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Imagery: effects on motor performance and exploration of neural substrates

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IMAGERY: EFFECTS ON MOTOR PERFORMANCE AND EXPLORATION OF NEURAL SUBSTRATES

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Summary

This thesis is written as a collection of research papers detailing four studies through which imagery perspectives, modality, ability and their neural substrates were investigated. Study 1 explored the effects of internal visual imagery and external visual imagery on the performance of a slalom-based motor task, with the results demonstrating beneficial performance effects for internal visual imagery over external visual imagery. Study 2 followed the design of study 1, and further examined the effects of imagery modality (visual and kinaesthetic) on the performance of the slalom-based task. The results revealed that kinaesthetic imagery provided beneficial effects over internal visual imagery. Study 3 applied the Vividness of Movement Imagery Questionnaire-2 (VMIQ-2) and fMRI to study the brain activation underpinning internal visual imagery, external visual imagery and kinaesthetic imagery. Results showed internal visual imagery, external visual imagery and kinaesthetic imagery elicited both common areas of activation (in the right supplementary motor area, BA6) and dissociated areas of activation. Specifically, internal visual imagery compared to both external visual imagery and kinaesthetic imagery activated occipital and parietal and frontal brain areas (i.e., the dorsal stream) while external visual imagery activated the occipital ventral stream areas and kinaesthetic imagery activated caudate and cerebellum areas. Study 4 investigated the neural substrates of high and low imagers for different visual imagery perspectives and modality using fMRI. More brain activations were detected in the low imagers than the high imagers during all imagery conditions. Specifically, the medial temporal lobe and the superior temporal gyrus showed more activation in the low imagers. From these results it can be suggested that individuals with lower imagery ability are less efficient in recruiting relevant brain areas to generate vivid images than those with higher imagery ability.

Outputs from the thesis

Chapter 2 Different visual imagery perspectives on the performance of a slalom-based task: This study forms part of the multi study paper: Callow, N., Roberts, R., Hardy, L. Jiang, D. Edwards, MG., (2013). Performance improvements from imagery: Evidence that internal visual imagery is superior to external visual imagery for slalom performance. *Frontiers in Human Neuroscience, 6,1-8* doi: 10.3389/fnhum.2013.00697
This study has been presented: Jiang, D., Callow, N., & Edwards, MG., (2012, April). *Movement imagery: effect on motor performance, brain mechanisms and ability.* Presentation at Imagery and Observation group symposium, Liverpool, UK.

Chapter 3 The additive effects of kinaesthetic imagery to internal visual imagery on the performance of a slalom-based task: This study is in preparation to be submited to the journal of sports psychology.
This study has been presented: Jiang, D., Callow, N., & Edwards, MG., (2012, April). *Movement imagery: effect on motor performance, brain mechanisms and ability.* Presentation at Imagery and Observation group symposium, Liverpool, UK.

Chapter 4 The neural substrates for the different modalities of movement imagery: This study is under review of the journal of brain and cognition.
This study has been presented: Jiang, D., Callow, N., Mullins, P., & Edwards, MG., (2012, June). *Common and dissociated neural activity for the different modalities of movement imagery.* Poster presented at the meeting of Human Brain Mapping, Beijing, China.

Chapter 5 The neural basis of imagery ability for different imagery modalities: This study has been presented: This study has been presented: Jiang, D., Callow, N., & Edwards, MG., (2012, April). *Movement imagery: effect on motor performance, brain mechanisms and ability.* Presentation at Imagery and Observation group symposium, Liverpool, UK.

Chapter 1

General Introduction

Introduction and history of imagery

Imagine yourself walking along the beach. It is already evening; you can see that the sun is just setting over the horizon of the sea, a warm breeze gently pushing your hair back. You walk down to the water's edge, you can feel the warm waves roll over your feet, and it feels good on your skin. You pick up a pebble and you feel the smoothness of the stone in your fingertips. You take a deep breath; the salt air smells wonderful. You feel relaxed and happy. This thesis is about the phenomenon you just experienced. The phenomena is referred to as "mental imagery", and is often interpreted as seeing in the mind's eye, a quasi-perceptual experience resembling perceptual experience, but in the absence of external stimuli.

Mental imagery (from now on referred to as "imagery") has aroused research interest for many years, with numerous researchers proposing definitions of imagery and describing the nature of imagery. Socrates, the early Greek philosopher, discussed imagery in his works, and he believed that visual sensory experience created the possibility for images to be 'viewed' in human mind, representing the real world. Aristotle also considered that 'thought was impossible without an image'. In the beginning of 18th century, Bishop Berkeley proposed, "Our whole perception of the external world consists only of mental images". Towards the end of 19th century, Wilhelm Wundt, considered to be the founder of experimental psychology and cognitive psychology, raised the idea that imagery, sensations and feelings form the basic elements of consciousness. These early opinions were supportive of the idea that we can perform imagery. However, in the early 20th century, with the increasing popularity of behaviourism theory, Watson, one of the original founders of the behaviourism movement, held the controversial opinion (at least for this thesis) that there was no visible evidence of images in human brains and therefore he proposed that the study of imagery was worthless. With the influence of this idea, and the popularity of the behaviourism movement, imagery studies reduced in popularity until the birth of cognitive psychology in the 1950s to 1960s. For example, Shepard and colleagues conducted several experiments involving the mental rotation of objects, revealing that imagery could be experimentally examined (Shepard & Metzler, 1971; Shepard & Feng, 1972; Cooper & Shepard, 1973). With the increasing acceptance of mental imagery, and the possibility to experimentally measure and manipulate imagery, the research in this phenomenon has steadily increased. Now, there are many different definitions of imagery, a good theoretical understanding of how imagery is represented in the brain, and good evidence showing that the use of imagery can be used to facilitate real behaviours, such as action performance. We will present this information in more detail in the following sections of this introduction chapter.

Definition of imagery

Imagery has been defined in various different ways. For example, Lang (1979) described imagery from the perspective of brain's information processing abilities in relation to the bio-informational theory; an image is 'a finite information structure which can be reduced to specific propositional units' (p.109). Anderson (1981) with the background of imagery assessment defined imagery, "at a minimum, to awareness of sensory like qualities (usually visual, but not always) in the absence of environmental stimuli appropriate for sensation perception. Along with the minimum requirement of sensory awareness, imaginary experiences may also include thought segments that are part of, or that occur in the context of, the imagine sensory awareness" (p. 151). Finke (1989; within the field of cognitive psychology), proposed mental imagery as "the mental invention or re-creation of an experience that in at least some respects resemble experience of actually perceiving an object or an event, either in conjunction with, or absence of, direct sensory stimulation" (p. 2). Similarly, Paivio (1971; from the perspective of learning and memory) proposed that imagery can be "used to refer to a memory code or associative mediator that provides spatially parallel information that can mediate overt responses without necessarily being consciously experienced as a visual image" (pp. 135-136).

Of all the definitions, Richardson's (1969) definition is regarded as the 'classic definition' having had a great value in sport psychology (Murphy & Jowdy, 1992). Richardson's (1969) defined imagery as "(1) all those quasi-sensory and quasi-perceptual experiences of which (2) we are self-consciously aware and which (3) exist for us in the absence of those stimulus conditions that are known to produce their genuine sensory or perceptual counterparts, and which (4) may be expected to have different consequences from their sensory or perceptual counterparts" (Richardson, 1969, pp. 2-3). Murphy and Jowdy (1992) outlined three important features of this definition: (1) imagery mimics sensory or perceptual experience; (2) the individual is conscious of imagery; (3) imagery takes place without stimulus antecedents. Although this definition has been criticised for failing to supply sufficient distinctions between imagery and other cognitive processes (Perry & Morris, 1995), it still provides enough complexity and flexibility to have been used in the sports psychology domain.

Imagery modalities and perspectives

Within the definition of imagery, there are seven imagery modalities that have been defined, with each of them corresponding to a human sense, feeling, or action. These are: (1) visual imagery that relates to the human sense of sight; (2) auditory imagery that relates the human sense of sound perception; (3) olfactory imagery that relates to the human sense of odour perception; (4) gustatory imagery that relates to the human sense of taste perception; (5) tactile imagery that relates to the human sense and feeling of touch; (6) kinaesthetic imagery that relates to the human feeling of an action, and; (7) organic imagery that relates to human senses and feelings of the body, including feelings of hunger, thirst, and fatigue. The current thesis focuses only on the modalities of visual imagery and kinaesthetic imagery.

Within the modality of visual imagery, there has been a further separation of perspective proposed. Mahoney and Avener (1977) first distinguished between internal and external visual imagery perspectives. Internal imagery was defined as "an approximation of the real life phenomenology such that a person actually imagines being inside his/her body and experiencing those sensations that might be expected in the actual situation" (p.137). External imagery was defined as "when a person views himself from the perspective of an external observer" (p.137). However, the definition has been criticized for confounding internal visual imagery with kinaesthetic imagery (Hardy & Callow, 1999). Therefore, it could be that the modalities of visual and kinaesthetic imagery have shared processes, but only for internal visual imagery. Furthermore, external visual imagery may be conceived as independent of kinaesthetic imagery, thus supporting the modality independence.

Researchers have shown that different imagery perspectives and modalities could lead to different effects on motor performance. For example, external visual imagery has been shown to lead to more beneficial effects than internal visual imagery on form-based tasks (White & Hardy, 1995; Hardy & Callow, 1999). In addition, studies have also suggested kinaesthetic imagery may have more beneficial effects over the visual imagery perspective (Hardy & Callow, 1999). In Chapters 2 and 3 of this thesis (see also Callow, Roberts, Hardy, Jiang, Edwards, 2013), we showed that internal visual benefitted slalom performance compared to external visual imagery and a control condition, and furthermore, Chapter 3 showed that internal visual imagery combined with kinaesthetic imagery further enhanced the action effects (supporting Hardy & Callow, 1999).

In the current thesis, we used a definition of imagery that clearly distinguished between the imagery perspectives and modalities of imagery. For clarity, we state the definitions of imagery that we supported: (i) internal visual imagery: the view performers would have if they imagined looking out through their own eyes, and allowing the performer to mentally rehearse the precise spatial locations, environmental conditions, and timings at which key movements could be initiated; (ii) external visual imagery: the view performers would have if they imagined watching themselves from a third person perspective, enabling the performer to "see" the precise positions and movements that are required for successful performance (Hardy & Callow, 1999), and; (iii) kinaesthetic imagery: how it feels to perform an action, including aspects such as the force and effort involved in movement (Callow & Waters, 2005). Although we propose a clear distinction between the imagery modalities and perspectives, we propose that these imagery modalities and perspectives could be combined.

Theories of imagery

A variety of theories and models have been proposed to explain the operation of imagery and how imagery can have beneficial effects on performance. In this section of the introduction, outlines of several theories, a model and a notion are presented.

Psychoneuromuscular theory

Psychoneuromuscular theory was first proposed by Jacobson (1930) to explain the relationship between imagery and motor performance. The theory is based on neuromuscular responses being similar during imagery and during the actual experience of a movement. In an experimental investigation, Jacobson (1930) found the same pattern of neuromuscular impulses were transmitted when the participant was asked to imagine bending their arm and also when asked to perform the same action, though the neuromuscular impulses of the imagery occurred at a much lower magnitude than that for the action. Although a number of research has provided support for this theory (e.g., Hale, 1982; Guillot et al., 2008; Lebon, Byblow, Collet, Guillot, & Stinear, 2008), debate still exists on whether or not imagery is truly accompanied by subliminal muscle contractions, or whether the participants make movements during the imagery to help them to imagine. The latter possible confound has been proposed as many researchers have failed to replicate the findings of neuromuscular impulses during imagery (e.g., Demougeot & Papaxanthis, 2011; Roosink & Zijdewind, 2010; Personnier, Paizis, Ballay, & Papaxanthis, 2008). Further criticism of the theory comes from no direct evidence of a relation between muscle activation during imagery and a change in motor performance. Consequently, this theory remains tentative as an explanation of how imagery may improve performance.

Symbolic learning theory

The symbolic learning theory was first proposed by Sackett (1934), and is primarily concerned with the cognitive process associated with imagery. The theory suggests that imagery enables the rehearsal of movements as symbolic components of the task. For example, imagery can help to run through different parts of a task in a suitable order, to consider spatial task characteristics, potential problems and goals, and to plan movement execution. Through rehearsing these components, one can facilitate performance. Feltz and Landers' (1983) meta-analysis provided support for the symbolic learning theory, though with effect sizes typically much larger in studies of cognitive tasks than studies involving motor tasks. Similar effects have been reported in a number of other mental rehearsal studies, where imagery was more effective on tasks with large cognitive components than on motor tasks (Hird, Landers, Thomas, & Horan, 1991; Ryan & Simons, 1982). Despite this bias, there are studies showing positive effects for imagery on motor tasks with fewer cognitive elements (e.g., Lee, 1990), and further, Hecker and Kaczor (1988) discussed the existence of possible problems with the theory related to performance enhancement of established athletic skills, perhaps explaining the failure to support effects in action. Another criticism of the theory comes from Martin, Moritz, and Hall (1999) who proposed that the symbolic learning theory failed to explain the effectiveness of the variety of imagery interventions frequently used by sport psychologists (Murphy, 1990; Perry & Morris, 1995).

Bio-informational theory

Lang (1977, 1979) proposed bio-information theory as an information-processing model to explain the operation of imagery. The theory suggests that an image is stored in the long-term memory as a functionally organised set of propositions, and the adjust these propositions could lead to changes in behaviour. Three basic types of propositions are proposed: stimulus proposition, referring to the content of image; response proposition, including the imager's overt and covert response to the image and meaning proposition, to analysis and explain the image by performer. Research support for bio-informational theory has come from the finding that modification of imagery variables leads to physiological responses (e.g., Hale, 1982; Slade, Landers, & Martin, 2002; Guillot et al., 2008). For example, research has found the magnitude of EMG activity is correlated to the mental effort required to imagine the movement (Guillot et al., 2008). In addition, there are research evidence showing imaging scenes containing response propositions results in higher heart rates than scenes that do not contain response propositions (Hecker & Kaczor, 1988; Cumming, Olphin, & Law, 2007). Recent research provides supports by demonstrate that layered stimulus response training can facilitate imagery ability and movement execution (Williams, Cooley, & Cumming, 2013).

Ahsen's triple code model

Ahsen's triple code model (1984) is concerned with the interactive relationships between the image (I), the psychophysiological response (S) and the meaning of the image (M). In these terms, the image is the act that the individuals will do if they were in the real world, the psychophysiological response is the somatic response that the individuals will have when they become aware of what is required of them and the

Meaning (M) refers to the way the performer understands how the motor skill should be done. These I, S and M factors are proposed to be combined in various orders. For example, ISM is the most useful order of the triple code model that allows firstly to evocate a visual image, followed by a somatic response, and then by a meaning. Ahsen's triple code model is thought to improve psychoneuromuscular and symbolic learning theories as the model considers the individual differences in the meaning of an image, and it "reminds sports psychologists to pay attention to the meaning of the images they employ and their clients report" (Murphy & Jowdy, 1992). Although supported in the some clinical research, the model fails to explain some of the underlying processes and mechanisms that may allow for moderations in behaviour, of how and why imagery may benefit performance (Callow & Hardy, 2005).

The notion of functional equivalence

The term and notion of functional equivalence has emerged from neuroscience research demonstrating that similar brain areas become activate when a person either imagines or performing actions (Grezes & Decety, 2001; Jeannerod, 1994). For example, Lacourse, Orr, Cramer, and Cohen (2005) used functional magnetic resonance imaging (fMRI) to compare functional neuroanatomy associated with executed and imagined hand movements in novel and skilled learning phases. They found congruent activation of the cortical and subcortical motor system during both novel and skilled learning phases. Some researchers have extended these findings to suggests that the more similar (or functionally equivalent) the action imagery is to actual performance, the more effective the imagery might be for moderating performance (cf. Holmes & Collins, 2001; Smith, Wright, & Cantwell, 2008; Wakefield, Smith, Moran, & Holmes, 2013).

Hardy's notion

Hardy (1997) suggested that imagery could exert a beneficial effect on performance through the images being generated supplementary to the information that is already available to the performer. This notion was first proposed to explain the effects of imagery perspectives on motor performance. For example, for tasks relying upon the use of form, external visual imagery may be more suitable with correct movement, because from the external point of view, it enable the performer to "see" the precise positions and movements that are required for successful performance (Hardy & Callow, 1999). Conversely, for slalom-based motor tasks, internal visual imagery may allow a performer to see the precise temporal and spatial locations where key movements need to be initiated (e.g., changing direction or "braking"). Currently however, there is no research that has identified whether internal visual imagery will benefits for slalom-based motor tasks.

PETTLEP model

Holmes and Collins (2001) created the PETTLEP model to provide athletes with a 7-point practical guideline to understand effective use of imagery. The model PETTLEP is an acronym with each letter representing an important factor: Physical, Environment, Task, Timing, Learning, Emotion and Perspective. This model is based on the notion of functional equivalence (explained above), where each factor might be associated to equivalent processes between imagery and actual behaviour. The model proposes that the seven factors should be correctly incorporated when using imagery to enhance athletic performance since the additive accumulation of equivalence might lead to increased improvements in the desired outcome performance. Much research has provided support for the model, and showing that more elements of PETTLEP model that are incorporated in the imagery, the more successful the imagery effects tends to be on athletic performance (e.g., Cumming et al., 2012; Wakefield et al., 2013).

The current thesis is based on a combination of theories. The core theory relevant to the thesis is the cognitive approach of functional equivalence. However, we also follow Hardy's notion of imagery perspectives and modality on motor performance, where external visual imagery may be more equivalent to form-based tasks than internal visual imagery (Hardy & Callow, 1999; Hardy, 1997), but internal imagery may be more equivalent to slalom-based tasks than external visual imagery. In Chapters 2 and 3, we tested the latter proposal, and we expected superior performance of internal visual imagery over external visual imagery on a slalom-based motor task, due to internal visual imagery being more functionally equivalent to the task. In addition, we extended this proposal to the use kinaesthetic imagery in Chapter 3, proposing a more beneficial effect over external visual imagery, again because the kinaesthetic imagery may be more functionally equivalent to performing slalom-based actions.

Functions of imagery

Paivio (1985) proposed that imagery can serve both cognitive and motivational functions in performance, and both of these functions can serve at a specific or a general level (cognitive specific, cognitive general, motivational specific, and motivational general). Motivational general can further divide into motivational general arousal and motivational general mastery (Hall, Mack, Paivio, & Hausenblas, 1998). Cognitive specific is associated to skill development and techniques to improve performance, while cognitive general includes the strategies of planning, development, and execution. Motivational specific relates to imaging goal-directed behaviour, such as help to understand how to achieve the goals. Motivational general arousal is to use imagery to regulate emotions associated with performance; and motivational general mastery is using imagery to staying focused, confident and mentally tough during performance. For example, athletes have used imagery to being self-confident, to keep focused, that is using imagery for its motivational general mastery function. The sport imagery questionnaire (SIQ; Hall et al., 1998) was designed to assess athletes' use of the five cognitive and motivational functions of imagery. Research has shown athletes tend to use all the five functions of imagery, and imagery generated by an athlete can serve more than one purpose (e.g., Abma, Fry, Li, & Relyea, 2002; Munroe, Hall, Simms, & Weinberg, 1998). The current thesis will focus on the cognitive specific function of imagery.

Imagery ability

Imagery ability is related to how well an image can be formed in the minds, how vivid and realistic they are, and how well the images can be controlled. Vividness and controllability are two crucial factors to affect individual's imagery ability (Callow & Hardy, 2005; Holmes, 2007; Williams, Pearce, Loporto, Morris, & Holmes, 2012). Vividness refers to the clarity and realism of the image, whilst controllability refers to the ability to manipulate and direct the image (Murphy & Martin, 2002). Imagery ability has been demonstrated to be an important moderator of imagery interventions (e.g., Goss, Hall, Buckolz, & Fishburne, 1986; Hall, Buckolz, & Fishburne, 1989). Athletes with higher levels of imagery ability are reported to have more beneficial effects in imagery interventions (e.g., Isaac, 1992; Weinberg, 2008).

Imagery ability is subject to individual differences as a result of a number of factors, including motor experience, age and gender (Isaac & Marks, 1994; Kosslyn, 1980, 1999; Richardson, 1994). For example, Isaac and Marks (1994) have administered the Vividness of Visual Imagery Questionnaire and the Vividness of Movement Imagery Questionnaire to 547 individuals in age groups from 7–8 to 50 + years of age. They found significant increases in imagery vividness in females at 8–9 and in males at 10–11 years. They also examined imagery differences in specialist groups using the same two questionnaires with a total of 655 participants. They found that physical education students reported more vivid imagery than students specializing in physics, English, and surveying, and significant differences were revealed between elite athletes' imagery and that of matched controls. Given these individual differences, it is very important to make the measurement of imagery ability prior to an imagery experiment.

Researchers have used a number of ways to measure imagery ability. Within the sports psychology literature, the most commonly used method is through the validated self-report questionnaires, and within the motor domain, these questionnaires can be distinguished into two collections. The first collection includes the Vividness of Visual Imagery Questionnaire (VVIQ; Marks, 1973), the Vividness of Movement Imagery Questionnaire (VMIQ; Isaac, Marks, & Russell, 1986) and Vividness of Movement Imagery Questionnaire-2 (Roberts, Callow, Hardy, Markland, & Bringer, 2008). These questionnaires focus on the assessment of imagery vividness specifically. The other collection contains Movement Imagery Questionnaire (MIQ; Hall & Pongrac, 1983) and its revised version the MIQ-R (Hall & Martin, 1997). Although, vividness is included in these questionnaires, their focus is on general imagery ability (Hall, 1998). As imagery control is much harder to manipulate and assess than the vividness, there are hardly any image controllability measures within the literature, but imagery vividness and controllability are linked such that control is a pre-requisite for vividness (Marks, 1999).

Within the different questionnaires, the VMIQ-2 and MIQ-R are the most commonly used to assess the imagery ability (Smith & Holmes, 2004) in the previous research. They both require participants to imagine a variety of movements and they are commonly used to assess the imagery ability of participants prior to undertaking an imagery experiment to aid the performance of different motor skills (Smith & Holmes, 2004). The MIQ-R has a crucial limitation in comparison to the VMIQ-2, it measures visual and kinaesthetic imagery, but the visual subscale does not distinguish between imagery perspectives. As a consequence, any differences in the ability to use internal visual imagery or external visual imagery cannot be explored using this questionnaire. In the sports psychology literature, studies have showed that the two imagery perspectives (internal visual imagery and external visual imagery) can have different effects on motor performance (White & Hardy, 1995; Hardy & Callow, 1999). Therefore, it could be important to differentiate the two visual perspectives. Alternatively, VMIQ-2 makes a clear distinction between imagery perspectives; it has three subscales, which are internal visual imagery, external visual imagery and kinaesthetic imagery. However, since the data collection period of this PhD, the MIQ-3 has been published (Williams, Cumming, Ntoumanis, Nordin-Bates, & Hall, 2012), it assesses individual's ability to image four movements using internal visual imagery, external visual imagery, and kinaesthetic imagery. With the clear distinction between imagery perspectives and modality, MIQ-3 is also a good choice to measure imagery ability, but as this PhD started in 2009, we chose VMIQ-2 since MIQ-3 has not published at that time.

Apart from self-report questionnaires, a number of other paradigms have also been used to investigate imagery ability. These include mental chronometry, prospective action judgment, and motorically driven perceptual decision paradigms. In the next paragraphs, a more precise review is provided for each of these paradigms.

Mental chronometry paradigms are based on the assumption that the cognitive processes underlying the mental imagery involve the same action planning processes as those used to perform the task (Jeannerod, 1997; Milner, 1986). Based on this principal, it is expected, and it has been shown that the time taken to imagine an action is similar to the time taken to execute actions (e.g., Decety, 1996). Use of the mental chronometry paradigm has been widely used in clinical studies to detect motor imagery impairments. In patient populations, research has shown evidence of a deviation between actual and imagined movement times, where the imagined movement time is more variable than the executed action time (Danckert et al., 2002; Dominey, Decety, Broussolle, Chazot, & Jeannerod, 1995; Maruff & Velakoulis, 2000; Maruff, Wilson, Trebilcock, & Currie, 1999; Sirigu et al., 1995, 1996). Using this relationship, the paradigm assumes good imagery ability with the least variance between the imagined and executed actions. So far in the scientific literature, these paradigms have not been used to measure individual differences in imagery ability within the normal population, making their use inappropriate for the current experimentation. Furthermore, there is some debate about whether the paradigm is as reliable as the questionnaire paradigms. For example, it is unclear why people or patients show reduce similarity between imagination and execution in particular cases. If imagery was based on action execution processes, one might expect both the imagery and the execution to be impaired in patients, and thus similar in timing. If there is a difference, it must be that the patients can use an alternative cognition for imagery. Clearly, this paradigm requires further investigation.

Prospective action judgment is a paradigm where participants have to make judgments about how they would perform an action. Research has shown that in order to make a prospective judgment, the participant has to simulate the action execution mentally (Johnson, 2000; Frak, Paulignan, & Jeannerod, 2001; De'Sperati & Stucchi, 1997, 2000). This paradigm is again based on motor planning processes for execution, and is a popular method to assess motor imagery ability in clinical populations (Buxbaum, Johnson-Frey, & Bartlett-Williams, 2005; Johnson, 2000). However, as with mental chronometry paradigms, these tasks have not been popular used to differential individual imagery ability in the normal population, and as a result, are not useful for the aims of the thesis.

