken. They were encouraged to ask any questions with regard to the procedure prior to signing the consent form. Participants then completed the Edinburgh Handedness Inventory (Oldfield, 1971) to confirm their handedness. Participants were randomly assigned (for both tasks) to either the right hand or left hand training group, and within each group to one of the four feedback conditions. The experiment began with the finger tapping task. Participants completed 10 trials each of 15 seconds duration as follows:

Pre-training:	1 trial with **untrained hand** to gauge level of performance prior to opposite hand training.
Training Phase:	Participants then switched to **training hand** for: 2 blocks of 3 trials, with a 10 second break between trials and 20 second break between the two blocks.
Transfer Phase:	Participants switched back to **untrained hand** for: 1 block (3 trials) with untrained hand.

The number of training trials was set to 6 in both the finger tapping (15 sec trials) and finger sequencing (30 sec trials) task for two reasons: 1) duration of experiment and 2) fatigue or boredom factor. Each participant took part in the study on a voluntary basis (no payment or course credits received) therefore it was felt that 45 minutes was probably the longest duration of time that participants might commit to as most would give their time between lectures. 2) Testing of the experiment prior to going live suggested that fatigue (finger tapping) or boredom (finger sequencing task) was likely after a certain period (e.g. participants could complete up to 70 repetitions of the sequence in 6 trials). Participants were seated in front of the vise grip which was secured to the table with suction pads. The pre-test hand was positioned comfortably on the arm of the vise grip. The index finger placed over the push button switch and the elbow pad was placed under the participant's elbow. Participants who took part in the Vision- and Auditory- conditions were fitted with the blackout goggles. Participants in the Auditory- condition were also fitted with headphones and the levels of white noise adjusted to a comfortable level for each participant. Each trial began and ended with a verbal instruction (KR+, KR-, Vision-) or an auditory tone was sounded (Auditory-). Participants were informed in a similar way when to change hands (verbal instruction or 3 short tones). Participants were required to depress the push-button switch fully to register one tap. Participants were allowed to try out the button before beginning the experiment. The software could not record the number of mis-taps but a trace displayed during the trial indicated if the button was not being depressed fully and participants were informed of this fact. This happened only in a small number of cases. The Lab Chart Pro software recorded the number of taps completed for each 15 second trial. In the full feedback condition (KR+) participants were informed of the number of taps completed at the end of each trial. The transfer phase (finger tapping and finger sequencing task) consisted of 3 trials (1 block) given 20 seconds after the training phase. Participants were required to replicate the task carried out by the training hand. Feedback conditions were the same as in the training phase. Sole exposure of the transfer hand to the task was at pre-test (1 trial to provide a benchmark). The purpose of the transfer phase was to a) measure any gains in performance for the transfer hand following opposite hand training (within groups) and b) to investigate the effect of the different feedback conditions on transfer gains (between groups).

After a short interval (5 minutes) participants began the finger sequencing task. They were shown the sequence and allowed using a template of the response pad, but not the response pad itself (haptic feedback withheld), to try out the sequence (see appendix F). Participants were allowed enough time to become familiar with the sequence then the template was removed. Participants placed their index, middle and ring finger on the 3 keys (right or left) to be used. Ten trials were performed as per the schedule for task 1 but the length of each trial was increased to 30 seconds. Participants who took part in the Vision- and Auditory- conditions were again fitted with the blackout goggles. Participants in the Auditory- condition were also fitted with headphones and the levels of white noise adjusted to a comfortable level. Participants were given verbal instructions (KR+, KR-, Vision-) or a short auditory tone was sounded (Auditory-) to begin and end each trial and to indicate when to change hands (one long tone). Participants were also informed (verbally or 3 short auditory tones) if they made an error in the sequence, which required them to begin the sequence again. The total numbers of correct and incorrect key presses were recorded for each participant. Participants in the KR+ condition were informed of the number of correct sequences completed after each trial.

On completion of the two experiments the experimenter completed a closing questionnaire with the participants. The experimenter asked questions as to whether the participants used a strategy to remember the sequence and what that might have been. The participants were also asked if they played a musical instrument, had taken typing lessons, or played Xbox or PlayStation. Participants were then given a debriefing statement and thanked for their participation (see appendix G).

Data Analysis: The data (number of taps (finger tapping) and the number of keypresses and which key was pressed with times to the nearest ms (key sequencing)) were exported from Labchart Pro and Superlab to MS Excel for initial descriptive analysis. The data was then imported into the IBM SPSS Statistics 21 package and R version 3.01 from MS Excel for statistical analysis.

4.4 Results & Discussion

Closing Questionnaire

Analysis of the descriptive data from the closing questionnaire revealed that 50% of participants played a musical instrument; three were semi- professional musicians. 30% had taken formal typing lessons and 14% played video games on a regular basis. The participants were asked if they had employed any strategies to help them remember and/or produce the finger sequences. The majority (74%) reported the use of a least two strategies one of which was verbalisation. 16% of participants stated that they used their finger position alone while 6% participants responded that they had engaged a rhythm to remember and produce the sequence. 4% of participants (3 individuals) did not think they had used any strategy.

4.1 Finger Tapping Task

Training Phase (Trials 1 – 6)

Within Hand – Between Conditions

The average numbers of taps per trial were calculated for each hand by condition. A mixed design ANOVA (Analysis of Variance) incorporating both between group (feedback conditions - KR+, KR-, Vision-, Auditory-) and repeated measures (training trials - trials 1 to trial 6) variables was used to analyse the data (Field, 2009). All effects are reported as significant at $p<.05$.

Right Hand: Figure 4-3 shows the number of taps completed at pre-test (left hand), training trials 1-6 (right hand) and transfer trials 1-3 (left hand) for the right hand trained group. The performance of the right hand did not increase in a linear fashion over successive trials as indicated by figure 4-3. The average tap rate did show an increase from trial 1(T.1) (*M* = 47, *SD* = 17) to trial 6 (T.6) (*M* = 51, *SD* = 10) in the KR- condition. In KR+ (T.1: *M* = 65, *SD* = 8; T.6: *M* = 64, *SD* = 10), Vision- (T.1: *M* = 56, *SD* = 15; T.6: *M* = 55, *SD* = 8) and Auditory- (T.1: *M* = 50, *SD* = 15; T.6: *M* = 52, *SD* = 16) conditions the tap rate showed no improvement.

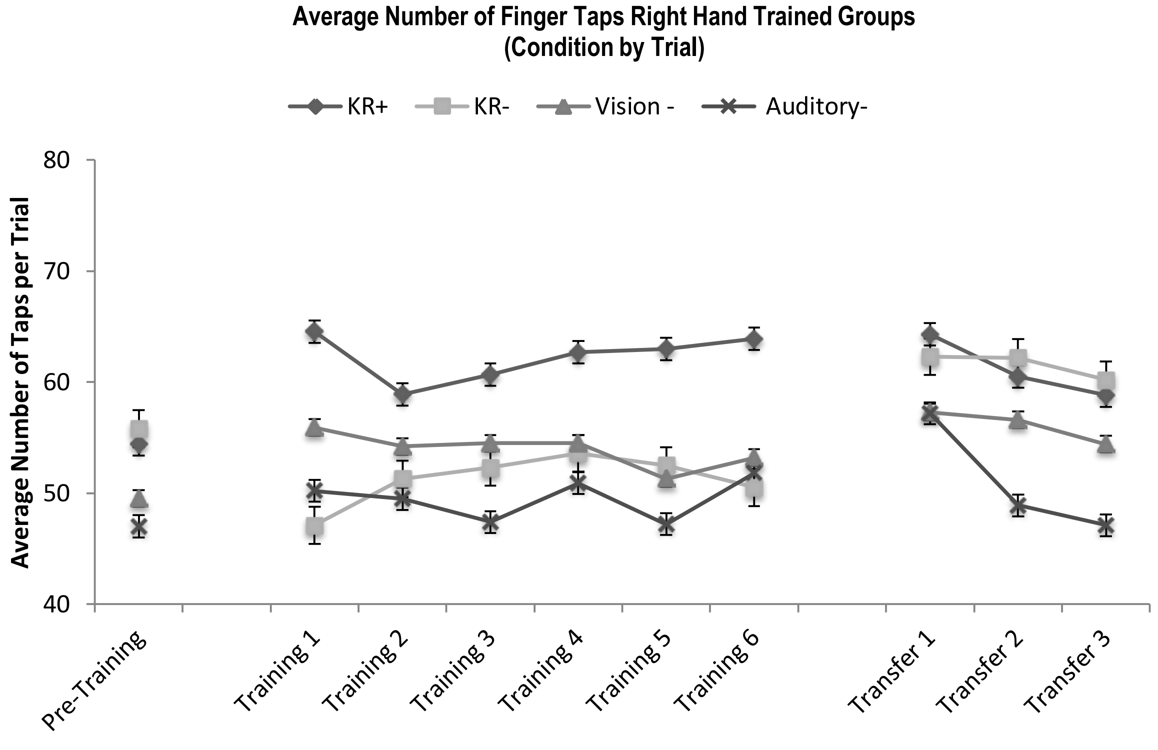


Figure 4-3: The average taps per trial and standard error (SE) are displayed for each condition. Note that pre-training and transfer trials represent the left hand pre and post right hand training (KR+ *n*=10, KR- *n*=10, Vision- *n*=10, Auditory- *n*=10).

The average tap rate did vary between conditions. Participants in the KR+ condition completed more taps on average than participants in the other three conditions(see table 4-1). The KR- condition yielded the lowest tap rate in trial 1(*M* = 47, *SD* = 17) and trial 6 (*M* = 51, *SD* = 10) with the Auditory- group having the lowest tap rate trials 2 through trials 5.

Trial 3 violated the assumptions of the Levene's test and was removed from the analysis for the right-hand training group. Levene's (1960) test is used to assess the assumptions of equal variance and tests whether there are any significant differences between group variances. A significant result ($p<.05$) indicates that the assumptions have been viloated (in Field, 2009, p.150). A mixed design ANOVA indicated that there was no effect for training trials $F(4, 36) = 1.06$, $p = .38$ but the effect for conditions approached significance $F (3, 36) = 2.56$, $p =.07$. Tukey comparison of KR+ and Auditory- showed that the lower bound for confidence levels was just below zero (-.98) ($p = .08$).

Left Hand: Results for the left hand trained group revealed that the level of performance decreased from trial 1(T.1) to trial 6 (T.6) for all conditions: KR+ (T.1 $M = 58$, $SD = 19$; T.6 $M = 52$, $SD = 12$); KR- (T.1 $M = 57$, $SD = 18$; T.6 $M = 52$, $SD = 16$); Vision- (T.1 $M = 52$, $SD = 19$, T.6 $M = 48$, $SD = 13$); Auditory-: (T.1 $M = 50$, $SD = 10$; T.6 $M = 45$, $SD = 12$). The results are presented graphically in figure 4-4. There was a significant effect for training trials $F (5, 36) = 4.79$, $p < .00$. Contrasts were performed comparing each trial with trial 6. These revealed significant interactions for trial 1 vs. trial 6 $F(1,36) = 9.44$, $r =.46$; trial 2 vs. trial 6 $F(1,36) = 6.72$, $r = .40$ and trial 4 vs. trial 6 $F(1,36) = 8.84$, $r = .44$. The average tap rate was not significantly different between conditions. This was confirmed by a non significant effect for the between groups element of the mixed design ANOVA.

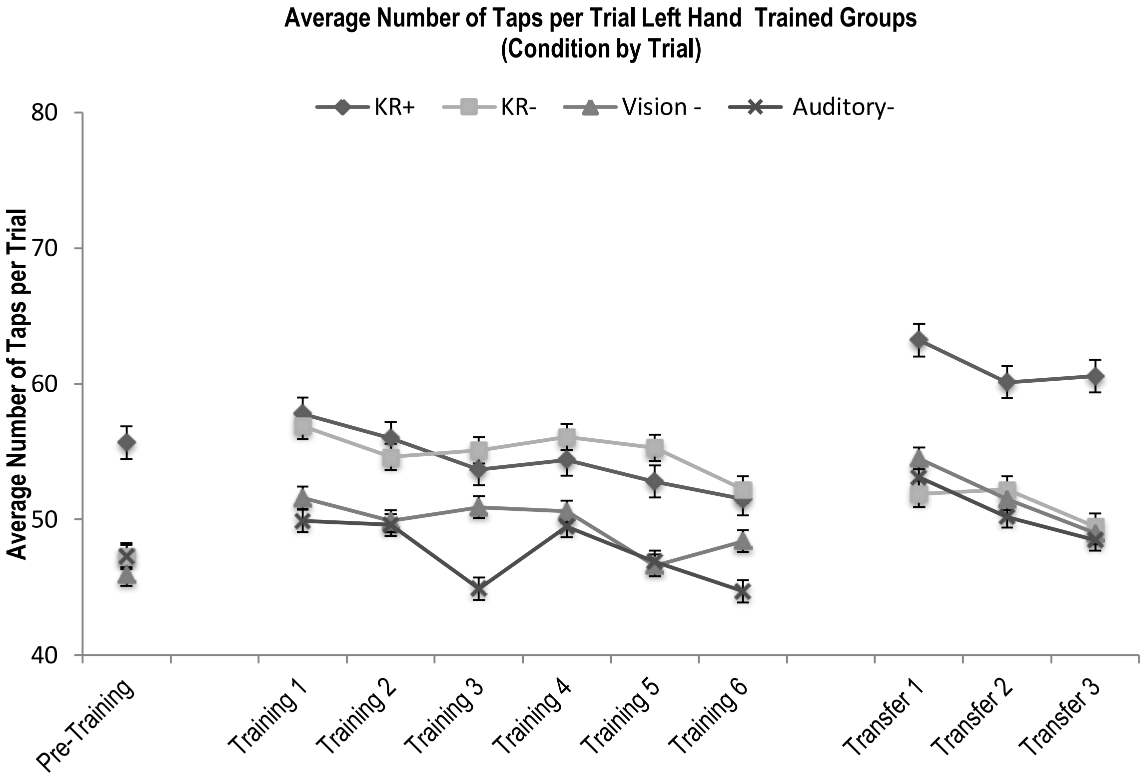


Figure 4-4: The average number of taps per trial and SE are displayed for each condition. Note that pre-training and transfer trials represent the right hand at pre and post left hand training. (KR+ *n*=10, KR- *n*=10, Vision- *n*=10, Auditory- *n*=10).

Between Hands - Within Condition

The data was split by condition by hand to facilitate analysis of the effect of feedback on the average number of taps per trial produced by each hand. The data presented in table 4-1 revealed that the overall superiority of the right hand performance diminished from KR+ to Auditory- conditions. In the KR- condition the left hand performed slightly better than the right hand but the right hand regained its superiority in the Vision- condition. However by the Auditory- condition there was no difference in average tapping rate between the hands. The minimum and maximum average tap rate decreased for the right hand from KR+ (*Min* = 59, *Max* = 65) to Auditory- (*Min* = 47, *Max* = 52). The left hand did not reach the same levels of performance of the right hand in KR+ (*Min* =52, *Max* =58) and so the decrease was less marked by Auditory-(*Min* = 47, *Max* = 50).

Table 4-1: The number of taps per trial (mean and standard deviation (*SD*)) for each condition by hand trained group.

Condition	**Trial 1** **Mean(*SD*)**	**Trial 2** **Mean(*SD*)**	**Trial 3** **Mean(*SD*)**	**Trial 4** **Mean(*SD*)**	**Trial 5** **Mean(*SD*)**	**Trial 6** **Mean(*SD*)**
KR+						
Right Hand (*n*=10)	65 (*8*)	59 (*9*)	61 (*7*)	63 (*8*)	63 (*9*)	64 (*10*)
Left Hand (*n*=10)	58(*19*)	56(*17*)	54(*15*)	54(*14*)	53(*13*)	52 (*12*)
KR-						
Right Hand (*n*=10)	47(*17*)	51(*15*)	52(*14*)	54(*13*)	53(*12*)	51(*10*)
Left Hand (*n*=10)	57(*18*)	55(*16*)	55(*16*)	56(*17*)	55(*16*)	52(*16*)
Vision-						
Right Hand (*n*=10)	56(15)	55(*12*)	55 (*9*)	55(*10*)	52 (*8*)	55 (*8*)
Left Hand (*n*=10)	52(*19*)	50(*16*)	51(*16*)	51(*19*)	47(*17*)	48(*13*)
Auditory-						
Right Hand (*n*=10)	50(15)	50(*13*)	47(*10*)	51(*15*)	47(*16*)	52(*16*)
Left Hand (*n*=10)	50(*10*)	50 (*9*)	45(*10*)	50(*11*)	47(*11*)	45(*12*)

Four mixed design ANOVAS were performed to investigate the effect of feedback on the performance of right and left hand trained groups for each condition. Robust methods conducted in R were used to examine the KR+ data following violation of a Levenes test. The results indicated that there was no significant interaction effect for the hand trained groups. The KR-, Vision- and Auditory- groups (no violation of Levenes) did not reveal a significant effect using a general linear model (GLM) repeated measures test.

Transfer Phase

Transfer was investigated in two ways: firstly by a within group comparison of performance at the pre-training and transfer phase (trial 1). The objective was to investigate if performance of the untrained hand improved following opposite hand training. Secondly, a between groups comparison of training (trial 6) and transfer phase (trial 1) was conducted to ascertain whether same hand training was superior to opposite hand training.

Table 4-2 shows the average taps per trial for both the right and left hand at pre-training, training trial 6 (T.6) and transfer trial 1(TF.1). TF.1 was used to avoid any “practice effect” in subsequent trials (Bray, 1928). The right and left hand completed more taps at TF.1 than at the pre-training trial for all feedback conditions. The left hand completed considerably more taps in the KR+ condition following opposite hand training (*M* = 63, *SD* = 9) than when trained itself (*M* = 52, *SD* = 12). There was very little difference in performance for the right hand in KR+ with the tap rate being equal when the hand was trained itself (*M* = 64, *SD* = 10) or tested after opposite hand training (*M* = 64, *SD* = 21). The right hand in KR- condition showed higher levels of performance following opposite hand training (*M* = 62, *SD* = 18) than when trained itself (*M* = 51, *SD* = 10). In the Vision- and Auditory- conditions both the right and left hand appeared to benefit from opposite hand training.

Table 4-2: Between Hand Comparison of the Number of Taps per Trial (mean and standard deviation (SD)) at Pre-training, Training Trial 6 (T.6) and Transfer Trial 1 (TF.1).

	Right Hand			**Left Hand**		
Condition	**Pre-Training Mean (SD)**	**Training Trial 6 (T.6) Mean (SD)**	**Transfer Trial 1(TF.1) Mean (SD)**	**Pre-Training Mean (SD)**	**Training Trial 6 (T.6) Mean (SD)**	**Transfer Trial 1(TF.1) Mean (SD)**
KR+ (*n*=10)	54 (20)	64 (10)	64 (21)	56 (11)	52 (12)	63 (9)
KR- (*n*=10)	56 (19)	51 (10)	62 (18)	47 (19)	52 (16)	51 (13)
Vision- (*n*=10)	50 (19)	53 (9)	57 (17)	46 (8)	48 (14)	54 (8)
Auditory- (*n*=10)	47 (8)	52 (16)	57 (12)	47 (17)	45 (12)	53 (15)

Within Groups Analysis

A parametric repeated measures t-test for each hand by condition was conducted between the pre-training and transfer trial 1(TF.1). In the case of the right hand the % increase in performance from the pre-training to transfer phase was significant for KR+ (15%) and Auditory- (18%). In KR+ the tapping rate increased from pre-training (*M* = 54, *SE* = 6.28) to transfer (*M* = 64, *SE* = 6.73), *t* (9) = -3.53, *p*< .05, *r* =.76. In Auditory- the tapping rate increased from pre-training (*M* = 47, *SE* = 2.65) to transfer (*M* = 57, *SE* = 3.65) *t* (9) = -4.30, *p*< .05, *r* = .82. Results for the left hand indicated that there was a significant % increase in performance in KR+ (12%) and Vision- conditions (16%). In KR+ the tapping rate increased from pre-training (*M* = 55, *SE* = 3.58) to transfer (*M* = 63, *SE* = 2.75), *t* (9) = -

5.40, *p*< .05, *r* =.87. In Vision- the tapping rate increased from pre-training (*M* = 46, *SE* = 2.63) to transfer (*M* = 55, *SE* = 2.36), *t* (9) = -4.21, *p*< .05, *r* = .82. The percentage increase in performance from pre-training to TF.1 for each hand by condition and is presented graphically in figure 4-5.

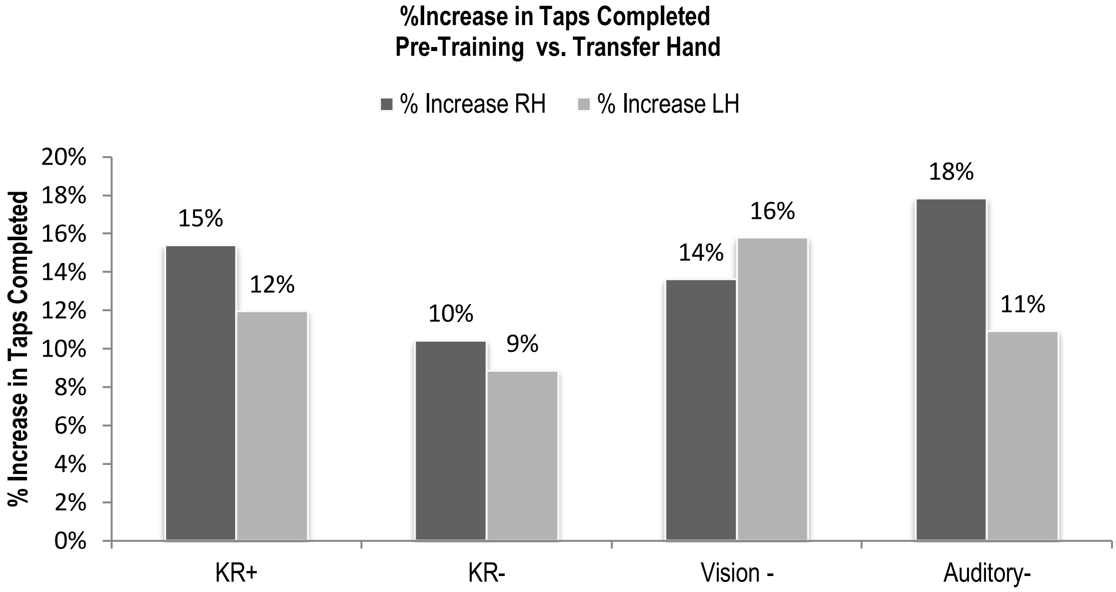


Figure 4-5: The percentage increase in tap rate for the un-trained hand from pre-training to transfer trial 1 following opposite hand training was calculated for the right (RH) and left hand(LH). KR+ *n*=10, KR- *n*=10, Vision- *n*=10, Auditory-*n*=10.

Between Groups Analysis

A comparison of trial 6 of the training phase (T.6) and trial 1 transfer phase (TF.1) was performed to investigate differences in performance between same hand and opposite hand training. Following violation of tests for homoscedasticity, non-parametric independent t-tests were carried out for each hand by condition. The results for the right hand (KR+, KR-, Vision-, & Auditory-) were not significant although the results for KR- (% positive difference = 23%) were approaching significance (*p* = .07, with a medium effect size (*r* = - 0.40). The % difference in performance between same and opposite hand training is displayed in figure 4-6.

The results for the left hand group showed a significant difference in performance in KR+ (+23%) with the hand performing more taps following opposite hand training (*Mdn* = 62.5) than when trained itself (*Mdn* = 51) *p* =. 049 *r* = -.44 Same hand versus opposite hand training differences did not reach significance for the KR- (-1%), Vision- (+13%) & Auditory- (+19%) conditions.

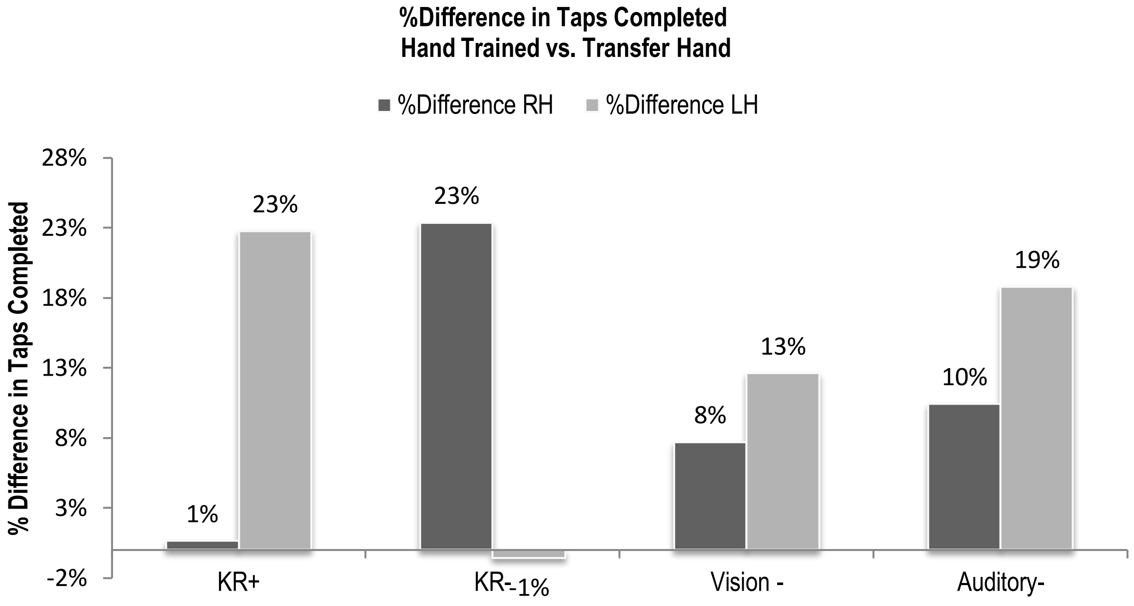


Figure 4-6: The percentage difference in performance between hand trained and transfer groups were calculated for the right (RH) and left hand (LH). KR+ *n*=10, KR- *n*=10, Vision- *n*=10, Auditory-*n*=10.

Discussion – Finger Tapping

Training Phase

Performance levels did not increase in a linear fashion for the right hand across the training phase (trials 1 – 6). Small increases in average tap rate were recorded for the right hand in KR- and Auditory- conditions but not in KR+ and Vision- where the tap rate did not increase from trial 1 to trial 6. Performance levels of the left hand decreased significantly from trial 1 to trial 6 of the training phase for all conditions. It may be that the left hand tired more easily than the right hand which may be attributed to lack of practice in general with the left hand (Provins & Glencross, 1968). When feedback was reduced across conditions the average tap rate for the right hand decreased for all conditions, in particular, in the KR- and

Auditory- conditions. Although this decrease did not reach statistical significance, the difference between KR+ and Auditory- was approaching significance (p = .07). The performance of the left hand did not vary as much with the successive reduction in feedback from KR+ to Auditory- condition. It may be that the left hand is less sensitive to feedback and therefore to the loss of feedback than is the right hand. Laszlo et al. (1970) hypothesised that the right hand could make greater use of available feedback to create a better STD than the left hand which accounted for its greater proficiency when full feedback was available. The results from the finger tapping task in the current study provides some support for their hypothesis. Taylor & Heilman hypothesised that the right hand would acquire a skill faster than the left hand because it has direct access to the motor program. The results from the training phase of the finger tapping task do not support this model in terms of faster acquisition rates for the right hand. The performance levels of right hand did not increase over the training phase and the left hand performance level decreased significantly. In KR- the left hand outperformed the right hand and in Auditory- there was no difference between the performance levels of both hands. The results indicate that it is likely that feedback has a greater role to play in acquisition of a skill than Taylor & Heilman might have considered.

The introduction of four levels of feedback in the current study allows exploration of which type of feedback might have the greatest effect on performance. The results from the current study are consistent with the notion that knowledge of results (KR) is crucial for optimum performance of the right hand in a finger tapping task. It is at the point of removal of terminal KR that the right hand begins to lose its superiority which decreases further with the loss of vision and auditory feedback (here to an almost significant level). The benefit of terminal KR in a guiding and/or motivational role is supported for the right hand (Salmoni et al, 1984). The left hand seems less sensitive to or makes less use of available terminal KR.

Transfer Phase

Transfer was examined in two ways: firstly the pre-training trial was compared to transfer (trial 1) to examine the effect of opposite hand training. Secondly, same hand training (training phase - trial 6) was compared to opposite hand training (transfer – trial 1) to investigate the effect of each on performance.

Right Hand: There was a statistically significant increase in performance for the right hand from the pre-training trial to transfer (trial 1) in KR+ and Auditory- conditions. When these results were compared to results for the same hand trained group (training phase - trial 6) it can be seen that in KR+ the right hand performed at a similar level whether trained itself or following opposite hand training (see figure 4-6). In KR-, Vision- and Auditory- the right hand performance was greater following opposite hand training than when trained itself particularly in KR- were the loss of KR and the subsequent decrease in performance almost reached statistical significance. Laszlo et al. explain this in terms of the left hand being able to invoke the motor program in the absence of feedback, which the right hand can benefit from. Taylor and Heilman submit that the motor program is held in the left (dominant) hemisphere no matter which hand is trained, therefore the right hand naturally benefits from left hand training. The similar performance of the right hand when trained itself and following opposite hand training could provide some support for Taylor and Heilman's concept of the motor program residing in the left hemisphere. The lack of an increase in performance across the training trials (right hand) and the decrease in performance of the left hand adds further debate to what exactly has been transferred to the opposite hand. For example it is difficult to reconcile the superior performance of the right hand following opposite hand training than when trained itself. It may be that fatigue played a role. The training hand had performed six trials at which point it is was measured. In contrast the transfer hand had only performed one trial at the point of measurement.

Left hand: There was a statistically significant increase in performance level in KR+ and Vision- conditions from pre-training to transfer (trial 1). When compared to same hand training the left hand's performance level was significantly better in KR+ following opposite hand training than when trained itself (see figure 4-6). This supports Laszlo et al's hypothesis that the left hand benefits from right hand training because it has access to the STD created by the right hand. It is interesting to note that in KR- performance of the left hand is similar when the hand is trained itself and following opposite hand training. This may reflect a poorer STD created by the right hand in the absence of KR. This again supports Laszlo et al's hypothesis that the STD created by the right hand suffers when feedback is not available. It also provides support for the concept of the STD created by the right hand being available to the left hand. In the case of the KR- condition this STD was poorer than in the KR+ and so did not benefit the left hand as well as it might. It is evident from the current study that at the point of removal of KR the right hand begins to lose it's superiority of performance in the finger tapping task.

The results from the finger tapping task indicate that both hands gained from opposite hand training except for KR+ condition (right hand) and KR- condition (left hand). This suggests that transfer was symmetrical to a degree and that some sharing of resources (be that a motor program) or STD occurs. Inui (2005) found transfer to be symmetrical in a finger tapping task in which peak force and timing (inter-tap interval) variables were measured. Bilateral transfer was found for the timing element of the task which led them to support the concept of the hands sharing a central timekeeper. While speed rather than timing was measured in the current task it may be that some element of timing (self-paced) may have been involved. However there does appear to be some relationship between hand trained and feedback type as evidenced by the exception in transfer gain that occurred for the right hand in KR- condition. This supports to some degree Laszlo et al.'s proposal of the involvement of a STD but only for extrinsic information in the form of terminal KR. The results do not support the Cross Activation Model (Parlow & Kinsbourne) as transfer occurred in both directions. The finding that the left hand benefits from right hand training does not fit with the Taylor & Heilman model. The results from the current study suggest that rather than the program residing in the left hemisphere and therefore benefitting the right hand only, that it is somehow shared and therefore of benefit to both hands. In terms of feedback it seems that the right hand is more sensitive to feedback and can make better use of available feedback especially if that feedback is in the form of KR. The left hand did show some sensitivity to the loss of KR in the transfer phase which suggests that when a key element of feedback for the right hand was lost that this in turn affected the performance of the left hand and argues for some sharing of resources.

4.4.2 Finger Sequencing

Training Phase (Trials 1 – 6)

Within Hand – Between Conditions

The average number of correct sequences per trial was calculated for each hand (right/left hand trained) by condition (KR+, KR-, Vision-, and Auditory-). A mixed design ANOVA was performed to allow for examination of performance within conditions and between conditions. All effects are reported as significant at $p < .05$.

Right Hand: figure 4-7 shows that there was an increase in performance level for the right hand between trial 1 (T.1) and trial 6 (T.6) of the training phase. In the KR+ condition performance improved from T.1 (M = 6.4, *SD* = 1.71) to T.6 (*M* = 7.1, *SD* =3.7), in KR- T.1 (*M* = 9.0, *SD* = 3.2) to T.6 (*M* = 10.0, *SD* = 1.8), Vision- T.1 (*M* = 6.1, *SD* = 2.6) to T.6 (*M* = 8.0, *SD* = 2.1) and Auditory- T.1 (*M* = 6.6, *SD* = 2.5) to T.6 (*M* = 7.6, *SD* = 1.5). A mixed design ANOVA reported a significant effect for training trials (trial 6 removed due to violation of a Levenes test) *F* (4, 36) = 5.92, *p* = .00. Within subjects contrast revealed a significant increase in performance trial 1 versus trial 5 *F* (1, 36) = 11.90, *r* = .50.

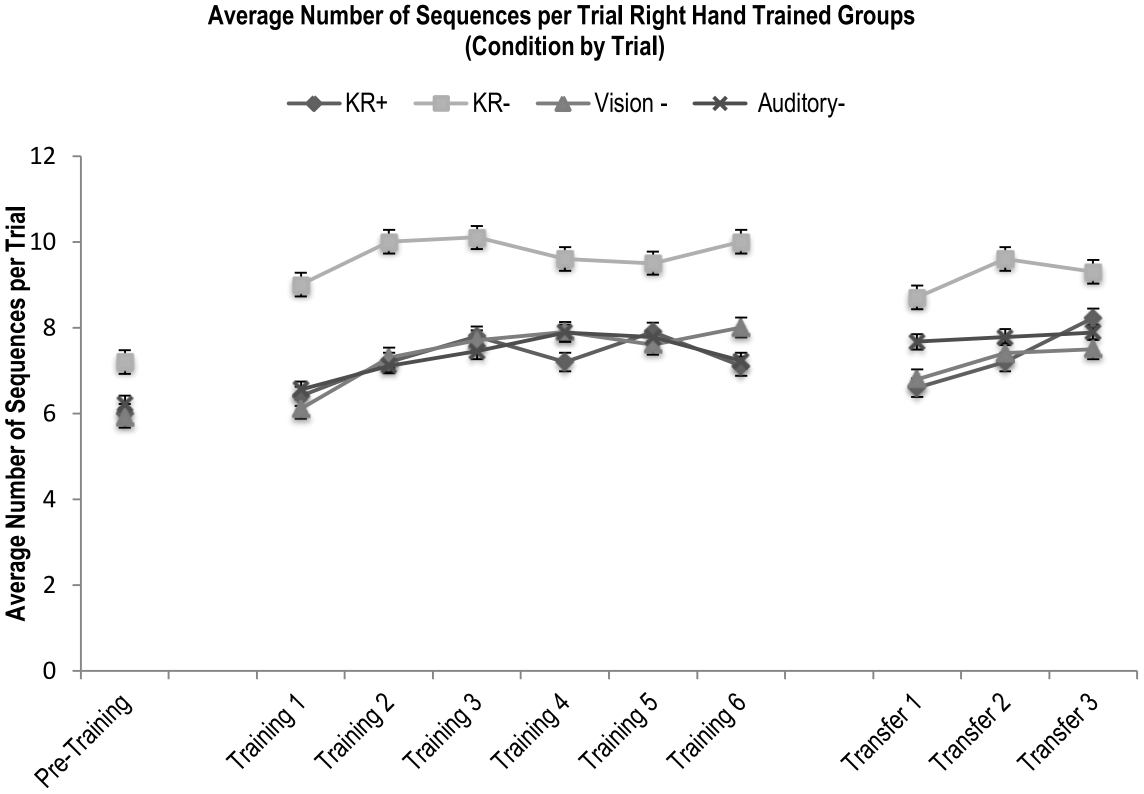


Figure 4-7: The average number of correct sequences per trial and SE are displayed for each condition. Note that pre-training and transfer trials represent the left hand at pre and post right hand training. (Condition 1 (KR+) *n*=10, Condition 2 (KR-) *n*=10, Condition 3(Vision-) *n*=10, Condition 4 (Auditory-) *n*=10).

The most superior performance levels across all conditions for the right hand were observed for the KR- condition (absence of terminal feedback). A mixed design ANOVA confirmed the significant effect for conditions *F (*3, 36) = 813.28, *p* = .00. Between group contrasts indicated a reliable difference between the KR- and Auditory- conditions.

Left Hand: Figure 4-8 shows that there was an improvement in performance for the left hand from trial 1 (T.1) to trial 6 (T.6) for all conditions in the training phase. In KR+ performance increased from T.1(*M* = 7.4, *SD* = 2.1) to T.6 (*M* = 9.6, *SD* =2.5) , in KR- T.1 (*M* = 6.2, *SD* = 3.0) to T.6 (*M* = 8.2, *SD* = 2.1), in Vision- T.1(*M* = 5.2, *SD* = 1.6) to T.6 (*M* = 6.4, *SD* = 2.1) and in Auditory- T.1 (*M* = 7.2, *SD* = 1.6) to T.6 (*M* = 8.0, *SD* = 1.8).

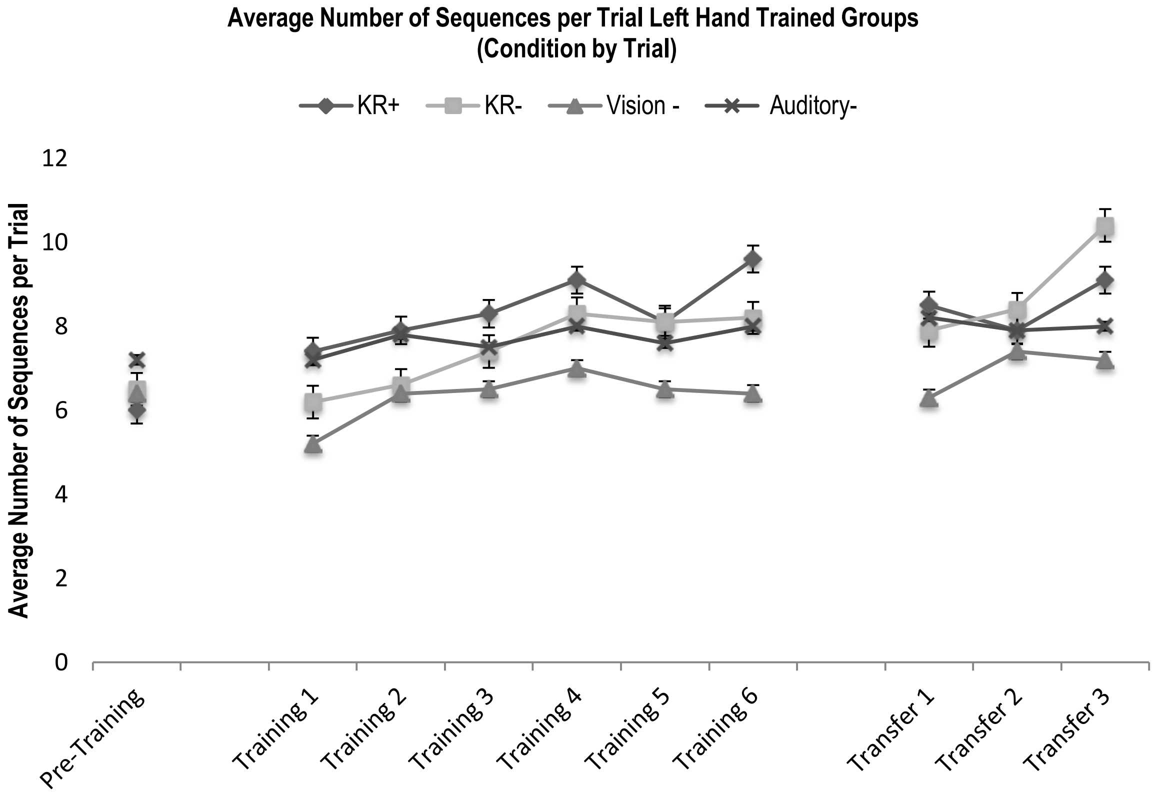


Figure 4-8: The average number of correct sequences and SE are displayed for each condition. Note that the pre-training and transfer trials are for the right hand pre and post left hand training. (Condition 1 (KR+) *n*=10, Condition 2 (KR-) *n*=10, Condition 3(Vision-) *n*=10, Condition 4 (Auditory-) *n*=10).

The results from the Mixed design ANOVA indicated that there was a significant effect for training trials (trial 5 excluded) *F* (4,36) = 9.19, *p* =.00. Within groups constrasts revealed a significant effect for trial 1 versus trial 6 *F* (1,36) = 16.73, *r* = .56 and trial 2 versus. trial 6 *F* (1,36) = 6.12, *r* = .38. The Vison- group produced less sequences than the other conditions but this result was not significant as confirmed by the mixed design ANOVA.

Between Hands - Within Condition

The data was then split by condition by hand to allow for investigation and analysis of the effect of feedback on hand trained. The data is presented in tabular form in table 4-2. The performance levels of left hand trained group (*Min* = 7.4, *Max* = 9.6) were higher than those of the right hand trained group (*Min* = 6.4, *Max* = 7.9) in the KR+ condition. In the KR-condition the right hand group's performance (*Min* = 9.0, *Max* = 10.1) was superior to that of the left hand trained group (*Min* =6.2, *Max* =8.3) and also in Vision- right hand trained group (*Min* = 6.1, *Max* = 8.0) and left hand trained group (*Min* = 5.2, *Max* = 7.0). In the Auditory- condition there was very little difference in the average number of correct sequences per trial for each hand.

Table 4-3: Comparison of the Correct Sequences (mean and standard deviation (*SD*)) Condition by Hand by Training Trial (1-6).

Condition	Trial 1 Mean(*SD*)	Trial 2 Mean(*SD*)	Trial 3 Mean(*SD*)	Trial 4 Mean(*SD*)	Trial 5 Mean(*SD*)	Trial 6 Mean(*SD*)
KR+						
Right Hand (*n*=10)	6.4 (1.7)	7.2 (1.9)	7.8 (1.6)	7.2 (1.6)	7.9 (*1.5*)	7.1 (*3.7*)
Left Hand (*n*=10)	7.4 (*2.1*)	7.9 (2.8)	8.3 (2.5)	9.1 (*2.4*)	8.1 (*3.0*)	9.6 (*2.5*)
KR-						
Right Hand (*n*=10)	9.0 (*3.2*)	10.0 (.02)	10.1 (2.1)	9.6 (1.8)	9.5 (*1.5*)	10.0 (*1.8*)
Left Hand (*n*=10)	6.2 (*3.1*)	6.6 (*2.3*)	7.4 (*2.1*)	8.3 (*2.3*)	8.1 (*2.1*)	8.2 (*2.1*)
Vision-						
Right Hand (*n*=10)	6.1 (2.6)	7.3 (*2.9*)	7.7 (*2.7*)	7.9 (*2.2*)	7.6 (*2.3*)	8.0 (*2.1*)
Left Hand (*n*=10)	5.2 (1.6)	6.4 (*1.8*)	6.5 (*1.5*)	7.0 (*2.1*)	6.5 (*1.0*)	6.4 (*2.1*)
Auditory-						
Right Hand (*n*=10)	6.6 (2.5)	7.1 (*2.0*)	7.4 (*1.6*)	7.9 (*1.2*)	7.8 (*2.0*)	7.6 (*1.5*)
Left Hand (*n*=10)	7.2 (1.6)	7.8 (*2.6*)	7.5 (*2.6*)	8.0 (*2.4*)	7.6 (*1.7*)	8.0 (*1.8*)

Following violation of a Levenes test a robust mixed design ANOVA was utilised to investigate the data for KR+ participants. The results indicated that there was a significant effect for training trials $Q = 6.09$, $p = .02$ but no effect for hand trained group. The KR-, Vision- and Auditory- groups were tested using a general linear model (GLM) repeated measures test following non-violation of Levenes tests. In the KR- condition there was no significant effect for training trials but there was a significant effect for hand trained groups F (1,18) = 9.27. $p = .01$, $r = .58$. The Vision- group results revealed a non-significant effect for hand trained groups but did show a significant effect for training trials F (5,36) = 5.56, $p = .00$. Within groups contrast indicated that there was a significant increase between trial 1 versus trial 6 F (1, 18) = 11.93, $r = .63$. There was no effect for hand trained or training trials in the Auditory- condition.

Comparison of Finger Tapping and Finger Sequence

The percentage difference (% difference) in performance rates from trial 1 to trial 6 of the training phase was calculated for each hand by condition by task. This facilitated a comparison of performance gains/losses for the finger tapping versus finger sequencing task in the training phase. Figure 4-9 presents the data graphically for the right hand trained groups. There was very little difference in performance gains/losses in the KR+, Vision- and Auditory- conditions. A significant % difference occurred in the Vision- condition with a large increase (26%) in performance from training trial 1 to trial 6 in the finger sequencing task. In the finger tapping task there was a slight drop in performance (-1%). The results from an independent T-Test confirmed the significance of the difference (t= (18) = -3.69, p = .00. This represents a large effect size r =.65.

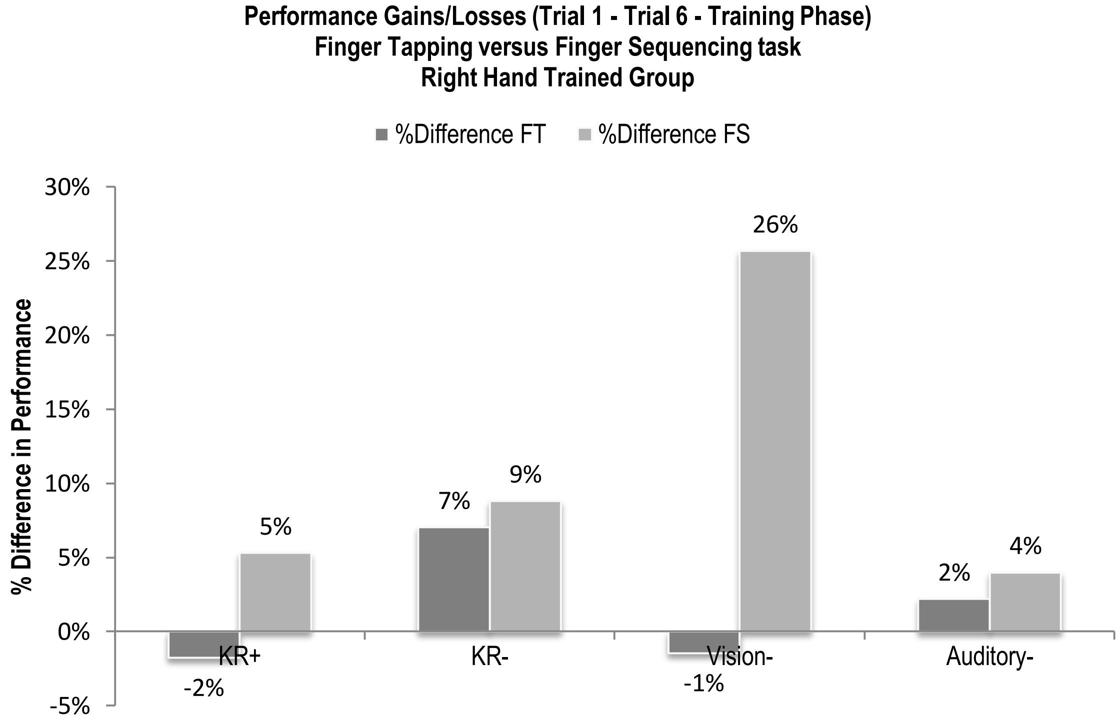


Figure 4-9: The % Difference in Performance Rates from Trial 1 to Trial 6 of the Training Phase were calculated for the right hand trained groups (condition by task).

The % difference in performance for the left hand is presented in figure 4-10. Performance decreased from trial 1 to trial 6 of the training trials in each condition for the finger tapping task. Conversely, in the finger sequencing task performance increased in all but the Vision- condition. Results from independent t-tests revealed a significant difference in performance gains/losses in the KR+ (t (18) = -5.02, p = .00, r = .76) and KR- (t (18) = -2.16, p = .04, r = .45).

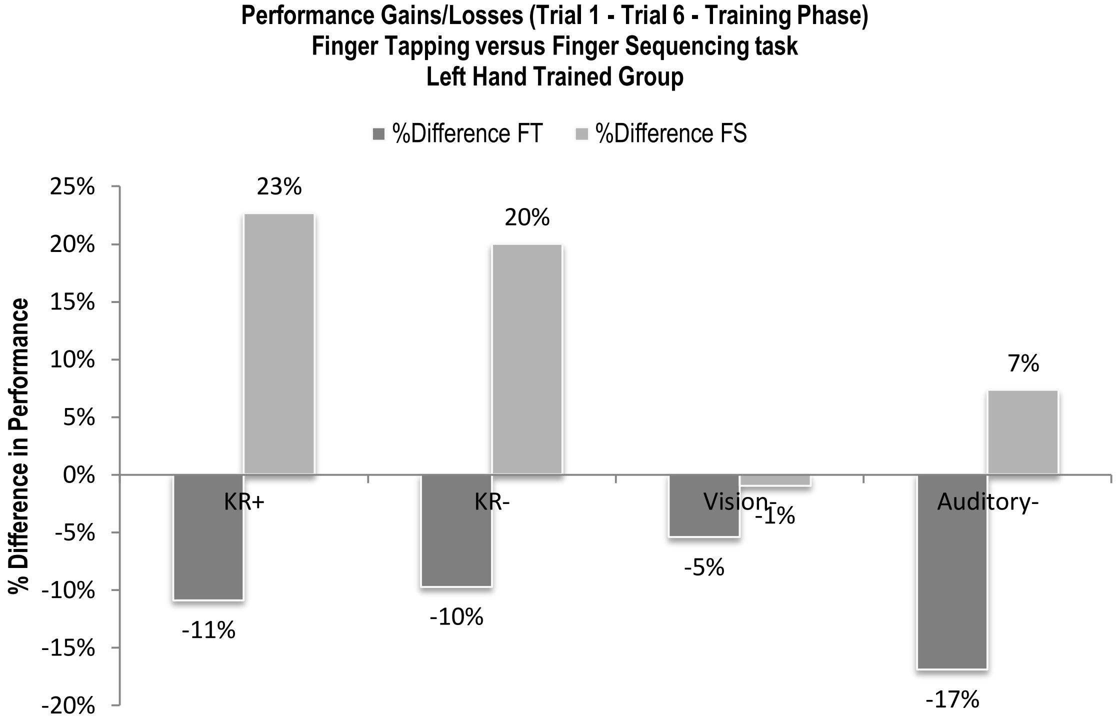


Figure 4-10: The %Difference in Performance Rates from Trial 1 to Trial 6 of the Training Phase were calculated for the left hand trained groups (condition by task).

Transfer Phase

As before transfer was investigated in two ways: firstly a comparison of performance levels at the pre-training and transfer phase (trial 1). The objective was to see if the performance of the hand improved following opposite hand training. Secondly, a comparison between the training (trial 6) and transfer phase (trial 1). The objective here was to ascertain whether same hand training was superior to opposite hand training.

Table 4-4: shows that performance of the right hand and left hand increased from pre-training to transfer trial 1 in all Conditions.