The final paradigm reviewed here is the motorically driven perceptual decision paradigm, which requires that the participants make decisions on the perceptual stimuli that would be involved in an action (e.g., based on motoric processes). For example, a participant might be asked to imagine an action and then judge the laterality of a visually presented body part. The most commonly used paradigm in this type is the Hand Laterality Task. Within this task, the participants are presented with hands rotated in different positions, and the participants have to decide as quickly as possible, whether the hand is a left or a right hand. Studies have shown that laterality decisions about a body part are made on the basis of motor simulations (Coslett Medina, Kliot, & Burkey, 2010; Parsons, 1994). Similar to the mental chronometry paradigm and prospective action judgment paradigm, the Hand Laterality Task has also been widely used in detecting motor imagery deficits in clinical populations (Coslett, 1998; Schwoebel, Friedman, Duda, & Coslett, 2001; Roelofs et al., 2001; Nico, Daprati, Rigal, Parsons, & Sirigu, 2003; Tomasino, Rumiati, & Umilta, 2003). In this situation, the patients are impaired in making correct decisions about the hand laterality. For example, a recent study applied this paradigm to a normal population to measure participant's imagery ability (Williams et al, 2012). In the study, they explored the correlation between imagery ability (using the Hand Laterality Task and VMIQ-2) and Muscle Evoke Potential (MEP) amplitude. Transcranial Magnetic Stimulation (TMS) was delivered to the primary motor cortex during observation and imagery of a finger-thumb opposition action sequence and MEPs were measured in the abductor pollicis brevis. They found that significant correlation between MEP (change in activity relative to each individual's baseline activity) for the imagery condition and imagery ability, with a greater change in MEP linked to faster decision times of hand laterality, and more vivid images. They also found that the result from Hand Laterality Task was significantly correlated with the subscale of kinaesthetic imagery scores from the VMIQ-2.

Considering these paradigms together, the self-report questionnaire is the paradigm most commonly used with the normal population. The paradigms of mental chronometry, prospective action judgment, and motorically driven perceptual decisions are popularly used in the clinical studies, and only a few studies have been performed with non-clinical participants. Because of the lack of research with healthy control participants, the present thesis selected to investigate imagery and imagery ability using the questionnaire type paradigm. However, one issue with the self-report questionnaires is that the paradigm of recording imagery ability is subjective. As a supplementary addition to the thesis, the questionnaire type paradigm for the evaluation of imagery ability in healthy participants will be used to investigate the neural basis underlying the questionnaire associated imagery, and provides biological validity to the questionnaires. For the other three paradigms that are presented above, it is possible to use these paradigms in the future, providing supplementary studies to the current thesis that will, attempt to replicate the imagery ability findings of this thesis. In particular, these studies might provide support for the different modalities and perspectives of imagery. For the moment, the paradigms other than the questionnaire have found only some relationship to particular modalities or perspectives. For example, the Hand Laterality Task was found out to only correlate with kinaesthetic imagery (Williams et al, 2012), and a The Grasping Task (Jeannerod, 2001) using the prospective action judgment paradigm was only involved in internal visual imagery and kinaesthetic imagery and not external visual imagery. Further research is needed to understand how these paradigms are related to imagery perspective and modality.

Neuroscience techniques to measure imagery

In the past twenty years, there has been a growth in the use of neuroscience methods to explore the neural basis of imagery. These studies have included methods such as Positron Emission Tomography (PET) (i.e., Decety et al., 1994; Naito et al., 2002; Roland, Larsen, Lassen, & Skinhoj, 1980; Stephan et al., 1995), electroencephalography (EEG) (i.e., Beisteiner, Hollinger, Lindinger, Lang, &

Berthoz, 1995; Rodriguez, Muniz, Gonzalez, & Sabate, 2004; Thayer & Johnson, 2006), and functional magnetic resonance imaging (fMRI) (i.e., Lotze et al., 1999; Porro et al., 1996; Roth et al., 1996), and magnetoencephalography (MEG) (i.e., Lang, Cheyne, Hollinger, Gerschlager, & Lindinger, 1996; Nagakawa et al., 2011; Schnitzler, Salenius, Salmelin, Jousmaki, & Hari, 1997). These neuroscience methods differ in their spatial and temporal resolution. Spatial resolution is known as the ability to distinguish different locations within a brain image whereas temporal resolution is the rate at which a technique acquires images, and the ability to distinguish changes in the (functionally related) image (Huettel, Song, & McCarthy, 2004).

Each technique has advantages and limitations. PET was one of the first possible brain imaging measures, and worked by measuring the breakdown of radioactive materials (usually glucose or oxygen) within the body. When the brain was functionally active, the neurons would use the radioactive glucose or oxygen, and release isotopes that could be measured by the scanner. The use of PET was problematic and limited due to safety concerns about radiation exposure to the participants. The use of EEG is also a method that has been used, and is still frequently used for measuring brain activity. EEG records the electrical activity of the brain, where functional activity caused depolarization of neuron axons, and a change in electrical activity (Niedermeyer & Lopes da Silva, 2004). The method provides excellent temporal resolution that can detect changes over milliseconds, but the method has poor spatial resolution, and can only measure surface cortex activity (e.g., occipital, parietal and frontal lobes). The method quality is reduced with deeper brain structures such as the basal ganglia, hippocampus or cingulate cortex etc. The use of

MEG brain imaging works by recording magnetic fields produced by electrical currents that occur in active regions of the brain. Similar to EEG, MEG also has good temporal resolution, but in addition, it has relatively better spatial resolution than EEG. The final method of brain imaging presented here has been the most common neuroscience method for measuring imagery, namely fMRI. This method assesses a composite of measures associated to functional brain activity that include the blood-oxygen-level-dependent contrast (BOLD) signal (neural activity, metabolism, blood flow) (Huettel, et al., 2004). fMRI provides excellent spatial information, but with improved methods, can also provide reasonable temporal resolution. With the greater use of fMRI, and the balance of advantages to limitations, we chose to explore the neural basis of imagery using the technique. In Chapters 4 and 5, a detailed review of the research that has explored imagery using fMRI will be presented. In the next section, the typical analyses and designs used for fMRI are reviewed to place the thesis with a contemporary framework.

Statistical analysis of fMRI data

The aim of the statistical analyses of fMRI is to find out whether experimental manipulations have any effects on brain activations. There are two commonly used methods to perform statistical analysis on fMRI data. The more common of the two is the whole brain analysis and the second is the region of interest analysis. Whole brain analysis examines the activations across the brain, and is usually used when there is no strong assumption or prediction of activity. The region of interest analysis extracts brain activation signal from specified regions of interest, based on a prior expectation or a hypothesis. Although some studies have reported both types of analysis, this is now not recommended. This is because of a statistical problem called the "double dipping problem". It refers to data that are first analysed, and then a selection of a subset area that was either significant or not significant, again being reanalysed to either obtain the same significant results as in the first analysis, or significant results that were not significant in the first analysis (Kriegeskorte, Simmons, Bellgowan, & Baker, 2009). To avoid double dipping, the current thesis only used the whole brain analysis on fMRI data, as we had no specific prediction of the areas expected for activation.

There are two major types of fMRI experimental designs, blocked designs and event-related designs. These two types of designs operate on the way stimuli are presented. In a block design, trials are presented in blocked conditions, but the trials are randomized in the blocks. Event related manipulations are when the trials and conditions are randomized, but the purpose is to measure brain activity that corresponds to a particular event (e.g., before the person images versus during imagery vs. after imagery etc). Block designs are good for detecting significant fMRI activity and can have superior statistical power, but they are poor at estimating the time course of activity in active voxels. Event-related designs mirror the block designs in that they have good time course estimation of how a manipulation corresponds to brain activity, but they have less detection power.

Both the block design and the event related design rely on contrasts between brain activity for the manipulated condition relative to a control condition. In the block design, brain activity for the controlled block designs are compared to the experimental blocked condition to a control condition. The typical control condition contains elements of the experimental condition that are considered to be of less importance. This can include for example attention to a fixation cross being subtracted from attention during the imagery condition. Aspects of the methods and conditions used in the fMRI studies of this thesis will be presented in greater detail in Chapters 4 and 5 of this thesis.

Overview of thesis

The current thesis consists of four empirical studies that explored the effects of imagery perspectives and modality on motor performance, the neural basis underlying these imagery perspectives and modality and the neural differences of brain activity for imagery ability.

The first part of the thesis (Chapters 2 and 3) reports the results of two studies on the effects of imagery perspectives and modality on motor performance. Chapter 2 presents a study to explore the effects of internal visual imagery and external visual imagery on a slalom-based task, and Chapter 3 followed-up the design of Chapter 2, and investigated the effects of internal visual imagery and internal visual imagery with kinaesthetic imagery on motor performance. Taken together, the results showed that, for a slalom-based task, internal visual imagery was superior to external visual imagery, and kinaesthetic imagery provided beneficial effects over the other imagery perspectives. The findings from these two studies have provided behaviour evidence supporting differences in imagery perspectives and modality. In Chapter 4 of the thesis, the self-report questionnaire (VMIQ-2) and neuroimaging techniques (fMRI) were combined to explore the neural substrates of internal visual imagery, external visual imagery and kinaesthetic imagery, and to explore the possible biological validity of VMIQ-2. From the fMRI results, common activity in the right supplementary motor area (BA6) was detected, while there were also divergent patterns of activation for internal visual imagery, external visual imagery and kinaesthetic imagery. Specifically, internal visual imagery activated the parietal lobe, external visual imagery showed some temporal activation, and kinaesthetic imagery activated sub-cortical parts and the cerebellum. In a final study, Chapter 5 investigated the neural basis of imagery ability. The results showed that participants with low imagery ability activated many more brain regions than participants with high imagery ability, indicating that focused brain activations were associated to the high than low imagers during all imagery conditions. Specifically, the medial temporal lobe and the superior temporal gyrus were more activated in the low imagers. In the final part of the thesis, in Chapter 6, a discussion of the thesis findings is presented, along with some suggestions for future studies that could follow-up the findings of this thesis, and a discussion of the impact that the research in the thesis could have on both the scientific literature and on applied research.

Research questions

The thesis addressed the following research questions:

1. What are the effects of internal visual imagery and external visual imagery on the performance of slalom-based motor tasks?
2. What are the effects of kinaesthetic imagery over the internal visual imagery on the performance of slalom-based motor tasks?
3. What are the neural substrates of internal visual imagery, external visual imagery and kinaesthetic imagery?
4. Are there any differences of the neural basis between high and low imagers?

Chapter 2

Different Visual Imagery Perspectives on the Performance of a Slalom-Based Task[1]

Abstract

Research has reported that external visual imagery (EVI) is superior to internal visual imagery (IVI) on tasks relying upon the use of form (Hardy & Callow, 1999; White & Hardy, 1995). However, the effect of visual imagery perspectives, or whether a particular perspective is selectively superior on slalom-based motor tasks, is currently not clear. This study investigated the effects of IVI and EVI for the performance of slalom-based motor tasks. Forty-five participants were allocated to an IVI, EVI or control condition group. After 90 minutes training on a driving-simulation slalom task, they performed 5 pre-condition test trials, and 5 post-condition test trials. The imagery groups listened to the corresponding imagery scripts, and the control group solved simple math questions before each trial. The time taken for each trial was recorded. The results showed that on average, the IVI group achieved significantly quicker trial times than the EVI and control groups. The results provide evidence supporting the beneficial effects of IVI over EVI for slalom-based tasks.

[1] This study forms part of the multi study paper: Callow, N., Roberts, R., Hardy, L. Jiang, D. Edwards, MG., (2013). Performance improvements from imagery: Evidence that internal visual imagery is superior to external visual imagery for slalom performance. *Frontiers in Human Neuroscience, 6,1-8* doi: 10.3389/fnhum.2013.00697
This study has been presented: Jiang, D., Callow, N., Edwards, MG., (2012). Movement imagery: effect on motor performance, brain mechanisms and ability. Presentation. *Imagery and Observation group symposium*, Liverpool, UK.

Introduction

Research examining the effects of imagery on the acquisition and execution of motor performance has delineated imagery into modalities and perspectives. This delineation includes visual and kinaesthetic sensory modalities (e.g., Hardy & Callow, 1999; Fourkas, Ionta, & Aglioti, 2006; Guillot et al., 2009), with the visual modality being further separated into two visual imagery perspectives. These two perspectives are the internal visual imagery perspective (IVI: where the imaginer is looking out through his or her own eyes while performing the action) and the external visual imagery perspective (EVI: where the imaginer is watching him or herself performing the action from an observer's position; as if watching him or herself on television) (see Callow & Roberts 2012 for further details of visual imagery perspective conceptualization). The kinaesthetic imagery modality is defined as how it feels to perform an action, and includes aspects such as the force and effort involved in movement (Callow & Waters, 2005).

Research exploring the use of internal and external visual imagery has produced equivocal results. For example, early work by Mahoney and Avener (1977) revealed that successful qualifiers for the U.S. Olympic gymnastics team used internal imagery more than non-qualifiers. However, in contrast to this, Ungerleider and Golding (1991) found that successful U.S. track and field athletes used more external imagery than non-successful athletes. In addition, experimental studies (e.g., Epstein, 1980) found no differences between imagery perspectives on performance. Three possible explanations have been provided for these inconsistent results: (a) that specific visual imagery perspectives produce greater performance gains for certain motor tasks than for others (e.g., Hardy, 1997; Highlen & Bennett, 1979; for gymnastics versus track);

(b) that previous conceptualisations of internal imagery (such as that used by Mahoney & Avener 1977, or Epstein, 1980) have confounded internal visual imagery with kinaesthetic imagery (cf. Hardy & Callow, 1999); and (c) that it has been incorrectly assumed that kinaesthetic imagery can only be experienced with an internal perspective or is easier to use with an internal perspective (cf. White & Hardy, 1995; Taktek, 2012).

For the first explanation, Hardy and associates (e.g., Hardy, 1997; Hardy & Callow, 1999; White & Hardy, 1995) offered two hypotheses for the effects of different visual imagery perspectives on different motor tasks. They posited that external visual imagery (EVI) would be superior to internal visual imagery (IVI) for tasks relying upon the use of form, but that IVI would be superior to EVI for slalom-based tasks, where a performer has to follow a "line" through or around a set course (e.g., downhill slalom skiing). A cognitive explanation for these hypotheses has been provided by Hardy (1997). Specifically, Hardy suggested that imagery exerts a beneficial effect on performance only to the extent that the images generated supplement the information that is already available to the performer. Thus, for tasks relying upon the use of form, EVI may be more useful than IVI because EVI would allow a performer to see the desired form associated with the correct movement. Conversely, for slalom-based motor tasks, IVI may allow a performer to see the precise temporal and spatial locations where key movements need to be initiated (e.g., changing direction or "braking") from the actual viewing angle of the motor action. Thus, the temporal and spatial locations would be identified with reference to the performer's position on the actual line being taken, which would afford critical visuomotor information that would not be available using EVI. Indeed, in situations that rely on precise knowledge of temporal and spatial locations in the environment (e.g., reaching and grasping), aligning one's viewing angle with actual movement has been shown to modulate motor coordination and functional performance (e.g., Ustinova, Perkins, Szostakowski, Tamkei, & Leonard, 2010).

This hypothesis was first investigated by White and Hardy (1995) using a rhythmic gymnastics routine (relying upon the use of form) and a wheelchair slalom task (requiring a line to be followed through a set course of gates). Two groups of participants performed the two tasks, with one group using IVI and the other using EVI. In the gymnastics routine, the group using EVI proved to have superior performance than the IVI group, with fewer errors in performance. Hardy and Callow (1999) replicated this finding with a series of ecologically valid tasks relying upon the use of "form"; a karate kata, a gymnastics floor routine, and a technical rock climbing task. In all three tasks, the group of participants that used EVI showed superior performance compared to the group that used IVI. In the gymnastics and climbing tasks, a kinaesthetic imagery (KIN) participant group was also included and the results showed KIN to have a beneficial performance effect over and above both visual imagery groups in the climbing task. Note that in both papers, the baseline performance before imagery use was equal across the different groups in each experiment.

One criticism of the White and Hardy (1995) study was that the wheelchair slalom task did not fully support the hypothesis that the IVI group would show better performance than the EVI group. Specifically, although after initial practice on an acquisition course, participants using IVI completed a transfer trial with significantly fewer errors than participants using EVI, participants using EVI completed the course significantly quicker than participants using IVI. In the paper, these results were interpreted as IVI causing a more accurate performance (with less errors made) compared to EVI, because participants may have been able to rehearse the responses required at each gate and this lead to the increase in accurate performance. In contrast, EVI improved the speed at which the task was performed, with the retrospective suggestion that EVI may have enhanced the competitive drive of the participants. However, an alternative suggestion is that the results showed a speed-accuracy trade-off, where performance was matched in the two groups, but one group showing a speed improvement with no change in accuracy, and the other group showing an accuracy improvement with no effect on speed. Therefore, within a speed-accuracy trade-off, both IVI and EVI groups showed increased performance.

More recently, a number of neuroimaging studies have shown differences in neural activity dependent on the imagery perspective taken (e.g., Ruby & Decety, 2001; Fourkas et al., 2006; Lorey et al., 2009). These neural differences have then been used to explain the differential effects of imagery perspectives on performance, via the notion of functional equivalence (e.g., Jeannerod, 1994, 2001; Hanakawa, Dimyan, & Hallett, 2008). That is, the more similar (functionally equivalent) the imagery is to the actual performance, the more effective the imagery is at moderating performance (cf. Holmes & Collins, 2001; Smith et al., 2008; Wakefieldet al., 2013). However, the conceptualization of imagery perspectives used in the neuroimaging studies differ markedly to both our conceptualisations of IVI and EVI, and the current view in the sport psychology literature (e.g., Cumming & Ramsey, 2008; Moran, 2009; Tobin & Hall, 2012). For example, neuroscientific conceptualisations of internal imagery confound visual and kinaesthetic modalities (e.g., Ruby & Decety, 2001; Lorey et al., 2009), and external imagery is usually of someone else (e.g., Ruby & Decety, 2001; Fourkas et al., 2006; Lorey et al., 2009). While several other fMRI (e.g., Guillot et al., 2009) and psychophysiological studies (e.g., Guillot, Collet, & Dittmar, 2004) are clear to make distinctions between imagery modalities (i.e., visual and kinaesthetic), these studies do not examine visual perspective differences. Consequently, a precise understanding of what neural areas are involved in internal visual imagery and external visual imagery is not known, and thus, the current neuroscientific research cannot be used to precisely explain the differential effects of visual imagery perspectives on performance. Having said this, we might assume similar neural functional equivalence between the specific visual imagery perspectives and the different tasks, with a slalom-based task being particularly moderated by internal visual imagery, or a form-based task being particularly moderated by external visual imagery (cf. Callow & Roberts, 2010).

In the present experiment, we wanted to find behavioural evidence in support of the differences in visual perspectives (for IVI compared to EVI), specifically for slalom performance. We hypothesised that for slalom-based motor tasks, IVI would have more beneficial effects than EVI.

Method

Participants

A sample of 45 male participants was recruited (M age 21.35 = years SD = 3.12). The participants were all right-handed and had normal or corrected-to-normal vision. All participants held a UK driving license for a minimum of 1 year, but reported that they had never played the specified driving game used in the experiment, and played computer games on average less than once per week in the preceding 6 months. All participants provided written informed consent, and ethical approval for the experiment was granted by the School's Ethics Board.

Experimental apparatus and task

The driving-simulation slalom task was undertaken in a purpose-built driving simulator, incorporating a rally car seat, a force feedback steering wheel (which could be turned ±900° to keep the car on the circuit), 6-speed gear shifter and pedals. The driving simulator was connected to a 22 inch LCD monitor displaying the Gran Turismo 5 Prologue game (Codemaster, Warwickshire). In a training phase of the experiment, the track used was the Suzuka Circuit, which was 3.61 miles long and consisted of 20 bends (nine left and 11 right). In the experimental phase, the chosen track was the Eiger Nordward circuit, which is 1.51 miles long and consists of 11 bends (five left and six right). In both phases, the circuits were driven as a time trial in dry, daylight conditions, with a Citroen C4 2.0 VTS Coupe'05 as the test car. The virtual reality display presented the driver's view out through the front window of the car as if actually driving the car.

Experimental phases

In order to train the participants to use the apparatus for the experimental phase, participants completed a 90-min training phase period where they had to achieve two criteria (derived from pilot testing). This included the completion of three consecutive laps under 170s and a plateau in performance, where the last three lap times fell within 5s of each other (cf. Wilson, Chattington, Marplehorvat, & Smith, 2007). If participants achieved the criteria, they then proceeded to the experimental phase. In the experimental phase, participants completed a total of 15 laps (five practice, five pre-imagery, five post-imagery) of the simulated rally driving circuit, with average lap time at pre and post-imagery condition used as the measure of change in performance. The participants were randomly assigned to one of three groups; internal visual imagery (IVI), external visual imagery (EVI), or maths-control. Following practice and pre-imagery performance measures, participants in the imagery groups were given an imagery script pertaining to the imagery group to which they were allocated. The IVI script detailed the task from a first person visual perspective, requiring the participants to image the task through their own eyes. The EVI script detailed the task from the perspective of a third person visual perspective, requiring the participants to see themselves performing the task. All scripts were developed using Lang's (1984) guidelines for including stimulus, response and meaning propositions into the script, and pilot tested (and amended based on feedback) prior to data collection. In order to maintain experimental control, the scripts were developed by the author. However, there was flexibility in the scripts (e.g., participants in the IVI group were asked to imagine their view change as they turned a corner). This flexibility allowed participants to develop their own images, thus providing a degree of individualization, and consequently the images being meaningful for the participants (cf. Wilson, Smith, Burden, & Holmes, 2010). The scripts took ~120 s to administer. Example excerpts from the scripts are presented in Table 2.1.

Table 2.1 Imagery scripts

Example for the IVI script	Crossing the start line, you see the long straight in front of the car. Notice as the front of the car is going downhill slightly; it is travelling over a couple of horizons. As you approach the S-shape bend head, you see the line you want to take. As the car approaches the bend, you break to take the perfect line, turning first to your right and then quickly to your left, staying close to the bend, and accelerating after the bend.
Example for the EVI script	As the car crosses the start line, see the long straight in front of it. Notice that the car is going downhill slightly and is travelling over a couple of little horizons. As you see the car approach the S-shape bend ahead, you see the line you want it to take. As the car approaches the bend, you see yourself allowing the car to break to take the perfect line, seeing yourself turn the wheel first to your right and then to your left, staying close to the bend, and accelerating after the bend.

In the control condition, participants were required to answer standard arithmetic questions (e.g., 14 + 4 + 6). This type of active control group has been demonstrated to prevent the use of imagery during the experiment, but does not interfere with performance on the dependent variable (cf. Driskell et al., 1994; Callow & Hardy, 2005).

Measures

The time-taken to complete each lap was measured automatically (in seconds) by the Gran Turismo 5 Prologue software, and recorded by the experimenter. Note that the line of driving moderated the time, with cutting corners reducing the time compared to driving in the centre of the road. Collisions with curbs, or driving on the grass further added to the lap driving time.

In order to determine participants' imagery ability, all participants completed the Vividness of Movement Imagery Questionnaire-2 (VMIQ-2: Roberts et al., 2008). The VMIQ-2 comprises 12 items that assess the ability to image a variety of movements. Participants are required to image each item using IVI, EVI, and kinaesthetic (Kin) imagery, and rate the vividness of the image produced on a five-point Likert scale from 1 (*perfectly clear and vivid*) to 5 (*no image at all*). Cronbach's alphas for the current study were 0.86 (EVI), 0.90 (IVI), and 0.84 (Kin). VMIQ-2 has demonstrated acceptable factorial validity, construct validity and concurrent validity (see Roberts et al., 2008).

In addition to the VMIQ-2, a manipulation/social validation questionnaire was also administered. The first question, asked all participants whether they had been able to adhere to the treatment group. The remaining questions were only given to participants in the two visual imagery groups, and they were asked whether they had experienced any switching of visual imagery perspectives during the task, and whether they had experienced any kinaesthetic imagery during their use of visual imagery. A 11-point Likert scale ranging from 0 (*not at all*) to 10 (*very much so*) was employed.

Procedure

One week prior to the commencement of the experiment, participants completed the VMIQ-2. All participants achieved a criterion of equal to or less than 36 on each of the VMIQ-2 sub-scales, indicating that their imagery ability was at least moderately clear and vivid. Participants attended the laboratory individually and they were instructed that the purpose of the experiment was to examine driving ability under different conditions. The experimenter read standardized instructions detailing the training and experimental phases to the participants. Participants then completed the 90 min training phase, and all participants achieved the criterion level. On completion of the training phase, participants were given a 15 min break before commencing the experimental phase. The experimenter read standardized instructions explaining that they were to complete a number of trials as fast as they could; five practice trials, then five pre-imagery test trials and then five post-imagery test trials. Before each of the post-imagery test trials, participants in the IVI and EVI groups listened to a recording of the imagery script detailing the driving task from the visual imagery perspective to which they were assigned, and were asked to use the imagery prior to performing each of the trials. Participants in the control group solved 10 maths questions prior to each post-test trial, as pilot testing had revealed that the calculation of 10 maths questions equated to the average time taken to complete the imagery scripts. Upon completion of each post-imagery test trial, participants rated the extent to which they drove as fast as they possibly could on an 11 point Likert scale from 0 (not at all) to 10 (very much so), with the intent that any participant who scored less than 5 would be asked to repeat the trial. In the event, no participants scored less than 5 for any trial. At the end of the post-imagery test trials, participants completed the manipulation/social validation questionnaire. On completion of the questionnaire, the participants were de-briefed as to the nature of the experiment and thanked for their participation.