Table 4-4: Between Hand Comparison of the Number of Correct Sequences per trial (mean and standard deviation (SD)) at Pre-Training, Training Trial 6(T.6) and Transfer Trial 1 (TF.1).

	Right Hand			Left Hand		
Condition	**Pre-Training Mean (SD)**	**Training Trial 6 (T.6) Mean (SD)**	**Transfer Trial 1(TF.1) Mean (SD)**	**Pre-Training Mean (SD)**	**Training Trial 6 (T.6) Mean (SD)**	**Transfer Trial 1(TF.1) Mean (SD)**
KR+ (*n*=10)	6.0(2.0)	7.1(3.1)	6.6(1.7)	6.0(1.8)	9.6(2.5)	8.5(1.9)
KR- (*n*=10)	7.2(2.8)	10.0(1.8)	8.7(1.3)	6.5(2.9)	8.2(2.1)	7.9(2.5)
Vision- (*n*=10)	5.9(3.0)	8.0(2.1)	6.8(1.9)	6.4(1.5)	6.4(2.1)	6.3(3.2)
Auditory- (*n*=10)	6.2(1.9)	7.2(1.5)	7.7(1.2)	7.2(2.1)	8.0(1.8)	8.2(1.8)

Within Groups Analysis

The performance of the right hand improved from pre-training to transfer trial (TF.1) for all conditions: KR+ Pre-Training (*M* = 6.0, *SD* = 2.0) TF.1 (*M* = 6.6, *SD* = 1.7), KR- Pre-Training(*M* = 7.2, *SD* = 2.8) TF.1 (*M* = 8.7, *SD* = 1.3), Vision- Pre-Training(*M* = 5.9, *SD* = 3.0) TF.1 (*M* = 6.8, *SD* = 1.9) and Auditory- Pre-Training (*M* = 6.2, *SD* = 1.9) TF.1 (*M* = 7.7, *SD* = 1.2). Results for the left hand trials also indicated that performance improved following opposite hand training for all conditions except Vision: (KR+: Pre-Training (*M* = 6.0, *SD* = 1.8) TF.1 (*M* = 8.5, *SD* = 1.9), KR-: Pre-Training(*M* = 6.5, *SD* = 2.9) TF.1 (*M* = 7.9, *SD* = 2.5), Vision-: Pre-Training (*M* = 6.4, *SD* = 1.5) TF.1 (*M* = 6.3, *SD* = 3.2) and Auditory-: Pre-Training (*M* = 7.2, *SD* = 2.1) TF.1 (*M* = 8.2, *SD* = 1.8)).

Following violations of test for normality a Wilcoxon signed rank test was used to measure performance for the finger sequencing task at pre-training vs. transfer (trial 1) for each hand by condition. The performance of the right hand improved following opposite hand training but this % increase in performance only reached significant levels in the Auditory- condition (19%). Performance increased from pre-training (*Mdn = 6.0)* to transfer

(*Mdn = 8.0*), p = .042, *r* = - 0.45. Results for the left hand trials also indicated that performance improved following opposite hand training for all conditions except Vision-, but these % increases only reached significant levels for KR+ (29%). Performance increased from pre-training (*Mdn* = 6.5) to transfer (*Mdn* = 8.5), *p* = .005, *r* = -0.63. The % increase in performance from pre-training to transfer trial 1 is presented graphically in figure 4-9.

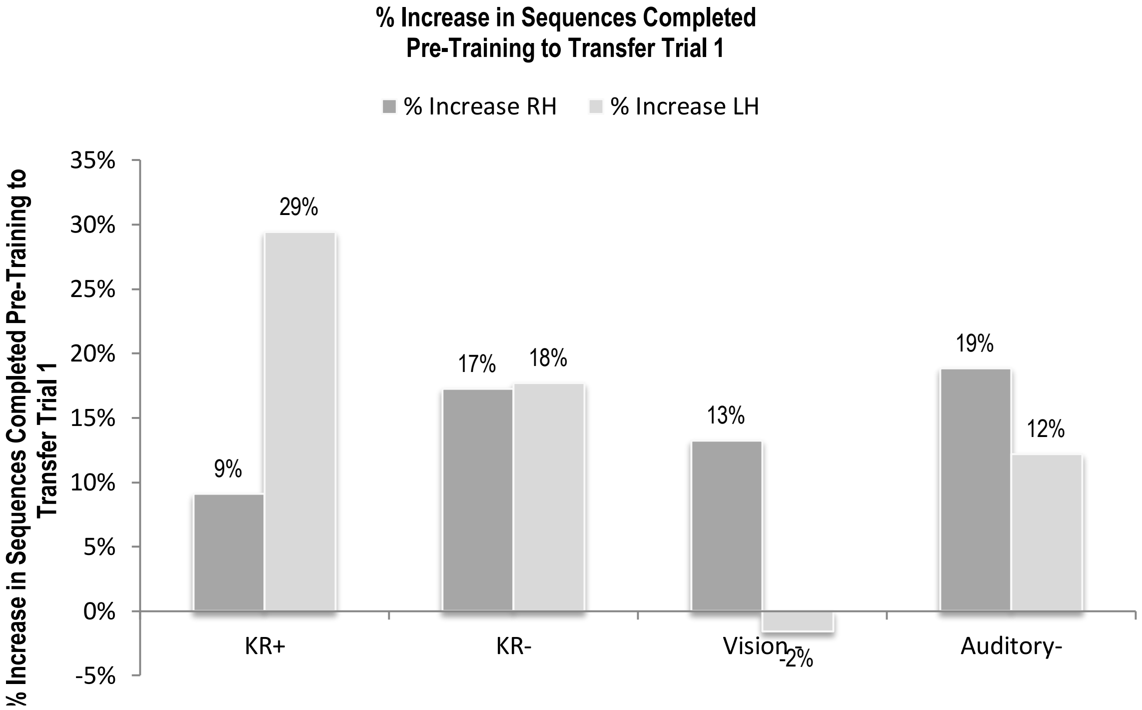


Figure 4-11: The percentage increase in correct sequences completed for the un-trained hand from pre-training to transfer trial 1 following opposite hand training was calculated for the right (RH) and left hand(LH). KR+ *n*=10, KR- *n*=10, Vision- *n*=10, Auditory-*n*=10.

Between Groups Analysis

A comparison of training phase (trial 6) versus transfer phase (trial 1) was carried out to investigate differences in performance when the hand was trained itself and following opposite hand training.

As can be seen in figure 4-10 the % difference in correct sequences completed shows a negative score indicating that performance levels after opposite hand training (TF.1) was less than when the hand was trained itself (T.6) in three conditions: KR+ (-7%), KR- (-13%), Vision- (-15%). The number of sequences decreased for each of these conditions: (KR+: (T.6

M = 7.1, *SD* = 3.1; TF.1 *M* = 6.6, *SD* = 1.7); KR-: (T.6 *M* = 10.0, *SD* = 1.8, TF.1 *M* = 8.7, *SD* = 1.3) and Vision-: (T.6 *M* = 8.0, *SD* = 2.1; TF.1 *M* = 6.8, *SD* = 1.9). Conversely in the Auditory- condition the performance levels for the right hand were higher (+ 6%) when tested following opposite hand training (T.6 *M* = 7.2, *SD* = 1.5; TF.1 *M* = 7.7, *SD* = 1.2). The number of correct sequences completed by the left hand was lower (-13%) following opposite hand training than when the hand was trained itself in the KR+ condition (T.6 *M* = 9.6, *SD* = 2.5; TF.1 *M* = 8.5, *SD* = 1.9) There was very little difference in performance between same hand training and opposite hand training in KR- (-4%), Vision- (-2%) and Auditory- (+2%) conditions.

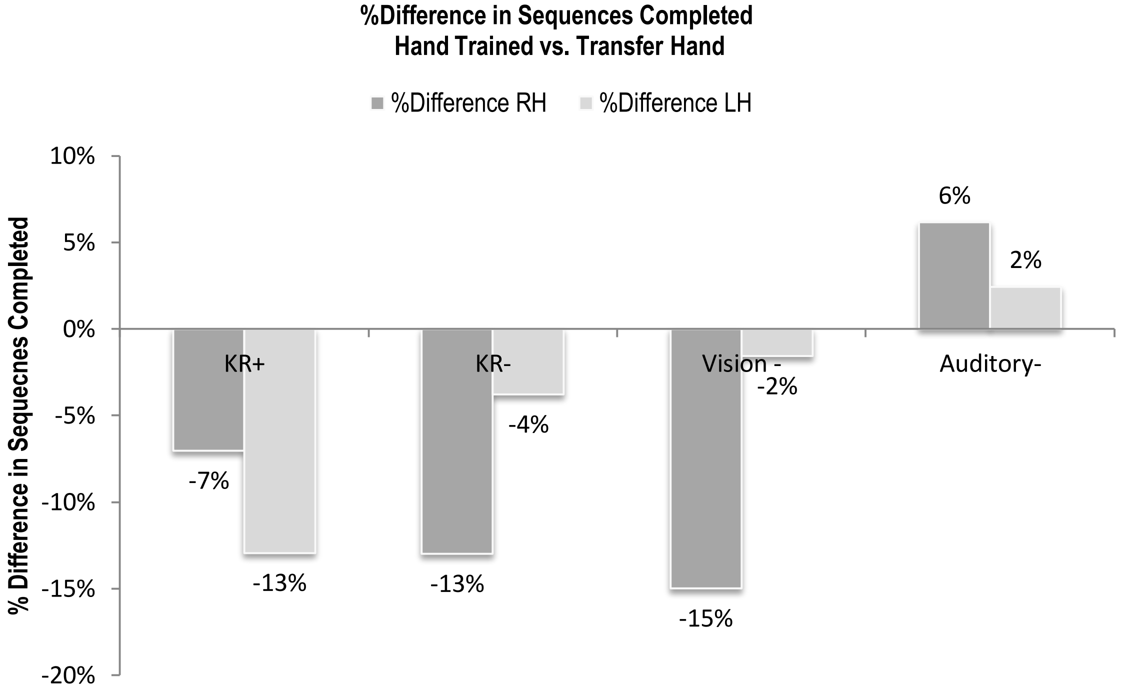


Figure 4-12: The percentage difference in performance between hand trained and transfer groups were calculated for the right (RH) and left hand (LH). KR+ *n*=10, KR- *n*=10, Vision- *n*=10, Auditory-*n*=10.

The data violated tests of normality so Wilcoxon rank-sum tests were carried out for each hand by condition. The results for the right hand (KR+, KR-, Vision-, Auditory-) were not significant although the results for KR- were approaching significance (*p* = .06, with a medium effect size (*r* = - 0.42). The results for the left hand group showed no significant difference in performance in any condition.

Analysis of Relative Errors

The relative error was calculated for each participant and trial (Total Number of Keystrokes-Correct number of Keystrokes)/Total Number of Keystrokes. The average relative error was calculated for each hand trained group for training (trial 1-6) and transfer (trial 1-3) phases. The figures are presented in table 4-5.

Table 4-5: The Percentage Relative Error (Hand by Condition) at Training (trials 1-6) and Transfer (trials 1-3).

	Right Hand		Left Hand	
Condition	Training	Transfer	Training	Transfer
KR+ (*n*=10)	19.43	10.83	08.10	20.09
KR- (*n*=10)	12.87	08.67	15.65	11.26
Vision- (*n*=10)	10.24	09.54	08.76	14.86
Auditory- (*n*=10)	12.05	12.92	10.81	08.74

The percentage relative error rates show that the right hand made more errors in the training phase than the left hand for all feedback conditions except KR-. The right hand made less errors following opposite hand training in all but the Auditory- condition where the recorded error rates were similar. The left hand made more errors following opposite hand training in the KR+ and Vision- conditions.

Discussion – Finger Sequencing (including Finger Tapping Comparison)

Training Phase

The pattern of results in the finger sequencing task were different than for the finger tapping task. This is consistent with the view that task type may have affected training and transfer outcomes (Teixiera, 2000). The participants in each feedback condition were the same for both the finger tapping and finger sequencing task which suggests that what changed was the nature of the task itself. Increases in performance levels progressed in a more linear fashion across the training trials compared to the training phase in the finger tapping task. There was a significant increase in performance for both the right and left hand trained groups. The learning that occurred across the training trials differed from the decrease in performance for the left hand in the finger tapping task and the static nature of performance across the training trials for the right hand. When feedback was reduced across conditions the performance level of the right hand was significantly greater when KR was removed. This is in complete contrast to the performance of the right hand in the finger tapping task. For each of the other conditions (KR+, Vision-, & Auditory-) in the finger sequencing task performance of the right hand was similar. One could argue that the inclusion of KR has a similar negative effect upon performance levels as does the elimination of vision and audition. In other words, it may be the case that terminal feedback detracts rather than enhances performance in the acquisition phase (in a finger sequencing task). This finding is consistent with other research that reports a detrimental impact of KR. Schmidt, Young, Swinnen & Shapiro (1989) argue that too much KR may preclude the creation of an internal error detection method. Guadagnoli and Kohl (2001) found that participants who had to estimate their own error rate prior to receiving KR had higher levels of performance on a force production task than those who received KR only.

In the finger sequencing task both concurrent and terminal feedback was available. Park, Shea & Wright (2000) found that concurrent KR given with terminal KR was more effective in a force production task than terminal KR alone. The result from the current study does not support their findings. It may be that concurrent and terminal feedback coupled with the use of verbal strategies (74% of participants reported using verbal strategies) meant that too much information was available. Annett (1991) has argued that “providing more information than the learner can handle induces a type of ‘hunting behaviour’ which could itself interfere with long-term storage” (p. 36). There was no significant difference in performance of the left hand across feedback conditions. The left hand was not as sensitive to the removal of feedback (which is supportive of the findings from the finger tapping task) except in the case of the removal of visual feedback (Vision-). This might be an indicator of a role for the right hemisphere in left hand learning (Woolley, Wenderoth, Heuninckx, Zhang, Callaert, & Swinnen, 2010). The absence of visual feedback during left hand as opposed to right hand training may have a greater impact on performance because of an enhanced dependence on visual feedback for the non-dominant hand. The elimination of visual feedback and subsequent decrease in performance level of the left hand occurred only in the finger sequencing task. This may indicate that as the cognitive requirement of the task increases the left hand may reply more on visual feedback. When the right hand performance was compared to that of the left hand in the KR+ condition, the left hand outperformed the right hand, although not to a significant level. This finding is inconsistent with those models of intermanual transfer that propose the right hand is more proficient namely the Proficiency Model and the Cross Activation Model or has access to the motor program directly (Callosal Access Model). It would appear that in some way KR contributes to the poor performance of the right hand; when KR is removed the right hand regains its superiority, as evidenced by the significant difference in performance found in the between hand analysis (KR- condition). In Vision- condition the right hand produced a superior performance than the left hand but not to the same degree as in the KR- condition. In the Auditory- condition both hands perform at the same level. These findings do to some degree support Laszlo et al's concept of the STD, but the data indicate that other variables, such as the nature of the task and the relevance of the terminal feedback may impact upon the proficiency of the STD.

The results from the training phase are not supportive of Taylor and Heilman's hypothesis because the left hand did perform more correct sequences in the KR+ condition than the right hand. It appears that the relationship between task type and feedback conditions in the training phase affected the acquisition rates for both hands. Analyses of the relative errors (RE) for each hand indicate the right hand made more errors in the training phase than did the left hand except in the KR- condition. This may be evidence of the guiding role (Salmoni et al., 1984) of KR for the right hand; in the absence of KR the right hand may have created a better internal error detection mechanism which is responsible for the better performance of the right hand in the KR- condition. The removal of KR had the opposite effect on the RE rate for the left hand. In the training phase the left hand made the greatest number of REs when KR was removed. This suggests the both hands use KR differently; an explanation for this might be that the left hand in right handers makes less error perhaps because participants are more cautious when using their non-dominant hand. The error rates for the right hand deceased further in the Vision- condition but this did not lead to better performance of the right hand. Therefore speed and accuracy may transfer independently of each other. This is supportive of the finding by Taylor and Heilman in their reduced feedback condition.

Transfer Phase

Right Hand Transfer Group

The level of performance of the right hand improved from pre-training to transfer phase (reaching significance in Auditory-). This may indicate that resources could be shared across hands and/or hemispheres. When opposite hand training was compared to same hand training the right hand performed marginally better when trained itself than following opposite hand training except for Auditory- condition, when the reverse was true. None of these differences reached significance (although KR- approached statistical significance). These results do support the idea mentioned earlier (p. 32) that the right hand in particular may reflect greater sensitivity to KR. Other researchers reason that verbal feedback “may become redundant when feedback is inherent in the task” (Van Vliet & Wulf, 2006 p. 832) or instantaneous KR may degrade performance because it impacts upon participants’ error-detection capabilities (Swinnen, Schmidt, Nicholson & Shapiro 1990). The right hand’s sensitivity to feedback would, as before, provide some support for Laszlo et al's concept of the STD. However extrinsic terminal feedback seems to detract from the usefulness or proficiency of the STD. In the case of the finger sequencing task terminal feedback appears to be at best redundant.

Analysis of the percentage relative errors for the right hand in the transfer phase revealed that the hand made less errors (KR+, KR- Vision-) than when trained itself. This does suggest that the trained left hand exerts influence on the right hand performance level.

Left Hand Transfer Group

The within groups analysis revealed that the level of performance of the left hand improved across all conditions bar the Vision- group. The lack of improvement in this condition provides additional support for the view that visual feedback may be important for left hand skill acquisition. The enhanced performance level was statistically significant in the KR+ condition. This supports the concept of the left hand's ability to utilise the superior STD created by the right hand when full feedback is available. When same hand training was compared to opposite hand training there was no significant difference in performance. This may indicate that both hands had access to a similar motor program whether trained itself or following opposite hand training. The between hands comparison again shows that in the vision- condition the left hand's performance level was at its lowest which provides further support for the importance of visual feedback in left hand performance.

It should be noted that all participants completed the finger tapping task followed by the finger sequencing task (task order was not counterbalanced). The effect of task order if any on performance could not be analysed and may be considered as a variable for inclusion in future studies.

Analysis of the relative errors (RE) revealed that in general the right hand made less errors following left hand training whereas the left hand made more errors following right hand training. This finding suggests that each hand influences the performance of the other but that speed and accuracy transfer differently.

4.5 Summary

The current study set out to examine intermanual transfer in relation to the three main models: The Proficiency Model (Laszlo et al., 1970); Callosal Access Model (Taylor & Heilman, 1980) and the Cross Activation Model (Parlow & Kinsbourne, 1989). It was hoped to be able to refute one or more models and perhaps strengthen the case of the remaining model(s). The introduction of four levels of feedback in the current study allowed for a much more comprehensive picture of intermanual transfer to emerge: one in which the type of feedback available, task type and hand trained all impacted upon the direction and level of intermanual transfer that occurred. Initial results from this current study suggest that some sharing of resources be that a) a motor program and/or b) a STD occurs, evidenced by the fact that in both tasks the performance of the transfer hand increased following opposite hand training. Analysis of the relative errors indicated that each hand exerted an influence on the other hand's performance following opposite hand training. These findings do not support the Callosal Access model as both hands benefitted from opposite hand training and in certain feedback conditions the left hand performed better than the right hand in the training phase. These results contradict predictions of the Cross Activation model and suggest that the results found in the original study may be due to the dominant hand's proficiency with the letter producing element of the task. The results of the current study are consistent with Laszlo et al.'s notion of a STD. For example the right hand's performance on both tasks diminished to the level of the left hand once the Auditory- condition was reached. Furthermore, the performance of the left hand differed little between conditions except in the case of the removal of visual feedback in the fingers sequencing task. It may be the case that the left hand is less sensitive to feedback than the right hand and therefore cannot use it as proficiently as the right hand which again provides support for Laszlo et al's STD concept. The exception to these findings was the case of KR which seemed to affect the right hand very differently in both tasks and requires further investigation.

Chapter 5

Study 2: Exploring the Role of Knowledge of Results in Hand Skills Acquisition and Transfer

5.1 Introduction

The aim of Chapter 4 (Study 1) was to address some of the methodological differences inherent in past research relating to intermanual transfer. Specifically, Study 1 re-investigated the effect of task type (low/high perceptual load; simple/complex motor sequence) and feedback (concurrent and terminal knowledge of results (KR), visual and auditory) on intermanual transfer of acquired skilled hand movements. The study focussed on the possibility that task and feedback type coupled with the heterogeneous nature of participant groups may have confounded the results of the studies carried out by Laszlo, Bagulay & Bairstow (1970), Taylor & Heilman (1980) and Parlow & Kinsbourne (1989) and that informed the three models of intermanual transfer (Proficiency, Callosal Access & Cross Activation). The results from my first study indicate an interaction between task and feedback type (especially KR). This interaction may underpin the different patterns of acquisition and transfer observed for the two tasks (finger tapping and finger sequencing). The right hand performance in the training phase appeared to be influenced to a greater extent by terminal KR than the left hand; in the finger tapping task the greater proficiency of the right hand was lost once KR was eliminated. Conversely, the proficiency of the right hand increased once KR was eliminated for the finger sequencing task. The results are consistent with the ideas of researchers who stress the role KR may play in guidance and motivation of skilled movements (Salmoni, Schmidt & Walters et al. 1984, Van Vliet & Wulf, 2006). In the finger tapping task, participants were informed of the number of taps produced after each trial (terminal KR). The terminal KR may have provided either a guiding and/or motivational effect: this would be lost once KR was eliminated. In the finger sequencing task participants received both concurrent extrinsic feedback in the form of error information and terminal KR in the form of the number of correct sequences produced. The performance of the RH deteriorated in the presence of both types of feedback. A possible explanation for the deterioration in RH performance in the finger sequencing task could be that such an abundance of feedback, supplemented with the use of verbal knowledge ((64% of participants reported using verbal strategies) may have led to a form of information overload or fatigue. Van Vliet and Wulf suggest that KR may be superfluous when feedback is intrinsic to the task. It may also be that instantaneous KR may degrade performance because it impacts upon participants' error-detection capabilities (Swinnen, Schmidt, Nicholson & Shapiro 1990).

The tasks employed in Study 1 (finger tapping and finger sequencing) were 'mirror tasks' in that they required participants to mirror a trained hand. In the studies conducted on the models both Laszlo et al. (1970) and Taylor and Heilman(1980) utilised a mirror transfer task but the inversed reversed printing task adopted by Parlow and Kinsbourne (1989) was spatial in nature (both hands produced the letters in the same direction). Taylor & Heilman queried whether such a task favoured one hand over the other. More recently it has been suggested that acquisition of sequences develops through the parallel development of two systems: a fast developing effector independent spatial system and a slower developing effector dependent motor system (Kleine & Verwey, 2009). Under such a dual system, one would expect that tasks that do not include a spatial component could only progress under the influence of the slower effector dependent system. In contrast, tasks that include a spatial component would receive the additional and earlier benefit of the fast developing effector independent spatial input. For example, a spatial transfer task conducted after a relatively short training session might be more effective (greater performance achieved by the untrained hand) than a mirror transfer task. Previous work by researchers distinguished between spatial and motor components in the acquisition of skills. Hikosaka, Nakahara, Rand, Sakai, Lu and Nakamura et al. (1999) proposed a neural network schema which describes the acquisition, storage and production of sequential movements. The schema is shown in figure 5-1. Model A is reminiscent of the open loop models postulated by Keele (1968) and Laszlo and Manning (1970) in that movement progresses from initiation to execution in a serial fashion. In Hikosaka et al.'s schema sequence learning moves from serial processing of each element of the movement sequence in the very early stages of acquisition to a spatial representation of the sequence in the middle phase of learning and in the latter stages of learning to a motor representation of the sequence. According to Kleine and Verwey (2009) these two representations are learned independently but are active simultaneously (one is more dominant than the other) as evidence by the thickness of the arrows in Models B & C.

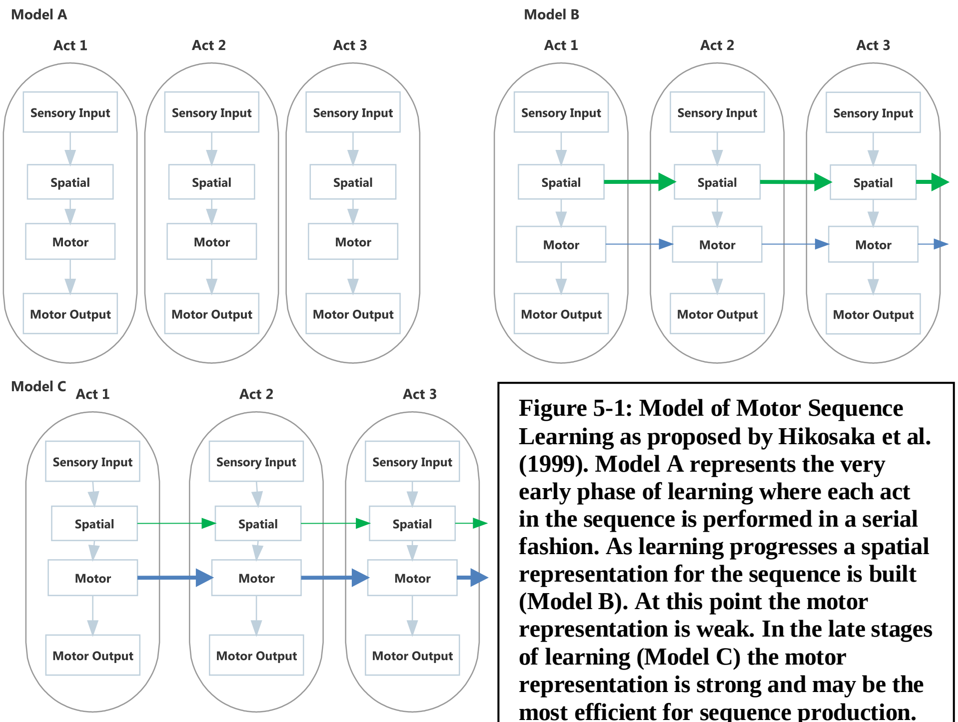


Figure 5-1: Model of Motor Sequence Learning as proposed by Hikosaka et al. (1999). Model A represents the very early phase of learning where each act in the sequence is performed in a serial fashion. As learning progresses a spatial representation for the sequence is built (Model B). At this point the motor representation is weak. In the late stages of learning (Model C) the motor representation is strong and may be the most efficient for sequence production. Model A, B &C adapted from Hikosaka et al. (1999) p. 466.