Results

Preliminary analyses

All participants reported on the manipulation/social validation questionnaire that they were able to adhere to their allocated groups with minimum reported switching of perspectives in either of the imagery groups (i.e., a score of less than 3 was used at the cut-off criteria and indicated that participants rarely, if at all, switched between IVI and EVI or vice versa). Therefore, no participants were removed from the analysis. Participants in the IVI and EVI groups reported some experience of kinaesthetic imagery during their visual imagery (see Table 2.2 for descriptive results), although there was no significant difference between the imagery groups in terms of their kinaesthetic imagery experience ($p = 1$, $d = 0$). Analysis of the VMIQ-2 data (using a Bonferroni adjusted α of 0.017) revealed no differences between the different participant groups for IVI imagery ability $F(2, 42) = 0.42$, $p = 0.66$, $\eta^2 = 0.02$ $1\text{-}\beta = 0.11$, and kinaesthetic imagery ability $F(2, 42) = 1.32$, $p = 0.28$, $\eta^2 = 0.01$ $1\text{-}\beta = 0.27$. However, for EVI imagery ability, there was a significant difference between the groups $F(2, 42) = 7.48$, $p = 0.002$, $\eta^2 = 0.26$ $1\text{-}\beta = 0.93$, with the EVI group showing significantly better EVI ability than the IVI group ($p = 0.003$, $d = 1.66$) and the control group ($p = 0.009$, $d = 1.45$).

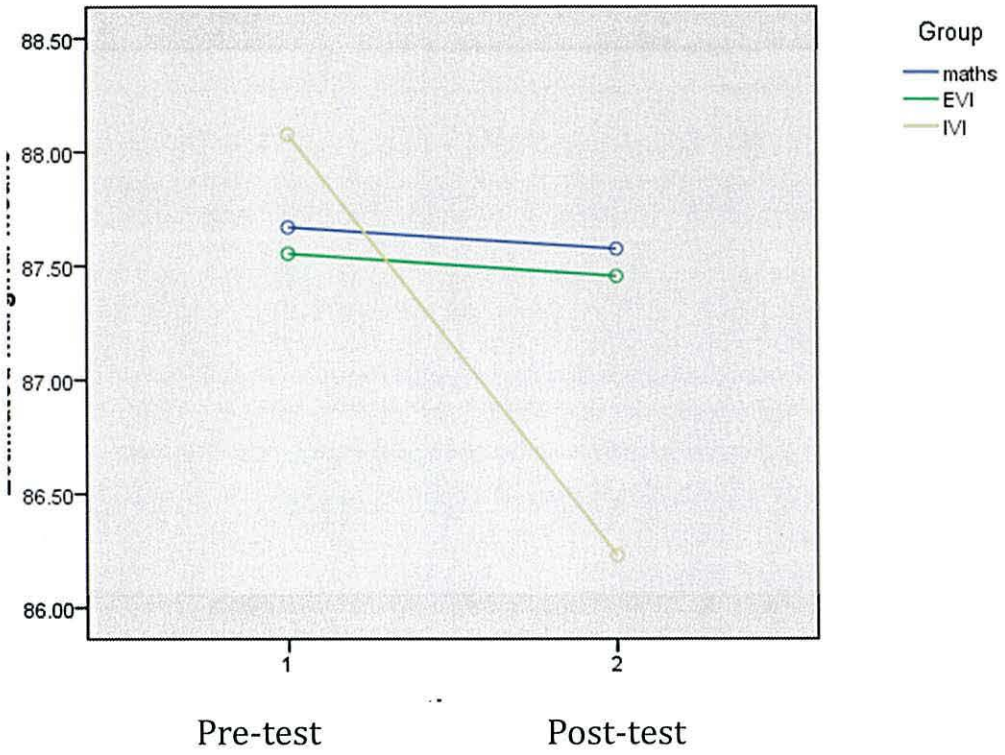
Performance score (time-taken)

A mixed-model (group × test) ANOVA was employed to analyse the average lap-time at pre and post-test. Box's M test for homogeneity of dispersion matrices was significant. Data transformations failed to rectify this problem. However, Stevens (2002) states that if Box's M test is significant with approximately equal numbers in each group, the Type I error rate will only be slightly affected, whereas power will be weakened. Thus, it remains relatively safe to interpret significant effects, because they are robust enough to show significance despite the low power. Consequently, the results from the analysis on the raw (non transformed) data are reported here. The analyses revealed no significant main effect for group, $F(2, 42) = 0.23$, $p = 0.80$, $\eta^2 = 0.01$ $1\text{-}\beta = 0.08$, a significant main effect for test $F(1, 42) = 18.57$, $p < 0.001$, $\eta^2 = 0.21$, $1\text{-}\beta = 0.99$ and a significant group by test interaction, $F(2, 42) = 13.65$, $p < 0.001$, $\eta^2 = 0.31$, $1\text{-}\beta = 0.99$. Tukey's tests on the significant interaction revealed that there was no significant difference between groups at pre-imagery tests. However, at post-imagery tests, the internal visual imagery group performed significantly better than the external visual imagery group $q(42) = 6.31$, $p < 0.05$, $d = 0.66$ and the control group $q(42) = 6.94$, $p < 0.05$, $d = 0.63$. In addition, the IVI group significantly improved performance from pre to post-test $q(14) = 9.56$, $p < 0.05$, $d = 0.98$. No other differences were significant. See Table 2.2 for descriptive results.

Table 2.2 Kinaesthetic experience and lap-time (seconds) at pre-test and post-test.

	Kinaesthetic experience	Pre-test lap time	Post-test lap time
Group	M (SD)	M (SD)	M (SD)
IVI	4.43 (3.00)	88.08 (2.10)	86.23 (1.78)
EVI	4.53 (3.02)	87.55 (1.94)	87.45 (1.92)
Control	-	87.67 (2.10)	87.57 (2.41)

Figure 2.1 *lap-time (seconds) at pre-test and post-test*



Given that kinaesthetic imagery can cause performance gains over and above those caused by visual imagery (Hardy & Callow, 1999), it was important to establish if the kinaesthetic imagery used in the two conditions could have influenced the results (despite there being no significant differences in the experience of kinaesthetic imagery in the two visual imagery groups). We examined the relationship between kinaesthetic imagery and performance and found no significant correlation between kinaesthetic imagery (reported from the manipulation/social validation questionnaire) and performance (average lap-time) at post-imagery test ($r_s = 0.06, p = 0.77$). Thus, the superior performance for the IVI group could not be attributed to differences in kinaesthetic imagery experience between the two groups.

Finally, although accuracy was not recorded due to the variety of possible race lines, and that an optimum race line would not be in line with the center of the road, we can confirm that there were no crashes or incidents where any participant drove off the road, in any of the experimental trials. Therefore, the lap-time results are all for trials where the participant correctly completed the circuit without incidents.

Discussion

The purpose of the present research was to examine the effects of IVI and EVI on a slalom-based task, where the performer had to follow a "line" through or around a set course. The results supported the hypothesis, showing that in the post-imagery trials, the IVI group had a better performance on the driving task than the EVI and control groups, and furthermore that the IVI group showed better performance post-imagery compared to pre-imagery. These results provide support for Hardy et al (1995; 1997; 1999) hypothesis that IVI would produce superior performance to EVI on slalom-based tasks, and here, the results could not be interpreted with the speed-accuracy trade-off. In addition, the results of the post-experimental questionnaire suggest that kinaesthetic imagery can be used with both visual perspectives (e.g., Callow & Hardy, 2004; Glisky, Williams, & Kihlstrom, 1996), and that there was no difference if participants used kinaesthetic imagery or not in combination to the visual imagery. The improved results in this study compared to those of White and Hardy (1995) and Hardy and Callow (1999) were possibly a consequence of training the participants to perform the task. In training, we established error-less (no incident) performances that were fast and consistent. This likely reduced variance in the dependent variable and led to the significant findings. In future research, we propose that it is not only important to show that participants of different imagery groups have matched baseline performance, but also to show that the performance is of a good standard and that performance across trials is consistent.

Other strengths in this research included the use of manipulation checks enabling greater experimental control (cf. Murphy & Jowdy, 1992), and defining specific inclusion and exclusion criteria for imagery ability (based on previous evidence, e.g., Callow, Hardy, & Hall, 2001), and baseline performance capability (as presented above; cf. Goss et al., 1986). Despite these strengths, there were some limitations that we propose future studies should consider.

The main limitation of the present research was the inability to control participants' spontaneous kinaesthetic imagery experiences. One possibility may be to have larger participant samples that test differences between participants that only use IVI and EVI compared to samples that use IVI and EVI with the addition of spontaneous kinaesthetic imagery. Based on our post-hoc analyses, we would propose the hypothesis that there would be no additional effects on the kinaesthetic imagery intrusion. Another more elaborate method would be to explicitly control for kinaesthetic imagery with repetitive transcranial magnetic stimulation (rTMS) to suppress the brain pathways involved in kinaesthetic imagery (cf. Jung, Shin, Jeong, & Shin, 2008). For example, Guillot et al. (2009) found kinaesthetic imagery to elicit bilateral activations of the inferior parietal lobule (BA10) as well as several motor-related regions (including the putamen, the caudate nucleus, and the cerebellar hemispheres). Using a 'knock-out' paradigm, future studies may apply rTMS to these brain areas, or indeed the brain areas associated to IVI or EVI in order to suppress specific imagery processes during an imagery task.

Another potential limitation of the present research could be the angle of the EVI perspective taken by performers (i.e., side-wards, behind, from above; never before investigated; Callow & Roberts, 2010). It could be that the particular angle of EVI could have beneficial effects for certain outcomes/tasks. Qualitative research indicates that external visual imagery is used and manipulated by athletes for achieving performance gains (Fournier, Deremaux, & Bernier, 2008). Thus, future research should explore differences in performance moderations that result from manipulations in angles of EVI.

Several applied implications are generated from the results of this research. First, the importance of considering task characteristics when recommending to athletes which imagery perspective may be more beneficial to use is highlighted. Second, for tasks requiring an effective use of line, where a performer is required to make specific changes in direction at precise spatial locations, here we present evidence to suggest that IVI provides the best imagery perspective to use to facilitate performance. Thus IVI is a meaningful psychological skill for sport psychologists and coaches to develop, and for athletes to use, when trying to achieve performance gains for slalom-based tasks. Third, some tasks require both form and changes in direction at precise spatial locations (e.g., a double straight-back somersault in gymnastics). With these types of task, switching between IVI and EVI might be relevant, though this may require more testing. To conclude, the results of this research provide evidence for the use of IVI to enhance performance on slalom-based tasks.

Chapter 3

The Additive Effects of Kinaesthetic Imagery to Internal Visual Imagery on the Performance of a Slalom-Based Task

Abstract

The current study aimed to extend the findings in the previous chapter by investigating whether the addition of kinaesthetic imagery (KIN) would provide beneficial effects to internal visual imagery on a slalom-based motor task of driving simulator performance. Three groups of participants performed the driving-simulation slalom task, before or after imagery conditions of internal visual imagery (IVI), kinaesthetic imagery combined with internal visual imagery (KIN and IVI), or as used in Chapter 2, a control mathematics task. The results showed that the KIN and IVI group achieved significantly quicker lap times than IVI and the control groups. The discussion of results includes an explanation of why the combination of imagery modalities might facilitate performance, with links made to research from the neurosciences. In addition, we discuss the difference between the present results and those from the previous chapter.

Introduction

Within the sports psychology literature, there are a number of studies that have demonstrated imagery to have beneficial effects on motor learning and performance (White & Hardy, 1995; Hardy & Callow, 1999). For example, Hardy and Callow (1999) studied the effects of two visual imagery perspectives; internal visual imagery and external visual imagery on the motor performance of tasks dependent on form for their successful performance. The results showed that the use of external visual imagery was superior to internal visual imagery for the acquisition and performance on form-based tasks. Further to this literature, the previous chapter presented results showing beneficial effects of internal visual imagery over external visual imagery and a control condition for driving simulator slalom-based performance. In addition, the results showed that the use of IVI benefitted performance relative to the participant's own performance before using imagery; an change effect not found in any other group.

In the previous chapter, we found that some participants used kinaesthetic imagery at the same time as internal visual imagery. In a preliminary post-hoc analysis, we showed that there was no relationship between performances for the participants who used IVI alone, or IVI with spontaneous KIN. However, this non-significance could be explained by a lack of power in the test, caused by small sample sizes of participants for those using IVI alone versus IVI with spontaneous KIN. In the discussion of the previous chapter, we recommended that follow-up study should investigate whether differences exist using a more systematic research protocol.

Theoretically, we might expect that KIN would provide additive performance improvements to IVI. KIN is defined as imagery involving the sensations of how it feels to perform an action, including the feeling of movement: the force, the effort, the spatial parameters etc (Callow & Waters, 2005). Like in the IVI, the participant has to represent the movement as if they themselves were performing the action. Thus, a combination of IVI and KIN may represent a richer experience of the action that either IVI or KIN alone (Hardy, 1997; Jeannerod, 1994).

Researchers have evaluated kinaesthetic imagery using a variety of different tasks. For example, Hardy and Callow (1999) investigated if kinaesthetic imagery had beneficial effects on motor performance with two experiments measuring form-based performance. In the first experiment, they tested participants without gymnastic skills and measured the participants learning of a simple gymnastics floor routine. They asked different four groups of participants to either use external visual imagery in two of the groups or internal visual imagery in the other two groups, with one group in each of the two groups either performing the respective visual imagery alone, or the visual imagery in combination with kinaesthetic imagery. The results showed no effect differences of whether the visual imagery conditions included kinaesthetic imagery. They discussed the results with cognitive theories of learning. In particular, they proposed that in early stages of learning, performers are more dependent on visual and verbal information (Fitts, 1964) and that kinaesthetic imagery may require experience (Fleishman & Rich, 1963). Since the participants were inexperience on the gymnastic task, they considered this might the reason for null results. In the second experiment, they conducted a further study with the same paradigm, but applied to participants with high-ability in rock climbing and decision making in boulder problems. A similar method was used, with four groups of participants, and this time, the results showed a significant main effect for integration of kinaesthetic imagery to the visual imagery conditions, a significant interaction between visual imagery perspectives and kinaesthetic imagery, thus supporting the proposition made in the discussion of the first experiment.

Within the neurosciences literature, there is evidence that the observation or the imagery of actions cause neural activations in similar areas of the brain as those used for executing action (Guillot, Di Rienzo, Maclntyre, Moran, & Collet, 2012). In the sports psychology literature, it is proposed that the closer that imagery is to actual performance, the greater the functional equivalence (Holmes & Collins, 2001; Smith et al., 2008). In this case, the functional equivalence concept refers to the shared or similarities between the neural processes or neural pathway activations underlying the cognition of imagery and actual movement performance. It is proposed that the more imagery is functionally equivalent to a performance, the more the imagery will have a beneficial effect on performance.

In the neurosciences literature, experimenters have investigated motor imagery (a combination consisting of internal visual imagery and kinaesthetic imagery). This research shows that motor imagery activates the same areas of the brain as those used in execution (Lacourse et al., 2005). Furthermore, researchers that have used brain imaging to separate IVI and KIN find complementary activations in areas of the brain used in action execution. For example, Guillot et al. (2009) investigated the brain networks used for IVI and KIN using fMRI. They found IVI and KIN have common and distinct areas of activations. The areas of common activity included motor-related regions and the inferior and superior parietal lobules, which are known to overlap with the areas involving motor execution. For the distinct areas of activity, they found that IVI activated the occipital regions and the superior parietal lobules, whereas KIN yielded more activity in motor-associated structures and the inferior parietal lobule. Therefore, these data show evidence of both integrated networks of brain activity for motor imagery, and evidence of independent neural networks.

Despite these findings, it is currently unknown whether kinaesthetic imagery alone, or in combination to IVI (i.e., motor imagery in the neuroscience literature), would show additive benefits for slalom-based tasks. Based on the findings of Hardy and Callow (1999), and on the concept of functional equivalence, we hypothesised that there would be more beneficial effects in a driving simulator slalom-based task when combing internal visual imagery with kinaesthetic imagery (motor imagery) than just using internal visual imagery alone. The rationale for the hypothesis was that the combination of IVI and KIN would provide richer equivalence and more likely influence subsequent performance.

Method

Participants

A total of 56 male participants were recruited (*M* age 21.77 years, *SD* 3.2) from Bangor University. In order to be included in the study, participants were required to have a VMIQ-2 score of equal to or less than 36 for each imagery perspective and modality. Four participants failed to achieve this criterion and their data were excluded from analyses. From this inclusion criterion, we were certain that the remaining 52 participants had at least moderately clear and vivid imagery ability. A post-experimental questionnaire showed that 7 participants reported switching or combining imagery perspectives or modalities. As a consequence, their data was also removed from the analysis.

The experiment consisted of a before and after imagery condition measure. In the experimental phase of the study, after the imagery condition, the 45 participants were separated into three groups (IVI, IVI+KIN, control; explained in more detail below), with each group consisting of 15 participants. All participants held a UK driving license for at least 1 year. Although the participants had no experience of playing the specified driving game used, we considered it necessary that all of the participants had a general expertise in the skill of actual driving. All of the participants reported playing computer games less than once per week in the preceding 6 months, and all had normal or corrected-to-normal vision. The participants provided written informed consent before participating to the experiment, and the Ethics Board of the School of Sport, Health and Exercise Sciences of Bangor University granted ethical approval for the study.

Experimental apparatus and task

As in the previous chapter, the task involved the completion of laps in a simulated rally driving circuit, with the average lap time used as the measure of performance. The driving-simulation slalom task was undertaken in a purpose-built driving simulator, incorporating a rally car seat, a force feedback steering wheel (which could be turned ±900° to keep the car on the circuit), 6-speed gear shifter and pedals. The driving simulator was connected to a 22 inch LCD monitor displaying the Gran Turismo 5 Prologue game (Codemaster, Warwickshire). In a training phase of the experiment, the track used was the Suzuka Circuit, which was 3.61 miles long and consisted of 20 bends (nine left and 11 right). In the experimental phase, the chosen track was the Eiger Nordward circuit, which was 1.51 miles long and consisted of 11 bends (five left and six right). In both phases, the circuits were driven as a time trial in dry, daylight conditions, with a Citroen C4 2.0 VTS Coupe'05 as the test car. The virtual reality display presented the driver's view out through the front window of the car as if actually driving the car.

Experimental phases

In order to train the participants to use the apparatus for the experimental phase, participants completed a 90-min training phase period where they had to achieve two criteria (derived from pilot testing). This included the completion of three consecutive laps under 170s and a plateau in performance, where the last three lap times fell within 5s of each other (cf. Wilson et al., 2007). If participants achieved the criteria, they then proceeded to the experimental phase. In the experimental phase, participants completed a total of 15 laps (five practice, five pre-imagery, five post-imagery) of the simulated rally driving circuit, with average lap time at pre and post-imagery condition being recorded.

The participants were randomly assigned to one of three groups; internal visual imagery (IVI), an internal visual imagery combined with kinaesthetic imagery (IVI&KIN), or maths-control. Following practice and pre-imagery performance measures, participants in the imagery groups were given an imagery script pertaining to the imagery group to which they were allocated. The IVI script detailed the task from a first person visual perspective, requiring the participants to image the task through their own eyes. The IVI & KIN script detailed the task from the same visual perspective, but also included all the physical feelings involved in driving. All scripts were developed using Lang's (1984) guidelines for including stimulus, response and meaning propositions into the script, and pilot tested (and amended based on feedback) prior to data collection. In order to maintain experimental control, scripts were developed by the author (rather than participants simply being asked to imagine driving). However, there was flexibility in the scripts (e.g., participants in the IVI group were asked to imagine their view change as they turned a corner). This flexibility allows participants to develop their own images, thus providing a degree of individualization, and consequently the images being meaningful for the participants (cf. Wilson et al., 2010). The scripts took ~120 s to administer. Example excerpts from the scripts are presented in Table 3.1.

Table 3.1 Imagery scripts

Example for the IVI script	Crossing the start line, you see the long straight in front of the car. Notice as the front of the car is going downhill slightly; it is travelling over a couple of horizons. As you approach the S-shape bend head, you see the line you want to take. As the car approaches the bend, you break to take the perfect line, turning first to your right and then quickly to your left, staying close to the bend, and accelerating after the bend.
Example for the IVI & KIN script	As the car accelerates, you feel the pressure through your right leg and foot to the accelerator pedal. As you come over the hill, you can see the start line in front of you. Crossing the start line, you see the long road in front of the car. Notice as the front of the car is going downhill slightly; it is travelling over a couple of horizons. As you approach the S-shape bend head, you see the line you want to take. As the car approaches the bend, you break to take the perfect line. As you break you feel your upper body move forward slightly, and hands tightening their grasp on the wheel, as you take the right then left hand turn, you feel your body moving with the turns, and you accelerate out of the bend.

Table 3.1 shows examples of the internal and external imagery scripts.

In the control condition, participants were required to answer standard arithmetic questions (e.g., 14 + 4 + 6). This type of active control group has been demonstrated to prevent the use of imagery during the experiment, but does not interfere with performance on the dependent variable (cf. Driskell et al., 1994; Callow & Hardy, 2005).

Measures

Time-taken to complete each lap was measured automatically (in seconds) by the Gran Turismo 5 Prologue software, and recorded by the experimenter. Note that the line of driving moderated the time, with cutting corners reducing the time compared to driving in the center of the road, but with collisions with curbs, or driving on the grass adding to the time.

In order to determine participants' imagery ability, all participants completed the Vividness of Movement Imagery Questionnaire-2 (VMIQ-2: Roberts et al., 2008). The VMIQ-2 has demonstrated acceptable factorial validity, construct validity and concurrent validity (see Roberts et al., 2008). The VMIQ-2 comprises 12 items that assess the ability to image a variety of movements. Participants are required to image each item using IVI, EVI, and KIN imagery, and rate the vividness of the image produced on a five-point Likert scale from 1 (perfectly clear and vivid) to 5 (no image at all). Cronbach's alphas for the current study were 0.86 (EVI), 0.90 (IVI), and 0.84 (KIN).

A manipulation/social validation questionnaire was also administered. The first question asked all participants whether they had been able to adhere to the treatment group. The remaining questions were only given to participants in the two imagery groups, and they asked whether the participant had experienced any switching of visual imagery perspectives during the task, and whether and to what extent they had experienced any kinaesthetic imagery during their use of visual imagery. An 11-point Likert scale ranging from 0 (*not at all*) to 10 (*very much so*) was employed.

Procedure

One week prior to the commencement of the experiment, participants completed the VMIQ-2. Participants attended the laboratory individually and were instructed that the purpose of the experiment was to examine driving ability under different conditions. The experimenter read standardized instructions detailing the training and experimental phases to the participants. Participants then completed the 90 min training phase, and all participants achieved the criterion level. On completion of the training phase, participants were given a 15 min break before commencing the experimental phase. The experimenter read standardized instructions explaining that they were to complete a number of trials as fast as they could; five practice trials, then five pre-imagery test trials and then five post-imagery test trials. Before each of the post-imagery test trials, participants in the IVI and IVI&KIN groups listened to a recording of the imagery script detailing the driving task from the visual imagery perspective to which they were assigned, and they were asked to use the imagery prior to performing each of the trials. Participants in the control group solved 10 maths questions prior to each post-test trial, as pilot testing had revealed that the calculation of 10 maths questions equated to the average time taken to complete the imagery scripts. Upon completion of each post-imagery test trial, participants rated the extent to which they drove as fast as they possibly could on an 11 point Likert scale from 0 (not at all) to 10 (very much so), with the intent that any participant who scored less than 5 would be asked to repeat the trial. In the event, no participants scored less than 5 for any trial. At the end of the post-imagery test trials, participants completed the manipulation/social validation questionnaire. On completion of the questionnaire, the participants were de-briefed as to the nature of the experiment and thanked for their participation.

Results

Preliminary analyses

Analysis of the VMIQ-2 data before the experiment revealed no differences in imagery ability between the different participant groups for IVI imagery ability $F(2, 42) = 0.46$, $p = 0.63$ and kinaesthetic imagery ability $F(2, 42) = 0.83$, $p = 0.45$.

Performance Scores

A two-factor mixed (between group × within test) ANOVA was used to analyse the data. The Box's M test of equality of covariance Matrices was not significant ($p= .270$), indicating the assumption of homogeneity of covariance across the groups was satisfied. The ANOVA revealed a significant main effect for test, $F(1, 42)=75.14$, $p<.001$, $\eta^2=.64$, indicating faster performance post-imagery compared to pre-imagery. There was also a significant group by test interaction, $F(2, 42)=22.30$, $p<.001$, $\eta^2=.52$, but the main effect for group was not significant, $F(2, 42)=.894$, $p=.417$. Tukey's corrected post-hoc tests on the significant interaction were conducted by comparing post-imagery to pre-imagery performance in each group. This analysis showed that there were significant improvements in performance in post-imagery compared to pre-imagery tasks for the internal visual imagery $F(1, 14)=22.28$, $p<.001$, and internal visual imagery and kinaesthetic imagery group $F(1, 14)=86.36$, $p<.001$. However, there was no difference in post-imagery performance compared to pre-imagery performance in the control group $F(1, 14)=.007$, $p=.935$. A second Tukey's corrected post-hoc analysis of the significant interaction was conducted between all groups in the pre-imagery performance and the post-imagery performance. The results for the pre-imagery performance showed no difference between the groups $F(2, 42)=0.41$, $p=.667$. Analysis of the post-imagery performance showed that performance was greater for the internal visual imagery and kinaesthetic imagery group than the control group $q(42)=13.06$, $p<.005$, and greater for the internal visual imagery and kinaesthetic imagery group than the internal visual imagery only group $q(42)=10.75$, $p<.005$. There was no significant difference between internal visual imagery group and the control group $q(42)=2.32$. As the none significant differences in the post-imagery test in the internal visual imagery and control group, an additional analysis was applied on the changed scores for these two groups, and Tukey's tests showed that performance improvement was significantly greater for the internal visual imagery than the control group $q(42)=7.64$, $p<.005$ (see Table 3.2).

Table 3.2 Driving Performance on Pre-imagery and Test

	Pre-imagery	Post-imagery
Group	M (SD)	M (SD)
Internal visual imagery	88.44 (2.14)	87.57 (1.76)
Internal visual imagery& kinaesthetic imagery	87.86 (2.00)	86.36 (1.69)
Control condition	87.84 (2.02)	87.83 (2.14)

Discussion

The aim of the present study was to test whether the combination of IVI with KIN would produce increased driving simulation slalom-based performance compared to IVI alone, and in comparison to a control condition. We hypothesized that increased functional equivalence between the imagery and the task performance would provide a better facilitation to performance. The results of the experiment replicated our previous study showing that IVI increased performance relative for post-imagery compared to pre-imagery performance, whereas there was no difference in performance for post-control compared to pre-control conditions. Furthermore, our hypothesis that the addition of KIN to IVI would cause an enhancement in performance relative to IVI alone was shown supported by the results.

The finding was robust despite the relatively small samples of participants tested. The main factors contributing to the effect was probably the fact that participants already had experience of the task, with all of the participants tested having held a UK driving license for at least 1 year (supporting the expertise proposal of Hardy & Callow 1999). Furthermore, within the study, all of the participants were trained to achieve an error-less and consistent performance (as in the previous chapter of the thesis). Both of these factors are related to the notion that performers had experience of having perceived the kinaesthetic components associated to actually performing the task. As we discussed in the introduction, experience of the performance may be critical for these effects (Fleishman & Rich, 1963; Hardy & Callow 1999).

These results provide an interesting first paper to demonstrate the additive benefits of IVI and KIN (commonly referred to as motor imagery in the neuroscience literature) on performance facilitation. We propose that these findings should be replicated in other slalom-based tasks, including tasks that use more ecologically valid tasks than the laboratory simulation task used in the present study. It could also be useful to evaluate how other tasks dependent upon a first-person, or body centered perspectives benefit from added use of the two types of imagery before performance. We propose that the main explanation of these effects is one of functional equivalence. It would therefore be interesting to show no differences in the use of IVI and KIN compared to IVI alone in tasks where a first-person perspective is less relevant. It could also be interesting to determine whether other types of task that more often rely in EVI, also show benefits from a combine EVI and KIN imagery condition.

Additional experimentation should investigate the neurological activations associated with IVI and KIN in order to create a hypothesis of a possible mechanism for the additive benefits of KIN and IVI in combination on performance. We propose two possible findings. One possibility is that the IVI and KIN activate independent areas of the brain, and perhaps the two independent areas being activated in the present study caused a double-priming effect. Another possibility is that IVI and KIN activate another brain area, not activated for IVI and KIN alone, and that this motor imagery activation is more closely related to the motor brain areas used in action execution. Therefore, in the first possibility, the enhance performance is caused by more brain activity in functionally equivalent brain areas, whereas the second possibility is that the specific brain areas activated more closely match to the brain areas used in execution.

The findings here advocate the use of IVI and KIN together for moderating sport performance. Furthermore, these findings support the use of motor imagery (consisting of IVI and KIN in combination) for patient rehabilitation in clinical practice (de Vries & Mulder, 2007). That said, there remains some debate about whether motor imagery can benefit patients (Ietswaart et. al., 2011). Based on the arguments above, and from the discussion of Hardy and Callow (1999), we might propose that the patient should have had experience in performing the actions in order for motor imagery to have an improvement on performance. While this will be true for the majority of stroke patients where motor imagery is often used, it could be that the time since the patient has had the stoke moderates the effectiveness of the motor imagery. That is to say that patients may forget their motor experience with time, and the KIN may become less effective when added to the IVI. We propose that studies in neuropsychology should consider this point when testing the effectiveness of motor imagery on rehabilitation.

In summary, the results of the current study provide evidence that the addition of KIN to IVI provides more beneficial effects over the IVI perspective alone on the performance of slalom-based task.

Chapter 4

The Neural Substrates for The Different Modalities of Movement Imagery

Abstract

Research from sport psychology highlights that internal visual, external visual and kinaesthetic imagery differentially effect motor performance (e.g. White & Hardy, 1995; Hardy & Callow, 1999). However, patterns of brain activation subserving these different imagery perspectives and modalities have not yet been established. In the current study, we applied the Vividness of Movement Imagery Questionnaire-2 (VMIQ-2) to study the brain activation underpinning these types of imagery. Participants with high imagery ability (using the VMIQ-2) were selected to participate in the study. The experimental conditions involved imagining an action using internal visual imagery, external visual imagery, kinaesthetic imagery and a perceptual control condition involved looking at a fixation cross. The imagery conditions were presented using a block design and the participants' brain activation was recorded using 3T fMRI. A post-experimental questionnaire was administered to test if participants were able to maintain the imagery during the task and if they switched between the imagery perspective/modalities. Four participants failed to adhere to the imagery conditions, and their data was excluded from analysis. As hypothesized, the different perspectives and modalities of imagery elicited both common areas of activation (in the right supplementary motor area, BA6) and dissociated areas of activation. Specifically, internal visual imagery compared to both external visual imagery and kinaesthetic imagery activated occipital and parietal and frontal brain areas (i.e., the dorsal stream) while external visual imagery activated the occipital ventral stream areas and

kinaesthetic imagery activated caudate and cerebellum areas. These results also provide initial biological validity for the VMIQ-2.

Introduction

Research demonstrated that the visual perception and visual imagination of images (from here on labelled as imagery) activates similar parts of the brain (for review, see Kosslyn & Thompson, 2003). This neural sharing between visual perception and visual imagery processes can be used to explain behavioural research showing matched perceptual performance to visually perceived versus visually imagined stimuli. For example, in Borst and Kosslyn (2008), participants were asked to perform a task that consisted of scanning over an array of dots in a perception condition, or in a mental image condition. After scanning, an arrow was presented and the participants had to decide whether the arrow pointed to the location that had been previously occupied by one of the dots. The time to scan the image increased with distance between the dots and arrow at comparable rates in the two tasks, and the rates of scanning in the perceptual tasks were highly correlated with the rates of scanning in the imagery tasks. These findings replicated earlier research carried out by Kosslyn, Ball, and Reiser (1978) showing that the time taken to make a perceptual judgement to an image increased with the distance that the participants needed to scan or imagine the image. In these two examples, as the time taken to scan the physical and imagined stimuli were similar, it can be suggested that the physical and imagery perception judgements relied on similar cognitive processes (see Smeets, Klugkist, van Rooden , Anema, & Postma, 2009; Shepard & Metzler, 1971; Kosslyn, 1975 for similar findings).

The shared neural processes between visually perceived and visually imagined stimuli are thought by some authors to involve motor planning processes (see for example Jeannerod, 1994). Consistent with this hypothesis, research demonstrates that prior imagery can moderate or prime subsequent execution behaviour. For example, in Ramsey, Cumming, Eastough, and Edwards (2010), participants were asked to imagine an action that was either congruent or incongruent to an action that the participant had to subsequently make. The data showed that participants were faster to initiate the subsequent action following the congruent compared to incongruent imagery conditions indicating that the shared processes between imagery and execution primed the action execution. As the effects were only to speed of action initiation, the authors argued that the priming was at the level of motor planning processes.

Although there is evidence for shared processes between visually perceived, visually imagined stimuli and action execution (McCormick, Causer, & Holmes, 2013), other authors have argued that not all neural processes for these behaviours are shared (Sirigu & Duhamel, 2001; Marzoli, Menditto, Lucafo, & Tommasi, 2013). This latter view is based on the characterizations of the dorsal and ventral systems, where visual perception and motor planning behaviours are posited to rely on independent neural processes (Goodale & Milner, 1992; Milner & Goodale, 2008; Goodale, 2011). Vision for perception is proposed to use a ventral stream (originating in areas V1 and V2 of the occipital lobe and extending into the temporal lobe, i.e. the what pathway) and vision for action is proposed to use a dorsal stream (originating in areas V1 and V2 of the occipital lobe and extending into the parietal lobe, i.e. the where pathway). Although this linear hierarchical pathway model has been challenged (Rizzolatti & Matelli, 2003; de Hann & Cowey, 2011), evidence for dissociated neural processing between the two behaviours is provided via a number of neuropsychology studies with brain-damaged patients. For example, research on patients with optic ataxia following damage to their dorsal stream showed errors in making actions to objects, but showed no difficulties in perceiving and identifying the same objects (Farah, 1990; Goodale et al., 1994). In contrast, research on patients with agnosia following damage to the ventral stream showed normal ability in making actions, but an inability to perceive or recognise the same objects (Goodale, Milner, Jakobson, & Carey, 1991). Further, recent stepwise logistic regressions supported this two system characterization (Borst, Thompson, & Kosslyn, 2011). Consequently, for the purpose of the present study we pursue the ventral dorsal distinction and importantly, in the context of the study's hypotheses, it follows that if vision for perception and vision for action are partly based on independent neural processes, there may also be dissociable neural processes between visual imagery and motor imagery (using vision for perception and vision for action processes).

In the sports psychology literature, for some time now, visual imagery and kinaesthetic imagery (i.e., the feeling of action; (Callow & Waters, 2005), which is somewhat analogous to motor imagery Jeannerod (1994) have been treated as separate processes. Further, visual imagery has been divided into two perspectives of internal visual imagery and external visual imagery. Internal visual imagery involves the participant imagining the visual scene as though looking through their eyes, and allows the performer to mentally rehearse the precise spatial locations, environmental conditions, and timings at which key movements must be initiated. External visual imagery involves the participant imagining the scene from a third person-perspective (looking at the self), and enables the performer to "see" the precise positions and movements that are required for successful performance (Hardy & Callow, 1999; Callow, Roberts, & Amendola, 2012).

Behavioural and neuroscience research provides support for these different visual perspectives and modalities of imagery. For example, external visual imagery has been shown to be more effective than internal visual imagery on tasks were form is important (Hardy & Callow, 1999), while internal visual imagery has been shown to be more effective than external visual imagery on tasks that require the rehearsal of precise spatial locations (Callow et al., 2013). Furthermore, a number of neuroimaging studies have shown distinct neural activity dependent on the imagery modality (e.g., Fourkas, Avenanti, Urgesi, & Aglioti, 2006; Lorey et al., 2009; Ruby & Decety, 2001). These distinctions in neural activity have then been used to explain the differential effects of imagery on motor performance, using the notion of functional equivalence (cf. Jeannerod, 1994, 2001). That is, the more similar (or functionally equivalent) the neural activity between imagery and the actual performance, the more effective the imagery is at moderating the performance (cf., Holmes & Collins, 2001; Smith et al., 2008).

Although research supports the idea that there are differences in the neural processes of imagery, there remains some debate about whether the different types of imagery defined in the sport sciences match those tested in the neurosciences (Callow & Roberts, 2012) and visa versa. Specifically, the conceptualization of imagery perspectives used in the neuroimaging studies differ markedly to both the conceptualization of internal visual imagery and external visual imagery, currently used in the sport psychology literature (e.g., Ramsey et al., 2010; Moran, 2009). For example, neuroscientific conceptualisations of internal imagery confound visual and kinesthetic modalities (e.g., Lorey et al., 2009; Ruby & Decety, 2001), and external imagery is usually of someone else (e.g., Fourkas et al., 2006; Lorey et al., 2009;

Ruby & Decety, 2001). Further, motor imagery as defined by Jeannerod (1994) involves internal visual and kinaesthetic imagery. While several other fMRI studies (e.g., Guillot et al., 2008) are clear to make distinctions between imagery modalities (i.e., visual and kinaesthetic), these studies do not examine visual perspective differences. Consequently, a precise understanding of what neural areas are involved in internal visual imagery and external visual imagery are currently not known, and, thus the current neuroscientific research cannot be used to precisely explain the differential effects of visual imagery perspectives on performance. Having said this, a neuroscientific explanation centering on functional equivalence and the matching of specific visual perspective with a slalom-based task (i.e., internal visual imagery) or form-based task (i.e., external visual imagery) does seem reasonable (cf., Callow & Roberts, 2010).

In the present study, to the best of our knowledge, we are the first to use fMRI brain imaging to evaluate the distinctions and relationships between neural activity during internal visual imagery (IVI), external visual imagery (EVI) and kinaesthetic imagery (KIN) to the same imagined action. While previous papers have shown behavioural and neural distinctions for the different imagery types, no paper has so far considered the unique activations for each imagery perspectives and modality to the same imagined action, and no papers have aimed to consider which parts of the brain show common activation for all of the imagery perspectives and modality. Based on the previous neuroimaging literature (Guillot et al., 2009; Vogeley & Fink, 2003), we hypothesised: (i) that there might be a common brain area activated by all of the imagery types in contrast to a control condition (most likely the supplementary motor area, premotor cortex or primary motor cortex); and (ii) that contrasts between the imagery types would reveal parietal lobe brain activation of the dorsal stream for internal visual imagery, bilateral ventrolateral occipito-temporal cortex activation of the ventral stream for external visual imagery and cerebella and basal ganglia activation for the kinaesthetic imagery (replicating Guillot et al., 2009).

In addition to investigating common and distinct brain activation for the three imagery types, we also aimed to demonstrate biological validity of the VMIQ-2 (Roberts et al., 2008). The VMIQ-2 has been behaviourally validated for quantifying internal visual, external visual and kinaesthetic imagery ability of movement (see Williams et al., 2012; Callow & Roberts, 2010 for examples of VMIQ-2 use in this context). Further, psychometrically the VMIQ-2 is robust with factorial, predictive and construct validity evident (Roberts, et al., 2008). However, these VMIQ-2 data are based on introspection and the self-report of a cognitive process, the objectivity of which has been criticized, with fMRI offered as more objective technique for measuring imagery (Guillot & Collet, 2005). In the context of the present study, if, when imaging an item from the VMIQ-2 during the fMRI scanning, distinct brain activity for the perspectives and modalities are evident, we will be provided with central evidence that the different imagery types delineated in the VMIQ-2 reflect those known to moderate behavioural effects reported in the literature. With the caveat that fMRI can only inform us on, rather than provide us with, a readout of mental contents (Aue, Lavelle, & Cacioppo, 2009) results of this nature (in conjunction with the other forms of validity previously demonstrated for the VMIQ-2) will offer initial biological validity for the VMIQ-2.

Method

Participants

From a screening of 200 volunteers who completed VMIQ-2, fifteen healthy participants who achieved a specified imagery criteria were selected for the experiment (see below for selection criteria). Participants were aged between19 and 29 years (M=21.87, SD=3.27), were all right handed, had normal vision, reported no neurological or psychiatric history and were under no medication. The Institution's School of Psychology Ethics Committee approved the experiment and informed consent was obtained from each participant prior to the experiment.

Imagery Assessments

The VMIQ-2 is a 12-item questionnaire designed to measure internal visual imagery, external visual imagery and kinaesthetic imagery of movement. Participants rate their ability to visually or kinaesthetically image the movement on a 5-point Likert scale ranging from 1 (*perfectly clear and as vivid, as normal vision or feel of movement*) to 5 (*no image at all, you only "know" that you are thinking of the skill*). The VMIQ-2 has demonstrated acceptable factorial validity, construct validity and concurrent validity (see Roberts et al., 2008).

Imagery ability criterion for the present experiment were devised by applying a cluster analysis to the raw VMIQ-2 data from Roberts et al. (2008; n=355). Specifically, the analysis showed a total of five clusters of participants, and in particular, a cluster of participants that had high imagery ability VMIQ-2 scores (i.e., EVI <33, IVI <20, KIN <21). These values were set as the criterion for the selection of the participants, ensuring that we only tested participants with high imagery ability. Fifteen of the 200 participants achieved these criteria.

After the brain-scanning phase of the study, all of the participants were asked to complete a second post-experiment questionnaire. The participants were asked to rate to what extent they were able to focus on each imagery perspective and modality during scanning (*1=not at all, 10=greatly*) and whether they switched between the perspectives and modality (*1=not at all, 10=always*). The participants also rated to what extent (*1=not at all, 10=greatly*) they were able to focus on the task and to what extent (*1=not at all, 10=greatly*) they were able to keep their eyes on the fixation cross during the rest period. if participants scored less that 5 on any of the questions would be excluded from the study. The questionnaire was used to assess if participants adhered to the experimental protocol, with those who scored 5 or less on any question being excluded from the study.

Conditions and Stimuli.

The experiment consisted of three experimental conditions (IVI, EVI and KIN). The visual stimulus consisted of the same one item from the VMIQ-2: "imagine yourself running up stairs". The control condition involved viewing of a fixation cross. There were four scanning blocks with six repetitions of each experimental condition, presented in a random order. This resulted in 18 trials in each block.

The visual stimuli for imagery conditions and control condition were presented with E-prime 2.0 software (Psychology Software Tools, Pittsburgh, PA), and they were projected onto a screen positioned behind the fMRI scanner that was viewed through a mirror mounted onto the head coil. All experimental condition were 26s long, and consisted of: an instruction period that informed the participants of the condition and the relevant stimulus (3000ms); the instruction "close your eyes and start imaging"

(2000ms); a blank screen presented while the participants conducted the imagery condition (10000ms); a sound to inform the participants that it was the end of the condition and to open their eyes (1000ms); and finally the baseline condition where the participants were required to keep their eyes fixed onto a cross in the middle of screen (10000ms).

Procedure

As a result of the VMIQ-2 screening, participants who were not selected for the experimental protocol were thanked for their time and did not proceed further in the study. Those who were selected attended a practice protocol procedure (not in the scanner) where: the meaning of three subscales of VMIQ-2 was explained; MRI safety issues were introduced; and; a practice session of the task was performed. The purpose of the practice was to familiarize the participants with the scanning procedure. Less than a week after the practice session, the participants attended the experimental scanning session. Following the scanning session, participants completed the post experimental questionnaire.

fMRI Data Acquisition and Data Analysis

The experiment was carried out at Bangor University using Phillips 3.0T scanner system fitted with EPI gradient overdrive. Head movements were minimized in all participants using foam pads. An anatomical scan (T1 weighted) (voxel size of 1.13*1.13*1mm, TR 7.45 s, TE 3.05, FOV 128x 3mm, matrix size 128x128mm, slice thickness 1.00mm, flip angle 20.00) was acquired for each participant before the functional scan. Functional MR images were acquired using a multislice two-dimensional gradient echo EPI sequence (voxel size of 2.5*2.5*2.5mm, TR 2.5s, TE

35ms, FOV 240*240*122mm, matrix size 96*96mm, slice thickness 2.5mm, flip angle 90.00) to measure the blood oxygenation level dependent (BOLD) signal as a function of time.

First-level analysis was processed for each run of each participant using FSL (5.98, Analysis Group, FMRIB, Oxford, UK). Motion correction was carried out using MCFLIRT (FMRIB's Linear Registration Tool) and slice correction was carried out using 'regular up' style correspondence with the actual slice acquisition. Spatially smoothing using a 5mm full-width-at-half-maximum Gaussian kernel and high pass filtered as 100s were chosen at this stage as well.

Separate model regressors for each task condition where developed to allow the general linear model to be applied to the data of each participant, the different parts of each trial were modeled separately. Nine contrasts were carried out on the imagery conditions. These included: external visual imagery vs. perceptual control condition; internal visual imagery vs. perceptual control condition; kinaesthetic imagery vs. perceptual control condition; external visual imagery vs. internal visual imagery; external visual imagery vs. kinaesthetic imagery; internal visual imagery vs. external visual imagery; internal visual imagery vs. kinaesthetic imagery; kinaesthetic imagery vs. internal visual imagery, and; kinaesthetic imagery vs. external visual imagery. Finally, a higher-level analysis was conducted for all the participants where a single group average was applied. A cluster correction was used with Z threshold set at 2.3, $P < 0.05$ for a whole brain analysis.

Results

The post-experimental questionnaire showed that 4 participants switched between imagery perspectives during the brain-imaging task (with a score greater than 5). As a consequence, their data was removed from data analysis. In the results, we first present the contrast between each imagery condition and the perceptual control conditions, and then we present the contrasts between the imagery conditions. The results were presented in terms of significant peak activations within significant clusters. The anatomical area and the associated Brodmann area for the MNI peak activation coordinate are presented. These multiple peak activations were presented in order to explore the multiple regions of activity within the clusters (see Guillot et al., 2008 for a similar reporting of analyses).

Imagery vs. Perceptual Control Conditions

The contrast between external visual imagery and the perceptual control condition revealed significant activations in the expected motor networks of bilateral precentral gyrus (BA6), right supplementary motor area (BA6) and extended to both sides of superior and inferior parietal lobule (BA7). There were also activations in the left superior frontal lobule (BA6) and right precuneus (BA5). The comparison between internal visual imagery and the perceptual control condition showed similar areas of activation, including bilateral precentral gyrus (BA6), right supplementary motor area (BA6) and left superior and inferior parietal lobule (BA7). Finally, the analysis of the contrast between kinesthetic imagery and the perceptual control condition showed significant activations in left precentral gyrus (BA6), bilateral supplementary motor area(BA6) and left cingulum (BA32) (Table 4.1).

Table 4.1. Coordinates of significant activations for the EVI, IVI and KIN conditions > the perceptual control condition

	EVI vs. control					IVI vs. control				KIN vs. control			
Anatomical areas	Hemisphere	x	y	z	z-value	x	y	z	z-value	x	y	z	z-value
Frontal sup (BA6)	L	-22	-4	54	4.39								
Precentral (BA6)	L	-38	-6	42	4.23	-38	-6	44	4.43	-40	-6	44	3.94
Precentral (BA6)	R	38	-2	44	4.32	48	2	42	4.45				
		46	0	44	4.31	36	-6	50	4.35				
		34	-8	44	4.23								
Supp motor area (BA6)	L									-8	-2	66	4.41
										-12	4	60	4.27
										-8	4	62	4.23
Supp motor area (BA6)	R	2	4	58	4.37	12	2	62	5.03	12	8	62	4.79
						4	6	62	4.9				
						8	4	60	4.88				
Parietal Inf (BA7)	L	-30	-52	54	4.79	-32	-50	54	3.79				
Parietal Inf (BA7)	R	34	-60	54	4.06								
		24	-52	54	3.72								
Parietal Sup (BA7)	L	-30	-66	64	4.36	-24	-60	54	4.26				
		-34	-62	58	4.08	-22	-56	52	4.17				
		-20	-72	66	3.69	-34	-66	62	3.84				
		-34	-70	58	3.64	-32	-60	56	3.84				
		-24	-62	54	3.6	-26	-68	66	3.65				
Parietal Sup (BA7)	R	24	-70	66	3.29								
Precuneus (BA5)	R	10	-50	48	3.87								
		6	-46	66	3.76								
		8	-58	52	3.6								
Cingulum Mid (BA32)	L									-4	10	46	4.26

Contrasts Between Imagery Conditions

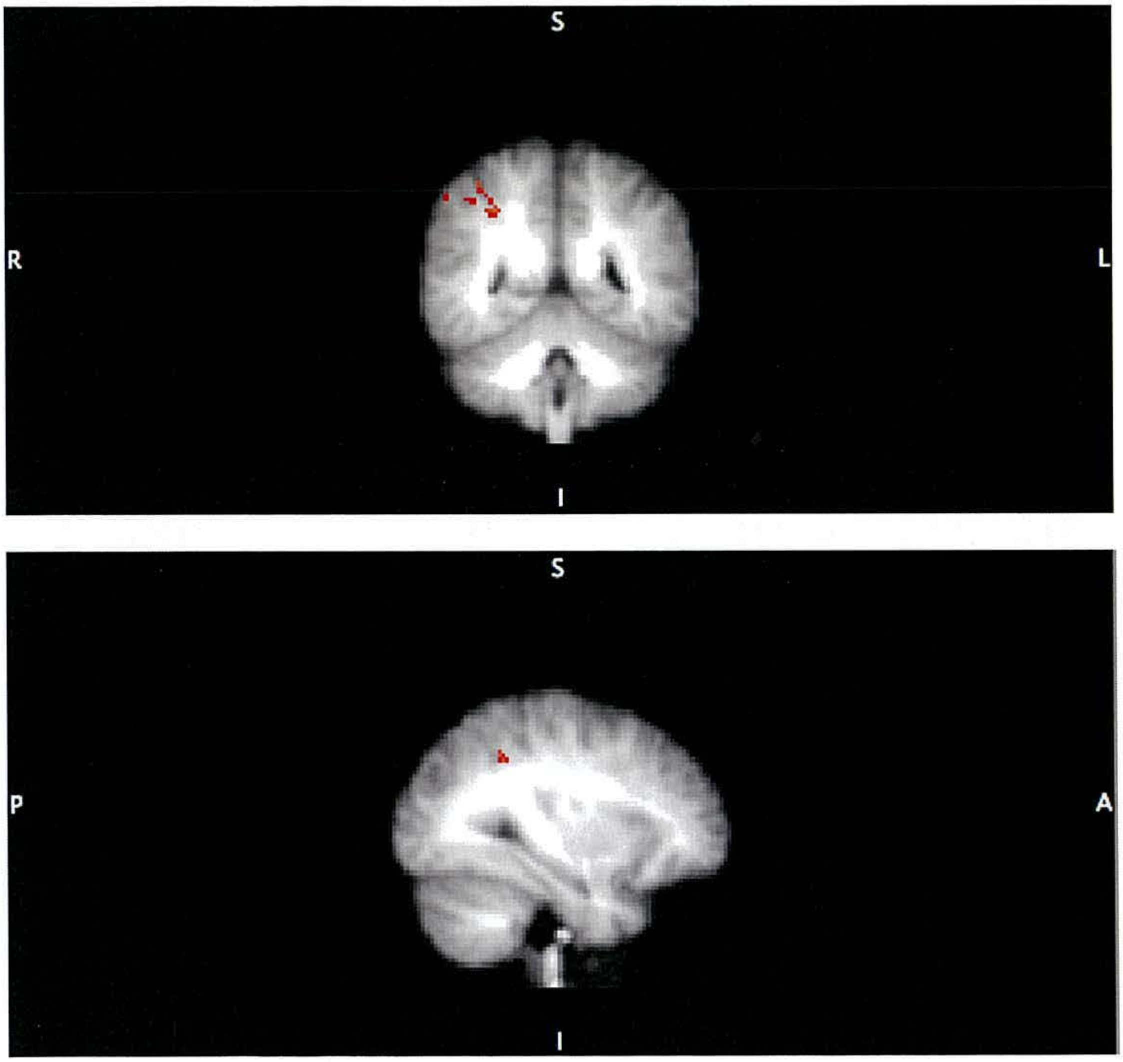
When IVI was subtracted from EVI, no significant activations were present. However, when KIN was subtracted from EVI, significant activations were found in right inferior parietal lobule (BA7), right superior and middle temporal gyrus (BA22, BA39), and right middle occipital cortex (BA39) (Table 4.2).