Hikosaka et al. 1999 cite unpublished observations by MK. Rand et al. of poor performance in monkeys with the untrained hand following extended long term practice of movement sequences with the trained hand. The sequences were “largely inaccessible” to the untrained hand (p.466). This was not the case early in practice trials. Hikosaka et al. suggest that early in practice a spatial (effector independent) representation of the sequence was available to both hands but that as practice progressed and the motor (effector dependent) representation is built up then transfer to the untrained hand was not facilitated. In support of Hikosaka et al.’s model Kovacs, Shea, and Muhlbauer (2009) found that a mirror transfer task (motor repesentation) required a longer timeframe to acquire than a visual-spatial transfer task (spatial representation). Three transfer conditions were tested: a retention test (practice arm), a spatial transfer test (unpracticed arm) and a mirror transfer test (unpracticed arm). The spatial transfer test was used to engage the fast developing effector independent component whereas it was expected that the slow developing effector dependent component would be difficult to engage in the mirror transfer test. Participants were trained with their right dominant arm and performed the transfer test with their left arm. The experiment was run over 1, 4 and 12 days – the logic being that the slower motor component may take longer than one day to develop. Kovacs et al.’s results showed better transfer on the visual-spatial transfer test regardless of the amount of practice (1, 4, or 12 days), interestingly transfer was symmetrical. At 12 days the mirror transfer test showed transfer from right to left hand but only when visual feedback was removed. The researchers noted that as participants became more practiced with the sequence that “chunking” occurred – participants appeared to break down the 14 arm movements into smaller subsequences (p.391). This finding indicates that the motor control system groups individual components into a number of sub-programs/representations. When portions of the sequence were changed there was a mismatch between the existing representation and the modified sequence. The transfer phase in the Taylor & Heilman study (1 trial) and in Study 1 of the current work (3 trials) were of short duration to avoid the possibility of a practice effect. If the development of a spatial representation is a relatively faster process than developing a motor representation, then performance at transfer phase (number of sequences completed) should be greater for a spatial transfer task.

Kleine and Verwey (2009) in a refinement of the Hikosaka et al. model proposed that sequence production may be under the influence of either one or both of the spatial and motor representations. The behavioural context determined which representation was ‘active’. Their proposed modification was based in part on experimental results that were consistent with the notion of simultaneous activation of spatial and motor representations in sequencing task. In one such experiment, Kleine and Verwey required participants to produce finger sequences (key presses) that corresponded to 7 digit spatial sequences (memorised prior to the experimental study). Participants used their left hand only in the training phase. A keyboard was placed either 90° to left or right of the participant’s body. This allowed for the left hand to be trained in both a mirror and spatial version of the sequence. Participants were cued by the first position of either sequence being displayed on the computer screen. Participants completed the seven digit sequence (e.g. n v b n v b c) with the left hand (index middle, ring and baby fingers). Terminal feedback was given in the form of the number of errors made during the sequence. On no error trials no feedback was given. In the transfer phase the participants practice the task on both sides of the body with both hands (mirror and spatial tasks). The results showed that participants were faster with the practiced than the un-practice hand which Kleine and Verwey suggest is evidence of the development of an effector dependent representation of the sequence. The results showed no effect for key position in the transfer phase for either the effector dependent (mirror) or independent (spatial) sequences. According to Kleine & Verwey this finding provides support for the notion that the two representations can be active simultaneously.

The results of my first study raised issues about the role of KR in different task types and require further investigation. The work of Hikosaka et al.(1999) , Kovacs et al. (2009) and Kleine & Verwey (2009) discussed in this chapter provide justification for a more detailed exploration of acquisition and transfer of skill in sequencing tasks. My second study

a) re-examines the effect of the provision or withholding of terminal KR on performance of the right hand in the training phase of a sequencing task
b) explores transfer of spatial and motor components of a sequencing task
c) tests some of the predictions of Kovacs et al. (2009) study with regard to chunking of sequence components.

The finger sequencing task employed in the first study was utilised again.

Study 2 included two feedback conditions (KR+, KR-) to investigate the results found for the right hand in the finger sequencing task (Study 1). Spatial and motor transfer where also investigated by engaging two transfer tasks (mirror and reverse of training sequence). Participants completed both a mirror and reverse transfer phase counterbalanced across training groups (mirror-reverse (MR) or reverse-mirror (RM)). For the mirror task the order of the finger sequence was index finger = 1, middle = 2 and ring finger = 3. For the reverse task, the spatial order of the sequence was reversed (ring finger = 1, middle finger remains the same (2) and index finger = 3). The transfer phase was counterbalanced across training groups (mirror-reverse (MR) or reverse-mirror (RM)). The logic behind this design was to allow for comparison of performance on a reverse (spatial) and mirror (motor) transfer task in the first instance. It also allowed for investigation of the effect of switching (disrupting the linkages) to the opposite transfer type on performance (number of correct sequences completed).

The aim of my second study was to investigate the results of Study 1 through re-examining the effect of the provision or withholding of terminal KR on performance of the right hand in the training phase. Introducing two types of transfer (mirror-reverse MR and reverse-mirror RM) allowed for a more detailed examination of intermanual transfer. It was expected that a different pattern of transfer might emerge when utilising a spatial transfer task. This could add to our understanding of the intermanual transfer in general but particularly in relation to the three models (Proficiency, Callosal Access and Cross Activation). It was hypothesised that performance (number of correct sequences completed) in the training phase would be greatest in the KR- condition. It was also hypothesised that performance in the reverse (spatial) transfer phase would be greater than that in the mirror (motor) transfer phase. Finally, in accordance with Kovacs et al.'s (2009) finding that participants chunk elements of the sequence as learning progresses (as evidenced by the disruption in performance when changes were made to their sequence), it was hypothesised that a decrease in performance would occur when switching between transfer types (mirror or spatial).

5.2 Methodology

Participants

Fifty right-handed participants (37 female) took part in this study which was conducted in the Psychology Laboratory at Mary Immaculate College. The average age of participants was 27.33 years (*SD* = 12.39). Participants were required to be free from hand or arm injuries/disability and visual/auditory problems. Participants were recruited through convenience sampling as the majority came from within the college community. Handedness was determined using the Edinburgh Handedness Inventory (see appendix A). Participants who scored between +40 and +100 (defined as right handed) on the inventory were included in the study. The participants received an information (see appendix H) and instruction (see appendix I) sheet outlining the study. Written consent was obtained from each participant (see appendix D). Ethical clearance was received from the Mary Immaculate College Ethics Committee (MIREC).

Design

This study used a 2x2 independent groups design. There were two independent variables: 1) Feedback condition (KR+ or KR-). Full feedback (KR+) included concurrent and terminal KR. KR- included concurrent KR, but eliminated terminal KR; and 2) transfer trial order: reverse then mirror (RM) or mirror then reverse (MR). Terminal KR (number of correct sequences completed) was provided in an auditory form by the experimenter at the end of each trial. Four right-hand trained and one left-hand trained groups took part in the study (number of hand trained groups un-balanced). The dependant variable measured at training and transfer phases was the number of correct/incorrect sequences completed by each participant.

Materials and Equipment

Participants completed two questionnaires: The ten item Edinburgh Handedness Inventory (Oldfield, 1971) and a short closing questionnaire created by the experimenter. The closing questionnaire included a question that asked participants if they had engaged in any type of strategy to remember the finger sequence. A copy of the closing questionnaire is contained in appendix (E).

Two Cedrus RB 830 series response pad with eight keys (2 unused) connected alternatively to a laptop (running Superlab 4.0 stimulus presentation software) recorded index, middle and ring finger flexion movements (keypresses) for a nine digit sequence. The keys to be used were marked as 1, 2 & 3. The sequence was as follows: (1 2 3 2 3 1 3 1 2).

Participants used their index (1), middle (2) and ring (3) finger of each hand to complete the sequence with either

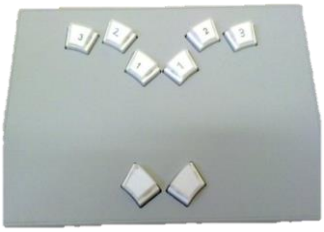


Figure 5-2: Cedrus RB 830 series response pad with the mirror transfer mapping for the right hand trained group. In the actual experiment the numbering on the keys for the trained hand were removed.

the dominant or non-dominant hand. Two keyboards were required so that the reverse and mirror sequences could be mapped out correctly for participants in the transfer phase (see figure 5-2 for example). The numbering was removed from the training keys to hide the true nature of the task from participants.

5.3 Procedure

Testing was carried out on a one-to-one basis in a quiet room in the Psychology Department Laboratory Suite at Mary Immaculate College. Participants were given the information and instructions sheets to read which explained the nature of the task to be undertaken. They were encouraged to ask any questions with regard to the procedure prior to signing the consent form. Participant's handedness was confirmed using the Edinburgh Handedness Inventory (Oldfield, 1971). Participants were randomly assigned to one of the two hand trained groups. Only one left hand (LH) trained group was used (LH RM+: full feedback, reverse-mirror); this facilitated comparison of left and right hand trained groups but avoided over complicating the design as one of the main focuses of the experiment was the effect of KR on the right hand during skills acquisition. The right hand trained groups were assigned to one of two feedback conditions (+/-) and within these to one of two transfer trials order (RM/MR). A schematic of the design is shown in table 5-1. Four right handed (RH) training groups (RH RM+, RH MR+, RH RM-, RH MR-) completed the finger sequencing task. There were two training blocks (3 trials per block) and two transfer blocks (3 trials per block). Each trial was of 30 seconds duration with a 10 second rest period between trials and a 20 second rest period between blocks. There was no pre-training trial with the untrained hand. In half of the transfer trials the untrained hand was required to produce the reverse sequence and a pre-training test with the mirror sequence could have interfered with transfer on the reverse sequence. The untrained hand's only exposure to the sequence was via the trained hand.

Table 5-1: A Schematic for Study 2 for the right hand (RH) and left hand (LH) trained groups with transfer order reverse-mirror (RM) or mirror-reverse (MR) in either the full (+) or reduced (-) feedback conditions.

Condition	**Training Phase Trained Hand**						**Transfer Phase Opposite Hand**			**Transfer Phase Opposite Hand**		
	Trial 1	**Trial 2**	**Trial 3**	**Trial 4**	**Trial 5**	**Trial 6**	**T/fer 1**	**T/fer 2**	**T/fer 3**	**T/fer 4**	**T/fer 5**	**T/fer 6**
RH RM**+**	**RH**	**RH**	**RH**	**RH**	**RH**	**RH**	RM	RM	RM	MR	MR	MR
RH MR**+**	**RH**	**RH**	**RH**	**RH**	**RH**	**RH**	MR	MR	MR	RM	RM	RM
LH RM**+**	**LH**	**LH**	**LH**	**LH**	**LH**	**LH**	RM	RM	RM	MR	MR	MR
RH RM-	**RH**	**RH**	**RH**	**RH**	**RH**	**RH**	RM	RM	RM	MR	MR	MR
RH MR-	**RH**	**RH**	**RH**	**RH**	**RH**	**RH**	MR	MR	MR	RM	RM	RM

In the first study the untrained hand did have exposure to the sequence pre-training which may have confounded the results at transfer stage to a degree. The disadvantage of no pre-training trial however was that only a between groups analysis could be carried out. The ability to investigate both spatial and mirror transfer outweighed the loss of a within groups comparison of pre and post training performance. Participants were shown the sequence and allowed using a template of the response pad, but not the response pad itself (haptic feedback withheld) to try out the sequence with the training hand only (see appendix F). Once participants were familiar with the sequence the template was removed. They placed their index, middle and ring finger on the 3 designated keys (right or left) to be used. Six trials were completed with the training hand. In the KR+ condition the number of correct sequences completed was reported verbally to the participants. Participants swapped to the first transfer phase (R/M) and completed 3 trials. The keyboard was then changed to the other transfer condition and participants were told to look at the direction of the keys before beginning the 3 final transfer trials. The total numbers of correct and incorrect key presses were recorded for each participant.

On completion of the task the experimenter completed the closing questionnaire with the participants. The experimenter asked questions as to whether participants had used a strategy to remember the sequence and if they had use one to describe it. The participants were also asked if they played a musical instrument, had taken typing lessons, or played Xbox or PlayStation. Participants were then given a debriefing statement and thanked for their participation (see appendix G).

Data Analysis

The data from one participant was removed due to their inability to memorise the numerical sequence.

5.4 Results

Closing Questionnaire

Analysis of the descriptive data from the closing questionnaire revealed that 17 (35%) participants played a musical instrument but none were professional musicians. Thirteen (27%) participants had taken formal typing lessons and seven (14%) indicated that they played video games on a regular basis. When asked if they used any strategy to remember the sequence 29 participants (59%) reported using verbalisation alone, 5 (10%) reported using finger position and 8(16%) reported using both verbalisation and finger position to remember the sequence. Four (8%) participants reported using a rhythm or verbalisation and rhythm to remember the sequence and the remaining 3(6%) participants reported using visualisation, finger direction or no strategy respectively to remember the sequence.

Training Phase

Between Conditions

The average numbers of correct sequences per trial were calculated for each condition (RH MR+, RH RM+, RH MR-, RH RM-, LH RM+ in the training phase (trial 1 – 6). The average number of correct sequences per trial at trial 1 for each condition was: RH MR+ (*M*=

6.8, *SD*= 3.2); RH RM+ (*M* = 6.9, *SD*= 2.7); RH MR- (*M* = 6.3, *SD* = 3.2); RH RM- (*M* = 5.7, *SD* = 1.2) and LH RM+ (*M* = 6.4, *SD* = 2.6). There were performance increases for all groups across the 6 training trials as indicated by the greater number of sequences completed in trial 6: RH MR+(*M*= 8.7, *SD*= 1.8), RH RM+ (*M* = 8.4, *SD*= 3.2), RH MR- (*M* = 8.6, *SD* = 1.8), RH RM- (*M* = 6.9, *SD* = 1.3) and LH RM+ (*M* = 8.6, *SD* = 2.3) The RH RM- group had the lowest average correct sequences per trial at both trial 1 and trial 6. The data is presented graphically in figure 5-3.

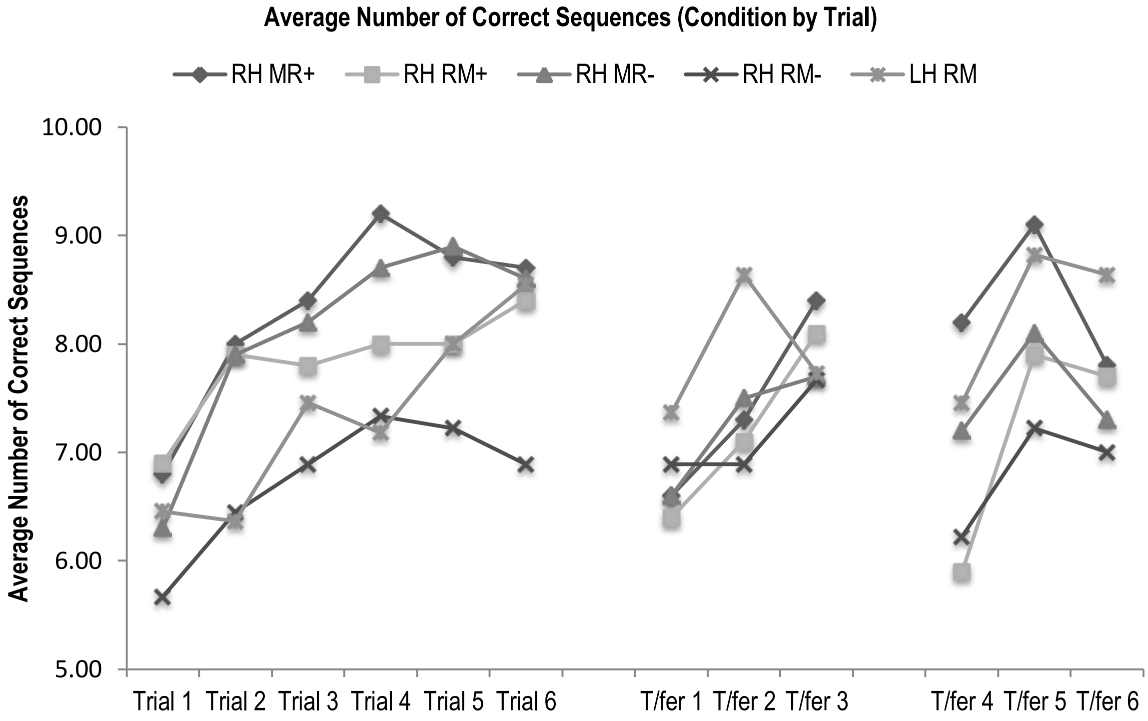


Figure 5-3: The average number of sequences for each hand trained group at training and transfer stages is displayed. Note that the data in the transfer trials 1-6 represents the opposite untrained hand.

The data was analysed using a mixed design ANOVA (Analysis of Variance). All effects are reported as significant at p<.05. Performance was assessed within conditions (training trials 1 to 6) and between feedback conditions (+/-). There was a significant effect for training trials *F* (5, 44) = 10.91, *p* <.00. Within group contrasts indicated that when each trial 2 -6 was compared to trial 1 the difference was statistically significant, this culminated in a significant increase in the number of sequences completed at trial 6 compared to trial 1 *F* (1,44) = 23.83, r = .59. There was no significant effect for feedback condition (+/-).

Transfer Phase

Between Hands Analysis

A between hands comparison for the RH RM+ and LH RM+ groups (training trial 6 (T.6) vs. transfer trial 1 (TF.1)) was conducted to investigate the effect of training on the opposite un-trained hand when completing the reversed sequence at TF.1. Figure 5-4 shows that both the right (RH) and left hand (LH) groups completed a similar number of correct sequences at training T.6 (RH *M* = 8.4, *SD* = 3.2; LH *M* = 8.6, *SD* = 2.3). The RH & LH values for number of correct sequences completed for both hands at transfer TF.1 were (RH *M* = 7.4, *SD* = 2.8; LH *M* = 6.4, *SD* = 2.7).

A series of non-parametric independent T-tests (Mann Whitney U) were conducted following violation of tests for normality. The results indicated that there was no significant difference in the number of correct sequences completed by the right and left hand when comparing their performance at training T.6. and transfer TF.1. When each hand was compared (T.6 versus transfer TF.1) there was no significant difference in the number of correct sequences completed for the right hand when trained itself or when tested following opposite hand training. The result for the left hand was nearing significance *z* (9) = -1.718, *p* = .09.

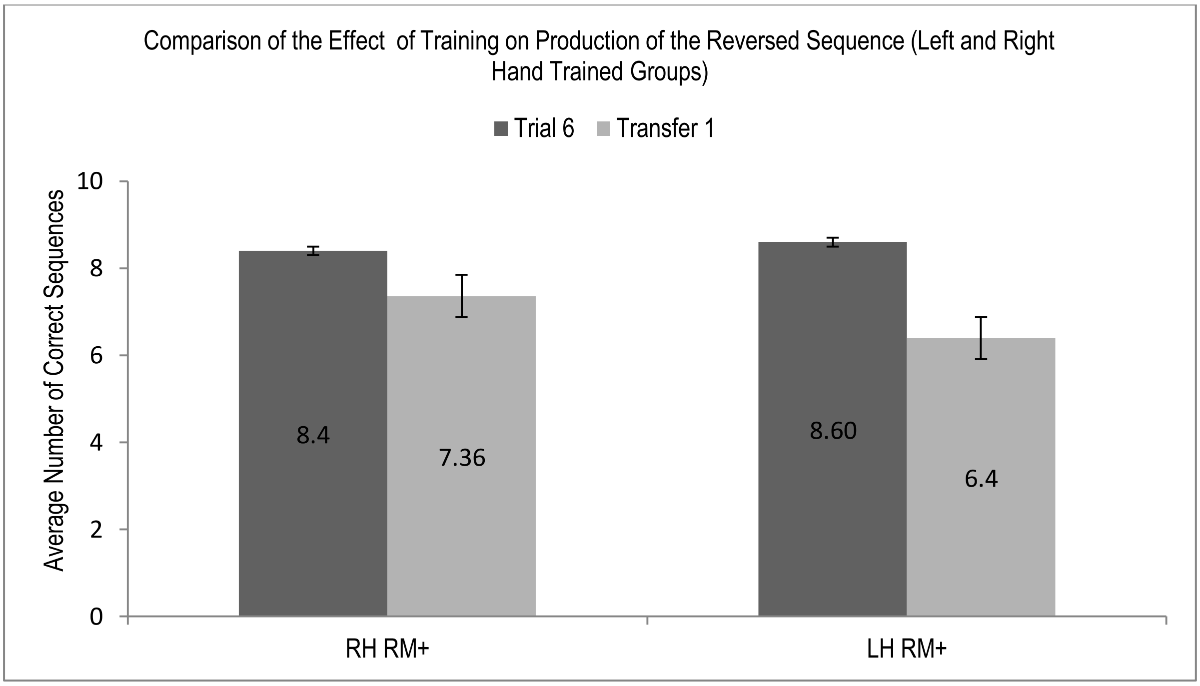


Figure 5-4: The average number of correct sequences for each hand trained group is compared to opposite hand training when competing the reversed sequence. Error Bars = 1 Standard Deviation. The data has been switched so that adjacent bars represent the same hand. (RH RM+ T.6 *n*=10, RH RM+ TF.1 *n*=10, LH RM+ T.6 *n*=10, LH RM+ TF.1 *n*=10).

Within Groups Analysis

The data from the transfer phase was analysed in three ways: performance on the first trial of each block (Transfer 1 vs. Transfer 4), the last trial in b1ock 1 versus the first trial of block 2 (Transfer 3 vs. Transfer 4) and the final trial in each block (Transfer 3 vs. Transfer 6). There were performance gains for each condition in transfer phase 1, for example the RH MR+ group completed more correct sequences in transfer trial 3 than transfer trial 1(Transfer 1 *M* = 6.6, *SD* = 2.2.; Transfer 3 *M* = 8.4, *SD* = 2.7). The figures for the remaining conditions are displayed in table 5-2. The results were a little more mixed in the second transfer block with 3 conditions (RH RM+, RH RM- and LH RM+) showing increases in performance but the RH MR+ and RH MR- decreasing slightly or remaining static respectively. When changing between transfer blocks there was a decrease in performance for the RH RM+ (Transfer 3 *M* = 8.1, *SD* = 2.5); Transfer 4 *M* = 5.9, *SD* = 1.9) and RH RM- (Transfer 3 *M* = 7.6, *SD* = 2.0); Transfer 4 *M* = 6.2, *SD* = 1.9) groups.

Wilcoxon Signed Rank tests were conducted to examine performance at the beginning of each block (Transfer 1 vs. Transfer 4), switching between blocks (Transfer 3 vs. Transfer 4) and end of each block (Transfer 3 vs. Transfer 6). The results showed that performance on the first trial of block 2 was significantly higher than on the first trial of block 1 for the RHMR+ group (Transfer 1 vs. Transfer 4) *Z* (19) = -2.2, *p* = .02. The results for the other groups were non-significant. Both the RH RM+ (Z (19) = -2.4, p = .02) and RH RM- group's (Z (18) = -2.4, p = .02) performance decreased significantly when changing from the reverse to the mirror sequence (Transfer 3 vs. Transfer 4). Analysis of performance at the end of each block revealed no significant difference in performance (Transfer 3 vs. Transfer 6). The data for the three comparisons are presented graphically in figure 5-5.

Table 5-2: The Average Number of Correct Sequences Completed By Condition Transfer Phase 1 & 2.

		Transfer Phase 1			**Transfer Phase 2**		
Training Condition	**Transfer Hand**	**Transfer 1**	**Transfer 2**	**Transfer 3**	**Transfer 4**	**Transfer 5**	**Transfer 6**
RH MR+ *n* = 10	Left	6.6 (2.2)	7.3 (3.1)	8.4 (2.7)	8.2 (1.8)	9.1(1.4)	7.8 (2.0)
RH RM+ *n* = 10	Left	6.4 (2.7)	7.1(1.8)	8.1 (2.5)	5.9 (1.9)	7.9 (2.2)	7.7 (1.5)
RH MR- *n* =10	Left	6.6 (2.7)	7.5 (3.5)	7.7 (2.6)	7.2 (2.7)	8.1 (2.6)	7.3 (2.4)
RH RM- *n* = 9	Left	6.9 (1.6)	6.9 (2.5)	7.6 (2.0)	6.2 (1.9)	7.2 (1.9)	7.0 (2.3)
LH RM+ *n* = 10	Right	7.1 (2.4)	8.4 (1.6)	7.7 (1.6)	7.7 (2.6)	9.1 (3.2)	8.5 (3.1)

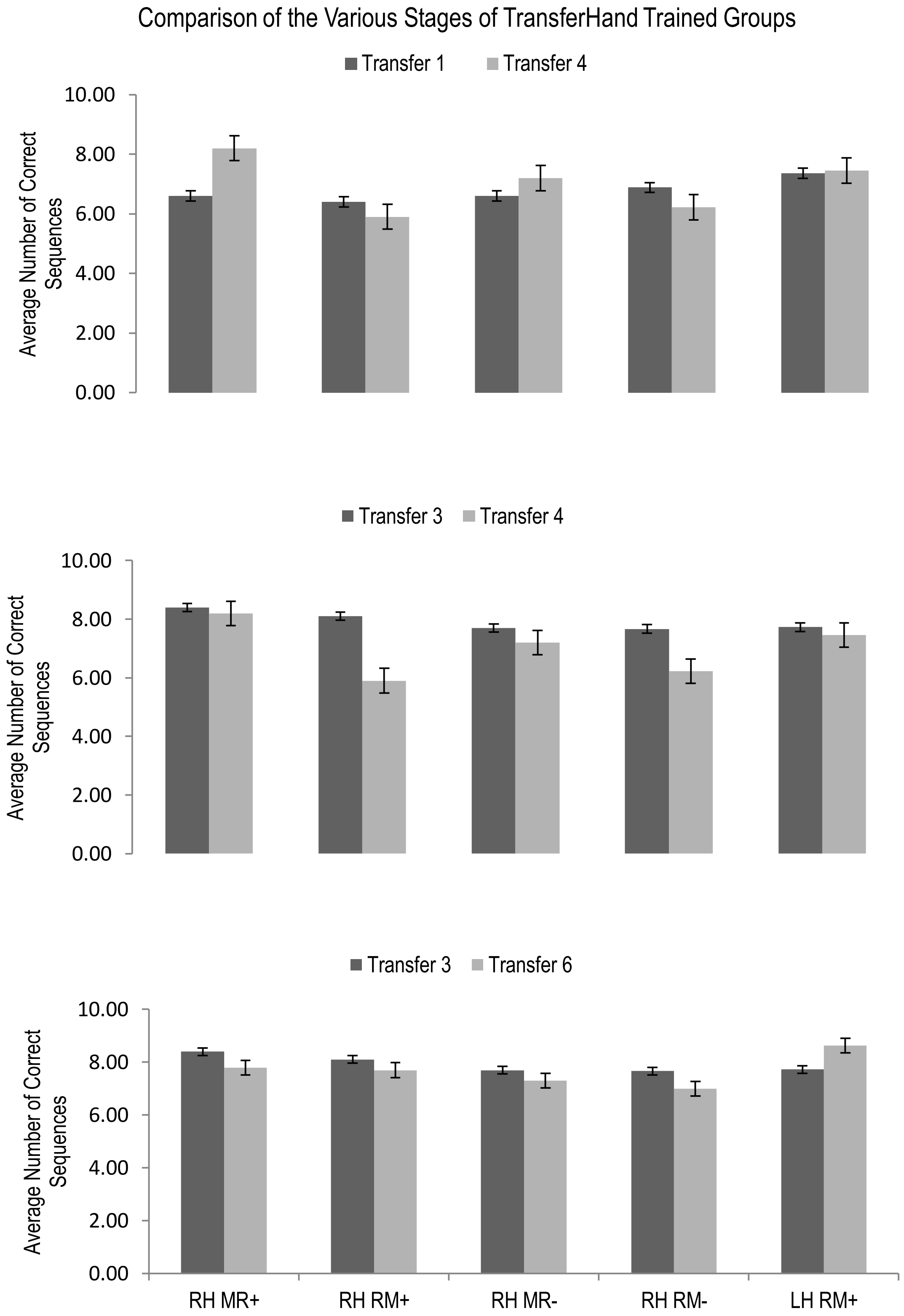


Figure 5-5: Comparison of (Transfer 1 vs. Transfer 4, Transfer 3 vs. Transfer 4 and Transfer 3 vs. Transfer 6). (RH MR+ *n*=10, RH RM+ *n*=10, RH MR- *n*=10, RH RM- *n*=9, LH RM+ *n*=10).

Analysis of Relative Errors

The relative error RE ((total keypresses-correct keypresses)/total keypresses) was calculated for each participant by trial. The average RE for each phase (training, transfer block 1 and block 2) was then calculated. The data is presented for the RM and MR transfer groups separately (see figure 5-6). The RE for the right and left hand trained groups in the RM condition was RHRM+ (11%), RHRM- (6%) and LHRM+ (10%). The RE for both RHRM groups (left hand transfer) increased over the course of the two transfer blocks (RHRM+ =14%, RHRM- = 10%). Conversely the RE for the right hand transfer group (LHRM+ = 5%) decreased. In the MR groups (left hand transfer) the RE decreased from training to the reverse transfer in the MR+ group (Training RE = 12%, Reverse RE = 10). In the MR group the reverse occurred (Training RE = 9%, Reverse = 15%).

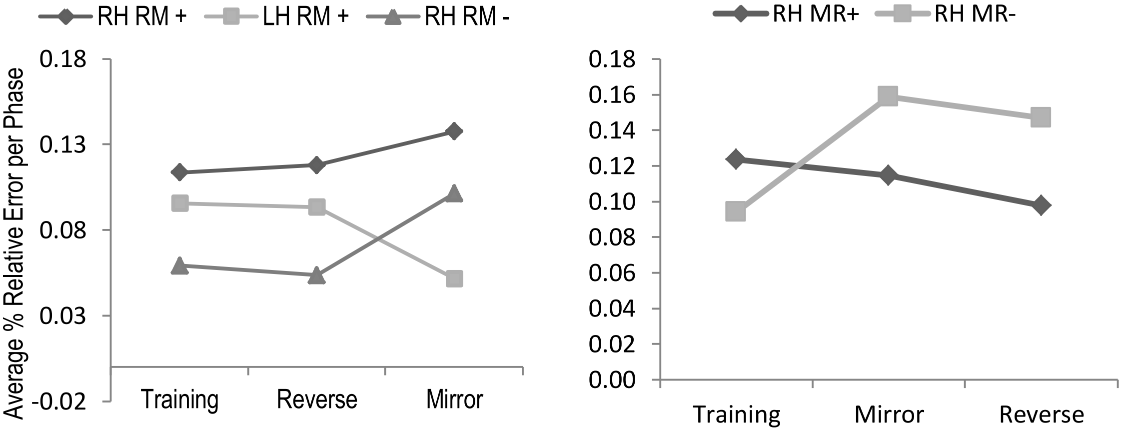


Figure 5-6: The Relative Error for each Condition (RM+ MR-) at training and transfer block 1&2. The relative error was calculated as follows (total key presses - correct key presses)/total keypresses. (RH MR+ *n*=10, RH RM- *n*=10, RH MR- *n*=10, RH RM- *n*=9, LH RM+ *n*=10).

5.5 Discussion

Training Phase

The significant increase in participant performance levels observed across training trials is indicative that learning did occur (supportive of Study 1 – finger sequencing task). On the basis of the results of Study 1, I had predicted superior levels of performance in the

KR- condition over that for the KR+ condition. The data from Study 2 did not support this hypothesis. Unlike Study 1 (where participants in the KR- condition completed the greater number of sequences) there was no significant difference in performance for these two groups (KR+/KR-) in Study 2. The RH RM- group produced the poorest performance in each trial of the training phase. They also produced the lowest RE of all groups. It may be that this particular group was more tentative than the others, but this doesn't detract from the fact that the results of this study did not show the same pattern of performance as the first study. The results from the current study suggest that terminal KR had neither a positive nor negative impact upon the overall performance of the groups. Van Vliet and Wulf (2006) contend that terminal verbal feedback may be redundant when feedback is integral to the task (e.g. visual feedback in an anticipatory timing task). Participants in the current study reported using verbalisation (59%) and other strategies to remember the sequence. Therefore terminal KR may not have provided either a guiding or motivational effect (Salmoni et al. 1984)

The number of sequences completed by the left hand group improved steadily over the 6 training trials. By the end of training there was no significant difference between left hand and right hand groups. Taylor and Heilman (1980) observed that males produced more sequences with their left hand in both conditions (Vision+/Vision-) of their experiment. Females conversely produced more sequences with the right hand. In the current experiment there were more females than males but the results indicate that the left hand was as capable of learning and producing the sequence as was the right hand. This finding supports the results from the first study which reported that the left hand completed slightly more sequences than the right hand in the full feedback condition. Laszlo et al. (1970) found that performance of the left hand in the finger tapping task was superior to the right hand when feedback was removed. It appears that in a finger sequencing task where visual feedback may be an important source of information that the provision of such feedback may level the playing field for both hands.

Transfer Phase

Introducing two types of transfer (MR and RM) allowed for a more detailed examination of intermanual transfer. A comparison of the right and left hands at the transfer phase (RM+) (Transfer 1) indicates that the left hand performed less correct sequences following right hand training than did the right hand following left hand training. Although this difference failed to reach significance, it is inconsistent with the data from the training phase where the left hand performed as equally well as the right hand. One explanation might be that in this instance, the left hand could not access/use the motor program or STD created by the right hand to the same degree as the right hand could the the left hand motor program and STD. Such an explanation is consistent with the predictions of the Callosal Access model. The reduction in the number of sequences completed by all groups from training trial 6 to transfer trial 1 is in keeping with Kleine & Verwey (2009). These authors observed superior performance of the practised hand over the unpractised hand. They attribute this finding to the practised hand utilising the effector dependent motor representation in the later stages of practice. It points to the unpracticed hand inability to utilise the motor representation to the same degree as the trained hand. The fact that the transfer hand for all groups was able to produce the sequence to a relatively high performance level suggests that the spatial representation of the sequence may still have been available to the transfer hand. This notion is supported by the significant increase in performance level on trial 1 of block 2 (Transfer 4) compared with trial 1 of block 1 (Transfer 1) for the RHMR+ (left hand) group when switching from the mirror to reverse sequence. The relative error (RE) for the MR+ showed a slight decrease also. The increase in performance in RHMR+ group might indicate that the spatial representation (reverse) of the sequence is effector independent. Equally there was a significant decrease in performance for the RM groups (left hand) with a slight increase in the RE also when switching from reverse to mirror transfer indicating that the motor presentation might be effector dependent. Interestingly there was no difference in performance levels for the right hand when switching from the reverse to the mirror sequence.

At the end of the second transfer block there was no significant difference in performance between all transfer groups. The results do not support Kovacs et al's finding of little improvement on a mirror transfer task involving an arm sequence. It may be as a result of the different effector system employed in their study (arms vs. fingers) or it may result from the presentation of the task. In the current study participants memorised the sequence but in the Kovacs et al. study the sequences unfolded one movement at a time through cueing the next position with a light. This may have resulted in participants becoming reliant on the external cues and not "bedding down" a motor representation of the movement. Kleine and Verwey (2009) argue that sequences can be "learned verbally or by responding to cues" (p.693). They noted no significant difference in performance levels between spatial and motor presentations of their task in the transfer phase. It may be that task presentation (cued or verbal) has an effect on the construction of a motor representation of the task. The findings from the current study also indicate that in terms of disruption to the linkages between chunks of the sequence it was only when moving from reverse to mirror that this disruption occurred and only for the left hand. This again supports the notion of the spatial representation of the sequence being effector independent and available in parallel with the motor representation.

5.6 Summary

This study set out to re-examine the effect of terminal KR (+/-) at the acquisition phase for the right hand (RH). The results showed that KR neither hindered nor enhanced performance for the RH groups and may have been superfluous to sequence acquisition and performance. The performance of the left hand group (LH RM+) equalled that of the right hand groups at the end of training which is inconsistent with any of the models of intermanual transfer discussed in this thesis. All transfer groups performed at a similar level for the first transfer trial (although at a performance level less than that of the trained hand) which suggests that the spatial representation of the sequence was available late in practice and so may operate in parallel to the motor representation. The groups switching from reverse to the mirror sequence experienced the most disruption to performance. This points to the spatial representation being more resilient than the motor representation but nevertheless both groups recovered in subsequent trials. The conflicting findings from the Kovac et al. study in which they found spatial transfer to be better than motor transfer (which only occurred on day 12 and then when vision was occluded) may be related to the type of task used (cued response). This will be examined in more detail in Chapter 6.

Chapter 6

Study 3: Investigating the Effect of Task Presentation in Intermanual Transfer

6.1 Introduction

Chapter 5 (Study 2) examined the relative importance of the provision or withholding of terminal KR when participants engage in verbal strategies. The effect of dual representation (motor and spatial) on intermanual transfer was also investigated. Study 2 manipulated terminal knowledge of results (KR+/-) at the acquisition phase for the Right Hand (RH). The results indicated that terminal KR neither hindered nor enhanced performance for the RH groups. This result raises questions as to the salience of terminal feedback in a finger sequencing task. Van Vliet and Wolf (2006) have argued that terminal KR may be redundant in a task where a wealth of information can be gained from other internal sources. This certainly appeared to be the case for Study 2 where only terminal KR was manipulated. Participants could avail of movement- generated concurrent intrinsic feedback. In addition, 75% of participants reported the use of verbal strategies. The specificity of practice hypothesis (Trembley & Proteau, 1998; Trembley & Proteau, 2001; Trembley Welsh & Elliot, 2001) maintains that early in practice the learner ‘decides’ the relative importance (salience) of available feedback sources, then focusses on the feedback from the most salient source. In the case of the key sequencing task (Study 1 and 2) where the sequence was memorised by the participants prior to completing the task, the most important source of knowledge may have been the verbal strategies employed to remember the sequence. The use of verbal strategies may have negated the need for terminal KR. Taylor and Heilman (1980) noted that female participants displayed symmetrical transfer for a finger sequencing task. They suggested that verbal strategies may have interfered with left hemisphere processing in female participants. Taylor and Heilman hypothesised that females may have engaged in verbal strategies to remember the sequence which interfered with left hemisphere processing. Research described in Chapter 3 reported that verbal interference with motor task execution affected both males and females (Lomas & Kimura, 1976; McGowan & Duka, 2000). Is it the case that Participants who use verbal strategies in the acquisition of a finger sequencing task in some sense 'demote' the salience of other forms of feedback? Such an explanation could account for observations about the seeming lack of importance of terminal KR in the acquisition of the finger sequence from my first two studies. Participants (male and female) in both Study 1 and Study 2 reported the use of verbal strategies and this may have impeded their use of other available feedback (e.g. both concurrent and terminal KR) during the acquisition phase.

Kleine and Verwey (2009) state that sequences can be learned verbally (overtly) or by responding to cues (covertly) (p.693). An example of a task that includes both covert and overt sequencing is that of a cash dispensing machine. When an individual withdraws cash from the machine he/she performs a finger movement sequence some of which is covert (menu driven – cued response) and some of which is overt (entering their password - verbal). Covert sequences can be thought of as those in which the participant is unaware of steps required to complete the task. It is only over successive movements that they begin to make the connection. At this point participants can anticipate the next movement and a reduction in reaction time for the task is observed. Once learned a covert sequence will become overt. This differs from implicit learning where a repeating pattern is hidden within a series of stimuli and the learner is largely unaware that they have acquired the pattern (Bennett, Howard & Howard, 2007). In the studies employed to investigate the three models of intermanual transfer (Proficiency, Callosal Access & Cross Activation), the tasks were overt in nature. The finger tapping task (Proficiency Model) involved a number of discrete movements with the index finger, participants in the finger sequencing task (Callosal Access Model) practiced the key sequence with both hands prior to completing the task, and participants in the inverted reverse printing task (Cross Activation Model) were informed of which letters of the alphabet to print. The tasks I employed in my first two studies were also overt in nature (finger tapping and a memorised nine digit sequence). My next study incorporated an attempt to reduce the Participants' reliance on verbal strategies in order to explore the impact on the relative importance of KR and verbal strategies.

A major focus of Study 2 was the effect of employing a mirror or reverse sequence at the transfer phase on the performance levels for each hand. There is considerable support for the idea that two representations may be formed during the acquisition of motor skills: a fast developing effector-independent spatial representation and a slower developing effector-dependent representation (Hikosaka, Nakahara, Rand, Sakai, Lu, Nakamara et al. 1999; Kleine &Verwey, 2009; Kovacs, Shea & Muhlbauer, 2009). Kleine & Verwey (2009) suggest that both these representations are formed independently but simultaneously and the use of one or the other is driven by the behavioural context. Kleine and Verwey asked participants to produce a pre-learned sequence of key presses with the left hand (mirror and spatial). They then tested both hands on mirror and spatial versions of the task. Results from their study indicated that there was no significant effect for key positions (mirror and spatial) in the transfer phase which supports the idea that the spatial representation was available in the transfer phase. However they only trained the left hand of participants with the hand placed at the ipsilateral side for half the participants and contralateral side for the other half. We do not know what effect right hand training would have on subsequent transfer to the left hand, and so we do not have a complete picture of mirror and spatial transfer. In my second study all transfer groups completed a similar number of correct sequences at Transfer 1 which supported the findings from Kleine and Verwey's study. The groups switching from reverse to the mirror sequence in block 2 of the transfer phase experienced the most disruption to performance, this may be indicative of the effector dependent nature of the motor representation. Performance increased for the groups switching from mirror to reverse. This finding is also consistent with the notion that the spatial representation is available late in practice. Study 2 contained only one left hand trained group with subsequent transfer to the right hand in the reverse mirror transfer condition. Although the inclusion of one left hand trained group allowed for some comparison of right and left hand transfer, it did not include a mirror to reverse transfer group for the right hand. I addressed this issue in Study 3 which included both a mirror reverse (MR) and reverse mirror (RM) transfer phase for left and right hand trained groups.

In Study 3 I wished to address the mixed and sometimes conflicting data, from both my own studies and that of preceding research with regard to acquisition (particularly for right hand trained groups) and transfer (mirror and reverse) in right and left hand transfer groups using a covert sequencing task. The covert element of the task was introduced to address the questions raised earlier in this chapter on the impact of the use of verbal strategies on participants' use of other feedback sources such as KR.

It was hypothesised that acquiring the sequence in a covert manner should reduce the importance of verbal strategies relative to KR. If KR becomes more salient as a result, and the right hand can make greater use of the available feedback (as hypothesised by the Proficiency Model), it may increase the accuracy of representation and thus lead to improved performance for the right hand trained groups. Both my second study and that of Kleine and Verwey (2009) partially examined the effect of mirror and spatial transfer. My study did not include transfer to the right hand in the mirror-spatial (MR) condition. Kleine and Verwey included only a left hand trained group. To provide a more complete picture of the effect of motor and spatial transfer on intermanual transfer, both right and left hand trained groups, counterbalanced across transfer order (mirror-reverse, reverse mirror) were included. Participants acquired the sequence covertly through trial and error with the fingers (index, middle and ring) of each hand. It was postulated that learning the task through the engagement of the fingers in this manner would lead to a strengthening of the effector dependent motor representation. According to Kleine & Verwey (2009) the motor representation does not transfer well because of its effector dependent nature therefore it was hypothesised that task presentation (covert) should lead to less transfer in the mirror (motor) transfer groups.

6.2 Methodology

Participants

Forty five right-handed participants (31 females) took part in this study. Twenty five participants were tested at the Sensory Motor Neuroscience (SyMoN) Laboratory, University of Birmingham and twenty participants were tested at the Psychology Laboratory at Mary Immaculate College. The average age of participants was 24.33 years (*SD* = 8.75). Handedness was determined using the Edinburgh Handedness Inventory (see appendix A). Participants who scored between +40 and +100 (defined as right handed) on the inventory were included in the study. Participants were required to be free from hand or arm injuries/disability and visual/auditory problems. Participants were recruited through convenience sampling as the majority came from within the two college communities (University of Birmingham and Mary Immaculate College). Participants at the University of Birmingham received course credits for taking part in the study. Participation at Mary Immaculate College was on a voluntary basis. Individuals who had taken part in Study 1 and 2 at Mary Immaculate College were excluded from participation in the current study. Written consent was obtained from each participant (see Appendix J). Ethical clearance was received from the Mary Immaculate College Ethics Committee (MIREC). Ethical clearance from the University of Birmingham was covered under the SyMoN Laboratory Ethics Licence.

Design

The experiment was a between groups design: the 1st independent variable was hand trained (right hand trained (RH), left hand trained (LH)). The 2nd independent variable was transfer order: mirror then reversed (MR), reversed then mirror (RM). The dependent variable measured at training and transfer phases was % of correct keypresses per trial (100% Correct Key presses = 36 per trial).

Material and Equipment

Figure 6-1: Cedrus RB 830 series response pad in which the keys have been left blank.

A Cedrus RB 830 series response pad with eight keys (2 unused) connected to the laptop (running Superlab 4.0 stimulus presentation software) recorded index, middle and ring finger flexion movement (keypresses) for a nine digit sequence.
The keys to be used were marked as 1, 2 & 3.
The sequence was as follows: (1 2 3 2 3 1 3 1 2).
Participants used their index (1), middle (2) and ring (3) finger of each hand to complete the sequence with either the dominant or non-dominant hand. The keys were blank so

that participants would not have any indication of the numerical pattern required to accomplish the task. Participants used their index (1), middle (2) and ring (3) finger to "fill" the glass of water. 36 correct keys (9 digit sequence x 4) were required to fill the glass. The sequence was the same as in Study 1 and 2: 1 2 3 2 3 1 3 1 2. The sequence was repeated 4 times in each trial. Adobe Illustrator CS5 was used to create 72 fills (36 correct and 36 incorrect) (see figure 6.2 for an example). Each correct key press added a blue segment(1/36th) to the glass, an incorrect key press added a red segment (1/36) which had to

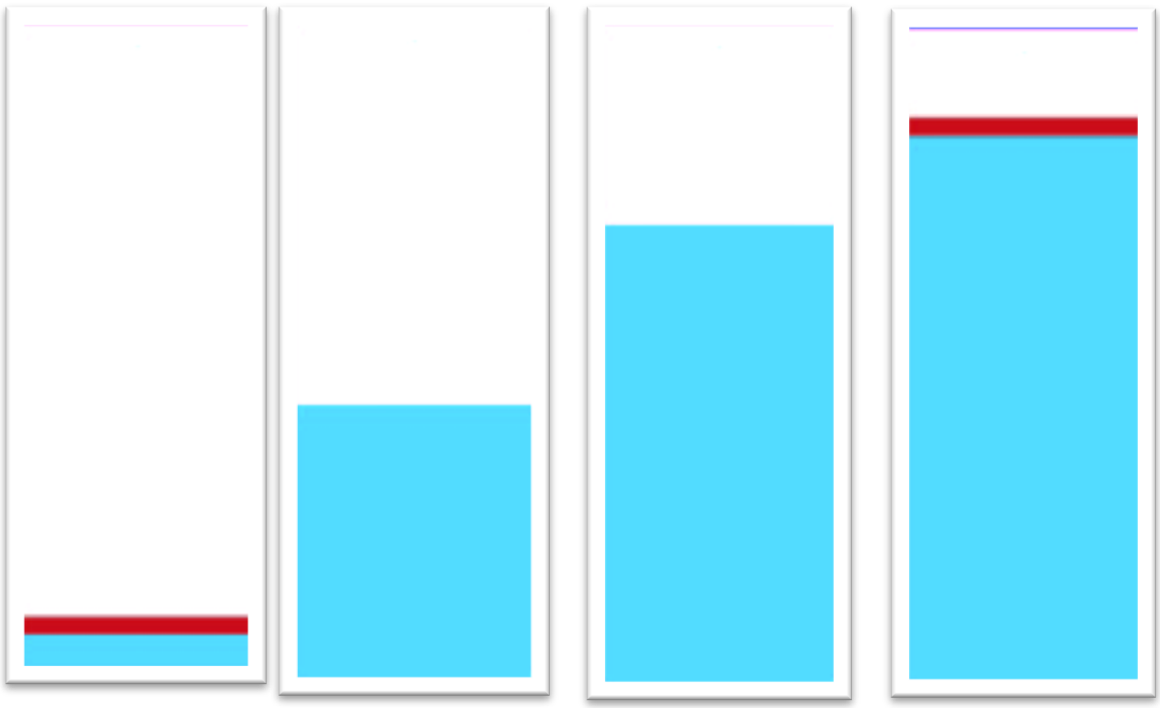
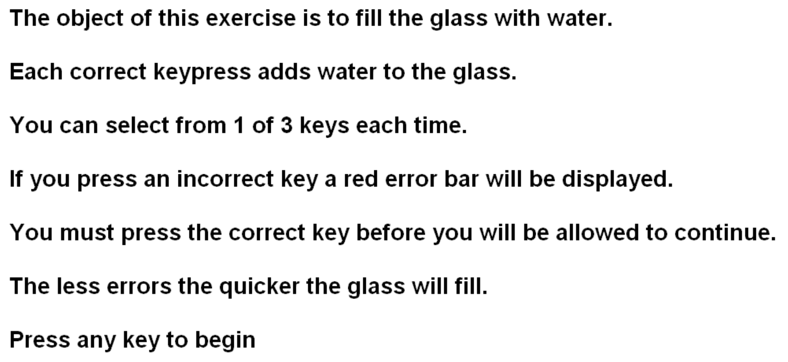


Figure 6-2: Example of 4 of a possible 72 fills (36 correct and 36 incorrect) required to "fill" a notional glass of water. The red bars indicate where the participant has made an error. The participant must correct the error (select the correct finger/key) to turn the bar from red to blue before progressing to the next segment.

be corrected (changed to blue) by selecting the correct key. Matlab ver. 2012A was used to produce a graph of each participant's progress during the training phase.

6.3 Procedure

Testing was carried out on a one-to-one basis in quiet rooms at the SyMoN Laboratory, University of Birmingham or at the Psychology Department Laboratory Suite at Mary Immaculate College. The Participant's handedness was confirmed using the Edinburgh Handedness Inventory (Oldfield, 1971). Participants were randomly assigned to one of the two hand trained groups (RH trained/LH trained) and within these groups to one of two transfer conditions (mirror-reverse (MR) or reverse-mirror (RM)). Participants were seated at a table containing the response pad. Participants were asked to place their index, middle, and ring fingers on either the left or right side keys depending on the training condition. Participants were told that the task involved attempting to "fill a glass of water" by choosing the correct key from one of three using their index, middle or ring finger. They were informed that no two successive keys were the same. They were then given the following on screen instructions.



The object of this exercise is to fill the glass with water.

Each correct keypress adds water to the glass.

You can select from 1 of 3 keys each time.

If you press an incorrect key a red error bar will be displayed.

You must press the correct key before you will be allowed to continue.

The less errors the quicker the glass will fill.