Table 4.2 Coordinates of significant activations for the EVI condition > the IVI and KIN conditions

		EVI vs. IVI				EVI vs. KIN			
Anatomical areas	Hemisphere	x	y	z	z-value	x	y	z	z-value
Parietal Inf (BA7)	R					34	-80	48	3.11
Temporal Sup (BA22)	R					68	-48	16	3.46
Temporal Mid (BA39)	R					62	-64	16	3.11
Occipital Mid (BA39)	R					42	-78	36	3.79
	R					42	-68	24	3.29
Occipital Mid (BA39)	R					50	-76	26	3.17

When EVI was subtracted from IVI, peak activations were found in left superior occipital lobe (BA7, BA18), right middle occipital gurus (BA7) extending to bilateral superior and inferior parietal lobule (BA7, BA40), both sides of the precuneus (BA7), right cuneus (BA7, BA19); in the frontal areas including bilateral inferior frontal gyrus (BA44, BA45), bilateral medial frontal gyrus (BA9, BA45, BA46, BA47), right superior frontal gyrus (BA45), right precentral cortex (BA6, BA9); and in the left SupraMarginal (BA40), left Thalamus, right caudate and putamen and both sides cerebellum (figure 4.1). Although the contrast of KIN subtracted from IVI showed less activations, there were significant activations located firstly in right middle occipital cortex (BA19), right middle temporal gyrus (BA21) and right superior and inferior parietal lobule (BA7, BA39) (figure 4.2); and secondly in the right inferior frontal gyrus (BA44), right superior frontal lobe (BA10), right middle frontal gyrus (BA9, BA46); activations were also found in right angular and right middle cingulum (BA23) (Table 4.3).

Figure 4.1: Peak activations for the IVI>EVI



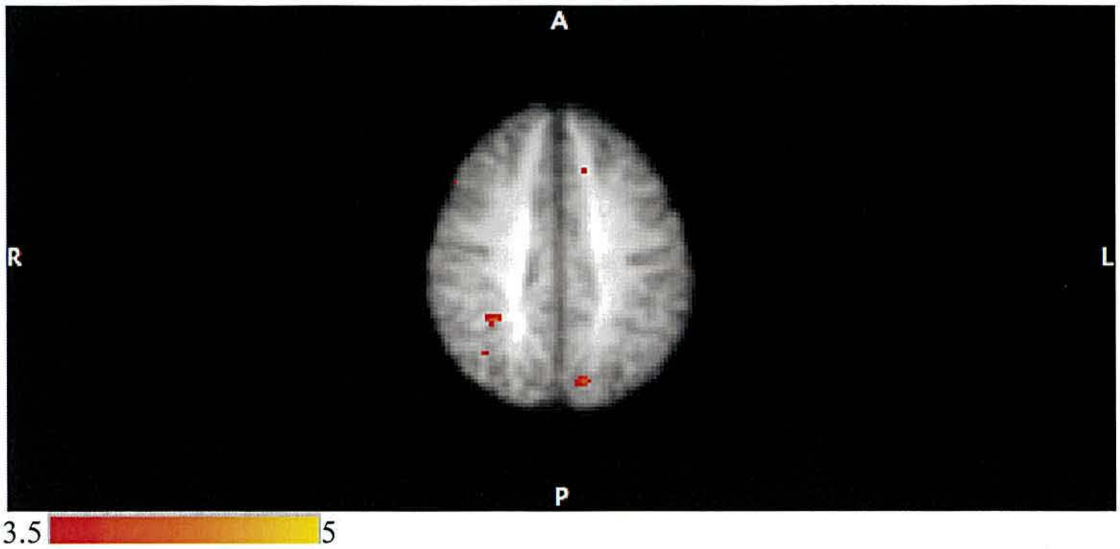
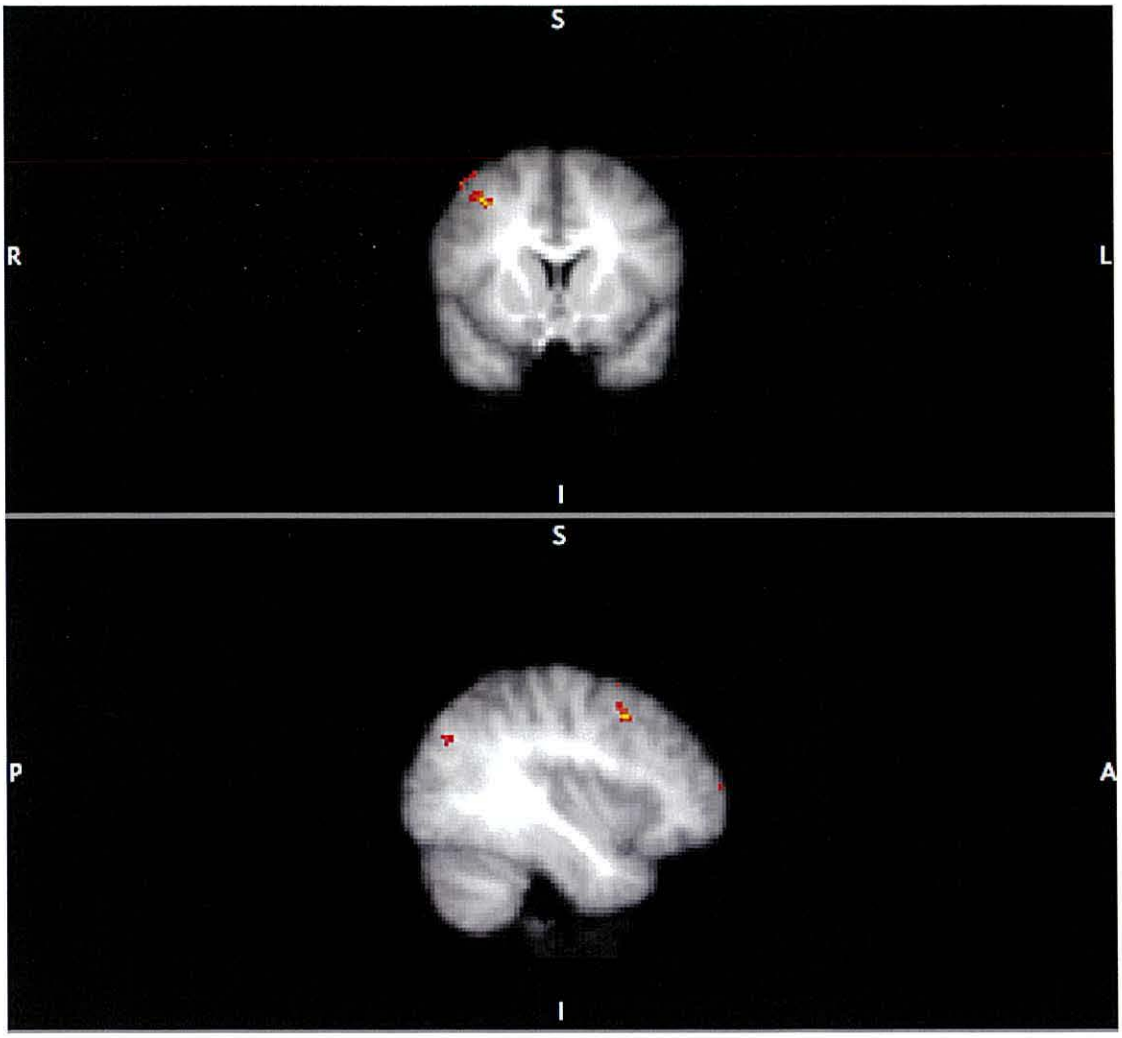


Figure 4.2: Peak activations for the IVI>KIN



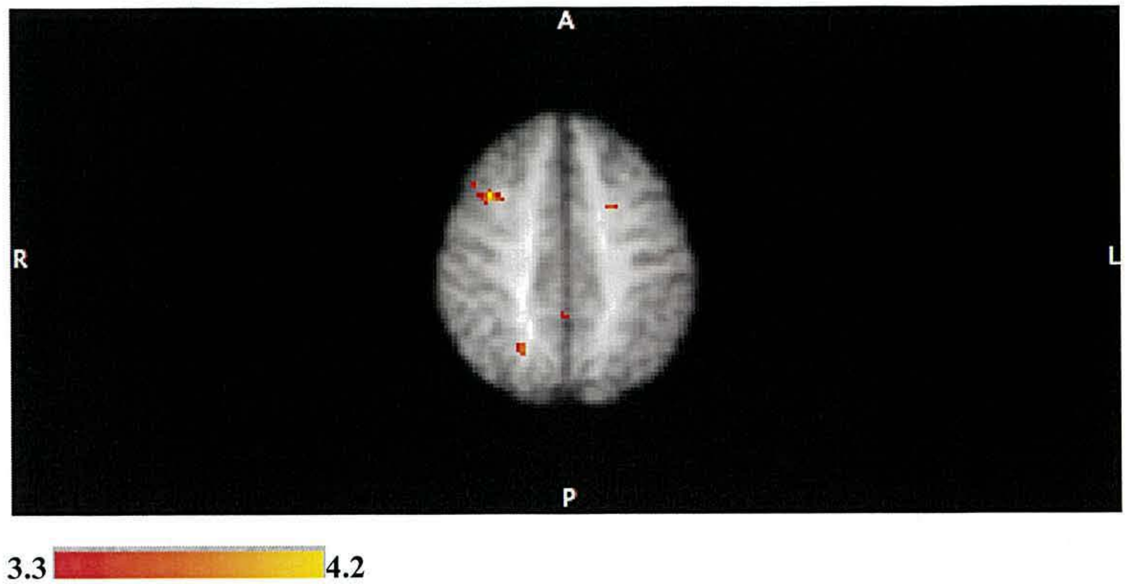


Table 4.3 Coordinates of significant activations for the IVI condition >the EVI and KIN conditions

		IVI vs. EVI				IVI vs. KIN			
Anatomical areas	Hemisphere	x	y	z	z-value	x	y	z	z-value
Frontal Mid (BA9)	R	36	12	48	3.29	38	14	46	4.45
						46	18	50	3.95
						46	18	42	3.72
						38	10	50	3.58
Frontal Mid (BA44)	R					50	20	42	3.65
Frontal Mid (BA45)	R	42	44	18	3.74				
Frontal Mid (BA46)	L	-38	36	22	3.22				
Frontal Mid (BA46)	R	52	52	6	4.26	40	58	10	3.62
		20	44	16	3.8	42	52	10	3.52
		48	54	10	3.23				
Frontal Mid Orb (BA47)	L	-32	46	-4	3.23				
Frontal Inf Tri (BA44)	L	-56	24	32	4.05				
Frontal Inf Tri (BA45)	L	-42	34	8	3.12				
		-40	36	14	3.71				
Frontal Inf Tri (BA47)	L	-40	36	2	3.11				
Frontal Inf Tri (BA45)	R	50	38	6	3.18				

		62	30	24	3.12				
Frontal Inf Oper (BA44)	R	54	22	40	3.74	56	20	38	3.76
		60	18	36	3.06				
Frontal Sup Orb (BA11)	R	24	62	-2	3.13				
Frontal Sup (BA10)	R					24	66	24	3.91
						26	66	18	3.69
						22	70	10	3.62
						26	68	6	3.46
Precentral (BA6)	R	62	12	38	3.12				
Precentral (BA9)	R	40	8	44	3.96				
Parietal Inf (BA40)	L	-40	-50	50	3.1				
		-36	-48	48	3.09				
		-46	-48	44	2.9				
Parietal Inf (BA40)	R	32	-48	42	4.17				
		40	-48	56	3.97				
		42	-46	48	3.88				
		56	-50	48	3.84				
		54	-40	44	3.42				
Parietal Inf (BA39)	R					42	-56	50	3.66
Parietal Sup (BA7)	L	-12	-70	44	3.28				
		-26	-60	52	3.71				
Parietal Sup (BA7)	R	8	-80	50	3.33	22	-62	46	3.72
Temporal Mid (BA21)	R					70	-48	0	3.98
SupraMarginal (BA40)	L	-52	-38	36	3.23				
		-64	-32	40	3.08				
Occipital Mid (BA7)	R	34	-62	38	3.73				
Occipital Mid (BA19)	R					48	-84	24	3.84
						40	-74	36	3.58
Occipital Sup (BA7)	L	-18	-66	40	3.83				
Occipital Sup (BA7)	R	14	-80	46	3.29				

Occipital Sup (BA18)	L	-18	-70	30	3.73				
Occipital Sup (BA19)	R	18	-76	44	3.23				
Precuneus (BA7)	L	-10	-78	46	4.49				
		-8	-76	56	4.4				
		-6	-80	54	4.29				
Precuneus (BA7)	R	6	-76	50	3.12				
Cuneus (BA19)	R	16	-80	40	3.08				
Thalamus	L	-6	-30	22	4.1				
		-16	-22	18	3.29				
Angular (BA39)	R					58	-66	34	4.19
Caudate	R	12	16	14	3.41				
Putamen	R	20	10	10	3.25				
Cerebellum Crus1	L	-34	-70	-34	3.87				
Cerebellum Crus2	L	-6	-76	-28	4.04				
		-40	-74	-36	3.05				
		-40	-62	-46	3.42				
		-46	-62	-48	3.33				
	R	6	-82	-28	3.8				
		4	-78	-28	3.65				
Cerebellum 6	L	-28	-54	-34	3.23				
Cerebellum 8	L	-30	-68	-46	3.82				
		-18	-68	-42	3.48				
Cingulum Mid (BA23)	R					6	-42	38	4.95

When EVI was subtracted from KIN, it showed activations in left medial frontal gyrus (BA47), left inferior frontal gyrus (BA45, BA47), and both sides of the caudate. When IVI was subtracted from KIN, no significant activations were present (Table 4.4).

Table 4.4 Coordinates of significant activations for the KIN condition > the EVI and

IVI conditions

		KIN vs. EVI				KIN vs. IVI			
Anatomical areas	Hemisphere	x	y	z	z-value	x	y	z	z-value
Frontal Mid Orb (BA47)	L	-32	42	-6	3.29				
Frontal Inf Orb (BA47)	L	-44	40	-4	3.35				
Frontal Inf Tri (BA45)	L	-44	42	0	3.42				
		-44	42	4	3.36				
		-44	34	8	3.22				
Caudate	L	-14	-4	20	7.68				
		-22	8	20	3.75				
Caudate	R	16	14	22	4.13				
		20	20	14	3.97				

Discussion

The current study used fMRI to identify and distinguish the brain networks used for different imagery perspectives and modalities. We hypothesized that different imagery perspectives and modalities might activate both common and distinct neural pathways. Firstly, we assumed that all the imagery perspectives and modalities might activate common motor related areas normally involved in action planning processes. At a general level, as expected, significant activations were found for all imagery conditions in the right supplementary motor area (BA6), an area associated with motor planning processes. Secondly, we expected that there would be some distinct neural activations when comparing the imagery conditions directly. Specifically that internal visual imagery might activate the parietal lobe, external visual imagery might show some temporal activation, and kinaesthetic imagery might activate regions of the cerebellum and basal ganglia. The results were mostly consistent with our expectations. Indeed, there were significant activations in both hemispheres of the parietal lobe for the internal visual imagery condition in contrast to external visual imagery. Also, as expected, the comparison between kinaesthetic imagery and visual imagery conditions showed significant activation in the caudate, within the basal ganglia.

More specifically, when comparing the visual imagery perspectives, consistent with previous studies, significant brain activations were found in supplementary motor cortex (BA6) during both internal visual imagery and external visual imagery conditions (Gerardin et al., 2000; Guillot et al., 2009; Lafleur et al., 2002; Lotze & Halsband, 2006; Stephan et al., 1995). Both conditions also activated the precentral gyrus (BA6), known from neuroimaging literature to be involved in spatial attention, spatial working memory and updating spatial mental operations (Boussaoud, 2001; Hanakawa et al., 2003; Picard & Strick, 2001). Given these previous results, activation in BA6 is likely involved with the updating of spatial information required to complete both types of visual imaging involved in our task.

Direct comparison between the two visual imagery perspectives showed no significant increased activation when internal visual imagery was subtracted from external visual imagery, leading to the suggestion that external visual imagery used all of the same areas of the brain as those used for internal visual imagery. However, parietal lobe activation in the dorsal stream was detected when external visual imagery was subtracted from internal visual imagery. This is consistent with Committeri et al. (2004) who found viewer-centered (internal) coding was mainly processed in the dorsal stream and frontal areas. In addition to this distinction, internal visual imagery activated a large area in the frontal lobe (consistent with findings reported by Guillot et al., 2009).

Although external visual imagery showed no areas with increased activation when compared with the internal visual imagery task, both visual imagery perspectives activated the primary visual cortex when contrasted with the kinaesthetic imagery task (replicating Klein, Paradis, Poline, Kosslyn, & Le Bihan, 2000; Kosslyn, Ganis, & Thompson, 2001; Kosslyn & Thompson, 2003; Slotnick, Thompson, & Kosslyn, 2005). This result somewhat supports the hypothesis that external visual imagery activates the ventral vision for perception brain areas. In fact, our results show that both internal and external imagery activate ventral stream areas, but that internal visual imagery additionally activates the dorsal vision for action brain areas.

In the sport psychology literature, researchers have found that different visual imagery perspectives can cause different effects on motor performance. For example, Hardy and Callow (1999) demonstrated that external visual imagery was superior to internal visual imagery for the acquisition and performance of criterion tasks that were heavily dependent on form for their successful performance. In the literature, these results are debated as some researchers hold the opinion that different imagery perspectives do not exist (see Callow & Roberts, 2012 for a narrative on this issue). Our results here refute this opinion. Indeed, we provide neuroscientific evidence that there are distinct brain areas underlying the two visual imagery perspectives, suggesting that the two visual imagery perspectives do exist (or at least that IVI activates more brain regions than EVI). For the application of these findings in sport, where imagery is used to moderate performance, as the two visual imagery perspectives activate distinct brain pathways, we suggest that athletes should be instructed with appropriate imagery perspectives that specifically facilitate their performance.

While the contrasts between IVI and KIN and EVI and KIN showed a large overlap in activity, divergent patterns of activity were also observed. For example, increased activation in the occipital lobe (BA19) was shown when KIN was subtracted from IVI. This supports previous neuroimaging studies that found visual areas to be involved in visual imagery (Jackson, Meltzoff, & Decety, 2006; Mellet, Petit, Mazoyer, Denis, & Tzourio, 1998; Solodkin, Hlustik, Chen, & Small, 2004; Kosslyn & Thompson, 2003; Zacks, Ollinger, Sheridan, & Tversky, 2002). Additionally, when EVI was subtracted from KIN, there was increased activation in sub-cortical brain regions, including bilateral caudate. These data are consistent with the study by Guillot et al. (2008), and studies reporting that the sub-cortical brain regions are associated with the control of action (Graybiel, 2000). Taken together, KIN may be more driven by the sub-cortical brain regions than the visual imagery perspectives.

With reference to the biological validity of the VMIQ-2, given that distinct brain activity for the perspectives and modalities was demonstrated, we have central evidence that the different imagery types delineated in the VMIQ-2 reflect those known to moderate behavioural effects reported in the literature. Coupling these results with the previous behavioural and psychometric validity, the VMIQ-2 seems to be a robust measure of perspective and modality for both a research and applied setting.

The current study has two limitations. First, we used high performers on the VMIQ-2, and as high performers may be the reason that they have such separable regions for performance of the task. By focusing on high performing visual and kinaesthetic imagers, the results may not entirely generalize. To overcome this limitation, and given that imagery ability is a very important moderator in motor learning effectiveness, future studies should consider whether different brain regions are moderated by imagery ability, and whether contrasts between high and low imagers (or vice versa) for each imagery perspective and modality moderates BOLD activity. Moreover, it would be interesting to know whether there are differences in the imagery ability moderation for the brain areas commonly activated for all imagery perspectives and modalities, or whether the imagery ability moderation is confined to the regions that are selectively active for each specific imagery perspective and modality.

The second limitation relates to the use of closed eyes during the task that may introduce some variations in the underlying BOLD signal due to typical eyes open eyes closed activations/deactivations for different regions of the visual cortex, however this is only a potential confound for the individual task verses control condition, and not for the between task comparisons, and so does not invalidate the main findings.

Despite these limitations the present study has relevant applied implications. In sports psychology, based on the notion of functional equivalence, researchers have advocated EVI for form-based tasks such as gymnastics (e.g., Hardy & Callow, 1999) and IVI for slalom-based tasks such as ski-slalom (Callow et al., 2013), the data here supports this delineation.

We suggest that IVI and KIN involve independent processes. This is consistent with Hardy and Callow (1999), who found that expert participants produced significant performance increases from the use of kinaesthetic imagery compared to the other visual imagery perspectives. From our results here, we might suggest that expertise facilitates the priming of performance through specific well-developed motor representations in the sub-cortical brain regions. That is to say that expertise will be associated with precise neural motor skill networks, specific to the individual, and it might be that kinaesthetic imagery is able to use these precise networks to moderate performance. On the applied side of this finding, athletes are advocated to use visual imagery with kinaesthetic imagery.

These results have implications for neurorehabilitation. Interestingly, researches on examination of the imagery in poststroke literature have report variations in imagery instructions regarding imagery perspectives and modality (de Vries & Mulder, 2007; Nilsen, Gillen, & Gordon, 2010). However, only one study has discussed the effects of different imagery perspectives used for post-stoke motor rehabilitation, and failed to find the differences (Nilsen, Gillen, DiRusso, & Gordon, 2012). Given our results, when using imagery for post-stoke motor rehabilitation, patients with their specified damaged brain areas should be assigned to using appropriate imagery type for their rehabilitation. For example, patients with temporal lobe damage may practice on external visual imagery to regenerate the inactive areas. Therefore, our results could help to select groups of patients that could benefit from this therapeutic approach.

Further, given the evidence here we suggest that clinical settings consider the imagery types as separate processes within intervention work as this may provide additional processing benefits.

In summary, the current study aimed to find common and distinguished brain networks for different imagery perspectives and modality. The results revealed common activity in the right supplementary motor area (BA6), while also showing divergent patterns of activation for internal visual imagery, external visual imagery and kinaesthetic imagery. Specifically, internal visual imagery activated the parietal lobe, external visual imagery showed some temporal activation, and kinaesthetic imagery activated sub-cortical parts of the cerebellum. These results expand the pervious study of Guillot et al. (2008) by examine visual perspective differences, suggesting that internal visual imagery and external visual imagery are distinguishable. In addition, as internal visual imagery and kinaesthetic imagery involve independent processes, careful consideration should be given to the actual visual perspectives and modalities that participants use during motor imagery.