Press any key to begin

Each “fill” required the participants to produce the nine digit sequence (123 231 312) four times in order to complete the trial. Participants were not made aware of the sequence or the repeating nature of it. Participants completed as many of the 24 possible trials (3 blocks x 8 trials) as required for them to reach a threshold of 85% correct key presses. A threshold of 85% was obtained by participants pressing 5 or less incorrect keys over the course of a trial (36 correct keys = 100% accuracy). It was felt that at 5 key press errors that the participant had acquired knowledge of the sequence but that it was not over-learned. There were no time constraints placed on participants. When a participant reached the threshold on two consecutive trials the training phase ended. In the initial phase of data collection, a number of participants failed to achieve the threshold (85% correct key presses). It was decided to introduce some signposting prior to blocks 2 and 3. If a participant did not reached the 85% threshold by the end of the first block they were told at the beginning of the second block that the pattern repeated (but not when or how many times). If participants failed to reach the threshold by the end of block 2 then they were told that the pattern repeated 4 times (every 9 digits). The introduction of signposting met with partial success. Some participants failed to reach the required threshold even when provided with signposting. However their subsequent performance in the transfer phase suggested that some learning had occurred as their transfer rates were at least as good as or better than some participants who had reached the threshold. Therefore their data was included for statistical analysis. Each Participant's progress was monitored after each block of trials using Matlab. Participants data was sampled every 72 key presses to calculate the % Correct key presses across the training block (8 trials). The number of correct key presses was plotted against the total number of key presses also. An example of the output for one participant is contained in figure (6-3).

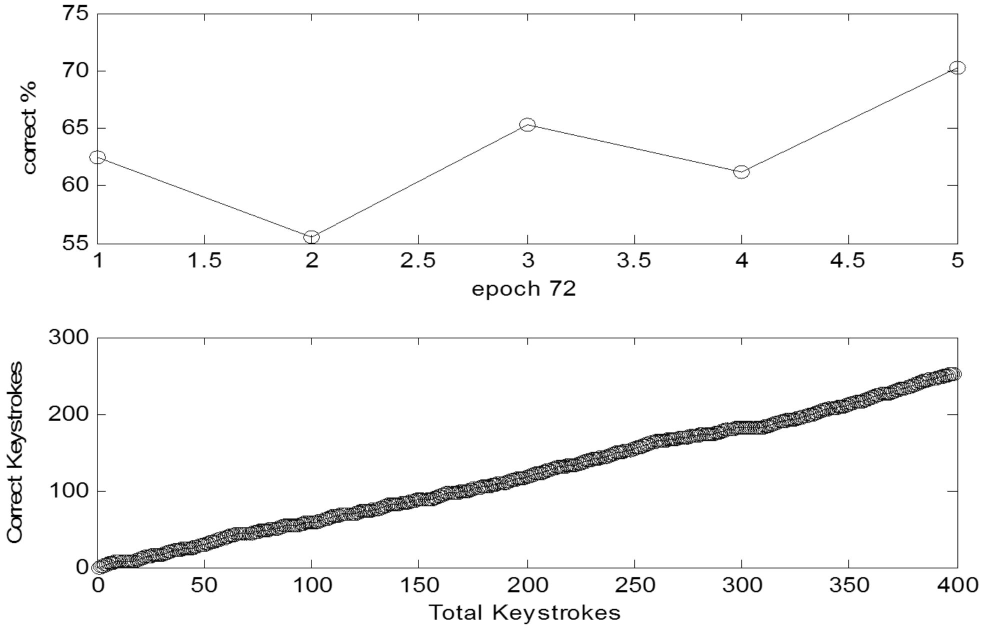


Figure 6-3: The output from Matlab shows the % correct key presses (top) and number of correct key presses (bottom) for one participant (block 1 (8 trials) of the training phase). The Matlab script is courtesy of Dr. Satoshi Endo, SyMoN Laboratory, University of Birmingham.

Participants then transferred to the untrained hand for the transfer phase. The procedure was the same as in training phase except that participants completed 2 blocks of four trials in either the MR or RM condition. Participants were given the same on screen instructions at the beginning of the transfer phase as that of the training phase. Many participants asked whether it was the same sequence to which the experimenter replied that they must see for themselves.

6.4 Results

Training Phase

A simple moving average (SMA) was used to track performance of the right (n = 22) and left (n = 23) hand trained groups during the training phase. The SMA was calculated using the average of 3 trials (t) (t, t-1, and t-2). There were 24 trials (3 blocks x 8 trials). Participants were deemed to have learned the sequence when they recorded correct scores of 85% on two successive trials. At this point the training phase was terminated. The participant's final score was recorded for any remaining trials in the training phase which he/she was not required to complete. For example, if a participant had reached or exceeded the threshold by trial six block 2 (e.g. 90%), the participants final score (90%) would be recorded for each of the remaining trials (2 in block 2 and 8 in block 3). Figure 6-4 shows that participants in both training groups progressed through the learning phase at similar levels with right hand producing on average 47% correct key presses (less than chance) and the left hand producing on average 42% correct key presses on trial 1. By the end of the training phase (trial 24) the right hand trained group had progressed to an average of 81% correct key presses with the left hand group slightly ahead at 85% correct key presses. The data was analysed using a mixed design ANOVA (Analysis of Variance). All effects are reported as significant at $p<.05$. Performance was assessed within training (training trials 1 to 24) and between hand trained groups (RH trained, LH trained). There was a significant effect for training trials F (23, 43) = 48.52, p = .00. There was no significant effect for hand trained.

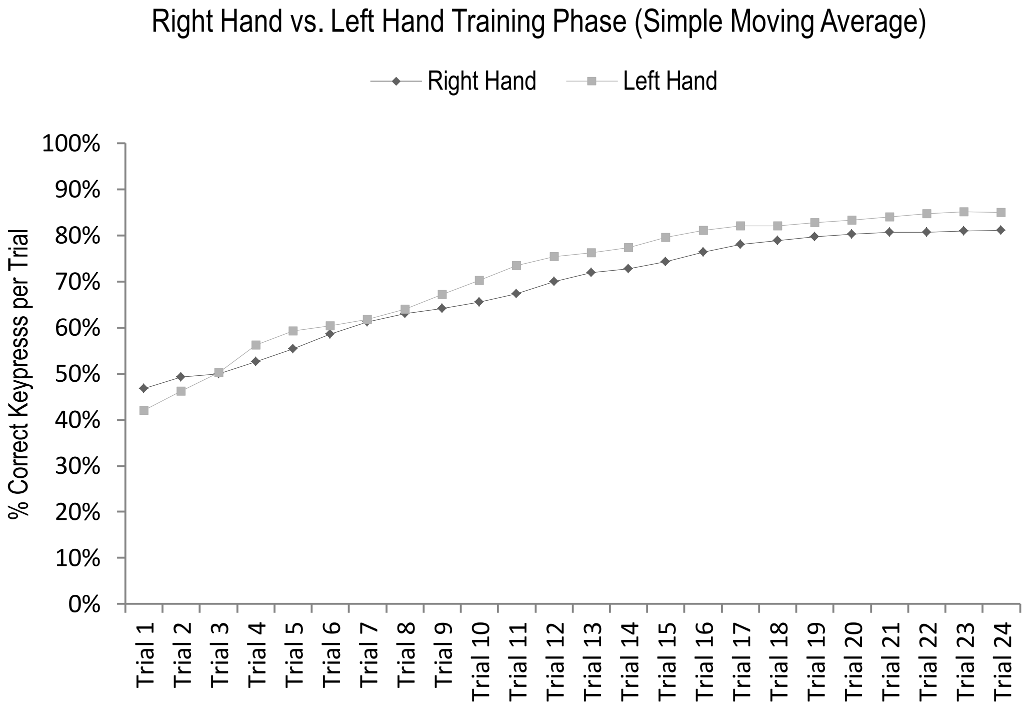


Figure 6-4: The simple moving average of 3 trials (t) (t, t-1, t-2) recorded for both right and left hand trained groups during the training phase. Right Hand Trained Group (n= 22), Left Hand Trained Group (n= 23).

Transfer Phase

There were 8 trials (2 blocks x 4 trials) in the transfer phase. Participants changed from the trained hand to untrained hand for the transfer phase. Four transfer groups (Right Hand Mirror-Reverse (RH MR), Right Hand Reverse-Mirror (RH RM), Left Hand Mirror-Reverse (LH MR), Left Hand Reverse-Mirror (LH RM) completed 4 trials with 1st transfer type (M/R) followed by 4 with the opposite transfer type (R/M). The % correct key presses for each participant were recorded.

Block 1

On the first transfer trial (Transfer 1) the hand trained groups (RH MR, RH RM, LH MR, LH RM) recorded similar average % correct key keypresses (69%, 68%, 69%, and 69% respectively). At the end of block 1 (Transfer 4) the average % correct keypresses had increased for all RH MR (72%), RH RM (77%), LH MR (87%) and LH RM (84%). A Wilcoxon Signed ranks test indicated that the increase in performance was significant for the

3 conditions: RH RM (t1: *Mdn* = 0.62, t4: *Mdn* = 0.94, p =.02, r = -0.49), LH MR (t1: *Mdn* = 0.71 t4: *Mdn* = 0.96, p =.02, r = - 0.48) and LH RM (t1: *Mdn* = 0.62, t4: *Mdn* = 0.71, p =.02, r = -0.50). The data for transfer block 1 and 2 is shown graphically in figure 6-5. Note that the legends refer to the training hand for example the RH MR group refers to the left hand at the transfer phase.

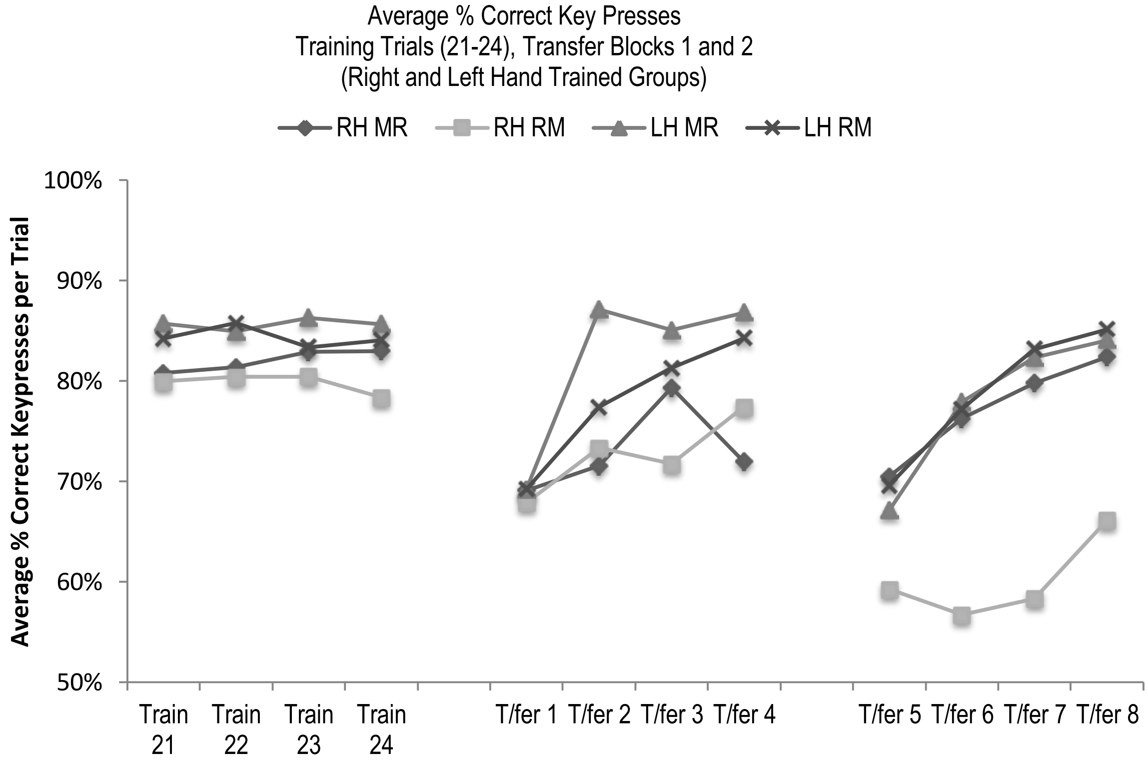


Figure 6-5: The Average % Correct Sequences for Right and Left Hand Trained Training Trials (21- 24), Block 1 (Transfer Trials 1 -4) and Block 2 (Transfer Trials 5 – 8). RH MR (n=11), RH RM (n=11), LH MR (n=12), LH MR (n= 11).

Block 2

The performance on the first trial of transfer block 2 (Transfer 5) indicated that the average % correct key presses for each group had returned to the level of Transfer 1 or less. The average % correct key presses for the RH MR, RH RM, LH MR and LH RM groups was 70%, 59%, 67% and 70% respectively. At Transfer 8 it was found that for all four groups the average % correct key presses had increased RH MR (82%), RH RM (66%), LH MR (84%) and LH RM (85%). A Wilcoxon Signed ranks test indicated that the increase in the average

% correct key presses was significant for three conditions: RH RM (t5: *Mdn* = 0.57, t8: *Mdn* = 0.62, p = .04, r = -0.43), LH MR (t5: *Mdn* = 0.70 t8: *Mdn* = 0.89, p =.01, r = -0.60), LH RM (t5: *Mdn* = 0.64, t8: *Mdn* = 0.92, p =.002, r = -0.66). Although there was a large increase in average % correct key presses for the RH MR group it did not result in a statistically significant increase using the Wilcoxon Signed ranks test. When two or more of the groups violated the assumptions of normality (differences in scores were analysed) non-parametric testing was used for all. The data for the RH MR group did not violate either the Kolmogorov-Smirnov or Shapiro-Wilkes test for normality and in this instance it was decided to run a parametric dependent t-test. The results showed a significant increase in the average % correct key presses t (10) = -2.37, p =.04

Transfer Phase Changeover

The effect of changing transfer type (MR, RM) was investigated by comparing Transfer 4 with Transfer 5. Table 6.1 shows that the average % correct key presses decreased when transferring from one transfer type to the other. The left hand of the RH RM group decreased by (16%) and the right hand of LHMR and LHRM groups experiencing decreases of 20% and 14% respectively.

Table 6-1: The Average % Correct Sequences for Hand/Transfer Group at Transfer 4, Transfer 5 and Transfer 8.

Group	Transfer Hand	Transfer 4	Transfer 5	Transfer 8
RH MR (n=11)	Left	0.72 (.20)	0.70 (.18)	0.82 (.17)
RH RM (n=11)	Left	0.77 (.15)	0.59 (.12)	0.66 (.12)
LH MR (n=12)	Right	0.87 (.16)	0.67 (.21)	0.84 (.17)
LH RM (n=11)	Right	0.84 (.18)	0.70 (.18)	0.85 (.16)

A Wilcoxon Signed ranks test confirmed that there was a significant decrease in performance when switching to the opposite transfer type in 3 conditions: RHRM (t4: *Mdn* = 0.71, t5: *Mdn*

= 0.58, p = .02, r = -0.50), LHMR (t4: *Mdn* = 0.96 t5: *Mdn* = 0.71, p = .02, r = -0.48), LHRM (t4: *Mdn* = 0.94, t5: *Mdn* = 0.64, p =.02, r = -0.49).

The final trials (Transfer 4 & 8) in block (1 & 2) revealed that there was very little difference in performance for the right hand in the final trial of each transfer order (MR/RM). The data did reveal that for the left hand in the RHMR group the average % correct key presses was greater at the end of the block 2(reverse) than block 1 (mirror). The converse was seen for the left hand in the RH RM condition with a decrease in the average % correct key presses at the end of the block 2 (mirror) than block 1 (reverse). Results from a parametric dependent T-test indicated that the increase was significant in the RHMR group *t* (9) = -2.44, p = .04 as was the decrease in the RH RM group *t* (10) = 2.60, *p*=.03.

6.5 Discussion

Training Phase

I had hypothesised that if the salience and /or utility of verbal strategies was reduced by making a movement sequence ‘covert’, the participants would focus on other sources of feedback such as KR. For example, in a covert task the right hand trained group should perform better than the left hand trained group because they can utilise available feedback to a greater extent than the left hand (as hypothesised by the Proficiency Model). This may increase the accuracy of representation and thus lead to improved performance for the right hand trained groups. The data from the current study does not support the hypothesis. There was a significant improvement in the % correct key presses for both hands across the training trials but little difference between the hands. The left hand trained group reached the threshold for learning of 85% while the right hand trained group was just below the 85% threshold (81%).

Taylor and Heilman (1980) speculate that non-significant differences in acquisition rates for females may be due to interference in left hemisphere processing. The results of

Study 3 are not consistent with this notion. Neither is data from the pegboard task of Schulze, Luders & Jancke, (2002) or the anticipatory timing task of Teixiera, (2000) (see Chapter 3). Both studies reported no significance differences in acquisition rates for both left and right hand trained groups. The overall group results in the Taylor and Heilman study showed symmetrical acquisition rates also. It may be that these studies reflect that both hemispheres have a similar capacity to process task related feedback. Another explanation may be that visual feedback is the most salient form of feedback in a finger sequencing task and both hand trained groups use it (Trembley & Proteau, 2001). In Study 1 the loss of visual feedback in the finger sequencing task affected the performance of left hand (although not at statistically significant level) more than that of the right hand. In the Taylor and Heilman study the right hand recorded more errors in the reduced feedback condition (visual feedback eliminated). This would be consistent with the notion that visual feedback is salient for both trained hand groups. The results from the training phase do not support the predictions of any of the 3 models of intermanual transfer (Proficiency, Callosal Access & Cross Activation) discussed this thesis. Both Laszlo et al. (1970) and Parlow & Kinsbourne (1989) found performance to be better for the dominant hand in the finger tapping and inversed reversed letter printing task. In the case of the letter printing element of the Parlow and Kinsbourne task the dominant hand has the advantage of having extended practice with that element of the task and so this may be the reason for the difference in performance between the hands. The results from my first study (finger tapping task) did show superior performance for the right hand trained groups in the full feedback condition. This supported the findings from the Lazlo et al. study. An explanation might be that in simple finger movements there may be asymmetry in acquisition rates, but for a complex novel finger sequencing task both hands (using the most salient form of feedback) may acquire the skill in a symmetrical fashion.

Transfer Phase

Both the right (RH) and left hand (LH) transfer groups recorded similar % correct key presses on the first trial (Transfer 1) of the transfer phase (approx. 69%). This was lower than the final scores in the training phase (RH trained group = 81%, LH trained group = 85%). Although the score was lower than the final trial of the training phase, it was much higher than the first trial of the training phase (RH trained group = 47%, LH trained group = 42%). This indicates that some learning was retained on transfer. At Transfer 4 (end of block 1) the LHMR and LHRM (right hand) transfer groups had reached the threshold (85%). The RHRM group (left hand transfer) performance had improved (77%) but had not reached the performance levels of the right hand transfer groups. The RHMR group had not improved to any great extent over the course of block 1 (72%). This may suggest that in the transfer phase (mirror task) the left hand had difficulty with accessing the spatial representation and could not make as much use of the motor representation. This was not the case for the right hand transfer groups which performed equally well in both the mirror (motor) and reverse (spatial) conditions.

At Transfer 5 (beginning of block 2) disruption occurred in performance for all groups with a significant decrease in performance levels occurring for the LHMR, LHRM and RHRM groups. At Transfer 8 (end of block 2) all but the LHRM transfer group had recovered and reached/almost reached the threshold for learning. These data are consistent with the idea that the LH (right hemisphere) has a difficulty with either utilising the motor or accessing the spatial representation when presented with a mirror transfer task. It appears that for the left hand, engaging in the mirror transfer task impeded its performance in block one (MR group) and block two (RM group). The right hand MR and RM groups both reached the learning threshold at the end of block 1 and block 2. The similar levels of % correct keystrokes produced by both right hand transfer groups, indicates that transfer was symmetrical for the right hand. The dissimilar levels of % correct key strokes produced by the left hand transfer groups, indicates asymmetrical transfer for the left hand. The results from the current study indicate that the left hand transfer groups lacked proficiency with motor transfer compared to the right hand transfer groups. The ability of the right hand to perform well on both spatial and motor transfer while the left hand struggled with motor transfer suggests that the right hand benefitted more from left hand training than did the left hand from right hand training. This provides some support for the Callosal Access Model in terms of transfer but not initial acquisition of the skill.

6.6 Summary

The results from Study 3 demonstrate that both hands achieve similar performance levels in the acquisition phase of the task when the sequence is presented covertly. In the transfer phase only the right hand reached the threshold for learning on both the mirror and reverse sequences. The left hand struggled at both transfer phases with the mirror sequence. A possible explanation for this disruption in performance may be because it could not make use of the spatial representation of task. The greater transfer gains for the right hand (mirror transfer) following left hand training provide some support for the Callosal Access model.

Chapter 7

Summary, Discussion and Conclusions

7.1 Motivation for the Research

A greater understanding of the processes, mechanisms and variables that inform the control of acquired hand movements has important ramifications for use of, and training in, hand skills in contemporary society. For example, skills that involve complex sequences of taps (e.g. keyboard skills such as texting or typing) or selection by simple or sequential pointing (touch screen skills) are of increasing relevance in a society where technology involves the skilled use of either or both hands. Many contemporary tasks may need to be transferable: i.e. intricate sequences of finger or hand movements acquired for use with one hand may need on occasion to be executed by the other hand (e.g. keying in the alarm code with our non-dominant hand as we juggle keys and shopping with the dominant one). The importance of understanding the intermanual transfer of skills extends to clinical populations: e.g. knowledge of the mechanisms which underpin the control of skilled hand movements will inform interventions for those whose movements have been impaired through unilateral brain damage e.g. stroke victims (Birbaumer, 2007).

This thesis set out to explore and help resolve conceptual differences and conflicting data for three models of the acquisition and transfer of acquired skilled hand movements: the Proficiency Model (Laszlo, Bagulay & Bairstow, 1970), Callosal Access Model (Taylor & Heilman, 1980) and the Cross Activation Model (Parlow & Kinsbourne, 1989). The three models are grounded in an information processing paradigm and in common propose the existence of the hypothetical constructs of Motor Program and standard (STD) to explain movement acquisition, production and transfer (Adams, 1971; Laszlo & Manning, 1970;

Schmidt, 1975). The motor program (MP) is a blueprint, a plan or pattern that represents the components and sequences of the movement to be. The STD embodies an internal error detection system that uses movement generated feedback and knowledge of results (KR). The models differ in the perceived role played by the motor program and STD in the acquisition and transfer of acquired hand skills and offer conflicting proposals as to the nature and direction of intermanual transfer of hand movements. The Proficiency Model describes the right hand's ability to use available feedback (intrinsic and extrinsic) to a greater extent than the left hand. This leads to the creation of a more comprehensive internal representation of the movement (motor program and STD) which can be transferred to the non-dominant (right) hemisphere for use by the left hand. The Callosal Access Model asserts that the motor programs for movement are held in the dominant (left) hemisphere no matter which hand is trained. The right hand has direct access to the motor program whereas the left hand must access the motor program via the Corpus Callosum. This indirect access results in the left hand's inability to utilise the motor program to the same degree (speed, accuracy) as the right hand. The Cross Activation model considers that when the right hand is trained the left hand "learns" about the task in a parallel fashion (two copies of the motor program are generated one in each hemisphere) but when the left hand is trained only one copy is generated in the non-dominant hemisphere. Conceptual differences described in the models underpin alternative predictions with regard to the direction of transfer of hand skills. The Proficiency and Cross Activation models both postulate that direction of transfer is from right to left hand whereas the Callosal Access Model posits that the direction of transfer is from left to right hand. An aim of this thesis was to provide some clarity with regard to the efficacy of each model. The objective was to further our understanding of the mechanisms involved in intermanual transfer of acquired skilled hand movements.

The motivation for the re-investigation of the models was derived from the heterogeneous nature of the tasks and feedback conditions engaged to test the predictions of each model: Laszlo et al. employed a finger tapping task because of its low perceptual load. Taylor and Heilman used a novel finger sequencing task to avoid giving an initial advantage to the dominant hand. Parlow and Kinsbourne engaged an inversed reversed printing task which had been previously used in other intermanual transfer research (Hicks 1974). The feedback conditions varied from full feedback available with terminal KR (Parlow & Kinsbourne), visual feedback removed (Taylor & Heilman) through to the elimination of visual, auditory and kinesthetic feedback (Laszlo et al.). The diversity of methodologies engaged to test the predictions of each model did not allow for a direct comparison of the data (Laszlo et al., 1970; Taylor & Heilman, 1980; Parlow & Kinsbourne, 1989). This diversity was further confounded by the fact that in some cases the results from the studies did not provide support for the predictions of the model they were designed to test. For example, Taylor and Heilman hypothesised that the participant's right hand (dominant hemisphere) would acquire their finger sequencing task faster (correct sequences completed) than the left hand. This was not the case. The right and left hand in female participants produced a similar number of correct sequences in the acquisition phase, and transfer was symmetrical. Laszlo et al. found that the left hand performance (number of taps) was greater in their reduced feedback condition and the direction of greatest transfer was from the left to the right hand. These anomalies coupled with equivocal results from more contemporary research (described in Chapter 3) led to the systematic review of the models undertaken in the experimental chapters (4, 5 & 6).

7.2 Experimental Findings – Acquisition Phase

The purpose of my first study (Chapter 4) was to address the issue of heterogeneous task type and feedback conditions used in the original studies. The aim of the study was to better understand the role of task type and feedback conditions in intermanual transfer, and to provide evidence which might lead to the refutation of at least one of the three models. A finger tapping and finger sequencing task were employed in the study (reminiscent of those use in the Laszlo et al. and Taylor & Heilman studies). Participants were tested with each in one of four feedback conditions (KR+, KR-, Vision-, Auditory-). It was hypothesised that the interaction of task type and feedback given would have a direct impact on the amount of transfer (number of taps/ sequences completed) and direction of transfer (right to left, left to right, symmetrical).

The results from the first study revealed a pattern of acquisition which differed between the tasks. In the finger tapping task the performance level (number of taps) remained static (right hand) or decreased (left hand) over the course of the 6 training trials. In the finger sequencing task the performance level (number of correct sequences completed) of both hands improved significantly across the 6 training trials. It could be argued that finger tapping was not a new skill for participants and a motor program for this movement may have already existed in their repertoire. Perhaps the greater strength that the right hand has acquired through everyday use may have allowed it to produce and maintain a similar level of performance across the 6 training trials. Lack of practice or lesser strength of the left hand may have meant that it was unable to maintain the level of performance produced on the first trial (Provins & Glencross, 1968). Conversely, in the finger sequencing task the novel movement pattern may have necessitated the creation of a new motor program and STD. In this instance performance may have increased as a function of improvement of the motor program and STD over the course of the training trials. One of the most interesting patterns to emerge from the results in the training phase related to the use of feedback by both hands (hemispheres). In the finger tapping and finger sequencing task the trained right hand was more sensitive to the loss of feedback than was the trained left hand. The pattern of decline in performance for the right hand does not reach significance (except in the finger sequencing task KR- to Auditory-) but the data indicate a consistent trend. This is supportive of Laszlo et al.'s concept of the STD. When full feedback is available the right hand can utilise it to create a more comprehensive STD than that of the left hand. When feedback is reduced the performance of the right hand decreases as a result of the creation of a less comprehensive STD. One exception to this trend related to terminal KR. In the finger tapping task the withdrawal of terminal KR led to a decrease in performance levels in the right hand. In the finger sequencing task the withdrawal of terminal KR led to an increase in performance levels of the right hand. The results from the finger tapping task are consistent with the concept that terminal KR provides guidance and/or motivation (Salmoni, Schmidt & Walter, 1984). The results from the finger sequencing task suggest that terminal KR did not provide the same guidance and/or motivation for the right hand. It has been proposed that too much KR may be detrimental to the creation of an internal error detection system (Schmidt, Young, Swinnen & Shapiro, 1989 or that terminal KR may not be as beneficial when other sources of feedback are more salient (Van Vliet & Wulf, 2006). The 'specificity of practice' hypothesis suggests that early in practice an individual will decide which form of feedback is most beneficial for the task in progress and process that above all others (Tremblay, Welsh & Elliot, 2001). The majority (74%) of the participants in my first study reported the use of at least one verbal strategy. I explored the possibility that the use of a verbal strategy may provide an explanation as to why too much information may have hindered performance of the right hand in the acquisition phase of the finger sequencing task. Taylor and Heilman submit that verbal strategies may interfere with left hemisphere processing and hence right hand acquisition rates. For the finger sequencing task, both concurrent and terminal KR were available and this, coupled with participants' use of verbal strategies, may have created an information overload in participants.

In Chapter 5 (Study 2) the role of terminal KR during the right hand acquisition of a finger sequencing task was tested. Participants were assigned to one of five training groups:three received terminal KR (KR+) (2 right and 1 left hand trained) and 2 groups in which terminal KR was withheld (KR-) (2 right hand trained groups). If a type of information overload is induced in participants through the availability of extrinsic feedback (concurrent and terminal) in addition to the use of verbal strategies, then withholding of terminal KR should reduce this information overload. I hypothesised that a reduction in the available extrinsic information (terminal KR) might lead to a greater performance level (number of correct sequences completed) in the right hand. There was a significant increase in performance levels across the training trials (consistent with the results from Study 1) but there was no significant difference between the right hand trained groups in either condition (not supportive of the hypothesis). The non significant result in Study 2 points to terminal KR not being the most salient form of feedback in a finger sequencing task. 74% of participants in Study 1 & 75% of participants in Study 2 reported using a verbal strategy. Could it be that the tasks used in these studies encouraged or facilitated the use of such strategies and thereby underpinned a reduction in salience of other available KR?

Chapter 6 (Study 3) focused on the issue of task presentation (overt versus covert) and speculated that a reduction in the need for participants to engage in verbal strategies might increase the salience of KR in right hand acquisition. If KR becomes more salient and it is the case that the right hand can make greater use of the available feedback (as hypothesised by the Proficiency Model), this might lead to improved performance for the right hand trained groups. The experiment engaged participant’s fingers (index, middle and ring) in a trial and error task which covertly presented the 9 digit sequence (utilised in Study 1 & 2). It was hypothesised that acquisition of the sequence in a covert manner should reduce the importance of verbal strategies relative to KR. The results from Study 3 did not support this hypothesis. There was no significant difference in acquisition rates for the right and left hand trained groups. The results from the training phase of my three studies would indicate that there are no observable differences between the right or left hand in acquisition rates and achieved performance levels for a novel finger sequencing task. My studies show that task type (finger tapping/finger sequencing) does appear to impact on acquisition of hand skills. It may be that modifications in training schedules and modality of KR might also impact on the acquisition of hand skills. The training phases in my three studies were all of short duration with terminal and concurrent feedback presented in an auditory form (Study 1 & 2). It would be informative to manipulate further the variables of training duration and KR modality: e.g. would we observe similar results if KR (Study 1 & 2) were presented in a different modality (e.g. visual), or if participants were given more extended practice. Similarly, much could be learned from a more detailed exploration of participants' use of verbal or other cognitive strategies. The participants' in Study 3 were presented with the task in a covert fashion to avoid the need to engage in verbal strategies. The signposting used in block 2 and 3 of the training phase may have led to the employment of some form of cognitive strategy. As the participants were not made aware of the numerical structure of the sequence and were not asked about sequence when they completed the task (to avoid giving an advantage to prospective participants) we cannot be sure what if any strategy was used.

Overall the results from the training phase of Study 1 do provide some support for Laszlo et al's concept of the STD. The right hand appears to be more sensitive to the loss feedback, a caveat being the inconsistent role played by KR in the finger tapping and finger sequencing task. The results from studies 2 and 3 are not supportive of any of the models: the ability of the left hand to acquire the novel finger sequence at a similar level to that of the right hand argues against a right hand that is more Proficient (Laszlo et al. 1970; Parlow & Kinsbourne, 1989) or has direct Callosal access to the motor program (Taylor & Heilman, 1980). An explanation might be that in a complex novel finger sequencing task both hands (using the most salient form of feedback) may acquire the skill in a parallel fashion.

7.3 Experimental Findings – Transfer Phase

In Study 1 intermanual transfer (finger tapping and finger sequencing task) was investigated in two ways: firstly by a within group comparison of performance at the pre-training and transfer phase (trial 1). The objective was to investigate if performance of the untrained hand improved following opposite hand training. Secondly, a between groups comparison of training (trial 6) and transfer phase (trial 1) was conducted to ascertain whether same hand training was superior to opposite hand training. The results from the within group analysis (finger tapping and finger sequencing) showed that both the untrained right and left hand benefitted from opposite hand training. This points to symmetrical transfer and may signify a sharing of resources by both hemispheres/hands. However the increase in performance levels from pre-training to the transfer phase reached statistical significance for some feedback conditions only, and these differed between the hands. For example, there were significant increases between the pre-training and transfer phase for the right hand in the KR+ condition (finger tapping) and in the Auditory- condition (finger tapping and finger sequencing). The left hand recorded significant increases in the KR+ (finger tapping and finger sequencing) and in the Vision- condition (finger sequencing). A common denominator in the case of the untrained right hand was the significant increase in performance levels following opposite hand training in the Auditory- condition (terminal KR, visual and auditory feedback eliminated). A common denominator for the left hand was the significant increase in performance when full feedback was available in the KR+ condition. The within group analysis of the data provided support for the Proficiency Model: Perhaps the left hand can trigger the motor program in the reduced feedback condition (Auditory-)

which the right hand can make use of in the transfer phase. The left hand benefits from the superior STD created by the right hand in the KR+ condition.

A between groups comparison of intermanual transfer presents a different picture. A pattern similar to the within groups comparison emerged for the finger tapping task i.e. both the left and right hand transfer groups' performance levels were higher following opposite hand training than when trained itself. However these differences only reached significance for the left hand trained group in the KR+ condition. The result strengthens the support for the concept of the right hand's ability to create a superior STD when full feedback is available which the left hand can avail of (Proficiency Model). The results of the between group analysis of the finger sequencing task revealed a pattern of similar performance levels whether the hand was trained itself or following opposite hand training. The non-significant differences (excluding KR+ left hand transfer) between same and opposite hand training for both the finger tapping and finger sequence task (using a between groups comparison) suggests a sharing of resources by the hands/hemispheres and may argue for parallel acquisition whether the dominant or non-dominant hand is trained. The different pattern of results for the within and between group comparisons highlights the need to exercise caution when interpreting the results from earlier studies of intermanual transfer.

In Study 2 and 3 intermanual transfer was analysed for both a motor (mirror) and spatial (reverse) representation of the finger sequencing task (between groups). Previous research conducted on intermanual transfer of motor and spatial representations of a task suggested that the level of transfer differs for each (Hikosaka, Nakahara, Rand, Sakai, Lu and Nakamura et al., 1999; Kovacs, Shea, and Muhlbauer, 2009). The effector dependent nature of the motor representation is less amenable to transfer than is the effector independent spatial representation (Kleine and Verwey, 2009). A comparison of motor and spatial transfer was conducted in both the overt (Study 2) and covert (Study 3) versions of the finger sequencing task. In Study 2 transfer was analysed for four left hand transfer groups (RHMR+, RHMR-, RHRM+, RHRM-) and one right hand transfer group (LHRM+). The results indicated that the left hand experienced significant decreases in performance levels when switching from the spatial to the motor sequence (RM). Conversely, the left hand showed a significant increase in performance levels on the first trial of the spatial sequence compared to the first trial with the motor sequence (MR). The results point to the left hand having a particular difficulty with the motor representation of the sequence. The performance level of the right hand transfer group (RM+) was the highest at the end of the transfer phase. This indicates that the right hand did not experience the same level of difficulty as did the left hand. Further investigation utilising random as well as mirror and reverse conditions might provide a further insight into this trend.

In Study 3 four transfer groups were analysed (2 right hand (MR/RM) and 2 left hand (MR/RM)). When the task was presented covertly a similar pattern of left hand difficulty with the motor representation emerged. At the end of block 1 of the transfer phase the performance level of both left hand transfer groups was less than that of the right hand transfer groups. The left hand MR group recorded the lowest % correct key presses in block 1. By the end of block 2 of the transfer phase all but the left hand RM group was nearing the threshold of 85%. This provides further support for the notion that the left hand had particular difficulty with the motor transfer task. The right hand reached the threshold for both training blocks which demonstrates an ability to deal with either a mirror or reverse presentation of the sequence. The results from Study 2 and 3 may be indicative of the right hands ability to make greater use of the motor and spatial representation created by the left hand than vice versa, when the task involves a complex finger sequence. It does provide some support for the Callosal Access model but only with regard to the transfer phase of the task. Table 7-1 sets out the findings from the three studies conducted as part of this thesis and the support they provide for the 3 main models of intermanual transfer.

Table 7-1: Summary of Study 1, 2 & 3 Hypothesis, Results and Support Found for the 3 Models of Intermanual Transfer

Chapter/ Study	**Task**	**Hypothesis**	**Supported**	Support for the three models
Chapter 4 Study 1	Finger Tapping Finger Sequencing	It was hypothesised that the interaction of task type and feedback given would have a direct impact on the amount of transfer (number of taps/ sequences completed) and direction of transfer (right to left, left to right, symmetrical).	Yes	Some support for STD (Proficiency Model) at acquisition and transfer phase
Chapter 5 Study 2	Finger Sequencing	It was hypothesised that **a)** performance (number of correct sequences completed) in the training phase would be greatest in the KR- condition.	No	Support for the Callosal Access model (motor transfer only)
		b) performance in the reverse (spatial) transfer phase would be greater than that in the mirror (motor) transfer phase.	LH Transfer Only	
		c) a decrease in performance would occur when switching between transfer types (mirror or spatial).	Yes	
Chapter 6 Study 3	Finger Sequencing (Covert)	It was hypothesised that **a)** acquiring the sequence in a covert manner should reduce the importance of verbal strategies relative to KR and thus lead to improved performance for the right hand trained groups.	No	Support for the Callosal Access model (motor transfer only)
		b) task presentation (covert) should lead to less transfer in the mirror (motor) transfer groups.	LH Transfer Only	

7.4 Conclusions

Adams 1987 argues that the “canons of scholarship are based on history because they require that (a) the origins of ideas be known so that one's own ideas are in perspective and, (b) earlier experiments be known so that the knowledge increment in one's own empirical findings is clear” (p.41). In this thesis I presented a systematic review of three models of intermanual transfer (Proficiency, Callosal Access & Cross Activation). This involved a re-examination of the studies conducted by each group of researchers to test the predictions of their own model (Laszlo et al, 1970; Taylor & Heilman, 1980, Parlow & Kinsbourne, 1989). The review uncovered a set of heterogeneous tasks and feedback conditions that prevented direct comparison of the predictions and results from each study. The review highlighted data from those experiments designed to test the predictions of a specific model but which failed to support the model. The question that arose was whether conflicts in the results of studies driven by the different models were due to the conceptual differences in the models or could be attributed to experimental artefacts (Schulze, Luders, & Jancke, 2002).

The results from the three studies undertaken provided limited support for the Proficiency model (acquisition phase) and Callosal Access model (transfer phase). The pattern of right hand sensitivity to the withdrawal of feedback is consistent with the Proficiency model’s concept of the STD. The exception to this was terminal KR in the finger sequencing task. This finding points to terminal verbal KR not being the most salient form of feedback when the task involves a complex sequence of finger movements. When full feedback was available both the left and right hand could acquire the novel finger sequencing task to a similar degree whether presented overtly or covertly. This does not conform to the predictions made by any of the models. Some of the data in the transfer study was subjected to both a within group and a between group comparison. These treatments yielded two distinctly different patterns of transfer. Within group results from the current research pointed to symmetrical transfer (this is not supportive of any of the models). Between groups' analysis of some of the same data (the mirror and reverse pattern of the finger sequence), revealed a particular difficulty for the left hand when producing the mirror sequence. Conversely, the right hand was equally adept at producing both the mirror and reverse of the sequence. This points to the right hand's ability to use the motor and spatial representations created during left hand training to a greater degree than could the left hand use the representations created during right hand training. This result from the between group analysis provided partial support for the Callosal Access model. The participants for each of the studies undertaken in this thesis were right handed. Future studies should include left-handers in order to investigate fully the effect of laterality on intermanual transfer.

At the start of my research I wondered if conflicts in the results of studies driven by the different models of intermanual transfer could be attributed to the fact that the studies used different tasks and a range of feedback sources. This question underpinned the aim of this thesis: namely to better understand the role of task type and feedback conditions in intermanual transfer, and to provide evidence which might lead to the refutation of at least one of the three models. The data from the studies undertaken in this thesis would support the idea that task type and feedback interact to influence acquisition and transfer of hand skills. The results from the studies provide partial support for the concept of the STD (Proficiency model) and greater right hand transfer following left hand training (mirror task) provides partial support for the Callosal Access Model. The results from the three studies did not provide support for the Cross Activation model: symmetrical acquisition rates and greater right hand transfer do not conform to the predictions of this model.

The role of terminal KR in a finger sequencing task, symmetrical acquisition rates for both hands on a novel finger sequencing task, and left hand difficulty with mirror (motor) transfer may provide avenues for research particularly for those engaged in rehabilitative interventions. The use of a covert task presentation may be of benefit in stroke rehabilitation. Todd & Barrow (2008) suggest that learning strategies which reduced the reliance on explicit knowledge may benefit motor learning. Types of feedback including visual and auditory sources also require more investigation within a rehabilitation setting (Van Vliet & Wulf, 2006). Research on the ageing brain could also be investigated using the experimental designs included in this thesis. Several authors have provided evidence for functional re-organization of the ageing brain in both the cognitive and motor domains (Berlingeri, Bottini, Danelli, Ferri, Traficante, Sacheli, & et al., 2010; Cabeza, Daselaar, Dolcos, Prince, Budde, & Nyberg, 2004; Ward & Frackowiak, 2003; Mattay, Fera, Tessitore, Hariri, Das, Callicott, & Weinberger, 2002). The authors concluded that this re-organization aids in maintaining good levels of performance (accuracy, grip force) in older adults. Gerloff, Corwell, Chen, Hallett, & Cohen (1998) argue that even though fMRI provides valuable information on areas of functional activation "associated with" a given task, such activation may not imply "necessity" for completion of said task (p.1706). Other factors may operate to influence age-related performance levels; these include mean age of participants, task type, hand used and, feedback conditions. The tasks and feedback conditions employed in the three studies conducted as part of this research could be used to investigate behavioural aspects of functional re-organisation of motor skills in older adults.

In conclusion, this thesis provides a systematic review of three models of intermanual transfer which may be used as a basis for future investigation.

References

Adams, J. (1971). A Closed-Loop Theory of Motor Learning. *Journal of Motor Behavior, 3*, 111-149.

Adams, J. (1987). Historical Review and Appraisal of Research on the Learning, Retention, and Transfer of Human Motor Skills. *Psychological Bulletn, 101*(1), 41-74.

Adams, J. A., Goetz, E. T., & Marshall, P. H. (1972). Response Feedback and Motor Learning. *Journal of Experimental Psychology, 92*(3), 391-397.

Amazeen, P. G. (2002). Is Dynamics the Content of a Generalized Motor Program for Rhythmic Interlimb Coordination? *Journal of Motor Behavior, 3*, 233-251.

Anderson, D. I., Magill, R. A., Sekiya, H., & Ryan, G. (2005). Support for an Explanation of the Guidance Effect in Motor Skill Learning. *Journal of Motor Behavior, 37*(3), 231-238.

Annett, M. (1970). The Growth of Manual Preference and Speed. *British Journal of Psychology, 61*(4), 545-558.

Annett, M. (1991). Skill Acquisition. In J. E. Morrison (Ed.), *Training for Performance: Principles of Applied Human Learning* (pp. 13-51). Oxford, England: John Wiley & Sons.

Ashworth-Beaumont, J., & Nowicky, A. (2013). A New Method for Tracking of Motor Skill Learning Through Practical Application of Fitts' Law. *Journal of Motor Behavior, 45*(3), 181-193.

Baumeister, R. (1984). Choking Under Pressure: Self-Consciousness and Paradoxical Effects of Incentives on Skillful Performance. *Journal of Personality and Social Psychology, 46*, 610-620.

Baynard, S., Gosselin, N., Manon, R., Lassonde, M. (2004). Inter- & Intra Hemispheric Processing of Visual Event-Related Potenetials in the Absence of the Corpus Callosum . *Journal of Cognitive Neuroscience,* 16(3), 401-414.

Beckmann, J., Gropel, P., & Ehrlenspiel, F. (2012). Preventing Motor Failure Through Hemisphere-Specific Priming:Cases from Choking Under Pressure. *Journal of Experimental Psychology:General*, 1-13.

Bennett, I. J., Howard, J. H., & Howard, D. V. (2007). Age-Related Differences in Implicit Learning of Subtle Third-Order Sequential Structure. *Journal of Gerontology: Psychological Science, 62B*(2), 98-103.

Berlingeri, M., Bottini, G., Danelli, L., Ferri, F., Traficante, D., Sacheli, L., & et al. (2010). With time on our side? Task-dependent compensatory processes in graceful ageing. *Exp. Brain Res., 205*, 307-324.

Birbaumer, N. (2007). Motor Learning: Passing a Skill from One Hand to the Other. *Current Biology, 17*(23), 1024-1026.

Blandin, Y., Toussaint, L., & Shea, C. (2008). Specificity of Practice:Interaction Between Concurrent Sensory Information and Terminal Feedback. *Journal of Experimental Psychology:Learning, Memory and Cognition, 34*(4), 994-1000.

Bray, C.W. (1928). Transfer of Learning. J*ournal of Experimental Psychology 11(6),* 443-467.

Cabeza, R., Daselaar, S. M., Dolcos, F., Prince, S. E., Budde, M., & Nyberg, L. (2004). Task-independent and Task-specific Age Effects on Brain Activity during Working Memory, Visual Attention and Episodic Retrieval. *Cerebral Cortex, 14*, 364-375

Cherbuin, N. & Brinkman, C. (2006). Efficiency of Callosal Transfer & Hemispheric Interaction. *Neuropsychology, 20 (2),* 178-184.

Chernikoff, R., & Taylor, F. V. (1952). Reaction Time to Kinesthetic Stimulation Resulting from Sudden Arm Displacement. *Journal of Experimental Psychology, 43*, 1-8.

Corey, D. M., Hurley, M. M., & Foundas, A. D. (2001). Right and Left Handedness Defined: A Multivariate Approach Using Hand Preference and Performance Measures. *Neuropsychiatry, Neuropsychology and Behavioural Neurology, 14*(3), 144-152.

Criscimagna-Hemminger, S.E., Donchin, O., Gazzaniga, M.S., & Shadmehr, R. (2008). Learned Dynamics of Reaching Movements Generalise from Dominant to Non-Dominant Arm. J*ournal of Neurophysiology, 89, 116-176.*

Dee, H.L., Benton, A.L., & Van Allen, M.W. (1970). Apraxia in Relation to Hemispheric Locus of Lesion and Aphasia. *Trans. Am. Neurol. Ass., 95*, 147-150.

Dovern, A., Fink, G. R., & Weiss, P. H. (2012). Diagnosis and Treatment of Upper Limb Apraxia. *J Neurol, 259*, 1269-1283.

Field, A. (2009). *Discovering Statistics Using SPSS* (3rd ed.). London: Sage.

Field, A., Miles, J., & Field, Z. (2012). *Discovering Statistics Using R*. London: Sage.

Gerloff, C., Corwell, B., Chen, R., Hallett, M., & Cohen, L. G. (1998). The role of the human cortex in the control of complex and simple finger movement sequence. *Brain, 121*, 1695-1709.

Glencross, D. (1977). Control of Skilled Movements. *Psychological Bulletin, 84*(1), 14-29.

Goldenberg, G. (2003). Apraxia & Beyond: Life & Work of Hugo Liepmann. *Cortex,* 39, 509-524.

Greer, K. (1984). Physiology of Motor Control. In M. M. Smyth, & A. M. Wing (Eds.), *The Psychology of Human Movement* (pp. 17-46). London: Academic Press, Inc.

Guadagnoli, M. A., & Kohl, R. M. (2001). Knowledge of Results for Motor Learning:Relationship Between Error Estimation and Knowledge of Results Frequency. *Journal of Motor Behavior, 33*(2), 217-224.

Hicks, R. (1974). Asymmetry and Bilateral Transfer. *American Journal of Psychology, 87,* 667-674.

Higgins, J. R., & Angel, R. W. (1970). Correction of Tracking Errors Without Sensory Feedback. *Journal of Experimental Psychology, 84*, 412-416.

Hikosaka, O., Nakahara, H., Rand, M. K., Sakai, K., Xiaofeng, L., Nakamura, K., & et al. (1999). Parallel Neural Networks for Learning Sequential Procedures. *Trends Neuroscience, 22*, 464-471.

Inui, N. (2005). Lateralization of Bilateral Transfer of Visuomotor Information in Right-Handers and Left-Handers. *Journal of Motor Behavior, 37*(4), 275-283.

Jeannerod, M. (2006a). *Motor Cognition.* London: Oxford University Press.

Jeannerod, M. (2006b). The Origins of Voluntary Action. History of Physiological Concept. C.R. Bilogies, 329, 354-362.

Karni, A., Meyer, C., Rey-Hipolilo, C., Jezzerd, P., Adams, M. M., Turner, R., & et al. (1998). The Aquisition of Skilled Motor Performance: Fast and Slow Experience Driven Changes in Primary Motor Cortex. *Proceedings of the National Academy of Science of the United States., 95*(3), 861-868.

Keele, S. (1968). Movement Control in Skilled Motor Performance. *Psychological Bulletin, 70,* 387-403.

Keele, S. W., & Posner, M. I. (1968). Processing of Visual Feedback in Rapid Movements. *Journal of Experimental Psychology, 77*(1), 155-158.

Kelso, J.A.S. (1997). Relative timing in brain and behaviour: Some observations about the generalized motor program and self-organized coordination dynamics. *Human Movement Science, 16,* 453-460.

Kimura, D (1977). Acquisition of a Motor Skill After Left-Hemisphere Damage. *Brain, 100,* 524-542.

Kleine, E., & Verwey, W. B. (2009). Representations Underlying Skill in the Discrete Sequence Production Task: Effect of Hand Used and Hand Position. *Psychological Research, 73*, 685-694.

Koeneke, S., Battista, C., Jancke, L., & Peters, M. (2009). Transfer Effects of Practice for Simple Alternating Movements. *Journal of Motor Behavior, 41*(4), 347-355.

Kovacs, A. J., Muhlbauer, T., & Shea, C. H. (2009). The Coding and Effector Transfer of Movement Sequences. *Journal of Experimental Psychology: Human Perception and Performance, 35*(2), 390-407.

Krigolson, O., Van Gyn, G., Tremblay, L., & Heath, M. (2006). Is there "Feedback" During Visual Imagery? Evidence from a Specificity of Practice Paradigm. *Candaian Journal of Experimental Psychology, 60*(1), 24-32.

Lashley, K. (1917). The Accuracy of Movement in the Absence of Excitation from the Moving Organ. *American Journal of Physiology, 43*, 169-194.

Laszlo, J. I., & Manning, L. C. (1970). The Role of Motor Programming, Command and Standard in the Central Control of Skilled Performance. *Journal of Motor Behavior, 2*, 111-124.

Laszlo, J. I., Baguley, R. A., & Bairstow, P. J. (1970). Bilateral Transfer in Tapping Skill in the Absence of Peripheral Information. *Journal of Motor Behaviour, 2*, 261-271.

Lee, T. D., & Carnahan, H. (1990). When to Provide Knowledge of Results During Motor Learning:Scheduling Effects. *Human Performance, 3*(2), 87-105.

Lomas, J., & Kimura, D. (1976). Interhemispheric Interaction Between Speaking and Sequential Manual Activity. *Neuropsychologia, 14*, 23-33.