Chapter 5

The Neural Basis of Imagery Ability for Different Imagery Modalities

Abstract

Research has shown that imagery ability is a very important moderator in the effective use of motor imagery (e.g., Isaac & Marks, 1994; Mantani, Okamoto, Shirao, Okada, & Yamawaki, 2005). As imagery ability varies across individuals, there may be varying patterns of brain activation underlying imagery ability in internal visual imagery (IVI), external visual imagery (EVI) and kinaesthetic imagery (KIN). The current study aimed to investigate the neural substrate of imagery ability for IVI, EVI, KIN and IVIKIN (combination of IVI and KIN) using block design functional magnetic resonance imaging (fMRI). The vividness movement imagery questionnaire-2 (VMIQ-2) was applied to select the high and low imagers. The experimental conditions involved imagining an action using internal visual imagery, external visual imagery or kinaesthetic imagery and a perceptual control condition involved looking at a fixation cross. Greater BOLD activity and more different areas of brain activity were detected in the low imagers than the high imagers during all imagery conditions. Specifically, the hippocampal regions, the medial temporal lobe and the superior temporal gyrus were more activated in the low imagers. These results highlight that people with higher imagery ability are more efficient in recruiting relevant brain areas to generate vivid images. Based on these results, the assessment of participants' imagery ability prior to clinical neurorehabilitation and sport psychology settings is recommended.

Introduction

Mental imagery plays an important role in human cognition. For example, it is thought to be engaged in the planning and execution of goal-directed movements (Jeannerod, 2001; Jeannerod & Jacob, 2005), it can assist motor learning and performance (e.g., Driskell et al., 1994), it is thought to contribute to conscious experience (Marks, 1999), it has been implicated within working memory (Bywaters, Andrade, & Turpin, 2004), and it is thought to underlie spatial and magnitude cognition (Coello et al., 2008). Within some of these areas of human cognition and functions, individual differences in imagery ability have been shown to influence the effective use of imagery (e.g., Isaac & Marks, 1994; Mantaniet al., 2005). These individual differences in imagery ability can be moderated by other factors. For example, we know that imagery ability is moderated by motor expertise, gender and age (Isaac & Marks, 1994; Kosslyn, 1980, 1999; Richardson, 1994). Given the importance of imagery for human cognition and functions, and the moderating role that imagery ability could have, it has been argued that the use of imagery for performance moderation should consider measuring imagery ability prior to an imagery engagement in order to understand and enhance the benefits that the imagery has on performance gains.

Vividness, controllability and temporal organization are three key characteristics of imagery ability (Callow & Hardy, 2005; Guillot & Collet, 2005; Holmes, 2007; Williams et al., 2012). Researchers have used a variety of techniques to measure these characteristics. Within sports psychology, the most commonly used method is through the validated self-report questionnaires such as Vividness of Visual Imagery Questionnaire (VVIQ; Marks, 1973), Vividness of Movement Imagery Questionnaire-

2 (VMIQ-2; Roberts et al., 2008) and Movement Imagery Questionnaire-Revised (MIQ-R; Hall & Martin, 1997). These questionnaires are used to measure individual differences in visual imagery and/or kinaesthetic imagery (the feeling of a movement) by asking participants to imagine themselves performing a number of movements and then rating the vividness of the image. Other methods such as mental chronometry are also used to measure imagery ability. This method compares the time taken to visually scan an object or to perform an action, in comparison to the mental imagery of the same activity. The research shows that greater congruence of temporal organization between actual and imagined activity is indicative of greater imagery ability (cf. Guillot & Collet, 2005). Further measurements have included the autonomic nervous system (e.g., skin resistance, temperature and heart-rate and respiratory frequency) and surface electromyography activity, with stronger responses and higher frequencies being associated with better imager ability (e.g., Guillot, et al., 2004).

With the advent of functional imaging techniques such as Positron Emission Tomography (PET) and more recently, functional Magnetic Resonance Imaging (fMRI), researchers have used these techniques to investigate the relationship between imagery ability and neural activation. These studies can be separated into two approaches. Firstly, research has compared the neural activation of motor imagery before and after training (Lacourse et al., 2005; Baeck et al., 2012). For example, Baeck et al. (2012) compared brain activity of 18 participants imaging shooting (motor imagery) before and after 90 hours of shooting practice. They discovered that basal ganglia showed increased activity after the shooting practice compared to before shooting practice.

The second approach has compared the neural activity of expertise with novices (Meulen, Allali, Rieger, Assal, & Viilleumier, 2014; Chang et al., 2010; Guillot et al., 2008; Wei & Luo, 2010). Within this approach, there are two ways of selecting expertise. The first way is to compare professional athletes with physical expertise to novices (Chang et al., 2010; Wei & Luo, 2010) with the assumption that the athletes have high imagery ability in comparison to novices. For example, Chang et al. (2010) compared neural correlates of motor imagery for elite archers and novice non-archers. The results showed that the premotor and supplementary motor areas, and the inferior frontal region, basal ganglia and cerebellum were active in the novice non-archers, whereas elite archers showed activation primarily in the supplementary motor areas. The second way is to use psychological tools (e.g., the VMIQ-2) or tasks coupled with mental chronometry to separate participants into good or poor imager groups (e.g., experts versus novices) based on their imagery ability scores (Meulen et al., 2014; Guillot et al., 2008).

The findings from this second approach (and its two ways) is mixed. Some studies showed higher brain activation in the expert participants than novices for imagery use (e.g., Baeck et al., 2012) and some studies showed that participants with high imagery ability had greater brain activity in comparison to those with low imagery ability (e.g., Meulen et al., 2014). In contrast, other studies showed more activation for novices in comparison to experts (e.g., Chang et al., 2010) and higher activations in specific brain areas for people with low imagery ability compare to those with high imagery ability (e.g., Guillot et al., 2008). Several reasons may explain these different results. One possible reason could be the way that expert participants were defined and selected. With the approach to define the expert athletes as good imagers, it is possible that these professional athletes in fact have moderate imagery ability, and the two groups may have no significant differences in their imagery ability. A second reason for the contrasting results may be that even with a measurement of imagery ability to select participants, different criterion may apply through these studies. For example, Guillot et al (2008) selected participants partly based on vividness questionnaire scores and physiological measures, whereas Meulen et al (2014) selected their participants based on mental chronometry tests (reporting no significant correlation between fMRI patterns and questionnaire scores). The third reason for the contrasting results may have been due to the different movements used to evoke the imagery during the brain-imaging task, such as imaging a finger sequence task (Lacourse et al., 2005; Guillot et al., 2008), gait imagery (Meulen et al., 2014) and the imaging of specific motor skills like diving (Wei & Luo, 2010) or archery (Chang et al., 2010). Among these movements, upper limb and whole body movements, and sequence versus discrete actions may have lead to different brain activations.

Another crucial reason for the contrasting results among these studies could relate to the different modalities and perspectives of imagery being administered and used by participants. The commonly investigated modalities of imagery are visual and kinaesthetic. The visual modality is frequently delineated into two visual imagery perspectives: internal visual imagery perspective (IVI: where the imaginer is looking out through his or her own eyes while performing the action) and external visual imagery perspective (EVI: where the imaginer is watching him or herself performing the action from an observer's position; as if watching him or herself on television) (Hardy & Callow, 1999). The kinaesthetic imagery modality is defined as how it feels to perform an action, and includes aspects such as the force and effort involved in movement (Callow & Waters, 2005), with motor imagery being a combination of internal visual imagery and kinaesthetic imagery (Jeannerod, 1994). Researchers administer different modalities and perspective across and within studies. For example, Wei and Luo (2009) used kinaesthetic imagery in their study while Meulen et al. (2014) used motor imagery (visual imagery and kinaesthetic imagery); Chang et al. (2010) asked their participants to imagine the movements from a first-person perspective (IVI), and in a later stage they asked them to imagine the movements kinaesthetically. Given that different imagery perspectives and modalities activate different brain networks (as shown in the previous Chapter 4), there could be differences in brain activity linked to the imagery ability of the different imagery perspectives and modalities (Guillot et al., 2009).

Apart from these potential explanations that may explain contrasting results in the scientific literature, other interpretations are also possible. For example, Charlot Tzourio, Zilbovicius, Mazoyer, & Denis (1992) applied a visual imagery task to study the brain activity in poor and good imagers. They found that the poor imagery group showed a global increased activation of the brain, while the good imagery group showed regional increases. They interpreted these results by suggesting that poor imagers had a low differentiation of the cognitive control of imagery, while good imagers had a more differentiated architecture. Related to this finding, other research has shown that good imagers showed a relative economy of motor planning processes. For example, Chang et al., (2010) found higher cerebellar activity in low imagers. In addition, studies that have observed more activations in poor imagers have interpreted their results by the good imagers being better able to activate specific brain networks for certain tasks (Meulen et al., 2014), while poor imagers need to recruit more mental resources in order to build a vivid representation of movements.

Based on the inconsistent findings in the current scientific literature, the present study administered four different imagery perspectives and modalities: EVI, IVI, KIN and motor imagery (i.e., the combination of IVI and KIN), and contrasted participants with high versus low imagery ability, while participants performed an imagery task in an fMRI scanner. The goal of current study was to measure the neural differences between two groups of high and low imagers for IVI, EVI, KIN and motor imagery in a population of healthy subjects, with the hypothesis that the good imagers will have less activations than the poor imagers through all imagery perspectives and modalities.

Method

Participants

A total of 321 volunteers completed VMIQ-2. From these, based on specified criteria (detailed below) twenty healthy participants (mean age=24.05, SD=4.07, 10 males) were selected for the experiment. They provided written informed consent prior to start of the experiment. All of the participants reported no neurological or psychiatric history and were not under medication. Ethic approval was gained from the Ethics Board of the School of Sport, Health and Exercise Sciences and School of psychology of Bangor University.

Imagery Assessment

Prior to being scanned, participants completed the VMIQ-2 (Roberts et al., 2008) to assess their movement imagery ability. The VMIQ-2 is a 12-item questionnaire designed to measure internal visual imagery, external visual imagery and kinesthetic imagery of movement. The participants rate their ability to visually or kinesthetically image movements on a 5-point Likert scale ranging from 1 (*perfectly clear and as vivid, as normal vision or feel of movement*) to 5 (*no image at all, you only "know" that you are thinking of the skill*). The VMIQ-2 has demonstrated acceptable factorial, construct and concurrent validity (see Roberts et al., 2008).

High and low imagery ability criterions for the present experiment were devised by using the original VMIQ-2 data from Roberts et al. (2008) (n=355). Specifically, we divided the original participants into three groups (with equal numbers of participants in each group; thus reflecting an estimation of the population distribution). From these three groups, we defined scores for the high and low imagery ability groups: VMIQ-2 high imagery ability scores of EVI<26, IVI<21, KIN<21 and low imagery ability scores of EVI>31, IVI>27, KIN>28. The middle imagery group represented the participants between these defined criteria (i.e., EVI=26-31, IVI=21-27, KIN=21-28). Using these criteria, we selected participants from the large sample of participants that we tested, but only selecting participants to create the high and low imagery participant groups. Participants in the middle imagery ability criteria were excluded in order to create a sufficient difference between the high and low imagery ability groups.

Post-scanner Questionnaire

After scanning, all the participants were asked to complete a post-experiment questionnaire. The participants were asked to rate to what extent they were able to focus on each imagery perspective and modality during scanning (*1=not at all, 10=greatly*) and whether they switched between the perspectives and modality (*1=not at all, 10=always*). The participants also rated to what extent (*1=not at all, 10=greatly*) they were able to focus on the task and to what extent (*1=not at all, 10=greatly*) they were able to keep their eyes on the fixation cross during the rest period.

Conditions and Stimuli

The experiment consisted of four experimental conditions, and each experimental condition contained an imagery condition and control condition. Imagery conditions were internal visual imagery (IVI), external visual imagery (EVI), kinaesthetic imagery (KIN) and the combination of IVI and KIN (IVIKIN). In all cases, the visual stimulus was to "imagine yourself running up stairs", an item from the VMIQ-2. The control condition was a fixation cross that was always presented after the imagery condition. There were four scanning blocks, and within each scanning block, there are six repetitions of each experimental condition presented in a random order. This resulted in 24 trials for each scanning block.

The visual stimuli for the imagery conditions and the control condition were presented with E-prime 2.0 software (Psychology Software Tools, Pittsburgh, PA). The presentation was projected onto a screen positioned behind the fMRI scanner, which could be viewed through a mirror mounted on a head coil. All experimental conditions were 26s, consisting of an instruction period for 3s that informed the participants of the condition and the relevant stimulus. Then, the instruction "close your eyes and start imaging" was presented for 2s, followed by a blank screen that was presented for 10s. In this 10s of the blank screen, the participants conducted the imagery condition. At the end of this period, a sound was made to inform the participants that it was the end of the condition and to open their eyes (1s). Finally, a baseline for 10s was presented where the participants were required to keep their eyes fixed onto a cross in the middle of screen.

Procedure

After participants completed the VMIQ-2 and were selected for the high or low imagery ability participant groups, they attended a practice protocol procedure (not in the scanner). During this protocol, the imagery perspectives and modalities were described in detail, MRI safety issues were presented, and participants performed the experimental protocol. The purpose of the protocol procedure was to familiarize the participants with the scanning procedure. A week after the practice protocol, the participants attended the real scanning session and experiment. On completing the scanning, the participant completed the post-experimental questionnaire.

MRI Data acquisition and Data analysis

The experiment was carried out at Bangor University using Phillips 3.0T scanner system fitted with EPI gradient overdrive. Head movements were minimized in all subjects using foam pads. Anatomical scan (T1 weighted) (voxel size of 1.13*1.13*1mm, TR 7.45 s, TE 3.05, FOV 128x 3mm, matrix size 128x128mm, slice thickness 1.00mm, flip angle 20.00) was acquired for each participant before the functional scan. Functional MR images were acquired during visual stimulation. A multi-slice two-dimensional gradient echo EPI sequence (voxel size of 2.5*2.5*2.5mm, TR 2.5s, TE 35ms, FOV 240*240*122mm, matrix size 96*96mm, slice thickness 2.5mm, flip angle 90.00) was used to measure the blood oxygenation level dependent (BOLD) signal as a function of time.

A first-level analysis was processed for each run of each participant using FSL (5.98, Analysis Group, FMRIB, Oxford, UK.) including pre-stats, stats, post-stats and registration. In pre-stats, motion correction was carried out using MCFLIRT (FMRIB's Linear Registration Tool), while slice correction used 'regular up' style correspondence with the actual slice acquisition. Spatial smoothing was performed with 5mm and high-pass temporal filtering as 100s were chose at this stage as well.

A General Linear Model was then applied to the first-level individual data. In order to make the model complete, and to reduce the effects from other parts of the trial, the different parts of a trial were modelled separately. Therefore, two regression variables were added that included the imagery condition and the control condition (the baseline period). From the model, a total of 16 contrasts were made, firstly, between the imagery condition and the perceptual control condition (EVI vs. perceptual control condition; IVI vs. perceptual control condition; KIN vs. perceptual control condition, and; IVIKIN vs. Perceptual control condition), and secondly, between the imagery conditions (EVI vs. IVI; EVI vs. KIN; IVI vs. EVI; IVI vs. KIN; KIN vs. IVI; KIN vs. EVI; IVIKIN vs. EVI; IVIKIN vs. IVI; IVIKIN vs. KIN; EVI vs. IVIKIN; IVI vs. IVIKIN; KIN vs. IVIKIN). For each of the contrasts, we performed a high-level analysis that compared brain activity between the high and low imagery ability groups. For all analyses, a cluster correction was used with Z threshold as 2.3, $P < 0.05$ and a whole brain analysis was used.

Results

The results for the analyses of the questionnaires are first presented, followed by the analyses of the fMRI data for the high-level analyses.

VMIQ-2

For the analysis of the VMIQ-2 questionnaire, we planned contrasts between the high and low imagery ability groups in order to demonstrate a reliable difference between the groups. For the planned contrasts, independent-samples t-tests were conducted to compare the scores of the high versus low imagery groups selected for the fMRI experiment, for each of the three imagery subscales (EVI, IVI and KIN) of the VMIQ-2. These analyses showed that there was a significant differences between the average scores of the high imagery ability group compared to the low imagery ability group for all of the different imagery perspectives and modalities (EVI: high $M=16.70$, $SD=4.74$ vs. low $M=40.00$, $SD=10.02$, $t=6.65$, $p<0.001$; IVI: high $M=15.40$, $SD=2.72$ vs. low $M=36.20$, $SD=9.77$, $t=6.49$, $p<0.001$; and KIN: high $M=15.00$, $SD=2.45$ vs. low $M=38.80$, $SD=12.45$, $t=5.93$, $p<0.001$). A further analysis showed that there were no significant differences between male and female scores ($t=-0.046$; -0.171, 0.261, $p>0.05$).

Post-experimental Questionnaire

The results from the post-experimental questionnaire showed that all the participants were able to adhere to the imagery conditions and perceptual control condition (all scored > 5) during the fMRI experiment, and no participant switched between imagery conditions (all scored < 5).

fMRI Data

We report the results for the high-level analyses that contrasted brain activity between the high and low imagery ability groups, for the different imagery conditions. In general, the results showed more intense activations (greater BOLD signal and more areas activated) for the low imagery ability group than the high imagery ability group for the different imagery conditions. Consistent with this finding, there were no significant activations when the low imagery ability group was subtracted from brain activity for the high imagery ability group.

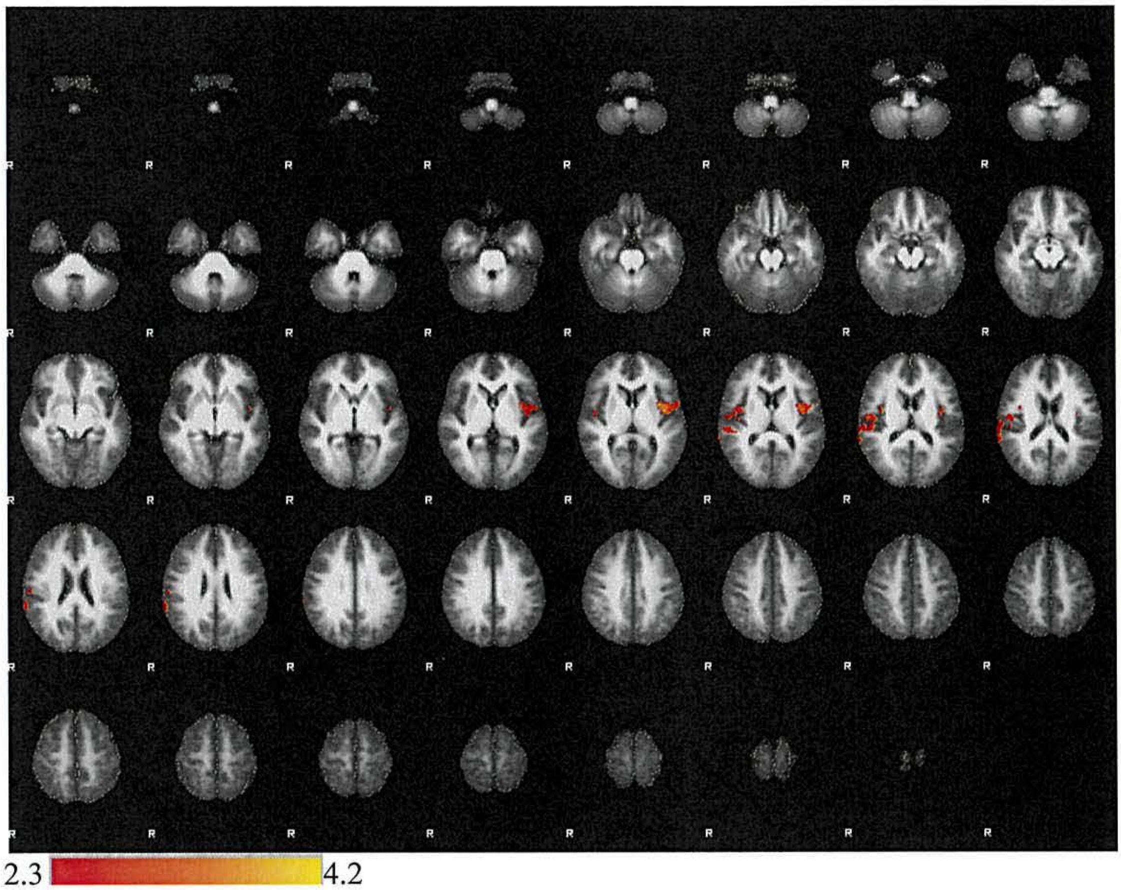
In the first results that we report, we contrasted the low imagery ability group with the high imagery ability group, for each of the imagery conditions contrasted to EVI. When IVI was subtracted from EVI, the low imagery ability group showed greater BOLD activations in right supramarginal gyrus (BA48), right superior temporal lobe (BA22, BA42), bilateral rolandic operculum (BA48) and left insula (BA48) (see Table 5.1 and Figure 5.1). When KIN was subtracted from EVI, the low imagery ability group showed greater BOLD activations in left frontal areas including middle frontal gyrus (BA44) inferior frontal gyrus (BA45, BA48), and in supramarginal (BA2, BA40, BA48), inferior parietal lobe (BA3), superior temporal (BA48), rolandic operculum (BA48), and insula, all in the left hemisphere (see Table 5.1 and Figure 5.2). The subtraction of IVIKIN from EVI showed no significant BOLD activations.

Table 5.1 Regions of significant activations for EVI versus IVI and EVI vs. KIN conditions for the contrast of Low imagers > High imagers

		EVI vs. IVI				EVI vs. KIN			
Anatomical areas	Hemisphere	x	y	z	z-value	x	y	z	z-value
Frontal Mid (BA44)	L					-46	24	36	3.15
Frontal Inf Tri (BA45)	L					-44	36	22	3.57
Frontal Inf Tri (BA48)	L					-42	18	22	2.95
						-32	12	24	2.83
						-50	18	30	2.77
Frontal Inf Oper (BA44)	L					-60	18	8	3.74
						-56	16	34	2.99
SupraMarginal (BA48)	L					-40	-26	32	3.77
SupraMarginal (BA2)	L					-48	-34	34	3.42
SupraMarginal (BA40)	L					-50	-42	36	2.97
						-56	-48	32	2.91
SupraMarginal (BA48)	R	68	-42	26	3.81				
Parietal Inf (BA3)	L					-32	-28	38	2.92
Temporal Sup (BA48)	L					-46	-4	-6	3.18
Temporal Sup (BA22)	R	68	-42	22	3.67				
		68	-36	20	3.19				
		70	-28	20	3.04				
Temporal Sup (BA42)	R	58	-28	12	2.89				
Rolandic operculum(BA48)	L	-38	-6	16	3.17	-54	0	6	3.17
		-52	2	8	3.04	-48	-2	4	2.92
Rolandic operculum(BA48)	R	56	-12	16	3.44				
Insula (BA48)	L	-34	4	6	3.83	-38	2	2	3.29
		-38	2	10	3.74	-36	0	12	2.86
		-42	-4	8	3.56				
		-44	2	10	3.45				

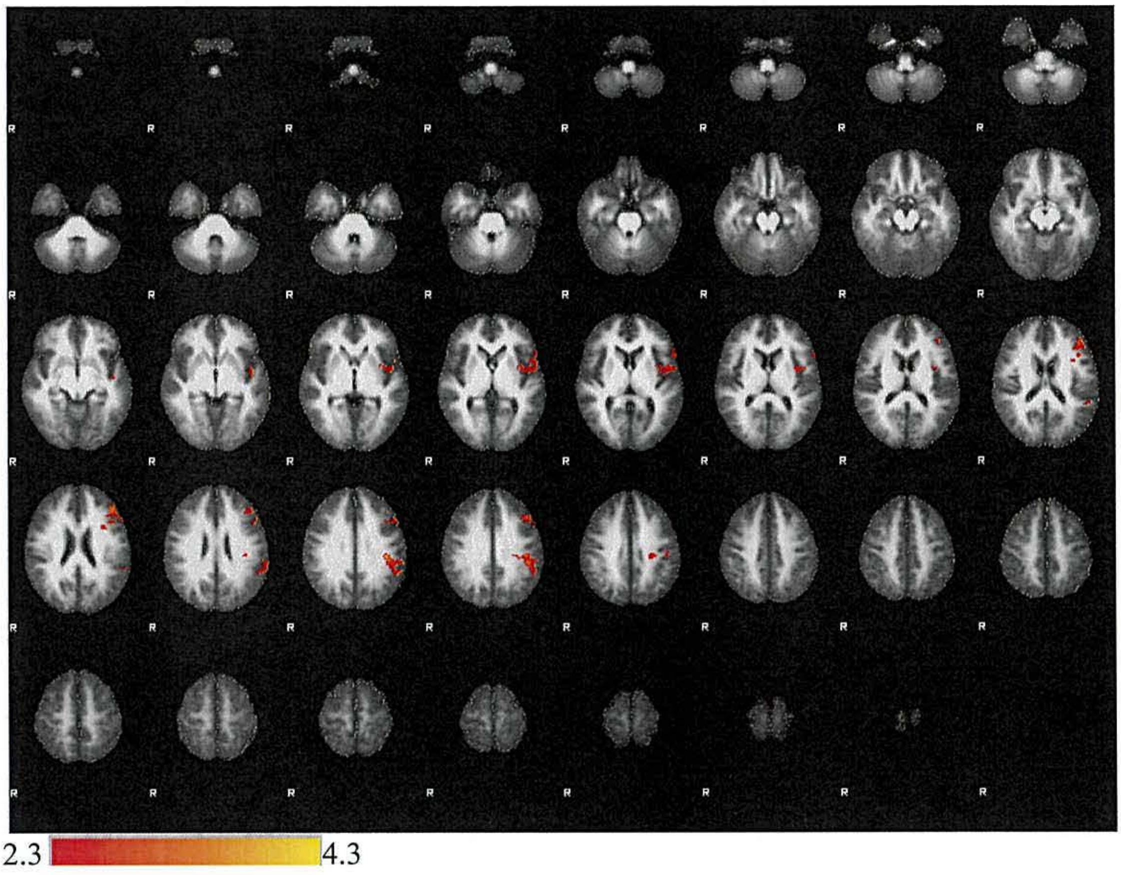
[2]

Figure 5.1 Regions of significant activations for EVI > IVI for Low imagers > High imagers



[2] *Note*. The table shows the MNI coordinates of significant fMRI activity clusters. In this table, as well as the other tables, differences in activation were considered significant when reaching a $p < 0.05$, $Z > 2.3$, BA = Brodmann area; L = left; R = right; EVI=external visual imagery; IVI= internal visual imagery; KIN= kinaesthetic imagery; IVIKIN=IVI+KIN; PC= perceptual control condition

FIigure 5.2 Regions of significant activations for EVI > KIN for Low imagers > High imagers

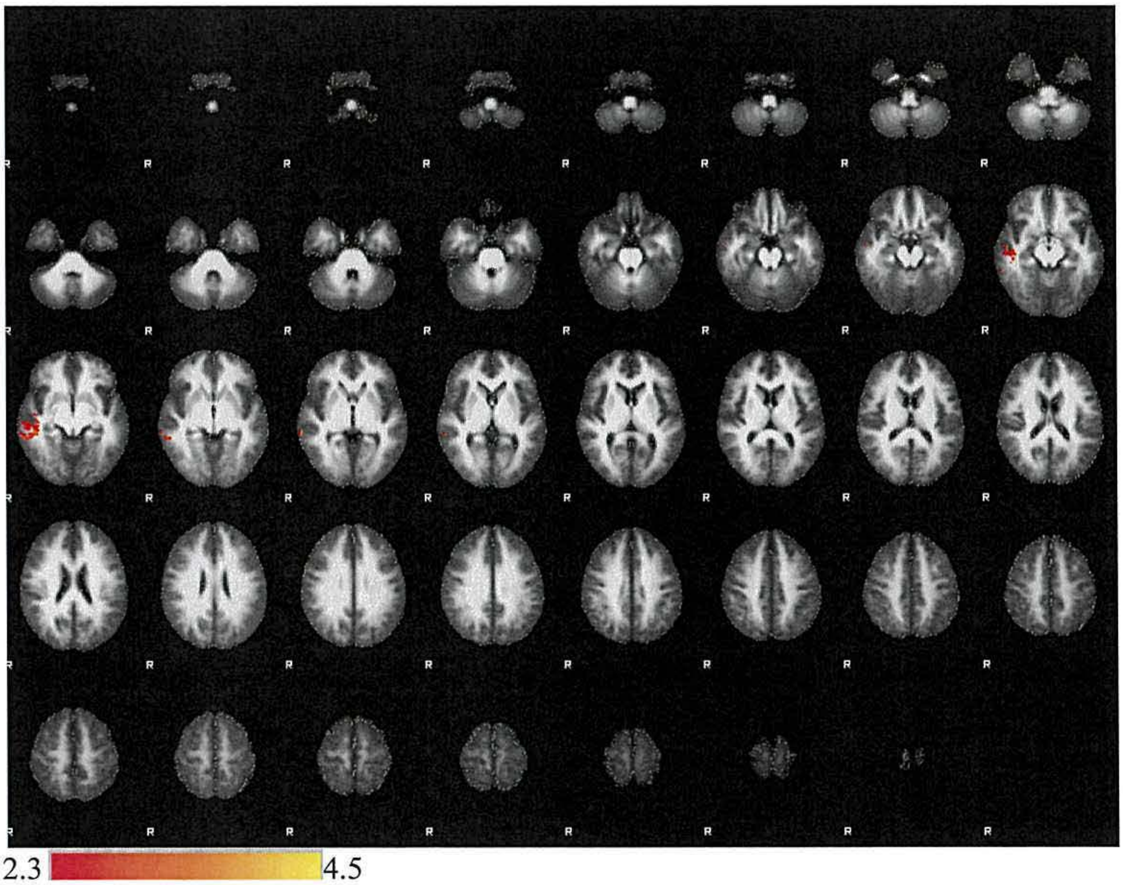


In the next results, we again contrasted the low imagery ability group with the high imagery ability group, for each of the imagery conditions contrasted to IVI. This time, only when KIN was subtracted from IVI were there significant activations. These were detected in right middle temporal lobe (BA21) and right superior temporal lobe (BA48) (see Table 5.2 and Figure 5.3,).

Table 5.2 Regions of significant activations for IVI versus KIN condition for Low imagers > High imagers

Anatomical areas	Hemisphere	IVI vs. KIN			
		X	Y	Z	z-value
Temporal Mid (BA21)	R	48	-36	-8	3.67
		60	-42	-6	3.25
		56	-32	-8	3.08
		56	-20	-12	2.87
Temporal Sup (BA48)	R	50	-10	-10	2.87

Figure 5.3 Regions of significant activations for IVI >KIN for Low imagers > High imagers



For the results of the low imagery ability group compared to the high imagery ability group, for each of the imagery conditions contrasted to KIN, there were no significant activations. However, there were significant activations for the same contrasts relative to IVIKIN. When IVI was subtracted from IVIKIN, increased activations were found in right precentral cortex (BA6), bilateral superior temporal lobe (BA21, BA22, BA38, BA48), left rolandic operculum (BA48) and left insula (see Figure 5.4). When KIN was subtracted from IVIKIN, left inferior frontal lobe (BA44), right supramarginal (BA40, BA48), right postcentral gyrus (BA3), left superior temporal lobe (BA48) and left rolandic operculum (BA48) showed increased activations for the low imagers (see Table 5.3 and Figure 5.5,).

Table 5.3 Regions of significant activations for IVIKIN versus IVI and IVIKIN versus KIN conditions for Low imagers > High imagers

Anatomical areas	Hemisphere	IVIKIN vs. IVI				IVIKIN vs. KIN			
		X	Y	Z	z-value	X	Y	Z	z-value
Frontal Inf Tri (BA44)	L					-58	20	22	3.13
SupraMarginal (BA40)	R					58	-32	38	3.2
SupraMarginal (BA48)	R					64	-38	26	3.44
						54	-32	28	2.83
Precentral (BA6)	R	56	6	40	3.63				
Postcentral (BA3)	R					38	-28	38	3.92
						44	-22	36	3.65
						46	-24	40	3.36
Temporal Sup (BA21)	R	50	4	-10	4.07				
Temporal Sup (BA22)	R	68	-28	18	3.47				
		68	-28	14	3.38				
Temporal Pole Sup (BA48)	L					-52	8	0	3.14
Temporal Pole Sup (BA38)	R	56	12	-12	3.33				
Temporal Sup (BA48)	L	-48	-36	24	2.92	-46	-12	-6	3.16
Temporal Sup (BA48)	R	50	-2	-4	3.38				

Rolandic operculum(BA48)	L	-46	-8	10	3.42	-52	0	6	3.2
		-44	0	10	3.41	-44	-22	12	3.18
		-44	-18	14	2.99				
		-54	2	6	2.9				
Insula (BA48)	L	-36	-8	12	3.89				

Figure 5.4 Regions of significant activations for IVIKIN > IVI for Low imagers > High imagers

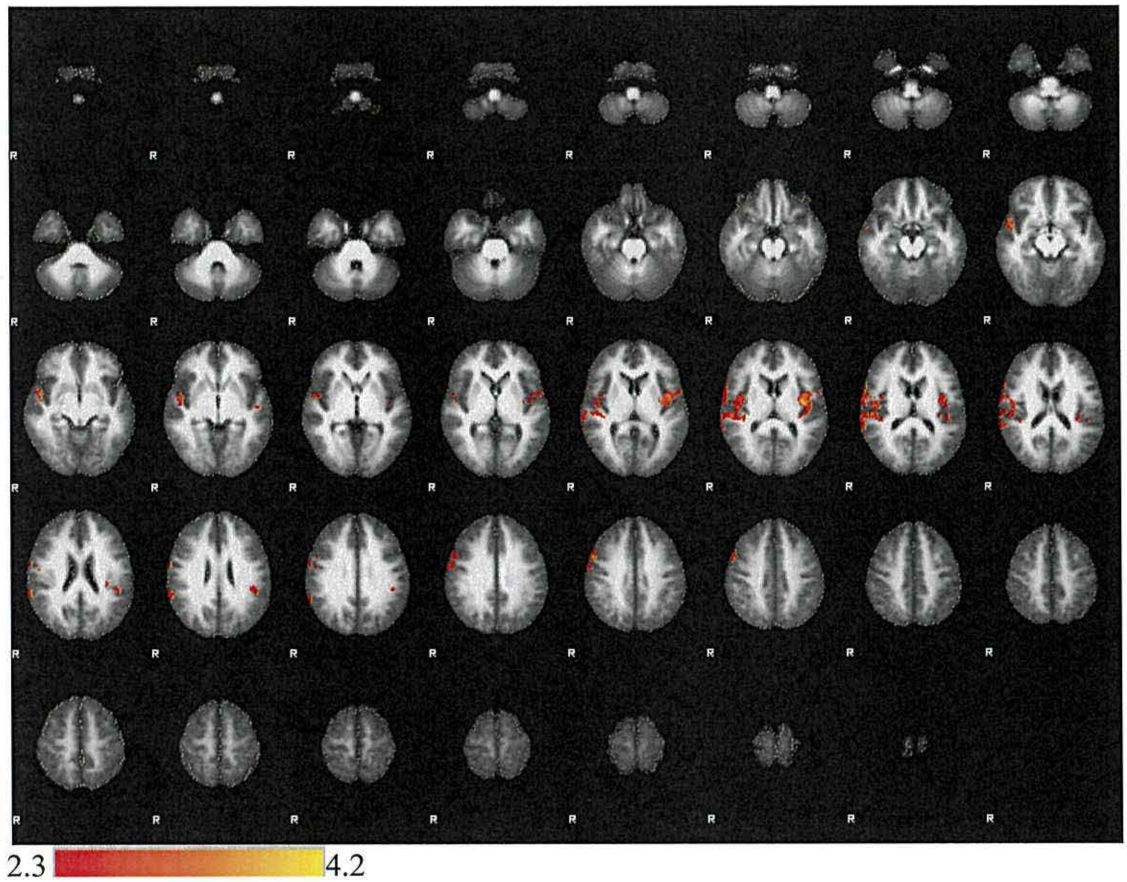
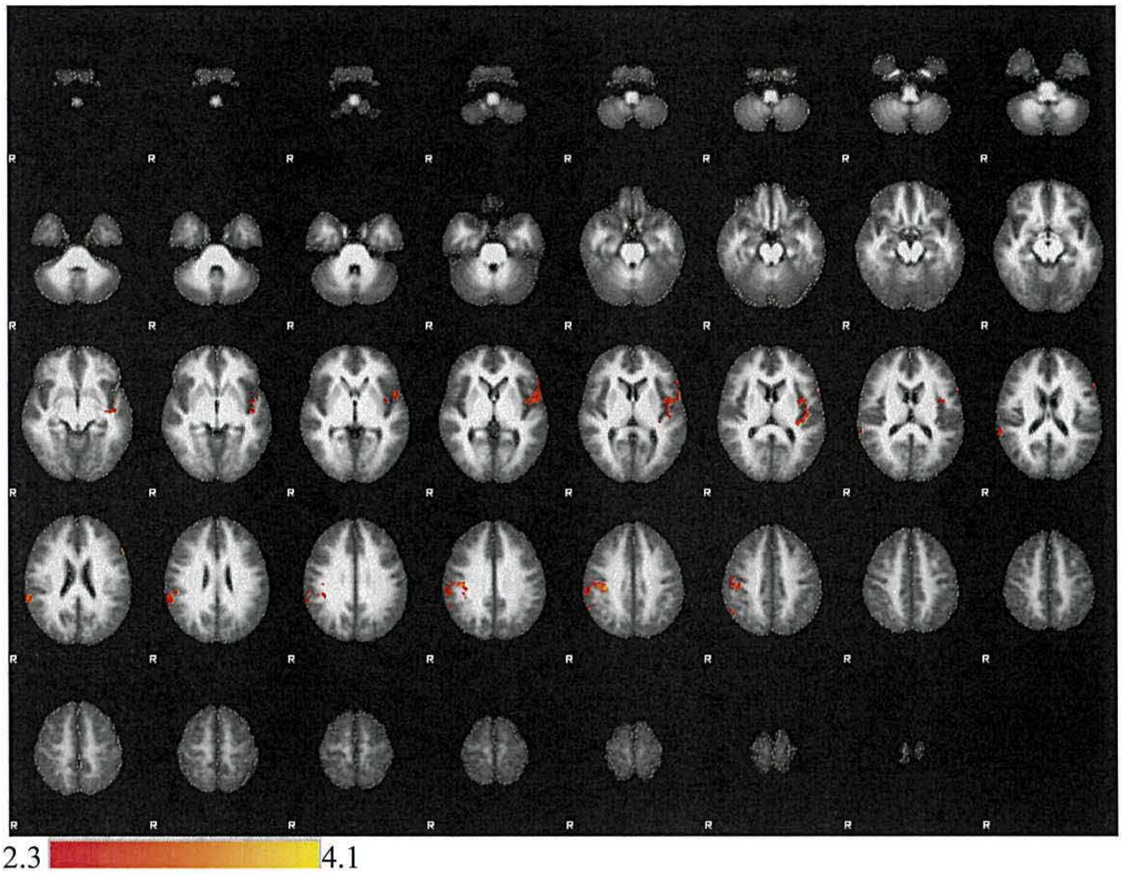


Figure 5.5 Regions of significant activations for IVIKIN > KIN for Low imagers > High imagers



Discussion

This study aimed to investigate how imagery ability moderated the different neural substrates associated to different imagery conditions (perspectives and modalities). Using fMRI, we contrasted a group of participants with low imagery ability to a group of participants with high imagery ability and found greater BOLD activity and more different areas of brain activity for the low imagers than the high imagers for all imagery conditions. However, there was no significant BOLD activity for contrasts between the high and low imagery ability groups. This general finding of greater activity and greater numbers of areas activated, for the low compared to high imagery ability groups, has already been reported by others. For example, Chang et al. (2010) showed that professional athletes compared to novices exhibited reduced or relative economy patterns of brain activations when imaging actions, and Lacourse et al. (2005) found decreased brain activation when performing imagery of a finger sequence task after one week of intensive training on physically performing the finger sequence task. Our results are consistent with these findings, and in general, the effect has been attributed to people with higher imagery ability having more efficient recruitment of brain areas to generate optimal vivid images.

From our results, we found that BA48 was the most frequent area activated for the contrast when high imagers data that was subtracted from low imagers data (e.g., for the contrasts of EVI vs. IVI; EVI vs. KIN; IVI vs. KIN; IVIKIN vs. IVI; IVIKIN vs. KIN). BA48 is located on the medial surface of the temporal lobe, surrounding the hippocampal region, and including hippocampus and parahippocampus. Although previous research has indicated these areas to be activated during the motor imagery (Wei & Luo, 2010; Meulen et al., 2014), our results may differ somewhat from these findings because in our findings, increased activations were found for the low imagers in comparison to the high imagers, indicating that expertise in imagery (with the high imagers) appears to less rely on hippocampal region cognitive processes. The reason for this conflict could be because the previous studies did not show a difference in imagery ability in the participants that were tested. For example, Wei and Luo (2010) tested sport expert versus novice participants, but did not assess participants' imagery ability. In their paper, they argued that the increased parahippocampus activation might have been caused by the experts activating long-term representations of their skilled movement, which the novices had no access to. Further, Meulen et al. (2014) did use the VMIQ-2, but they did not find significant differences between the high and low imagers on VMIQ-2 scores of their participant groups. Therefore, in these two papers (Wei & Luo 2010; Meulen et al., 2014), it could be the case that all of the participants tested had low imagery ability. If so, the data would be consistent to the current findings.

If we make the argument that our data are consistent with the findings of (Wei & Luo 2010; Meulen et al., 2014) who tested low imagery ability participants, we can make a similar argument to Wei and Luo (2010) that the BA48 activity might be associated with the retrieval of semantic information from the hippocampal regions supporting the imagery processes. To create vivid imagery, the participants might recall seeing related images to support their imagery. In contrast, people with higher imagery ability may be more efficient in recruiting relevant brain areas to generate vivid images, and these activations associated to the imagery cognition are lost in the contrast with the low imagery ability participants.

Another consistent finding in the results was with the activation of the superior temporal gyrus (BA21, BA22), when high imagers were subtracted from low imagers in EVI vs. IVI, IVI vs. KIN and IVIKIN vs. IVI. In the literature, the superior temporal gyrus is a crucial area involved in function of language (Bigler et al., 2007), and in particular, language comprehension. These activities may be related to the low imagery ability participants using verbal language scripts (or self-talk) of the imagery to support the imagery behaviour. Again, participants who have high imagery ability may less likely need these cognitions to activate the imagery.

More specific to mirror neuron system activity, the brain areas of Broca's area (BA44, BA45) and the supramarginal gyrus (BA40) also consistently showed greater activations in the low compared to high imagers. In this case, it could be that the mirror neuron system is more activate to support the imagery cognition, as proposed for the other activities. However, an alternative suggestion could be that access to semantic and language support cognitions may have lead to an increase in the mirror neuron system through the increased activity of input to the mirror neuron system.

Certain strengths and limitations can be associated with this research. The current study used the VMIQ-2 to select participants. The criterion of selecting high and low imagers was made based on the database of 355 participants (Roberts et al., 2008). Their VMIQ-2 scores were compared on IVI, EVI and KIN subscales, and significant differences were detected between the two groups of selected participants on each subscale. This is the first study testing imagery ability that has selected participants based on a pre-sample database of participants, creating a differential between the two groups that was reliable. The method also has a limitation in that only the VMIQ-2 was used to select participants, and not other possible methods of imagery ability. Future studies should use multiple methods to measure imagery ability, and it remains to be seen whether the different methods of measuring imagery ability yield differences in brain activity to that which we report in the present research.

The present study has relevant applied implications in neurorehabilitation. Mental practice ("rehearsing of imagined motor acts with the intention of improving their physical execution"; Malouin & Richards, 2010) has recently become a valuable new method for post-stoke motor rehabilitation (de Vries & Mulder, 2007; Braun et al., 2013). As our results showed differences in brain network activity associated to imagery ability, with low imagers showing increased activity, it is crucial to assess the patients' imagery ability prior to the rehabilitation. For example, it could be important that patients have relatively good imagery ability, and do not need support from a wide range of different brain networks. For example, patients with low imagery ability, and with lesion in the hippocampus, or to the temporal lobe may benefit less from the imagery because they will less be able to use the different supportive cognitions to generate the mental imagery.

In addition to the applied implications in neurorehabilitation, our study also has implications in sport psychology. As imagery ability is an important moderator in motor learning effectiveness, behavioural studies have already found that people with higher imagery ability could have more beneficial effects from observational learning, and they are more likely to have successful imitation performance (Lawrence et al., 2013). Our results here provide biological information about imagery ability moderation, specifically confined to the brain regions that are selectively active for each specific imagery perspective and modality. Here, we demonstrate the imagery ability of the participants moderated brain activity, suggesting that the reason for the moderation of sport action performance is linked to a change in cognition at the neural level.

In summary, the current study aimed to investigate the neural substrate of high and low imagers for different imagery perspectives and modality using fMRI. More brain activations were revealed in the low imagers than the high imagers during all imagery conditions. Specifically, the hippocampal regions, the medial temporal lobe and the superior temporal gyrus were more activated in the low imagers. The implications in neurorehabilitation and in sport psychology were discussed, and assessment of participants' imagery ability prior to clinical neurorehabilitation and sport psychology settings was recommended

Chapter 6

General Discussion

Summary

The purpose of this thesis was to examine imagery perspectives, modality and the neural substrates underpinning them. In Chapter 1, a general introduction to the thesis was presented, and the two main sections of the thesis were explained. The first section of the thesis explored the cognitive effects of imagery perspectives and modality. In this section, Study 1 (Chapter 2), investigated the hypothesis that internal visual imagery (IVI) would be superior to external visual imagery (EVI) for the performance of slalom-based motor tasks. Participants performed a driving-simulation slalom-based task in an IVI, EVI, or control group. The IVI group achieved significantly quicker lap times than the EVI and the control group. The second study (Chapter 3) followed the design of Study 1 in Chapter 2, but examined the hypothesis that imagery modality (visual and kinaesthetic) would provide beneficial effects on motor performance of a slalom-based task, rather than using visual imagery perspectives alone. Specifically, IVI, IVIKIN and control groups were employed. The results revealed that internal visual imagery combined with kinaesthetic imagery provided beneficial effects over the imagery perspectives. Taken together, the results of studies 1 and 2 in Chapters 2 and 3 provided evidence to support the beneficial effects of IVI over EVI and for KIN for a slalom-based (laboratory) task where responses are required to changes in the visual field.

The second section of the thesis explored the neural substrates underlying imagery perspectives, modality and ability. Chapter 4 expected both common and dissociated areas of activation for EVI, IVI and KIN. The Vividness of Movement Imagery

Questionnaire-2 (VMIQ-2) and fMRI were applied to study the brain activation of IVI, EVI and KIN. Participants with high imagery ability (using the VMIQ-2) were selected to participate in the study. The experimental conditions involved imagining an action using IVI, EVI, KIN or a perceptual control condition that involved looking at a fixation cross. The imagery conditions were presented using a block design, and the participants' brain activation was recorded using 3T fMRI. A post-experimental questionnaire was administered to test if participants were able to maintain the imagery during the task, or if they switched between the imagery perspective/modalities. As hypothesised, the different perspectives and modalities of imagery elicited both common areas of activation (in the right supplementary motor area, BA6) and dissociated areas of activation. Specifically, IVI compared to both EVI and KIN activated occipital and parietal and frontal brain areas (i.e., the dorsal stream) while EVI activated the occipital ventral stream areas, and KIN activated caudate and cerebellum areas. In addition to supporting the predicted effects, these results also provide initial biological validity for the VMIQ-2.

Following these findings, Chapter 5 investigated the neural substrate of high and low imagers for different imagery perspectives and modality using fMRI. Based on previous research, we hypothesised that low imagers would recruit more brain areas than high imagers. The VMIQ-2 was again applied to select the high and low imagers using a similar paradigm to Chapter 4. As hypothesised, more brain activations were detected in the low imagers than the high imagers during all imagery conditions. Specifically, the medial temporal lobe and the superior temporal gyrus were more activated in the low imagers. These results highlight that people with higher imagery ability are perhaps more efficient in recruiting relevant brain areas to generate vivid images, whereas low imagers recruit a variety of different brain areas, perhaps to try to build a visual image from memory.

The specific implications of these studies have already been presented in their respective chapters of this thesis. In this final chapter (Chapter 6), we draw together the central theoretical and applied issues raised by the chapters in an attempt to draw meaningful conclusions from the whole thesis. In addition, methodological and measurement strengths and weakness will be discussed, applied implication of these studies will be presented. Finally, future research directions will be suggested.

Before this main discussion, it is relevant to present the findings from two other recent visual imagery perspective studies performed in a related, but wider research programme. Note, these two studies were published together with Study 1 from the thesis in Callow et al., 2013), but these two studies were not conducted as part of the PhD Although Study 1/Chapter 2 used methods and procedures that afforded substantial experimental control, the participants were not actually moving through the visual field while performing the task, as they would do in tasks such as canoe slalom and slalom skiing. It therefore could be argued that the findings of Study 1 alone lacked in ecological validity. Thus, in the second study of the paper (Callow et al., 2013) a more ecologically valid task was applied. Specifically, the task involved downhill slalom running where participants actually moved through the visual field. In addition, in Study 1 of the thesis a measure of time was taken, but not accuracy. Given the results of White and Hardy (1995) it is perhaps important to measure both time and accuracy in studies that explore EVI and IVI. Specifically, using a wheelchair slalom task requiring participants to manoeuvre themselves through a set course of gates Hardy and White showed that after initial practice on an acquisition course, participants using IVI completed a transfer trial with significantly fewer accuracy errors than participants using EVI. Therefore, use of IVI compared to EVI led to a more accurate performance, explained by participants being able to rehearse the responses required at each gate. However, the results also showed that EVI improved the speed (time) at which the task was performed compared to IVI. White and Hardy suggested that these performance gains could have occurred because EVI allows participants to compare themselves with their own imagery, thereby enhancing their competitive drive. As IVI does not afford the comparison to the same extent as EVI, the motivation function was less evident for IVI. White and Hardy further discussed these findings in terms of a speed accuracy trade-off across imagery perspectives, where IVI caused slow, but accurate performance and EVI caused a fast, but inaccurate performance. Therefore, the second study of the paper (Callow et al., 2013) provided separate measures and analyses of time and accuracy. In this second study, a total of twenty-two participants performed the down-hill running task under both IVI and EVI conditions. To control for potential carryover effects as a result of the repeated measures design, a strict exclusion criteria was employed (Stevens, 2002). That is, participants were only retained for analysis if they were able to meet two criteria elicited via a manipulation/social validation questionnaire. First, participants were required to be able to report strong adherence to both the IVI and EVI conditions (as evidenced by adherence ratings of seven out of 10 or above for each imagery condition). Second, participants had to report minimal switching between imagery perspectives during each imagery condition (i.e., a score of less than 3 for each condition which would indicate that participants rarely, if at all, switched between IVI and EVI during a particular imagery condition when they were only supposed to be using one perspective). These criteria resulted in the data from 11 of the 22 participants being retained for analysis. Analyses showed that there was no difference in imagery ability across perspectives, but analysis of the performance data revealed significantly quicker (faster lap-times) in the IVI than the EVI condition, with no differences in accuracy. The results of this second study from Callow et al. (2013) again replicate the findings of Study 1 /Chapter 2, providing further support of the beneficial effects of IVI over EVI in an ecologically valid slalom based task. Further, the quicker times in the IVI group were not to the detriment of accuracy, and are in line with the reasoning that IVI should help to plan the most effective line in slalom based tasks.