Magill, R. (2007). *Motor Learning and Control Concepts and Applications* (8th ed.). London: McGraw Hill.

Malfait, N, & Ostry, D.J. (2004). Is Interlimb Transfer of Force-Field Adaptation a Cognitive Response to the Sudden Introduction of Load? *The Journal of Neuroscience, 24(37),* 8084-8089.

Maslovat, D., Brunke, K. M., Chua, R., & Franks, I. M. (2009). Feedback Effects on Learning a Novel Bimanual Coordination Pattern:Support for the Guidance Hypothesis. *Journal of Motor Behavior, 41*, 45-54.

Mattay, V., Fera, F., Tessitore, A., Hariri, A., Das, S., Callicott, J., & Weinberger, D. (2002). Neurophysiological correlates of age-related changes in human motor function. *Neurology, 58,* 630-635.

McGowan, J. F., & Duka, T. (2000). Hemispheric Lateralisation in a Manual-Verbal Task Combination: The Role of Modality and Gender. *Neuropsychologia, 38*, 1018-1027.

Newell, K. (1991). Motor Skill Acquisition. *Annual Review Psychology, 42*, 213-237.

Oldfield, R. (1971). The Assessment and Analysis of Handedness: The Edinburgh Inventory. *Neuropsychologia, 9*, 97-113.

Park, J.-H., Shea, C. H., & Wright, D. L. (2000). Reduced-Frequency Concurrent and Terminal Feedback:A Test of the Guidance Hypothesis. *Journal of Motor Behavior, 32*(3), 287-296.

Pendt LK, Reuter I, Muller H (2011). Motor Skill Learning, Retention, and Control Deficits in Parkinson's Disease. *PLoS ONE* 6(7): e21669.

Parlow, S. E., & Kinsbourne, M. (1989). Asymmetrical Transfer of Training between Hands:Implications for Interhemispheric Communication in Normal Brain. *Brain and Cognition, 11*, 98-113.

Pew, R. (1966). Acquisition of Hierarchical Control Over the Temporal Organisation of a Skill. *Journal of Experimental Psychology, 71*(5), 764-771.

Pfordresher, P. Q., & Kulpa, J. D. (2011). The Dynamics of Disruption From Altered Auditory Feedback: Futher Evidence for a Dissociation of Sequencing and Timing. *Journal of Experimental Psychology:Human Perception and Performance, 37*(3), 949-967.

Proctor, R. W., & Vu, K.-P. L. (2006). The Cognitive Revolution at Age 50:Has the Promise of the Human Information-Processing Approach Been Fulfilled? *International Journal of Human-Computer Interaction, 21*(3), 253-284.

Proteau, L., & Carnahan, H. (2001). What Causes Specificity of Practice in Manual Aiming Movement:Visual Dominance or Transformation Errors? *Journal of Motor Behavior, 33*, 226-234.

Proteau, L., Marteniuk, R. G., Girouard, Y., & Dugas, G. (1987). On the Type of Information Used to Control and Learn an Aiming Movement After Moderate and Extensive Practice. *Human Movement Science, 6*, 181-199.

Proteau, L., Tremblay, L., & DeJaeger, D. (1998). Practice does not Deminish the Role of Visual Information in Online Control of a Precision Walking Task: Support for the Specificity of Practice Hypothesis. *Journal of Motor Behavior, 30*, 143-150.

Provins, K. A., & Glencross, D. J. (1968). Handwriting, Typewriting and Handedness. *The Quarterly Journal of Experimental Psychology, 20*(3), 282-289.

Rhodes, G. (1985). Lateralised Processes in Face Recognition. British Journal of Psychology, 76, 249-271.

Roland PE, Larsen B, Lassen NA, & Skinhoj E. (1980). Supplementary motor area and other cortical areas in organization of voluntary movements in man. *J. Neurophysiol.* 43:118–136.

Rosenbaum, D. (2007). *MATLAB for Behavioral Scientists.* London: Psychology Press.

Rosenbaum, D. (2010). *Human Motor Control* (2nd ed.). London: Academic Press.

Rothwell, J.C. (2011). The Motor Functions of the Basal Ganglia. *Journal of Integrative Neuroscience,* Vol. 10 (3), 303-315

Rothwell, J. C., Taub, M. M., Day, B. L., Obeso, J. A., Thomas, P. K., & Marsden, C. D. (1982). Manual Motor Performance in a De-afferented Man. *Brain, 105,* 515-542.

Roy, E., & Marteniuk, R. G. (1974). Mechanisms of Control in Motor Performance: Closed-Loop Versus Motor Programming Control. *Journal of Experimental Psychology, 103*(5), 985-991.

Russell, D. M. & Newell, K. M. (2007). On No-KR tests in motor learning, retention and transfer. *Human Movement Science, 26,* 155-173.

Sainburg, R. L., & Wang, J. (2002). Interlimb Transfer of Visuomotor Rotations: Independence of Direction and Final Position Information. *Experimental Brain Research, 145*, 437-447.

Salmoni, A. W., Schmidt, R. A., & Walter, C. B. (1984). Knowledge of Results and Motor Learning: A Review and Critical Reappraisal. *Psychological Bulletin, 95*(3), 355-386.

Schmidt, R. (1969). Movement Time as a Determiner of Timing Accuracy. *Journal of Experimental Psychology, 79*, 43-47.

Schmidt, R. (1975). A Schema Theory of Discrete Motor Skill Learning. *Psychological Review, 82*(4), 225-260.

Schmidt, R. A., & Lee, T. D. (2011). *Motor Learning and Control A Behavioral Emphasis* (5th ed.). Leeds: Human Kinetics.

Schmidt, R. A., & Russell, D. G. (1972). Movement Velocity and Movement Time as Determiners of Degree of Preprogramming in Simple Movements. *Journal of Experimental Psychology, 96*(2), 315-320.

Schmidt, R. A., Young, D. E., Swinnen, S., & Shapiro, D. C. (1989). Summary Knowledge of Results for Skill Acquisition: Support for the Guidance Hypothesis. *Journal of Experimental Psychology:Learning, Memory, and Cognition, 15*(2), 352-359.

Schulze, K., Luders, E., & Jancke, L. (2002). Intermanual Transfer in a Simple Motor Task. *Cortex, 38*, 805-815.

Serrien, D., Ivry, R.B., & Swinnen, S.P. (2006) Dynamics of Hemisphere specialization and integration in the context of motor control. Nature Reviews Neuroscience 7, 160-167(accessed at www.nature.com/review/neuro).

Stamenova, V., Black, S.E., & Roy, E.A. 92011). A Model-Based Approach to Long-term Recovery of imb Apraxia After Stroke. Journal of Clinical & Experimental Neuropsychology, 33(9), 954-971.

Swinnen, S. P., Schmidt, R. A., Nicholson, D. E., & Shapiro, D. C. (1990). Information Feedback for Skill Acquisition: Instantaneous Knowledge of Results Degrades Learning. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 16*(4), 706-716.

Taylor, H. G., & Heilman, K. M. (1980). Left-Hemisphere Motor Dominance in Right Handers. *Cortex, 16*, 587-603.

Teixeira, L. (2000). Timing and Force Components in Bilateral Transfer of Learning. *Brain and Cognition, 44*, 455-469.

Thut, G., Cook, N. D., Regard, M., Leenders, K. L., Halsbrand, U., & Landis, T. (1996). Intermanual Transfer of Proximal and Distal Motor Engrams in Humans. *Ex. Brain Res., 108*, 321-327.

Todd, M. & Barrow, C. (2008). Teaching Memory-Impaired People to Touch Type:The Acquisition of a Useful Complex Perceptual Motor Skill. *Neuropsychological Rehabilitation, 18(4)*, 486-506.

Tremblay, L., & Proteau, L. (1998). Specificity of Practice: The Case of Powerlifting. *Research Quarterly for Exercise and Sport, 69*, 284-289.

Tremblay, L., & Proteau, L. (2001). Specificity of Practice in a Ball Interception Task. *Canadian Journal of Experimental Psychology, 55*(3), 207-218.

Tyszka, J.M. , Grafton, S.T., Chew, W., Woods, R.P., & Colletti, P.M. (1994). Parcelling Mesial Frontal Motor Areas During Ideation and Movement Using Functional Magnetic Imaging at 1.5 Tesla. *Annals of Neurology, 35(6),* 746-749.

Van Vliet, P. M., & Wulf, G. (2006). Extrinsic feedback for motor learning after stroke: What is the evidence? *Disability and Rehabilitation, 28*(13-14), 831-840.

Vieira, M. M., Ugrinowitsch, H., Oliveira, F. S., Gallo, L. G., & Benda, R. N. (2012). Effects of Knowledge of Results (KR) Frequency in the Learning of a Timing Skill:Absolute Verus Relative KR Frequency. *Perceptual & Motor Skills:Learning & Memory, 115*(2), 360-369.

Wang, J., & Sainburg, R. L. (2006). Interlimb Transfer of Visuomotor Rotations Depends on Handedness. *Experimental Brain Research, 175*, 223-230.

Ward, N. S., & Frackowiak, R. J. (2003). Age-related changes in the neural correlates of motor performance. *Brain, 126*, 873-888.

Weisenburg,T., mcBride,K.E. (1935). *Aphasia. A clinical and psycholigical study.* Oxford:Commonwealth Fund.

Wing, A.M. (1977). Perturbations of Auditory Feedback Delay and the Timing of Movement. *Journal of Experimental Psychology:Human Perception and Performance, 3*(2), 175-186.

Woolley, D. G., Wenderoth, N., Heuninckx, S., Zhang, X., Callaert, D., & Swinnen, S. P. (2010). Visual Guidance Modulates Hemispheric Asymmetries During an Interlimb Coordination Task. *Neuroimage, 50*, 1566-1577.

Wulf, G., Schmidt, R. A., & Deubel, H. (1993). Reduced Feedback Frequency Enhances Generalized Motor Program Learning but not Parameterization Learning. *Journal of Experimental Psychology:Learning, Memory and Cognition, 19*, 1134-1150.

Wyke, M. (1971). The Effects of Brain Lesions on the Performance of Bilateral Arm Movements. *Neuropsychologia* 9, 33-42

Yoshida, M., Cauraugh, J. H., & Chow, J. W. (2004). Specificity of Practice, Visual Information, and Intersegmental Dynamics in Rapid-Aiming Limb Movements. *Journal of Motor Behavior, 36*(3), 281-290.

Zelaznik, H. N. (Ed.). (1996). *Advances in Motor Learning and Control.* Leeds: Human Kinetics.

Zwinkels, A., Geusgens, C., van de Sande, P., Van Heugten, C. (2004). Inter-rater Reliability of a New Apraxia Test, Association Between Apraxia and Other Cognitive Deficits & Prevalence of Apraxia in a Rehabilitative Setting. Clinical Rehabilitation, 18, 819-827.

APPENDICES

Appendix A: The Edinburgh Handedness Inventory (Study 1, 2 & 3)

Edinburgh Handedness Inventory[1]

ID No:______________

Please indicate with a check (✓) your preference in using your left or right hand in the following tasks.

Where the preference is so strong you would never use the other hand, unless absolutely forced to, put two checks (✓✓).

If you are indifferent, put one check in each column (✓ | ✓).

Some of the activities require both hands. In these cases, the part of the task or object for which hand preference is wanted is indicated in parentheses.

Task / Object	Left Hand	Right Hand
1. Writing		
2. Drawing		
3. Throwing		
4. Scissors		
5. Toothbrush		
6. Knife (without fork)		
7. Spoon		
8. Broom (upper hand)		
9. Striking a Match (match)		
10. Opening a Box (lid)		
Total checks:	LH =	RH =
Cumulative Total	CT = LH + RH =	
Difference	D = RH – LH =	
Result	R = (D / CT) × 100 =	
Interpretation: (Left Handed: R < -40) (Ambidextrous: -40 ≤ R ≤ +40) (Right Handed: R > +40)		

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[1] Oldfield, R. C. (1971). The assessment and analysis of handedness: The Edinburgh inventory. *Neuropsychololgia*, *9*, 97-113.

Appendix B: Information Sheet – Study 1

How does your left hand know what your right hand is doing?

The inter-hemispheric transfer of acquired skilled hand movements.

Participants Information Sheet

What is the project about?

When a new skill is learnt by one hand information on how to carry out that skill is store in the opposite hemisphere of the brain (e.g. if the right hand acquires a new skill the information relating to that skill is stored in the left hemisphere of the brain). The current study will focus on how information about a skill that is learned by one hand, is transferred to the opposite side of the brain, so that the other hand can perform that skill. This study will focus on factors that could affect the learning of a skill by one hand. For example, how vision, hearing, or knowledge of how well we are carrying out a skill, can affect our learning of that skill. The study will look at what affect these factors have on the transfer of a skill to the opposite hand.

Who is undertaking it?

My name is Deirdre Ryan and I am a Postgraduate student attending Mary Immaculate College. I am presently completing an MA by research in the Department of Psychology under the supervision of Dr. Kerry Greer. The current study will form part of my thesis.

Why is it being undertaken?

The objective of the study is to revisit research into the transfer of acquired skilled hand movements and to address some the problems with the design of those experiments.

What are the benefits of this research?

It is hoped that the data gathered from participants will (a) enhance our understanding of the transfer of acquired skilled hand movements, (b) may benefit our understanding of the best way to train people to perform tasks with one or both hands, particularly for people who may have suffered impairments (for example, stroke patients), and (c) may have implications for how we learn to perform complex, but different skills, simultaneously with both hands

Exactly what is involved for the participant (time, location, etc.)

The study will consist of a short **pre-test questionnaire** to confirm your preferred hand (normally the one you use for handwriting) and two task based experiments. The tasks used for the experiment will be a finger tapping task and a finger sequencing task. It will take approximately thirty minutes to complete. The experiment will be conducted in the Psychology Laboratory in the Library building at Mary Immaculate College. **Detailed instructions on how each task will be carried out will be provided.**

As the experiment involves the use of both hands, participants must also be free of any hand injury or weakness.

Right to withdraw

Your anonymity is assured and you are free to withdraw from the experiment at any time without giving a reason.

How will the information be used / disseminated?

The data from your experiment will be combined with that of the other participants in this study and used to form the results section of my thesis. Summary data only will appear in the thesis, individual participant data will not be shown.

How will confidentiality be kept?

All information gathered will remain confidential and will not be released to any third party. A random ID number will be generated for each participant and it is this number rather than the participant's name which will be held with their data to maintain their anonymity.

What will happen to the data after research has been completed?

In accordance with the Data Protection Act (2003) all participant data will be stored for the length of time that it is required to produce this thesis at which time it will be destroyed.

Contact details:

If at any time you have any queries/issues with regard to this study my contact details are as follows:
Deirdre Ryan
Email: deirdre.ryan@mic.ul.ie
Mobile: 087 2057720

If you have concerns about this study and wish to contact someone independent, you may contact:
Emma Barry
MIREC Administrator
Mary Immaculate College
South Circular Road
Limerick
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Appendix C: Example of Participant Instruction Sheet (Right Hand – Full feedback condition) – Study 1

How does your left hand know what your right hand is doing?

The inter-hemispheric transfer of acquired skilled hand movements.

Instructions for Participants

Dear Participant,

In this study you are asked to complete a questionnaire and then complete two tasks. The tasks are a finger tapping task and a key sequencing task.

Part 1: Questionnaire

You are asked to complete the Edinburgh Handedness Questionnaire which contains 10 items related to hand use on a range of activities (e.g. Writing, Drawing, Using Scissors).

Part 2: Tasks (Finger tapping task and key sequencing task)

See attached instructions.

Participant Instructions

Task 1 – Finger Tapping

This experiment will take approx. 10 minutes to complete.

You will be instructed during the task to place the index finger of each hand on the red button.

For each trial you are required to tap as fast as you can with your index finger

Each trial will last for **15** seconds

Left hand:	You will have **1 trial** with your left hand.
Right hand:	You will have **2 blocks of 3 trials** with your right hand. Between each trial you will have a 10 second rest period. Between each block you will have a 20 second rest period.
Left hand:	You will have **3 more trials** of 15 seconds each with your left hand, again with a 10 second rest period between trials.

Participant Instructions

Task 2: Sequencing

This experiment will take approx. 15 minutes to complete

You will be required to complete a key sequencing task. You will be shown the sequence and given time to memorise it, but you will not be allowed to practice it on the keyboard.

You will then place your hands on the correct keys at the start of the task. You will be instructed as to which hand to use to complete the sequence during the task.

For each trial you are required to complete as many <u>correct</u> sequences as you can. If you make a mistake I will ask you to restart the sequence from the beginning.

Each trial will last for **30** seconds

Left hand:	You will have **1 trial** with your left hand.
Right hand:	You will have **2 blocks of 3 trials** with your right hand. Between each trial you will have a 10 second rest period. Between each block you will have a 20 second rest period
Left hand:	You will have **3 more trials** of 30 seconds each with your left hand, again with a 10 second rest period between trials.

Appendix D: Consent Form – Study 1 & 2

How does your left hand know what your right hand is doing?

The interhemispheric transfer of acquired skilled hand movements.

Informed Consent Form

Dear Participant,

As outlined in the **participant information sheet** the current study will investigate how information about a skill which is learned by one hand is then transferred to the opposite side of the brain so that the other hand can perform that skill.

Details of what each task in the experiment involves are contained in the **participant instruction sheets**. The participant information sheet and instruction sheets should be read fully and carefully before consenting to take part in the experiment.

Your anonymity is assured and you are free to withdraw from the experiment at any time. All information gathered will remain confidential and will not be released to any third party. In accordance with the Data Protection Act (2003) all participant data will be stored for the length of time that it is required to produce this thesis at which time it will be destroyed.

Please read the following statements before signing the consent form.

- I have read and understood the **participant information sheet** and **participant instruction sheets**.
- I understand what the project is about, and what the results will be used for.
- I am fully aware of **all** of the procedures involving myself, and of any **risks and benefits** associated with the study.
- I know that my participation is voluntary and that I can withdraw from the project at any stage without giving any reason.
- I am aware that my results will be kept confidential.

Signed: ____________________________________ Date: ___/___/___

Name in Block Capitals: ______________________

Appendix E: Closing Questions Study 1 & 2

Closing Questions ID: ______

What strategy did you use to learn the key sequence? (e.g. Verbalizing, finger position).

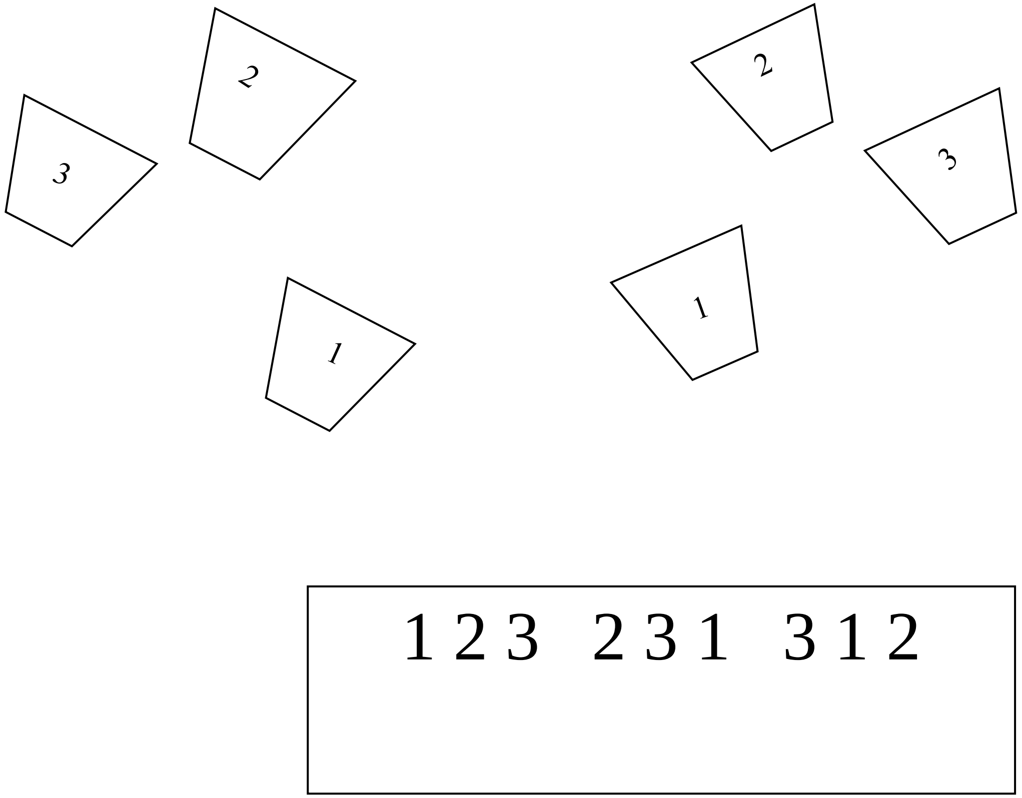
Do you play a musical instrument? Yes: ____ No: ____

If, yes what instrument do you play? __________________

Have you taken typing lessons? Yes: ____ No: ______

Do you play Xbox or PlayStation? Yes:_____ No:______

Appendix F: Example of Finger Sequencing Template used in Study 1 & 2



Appendix G: Debriefing Statement Study 1, 2 &3

Debriefing

Thank you for taking part in this study.

The objective of the study is to revisit research into the transfer of acquired skilled hand movements and to address some the problems with the design of those experiments.

If at any time you have any queries/issues with regard to this study my contact details are as follows:

Deirdre Ryan

Email: deirdre.ryan@mic.ul.ie

Mobile: 087 2057720

Appendix H: Participant Information Sheet – Study 2

How does your left hand know what your right hand is doing?

The interhemispheric transfer of acquired skilled hand movements.

Participants Information Sheet

What is the project about?

When a new skill is learnt by one hand information on how to carry out that skill is store in the opposite hemisphere of the brain (e.g. if the right hand acquires a new skill the information relating to that skill is stored in the left hemisphere of the brain). The current study will focus on how information about a skill that is learned by one hand, is transferred to the opposite side of the brain, so that the other hand can perform that skill. This study will focus on factors that could affect the learning of a skill by one hand. For example, how vision, hearing, or knowledge of how well we are carrying out a skill, can affect our learning of that skill. The study will look at what affect these factors have on the transfer of a skill to the opposite hand.

Who is undertaking it?

My name is Deirdre Ryan and I am a Postgraduate student attending Mary Immaculate College. I am presently completing my PhD in the Department of Psychology under the supervision of Dr. Kerry Greer. The current study will form part of my thesis.

Why is it being undertaken?

The objective of the study is to revisit research into the transfer of acquired skilled hand movements and to address some the problems with the design of those experiments.

What are the benefits of this research?

It is hoped that the data gathered from participants will (a) enhance our understanding of the transfer of acquired skilled hand movements, (b) may benefit our understanding of the best way to train people to perform tasks with one or both hands, particularly for people who may have suffered impairments (for example, stroke patients), and (c) may have implications for how we learn to perform complex, but different skills, simultaneously with both hands

Exactly what is involved for the participant (time, location, etc.)

The study will consist of a short **pre-test questionnaire** to confirm your preferred hand (normally the one you use for handwriting) and one task based experiment. The task used for the experiment will be a finger sequencing task. It will take approximately twenty minutes to complete. The experiment will be conducted in the Psychology Laboratory in the Library building at Mary Immaculate College. **Detailed instructions on how the task will be carried out will be provided.**

> As the experiment involves the use of both hands, participants must also be free of any hand injury or weakness.

Right to withdraw

Your anonymity is assured and you are free to withdraw from the experiment at any time without giving a reason.

How will the information be used / disseminated?

The data from your experiment will be combined with that of the other participants in this study and used to form the results section of my thesis. Summary data only will appear in the thesis, individual participant data will not be shown.

How will confidentiality be kept?

All information gathered will remain confidential and will not be released to any third party. A random ID number will be generated for each participant and it is this number rather than the participant's name which will be held with their data to maintain their anonymity.

What will happen to the data after research has been completed?

In accordance with the Data Protection Act (2003) all participant data will be stored for the length of time that it is required to produce this thesis at which time it will be destroyed.

Contact details:

If at any time you have any queries/issues with regard to this study my contact details are as follows:
Deirdre Ryan
Email: deirdre.ryan@mic.ul.ie
Mobile: 087 2057720

If you have concerns about this study and wish to contact someone independent, you may contact:
Emma Barry
MIREC Administrator
Mary Immaculate College
South Circular Road
Limerick
061-204515
emma.barry@mic.ul.ie

Appendix I: Participant Instruction Sheet – Study 2

Participant Instructions

This experiment will take approx. 20 minutes to complete

You will be required to complete a key sequencing task. You will be shown the sequence and given time to memorise it, but you will not be allowed to practice it on the keyboard.

You will then place your hands on the correct keys at the start of the task. You will be instructed as to which hand to use to complete the sequence during the task.

For each trial you are required to complete as many <u>correct</u> sequences as you can. If you make a mistake I will ask you to restart the sequence from the beginning.

Each trial will last for **30** seconds

Right hand:	You will have **2 blocks of 3 trials** with your right hand. Between each trial you will have a 10 second rest period. Between each block you will have a 20 second rest period
Left hand:	You will have **2 blocks of 3 trials** with your left hand. Between each trial you will have a 10 second rest period. Between each block you will have a 20 second rest period

Appendix J: Consent Form – Study 3

Consent Form

Dear Participant,

This study involves a keypress task. The task will be carried out using both the right and left hand. You will use your index, middle, and ring fingers to carry out the task.

You must be free from any arm/hand injury.

The task will take approximately one hour.

1. Your anonymity is assured and you are free to withdraw from the experiment at any time. All information gathered will remain confidential and will not be released to any third party. In accordance with the Data Protection Act (2003) all participant data will be stored for the length of time that it is required to produce this thesis at which time it will be destroyed.
2. Your participation is voluntary and you may withdraw from the project at any stage without giving a reason.
3. Your results will be kept confidential.

Signed: ___________________________________ Date: ___/___/___

Name in Block Capitals: ______________________