The measurement of accuracy in the second study from Callow et al. (2013) might be perceived as a rather crude measure. We do argue that if participants chose a line that was too close to a turn, they may have, for example, been more likely to collided with a cone on a slalom turn. However, this measure may not have been comprehensive enough to capture fine differences in accuracy of line (or trajectory) across the slalom line taken. Consequently, within Callow et al. a third study was conducted to explore both time-taken and accuracy using a more comprehensive measure of accuracy. In this third study, the effects of different visual imagery perspectives on a downhill ski slalom task (performed on an outdoor artificial ski slope) was examined. As in the previous studies, it was hypothesised IVI would produce superior performance for either time-taken or accuracy or both in comparison to EVI. The study used two criteria for judgments of accuracy: (a) closeness to the pole, and (b) choice of line. Each of these criteria was scored on a Likert scale from 1 (*far away from pole/very sharp change of direction*) to 10 (*just missing the pole/perfectly smooth change of* *direction*) and the average of these two scores was used for the accuracy measure. Participants were allocated to an IVI, EVI, or a control group. A sample of 30 recreational skiers were tested, two participants from the control group were unable to complete both trials, resulting in a final sample of 28 participants. Results revealed the IVI group to be significantly more accurate than the control group, with no significant differences in time taken to complete the task. These results provided further support for the hypothesis that IVI would produce superior performance than EVI in slalom based tasks, now with more accurate performance between the IVI group and the control group (with a large effect), whereas there was no difference between the EVI group and the control group. For time-taken performance, there were no significant differences between the groups. However, the IVI group was one second quicker than the EVI group, and three seconds quicker than the control group. These differences correspond to small and moderate effect sizes of 0.30 (IVI and EVI) and 0.66 (IVI and control), respectively (cf. Cohen, 1992). Considering the time and accuracy performance results together, the findings from this study were consistent with the idea that IVI may aid performance by helping to plan and execute the most accurate line.

Theoretical implications

The aim of this section is to draw together the main theoretical implications that the different studies presented in this thesis provide to the scientific literature. The main findings from Study 1/Chapter 2, and the two studies from Callow et al. (2013) presented in the section above showed that IVI consistently produced performance gains on slalom-based tasks that we can be interpret in accordance with the cognitive explanation provided by Hardy (1997). Hardy (1997) suggested that imagery exerts a beneficial effect on performance only to the extent that the images generated supplement the information that is already available to the performer. Taking this line for reasoning these findings for slalom-based motor tasks, IVI allows a performer to see the precise temporal and spatial locations where key movements need to be initiated (e.g., changing direction or "braking"). In comparison, EVI enables the performer to "see" the precise body positions and movements that are required for a successful performance, and may be more suitable for a form-based task. With a slalom-based task, IVI might provide a performer more useful supplement information than EVI, allowing them to image their actions relative to the external object placed in a slalom-based task.

With the results from Callow et al. (2013), there was no evidence that a speed-accuracy trade-off across imagery perspectives was the cause of the performance differences. Specifically, from Study 2 of Callow et al., there was no significant difference between accuracy for the IVI and EVI conditions, and in study 3, there was no significant difference in time taken between the IVI and control conditions. Together, these studies in combination with Study 1/Chapter 2 provide the first evidence supporting the theorised benefits of IVI in slalom tasks (supporting previous research; White & Hardy 1995; Hardy & Callow 1999; Hardy 1997).

The findings from Study 2/Chapter 3 further supported the advantages of IVI, but in addition demonstrated the additive benefits of KIN over imagery perspective (IVI) on slalom performance facilitation (KIN defined as imagery involving the sensations of how it feels to perform an action, including the feeling of movement: the force, the effort, the spatial parameters Callow & Waters, 2005). The findings are explained because the combination of IVI and KIN perhaps provides a richer experience of the action in comparison to either IVI or KIN alone (Hardy, 1997; Jeannerod, 1994) by offering the performer more supplement information than just IVI or KIN.

The findings of Chapter 4 showed that IVI, EVI and KIN elicited dissociated brain areas of activation. The main results from Study 1 (Chapter 2), and the two studies from Callow et al. that are presented in this discussion, showing IVI to produce performance gains on slalom-based tasks over EVI, could be interpreted as a consequence of functional equivalence. Specifically, based on the notion of functional equivalence that the more similar (or functionally equivalent) the neural activity of imagery of performance and that of the actual performance, the more effective the imagery is at moderating performance (cf. Holmes & Collins, 2001; Smith et al., 2008; Wakefield et al., 2013). If correct, the neural activity in the IVI compared to EVI condition may be considered as more functionally equivalent with the neural activity used in action execution for performing the task (cf. Holmes & Collins, 2001; Ruby & Decety, 2001; Fourkas et al., 2006; Lorey et al., 2009). The findings of Chapter 4 demonstrated evidence to support this suggestion, with IVI activating more dorsal stream regions of the brain, known to be involved in action processes (e.g., planning), while EVI activated more ventral stream regions of the brain, less associated to action processes.

Similarly, the findings from Study 2 demonstrating additive benefits of KIN over IVI on performance slalom facilitation could also be explained by functional equivalence, with the feeling of action being more associated to actual action. The results of Study 3/Chapter 4 perhaps support this claim, with KIN activating distinct areas, not activated by IVI and EVI, and specifically known to be important for action execution processes. Interestingly, performance benefits of IVI in combination with KIN (Study 2; Chapter 3) can be explained by KIN and IVI activating independent motor neural activity, making them perhaps more functionally equivalent to actual action execution than either activation alone (in this thesis, for IVI alone).

Related to the use of the kinaesthetic modality, an interesting additional finding in Study 1 was that some participants reported spontaneously using kinaesthetic imagery regardless of the imagery perspective being used, with no significant differences in the amount of reported experience between the IVI and EVI groups and no significant correlations between KIN and performance in the experiment. The interesting feature of these findings was that KIN was experienced with both visual perspectives, this result has been demonstrated previously (e.g., Glisky et al., 1996; Callow & Hardy, 2004). The fact that IVI, EVI and KIN activate independent brain regions supports this finding. It should be possible to activate either imagery perspectives and modality in any combination. However, for now it is unclear what performance moderations would exist for all of the different imagery combinations.

As imagery ability is a key component of imagery research (cf. Martin et al., 1999), it is important that valid imagery ability measurement instruments are available. The VMIQ-2 has been popular used in sports psychology. The findings from Chapter 4 and 5 (Studies 3 and 4) appear to support the VMIQ-2 as a valid measure of imagery ability, as evidence of biological validity was provided in these studies.

Applied Implications

The findings of this thesis can provide information for applied practice. Implications in sports practitioners and neurorehabitation are discussed in this section.

Sports practitioners

It is well understood that athletes use a variety of imagery strategies, either of cognition or motivation functions. For example, Paivio (1985) suggested that imagery can serve a number of different functions, including cognitive specific, cognitive general, motivational specific, motivational general-arousal, and motivational general-mastery (see also Hall, Mack, Paivio, & Hausenblas, 1998). For motivational general-mastery function, athletes can use imagery to improve self-confidence or to keep focused. The focus of the current thesis has been on the cognitive function of imagery, in particular cognitive specific imagery. Cognitive specific is considered the most suitable imagery for developing skills and techniques to improve performance. In support of this, our findings from the first two studies of this thesis (Chapters 2 and 3), and from Callow et al (2013), demonstrate that imagery can improve performance on slalom-based tasks.

In the literature, a variety of recommendations to maximise the efficacy of the cognitive function have been proposed. Some researchers (e.g., Hale, 1998) have advocated using IVI over EVI for performance benefits based on the early research finding that internal imagery tends to produce stronger EMG activity in the muscles involved in the imaged activity (Hale, 1982; Harris & Robinson, 1986). Other researchers suggested that multimodal imagery (combination of a visual perspective with another sensory modality; e.g., KIN) may have a more beneficial effect on performance (Suinn, 1984). They based their argument on that the idea that the use of two modalities might provide a more vivid image than just using one, and with more vivid imagery being associated with higher performance acquisition (e.g., Goss, Hall, Buckolz, & Fishbourne, 1986).

In addition to a cognitive emphasis of imagery, Hardy (1997) proposed that task characteristics should be taken into consideration to maximize the efficacy of imagery. He supported the proposal with the explanation that imagery exerts a beneficial effect on performance to the extent that the cognitive images generated supplement the information that is already available to the performer. With this argument, he proposed that EVI would be more efficient for performance of form-based tasks while IVI would be more beneficial for performance on slalom-based motor tasks. From the findings of the first two studies of this thesis, along with related literature, we support Hardy's recommendation that IVI would be more beneficial for performance on slalom-based motor tasks. We suggest the characteristics of the task should be considered when recommending to athletes, which imagery perspective to use. To be more specific, if the task requires changes in direction at precise spatial locations, such as slalom-based tasks, we can propose based on our findings, that IVI is recommend. For the tasks task relies heavily on the use of form (such as gymnastics for example) then external visual imagery may be more beneficial for performance than internal visual imagery (cf. Hardy & Callow, 1999). For tasks that require both form and changes in direction at precise spatial locations (e.g., a double straight-back somersault in gymnastics), switching between imagery perspectives could be recommended, as that may be most beneficial imagery to improve performance; though evidence to support the effective use of imagery switching is needed. For other motor skills that do not rely so much on the use of form or line (e.g., golf putting or dart throwing) perhaps use of IVI or EVI would have equal benefits (see Roberts et al., 2010).

Previous research has reported additional performance gains for KIN over and above those from visual imagery for form-based tasks in skilled performers (Hardy & Callow, 1999). Chapter 3of this thesis provides the evidence to demonstrate the additive benefits of IVI and KIN on performance facilitation in a slalom-based task, with functional equivalence used as a possible explanation for the effects. However, an alternative explanation can also be applied related to the expertise of the performer. Specifically, research reported in the literature shows that kinaesthetic cues may be more important in the later stages of learning (Fleishman & Rich, 1963), with Hardy and Callow demonstrating that relatively novice gymnast do not gain performance benefits from kinaesthetic imagery, whereas high-ability rock climbers do. Relating this literature to the method of Study 2, all the participants undertook the training session until they achieve two criteria (derived from pilot testing). This included the completion of three consecutive laps under 170s and a plateau in performance, where the last three lap times fell within 5s of each other (cf. Wilson et al., 2007), consequently it could be concluded that the participants were in the later stages of learning and thus kinaesthetic imagery enhance performance. Taking these findings together, along with the previous literature, we support the proposal of others that KIN is advocated to use by performers in later stages of learning (Fleishman & Rich, 1963; Hardy & Callow 1999).

Research shows that imagery ability moderates the effectiveness of imagery interventions (e.g., Goss, Hall, Buckolz, & Fishburne, 1986; Hall, Buckolz, &

Fishburne, 1989); whereby athletes with higher levels of imagery ability are reported to have more beneficial performance effects from imagery interventions (e.g., Isaac, 1992). From the findings of Studies 3 and 4 (Chapters 4 and 5) that high imagers elicit distinct brain areas for the different imagery perspectives and modality, and in line with the notion of functional equivalence, it could be tentatively suggested that the reason imagery ability moderates performance is because those with higher imagery ability have more functionally equivalent neural activity. To apply these findings and to advise sports practitioners, if practitioners and coaches are to begin imagery interventions with their athletes that utilise a particular imagery perspective, then the ability of performers to image using that particular imagery perspective should be assessed prior to the intervention commencing and at various occasions throughout the intervention. Therefore, with the measurement of the athletes' imagery ability prior to the intervention commencing, a more individualised intervention could be made, further with the measurement of the athletes' imagery ability at various occasions, the intervention could be adjusted throughout the training to maximise its effect.

Neurorehabitation

Brain damage resulting from stroke or traumatic brain injuries can cause action impairment and functional disability. A number of studies have provided evidence that imagery (often termed mental practice) as a rehabilitation intervention can be used to reduce these action impairments and improve the functional recovery of, for example, the upper limb (see Braun et al., 2006; Sharma et al., 2006 for review). One value of imagery is that the method can be carried out after an initial learning and can subsequently be practiced by the patient independent from the therapist. Imagery is also a safe (non-invasive) and affordable intervention (de Vries & Mulder, 2007; Braun et al., 2013). These factors mean that imagery is increasingly used for post-brain injury motor rehabilitation.

In an examination of imagery in the post-stroke literature, Nilsen et al. (2010) found differences in the nature of instruction given to participants regarding imagery perspectives. For example, some studies instructed patients to adopt an internal perspective (IVI) with KIN (e.g., Page, Levine, & Leonard, 2007), whereas some studies instructed participants to use an external perspective (e.g., Page, 2000), and others used a combination of the two (e.g., Dunsky, Dickstein, Marcovitz, Levy, & Deutsch, 2008). Based on findings from this thesis, and associated literature, we can suggest that using different imagery perspectives and modalities may affect the efficacy of the imagery intervention. Nilsen et al. (2012) further discussed the effects of different imagery perspectives used for post-stoke motor rehabilitation, but failed to find clear differences or consistencies on effects. There are two main issues that may have caused the null findings. First, most studies instructed their participants to either take the internal or external visual imagery perspective, but the role of KIN is not clarified. Second, participants are assigned into different imagery groups without consideration of the participants' lesion site. These two factors may have caused increased variance in the data sample, causing the null effects.

With our findings from Study 3 (Chapter 4), it is shown that different imagery perspectives and modalities activated distinct brain networks. Based on these results, it can be suggested that patients with specific damaged brain areas should be assigned to appropriate imagery perspectives and/or modality for their rehabilitation. For example, as EVI activates temporal lobe, patients with temporal lobe damage may consider to practice using EVI to regenerate the impaired brain areas. Alternatively, patients may use IVI using intact action brain areas in order to create a strategy to overcome a particular impairment. Therefore, the different imagery perspectives may provide specific separate processes for intervention benefits.

In addition to this advice, we can also use our findings from Study 4/Chapter 5 to suggest that imagery ability, shown to adopt different neural substrates when performing imagery, should be assessed in patients prior to imagery. Low imagery ability patients will need more intact brain areas in order to perform the imagery. Therefore, it may be that only high imagery ability patient's benefit from imagery in rehabilitation (i.e., because less brain activity is required).

Strengths of the Research Program

Several strengths are associated with the current research program. The first strength of the research program was that all the studies conceptually clarified IVI, EVI and KIN. In the cognitive neuroscience literature, the terms of motor imagery, kinaesthetic imagery, movement imagery, kinaesthetic motor imagery and kinaesthetic motor imagery have all been used in different studies with similar or different meanings (e.g., Hashimoto, Ushiba, Kimura, Liu, & Tomita, 2010; Hohlefeld, Nikulin, & Curio, 2011). The difference in these terms is unclear. For example, Gabbard and Bobbio (2011) claimed that motor imagery is 'also known as kinaesthetic imagery'. Other researchers have also defined kinaesthetic imagery as our ability to imaginatively sense the position and movement of our bodies (see Proske & Gandevia, 2009, for a review of research on kinaesthesia). Future research should take care to define these terms in order to better understand what types of imagery specifically lead to performance improvement. Based on the findings from this thesis, with specific moderations in performance, and from different brain area activation, we advocate the use of the imagery conceptions of IVI, EVI and KIN.

A second strength of the research program, related to the previous point, was that all the studies in the present thesis used precise instructions to explain the imagery perspectives and modality. This is particularly relevant because, in the literature, internal imagery (such as that used by Epstein, Mahoney & Avener) have confounded internal visual imagery with kinaesthetic imagery (cf. Hardy & Callow, 1999), and that it has been incorrectly assumed that kinaesthetic imagery can only be experienced with an internal perspective, or that it is easier to use with an internal perspective (cf. White & Hardy, 1995; Taktek, 2012). Further to this point, some cognitive neuroscience studies failed to provide enough information about the specific imagery perspective or modality used. For example, Bakker et al. (2008) intended to elicit their participants' motor imagery simply by asking them to imagine walking along the path shown in a photograph. They failed to provide the information about the perspective that participants should imagine from and whether or not the participants used KIN was unclear. In addition, some studies using imagery scripts to produce one perspective of imagery have also involved the use of other imagery perspectives. For example, in Fourkas et al. (2008): "Imagine yourself on a golf course at the teeing-off area starting the shot. The shot should be a long shot, well played, and with the correct direction which easily reaches the green (p. 2,389)". This script was intended to elicit internal imagery, however the term "easily reaches the green" can also elicit visual imagery from a third-person perspective.

A related strength included controls over the imagery conditions by maximising participants' understanding of the tasks. For example, in Studies 3 and 4, every attempt was taken to maximise understanding of the task by the participants. Specifically, all the participants attended a practice protocol procedure to make sure they understood the task, they practiced the task, and participants had a chance to ask questions if they were not sure about any part of the task. In addition, we used post-experimental questionnaires to validate our experimental instructions, and participants who failed to adhere to the expected imagery perspective or modality were excluded from the study.

A third strength of this thesis was that we used a mixture of research methods (e.g., behaviour driving simulator performance and fMRI brain imaging), and data analyses (e.g., ANOVA, GLM) to investigate our hypotheses. In addition, a number of software packages such as SPSS, FSL, E-prime were used by the present author through the programme. This allowed a firm foundation in research training and provided the present author with opportunities to expand her knowledge of research design and analysis.

The fourth strength of the research program was that all the studies used specific imagery ability criteria to screen the participants. Only the participants who achieve the criteria were retained for the experiments. With specific imagery ability criteria, greater experimental control was offered. In addition, the criterion of selecting the participants tested in Studies 3 and 4 was made based on a large database (Roberts et al., 2008), and Study 4's participants' imagery ability were compared on IVI, EVI and KIN subscales, causing significant differences between the high and low imagers on each subscale. This method made the differential imagery ability of two groups meaningful.

Weaknesses of the Research Program

Despite the strengths associated with this thesis, there were also several weaknesses. The first potential limitation of the present research was the inability to control participants' spontaneous kinaesthetic imagery experiences. For Study 1, we propose that this did not influence the current findings as there were no differences in kinaesthetic imagery experiences between the IVI and EVI groups, and furthermore that kinaesthetic imagery experience was not correlated with performance. For studies 3 and 4, we used post-experimental questionnaires to exclude participants who failed to adhere to the proper imagery condition, and we therefore suggest that this did not influence the current findings.

A second potential limitation relates to the measures employed in the first two studies. Specifically, although time-taken was a variable involved in the calculation of speed, we did not measured actual speed (i.e., distance/time). To overcome this limitation, the use of more advanced measures in slalom based tasks could be adopted; for example, using technology such as GPS tracking systems.

A third limitation was that we did not specify the angle participants should take when imagining from an EVI perspective. Although research has yet to examine whether angle of EVI affects performance, researchers (e.g., Fournier et al., 2008) have highlighted that athletes use different angles. Manipulating the angle of EVI could have been considered in the current studies (cf. Callow & Roberts, 2010), though the main aim of the present thesis was to investigate IVI and KIN relative to EVI. Future research should manipulate the angle of EVI and measure if the angle moderates performance. Related to this, it would be interesting to evaluate whether moderating imaged gaze points within the internal visual imagery of a slalom task would also moderate actual performance.

A fourth limitation of the research program is that imagery perspective preference was not considered. In the current thesis, Studies 1, 3 and 4 required the participants to image from both imagery perspectives, and therefore imagery perspective preference was not measured. Imagery preference is thought to moderate performance (e.g., Hall, 1997; Holmes, 2007). Callow and Roberts (2010) have found significant small correlations between imagery perspective preference and imagery perspective ability. Specifically, people with a particular preference for one imagery perspective are more likely to use this perspective, and be better at imaging from their preferred perspective. Therefore, imagery preference could have been used in Study 1 to allocate participants to groups; specifically, participants with preferences for external visual imagery would be given external visual imagery interventions, and those with internal visual imagery preferences would be given internal visual imagery interventions. Alternatively, imagery perspective preference could have been evaluated as a separate independent variable. Choosing the latter may have helped to prevent participants switching perspectives, and made them more likely to adhere to their respective interventions, therefore making participant removal less necessary. Also, imaging in their preferred perspective may have led participants to create more vivid images, which may have had a greater impact on performance.

A fifth limitation of the research program was that only VMIQ-2 was used to measure imagery ability when selecting participants. Although VMIQ-2 is a validated popular tool to measure imagery ability, due to the subjective nature of the evaluation, other methods could have been combined to strengthen the validity of measurement of imagery ability.

Future Research Directions

A number of research directions can be proposed based on the findings of the current research program. In the present thesis, it was difficult to control participants' spontaneous kinaesthetic imagery experiences. Therefore, future research should explicitly control for kinaesthetic imagery use. This may involve the inclusion of a kinaesthetic imagery (only) condition, or it might be possible to inhibit kinaesthetic imagery cognitive processes through the use of repetitive Transcranial Magnetic Stimulation (cf. Jung et al., 2008). In Study 3 of the current thesis, kinaesthetic imagery was found to activated caudate and cerebellum areas, and in Guillot et al. (2009), they found kinaesthetic imagery to elicit bilateral activations of the inferior parietal lobule (BA10) as well as several motor-related regions (including the putamen, the caudate nucleus, and the cerebella hemispheres). The application of rTMS to these brain areas may suppress kinaesthetic imagery, while visual imagery can still be used. Similarly, future studies could also use rTMS to help control the spontaneous switching of imagery perspectives. With our findings of Study 3, the brain areas were separable for internal visual imagery and external visual imagery. This again may allow for a future study to apply rTMS to the ventral versus dorsal brain pathways in order to suppress external or internal visual imagery.

Another issue discussed above that could be investigated further is the moderation of the angle of external visual imagery that performers use. When imaging from an external perspective, athletes reported imaging from a variety of external angles (Callow & Roberts, 2010). For example, in the driving simulator study, a participant imaging the task using external visual imagery could image from behind, bird-view, and/or from the side. Although Callow and Roberts (2010) found no differences between angles in terms of reported vividness, they discussed that these non-significant results may be due to imprecise measurement, and they recommend improving the method of assessing angle of EVI by using 3-dimensional pictures displayed via television or computer screen. Imaging from different external angles may lead to more information in the image, and therefore more impact on performance.

Based on the findings from Study 3, where IVI, EVI and KIN elicit different types of neural activation, future studies should carefully consider the experimental instructions they provide to elicit imagery, it is important to avoid potentially confusing instructions by explaining to participants exactly what movements to imagine and which visual perspective to use. In addition, manipulation checks to validate their experimental instructions are recommended.

With the measurement of imagery ability, using several methods to evaluate imagery ability is advocated in the further study. As mentioned in general introduction, mental chronometry paradigms, prospective action judgment and motorically driven perceptual decisions are all objective methods to measure imagery ability. However, it is unclear whether imagery ability defined by these different measures will moderate behavioural performance, and cause the same types of differences in brain activations. Further studies could consider the characters of these paradigms, using them to assess certain imagery perspectives or modality and combine their results with the imagery questionnaires to acquire a more comprehensive evaluation of imagery ability.

Another possible study may consider testing the effects of imagery preference. Specifically, when providing imagery interventions, first to measure the participants' imagery preference, given them the imagery interventions on their preferred perspective if possible. By doing this, participants may able to create more vivid images, and therefore have a greater impact on performance. In addition, it could be interesting to measure whether there are neural differences in imagery preference.

To summarise, this thesis had two purposes. Firstly, to explore the cognitive effects of imagery perspectives and modality, and secondly, to explore the neural substrates underlying the imagery perspectives, modality and ability. The thesis has successfully achieved these two purposes, providing significant results in each empirical thesis chapter. Further, the thesis has provided research that has already contributed to one peer-reviewed publication, one chapter is currently submitted for peer-review, and a further two chapters are being prepared for publication. Therefore, the work of the thesis has provided novel insights that will contribute to and extend the imagery scientific literature. In addition, a number of future research directions were provided that could insight future research funding and programmes of research.

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APPENDIX A

Vividness of Movement Imagery Questionnaire-2

Name: **Age:**
Gender: **Sport:**
Level at which sport is played at (e.g., Recreational, Club, University, National, International, Professional)
Years spent participating in this sport competitively:

Movement imagery refers to the ability to imagine a movement. The aim of this questionnaire is to determine the vividness of your movement imagery. The items of the questionnaire are designed to bring certain images to your mind. You are asked to rate the vividness of each item by reference to the 5-point scale. After each item, circle the appropriate number in the boxes provided. The first column is for an image obtained watching yourself performing the movement from an external point of view (External Visual Imagery), and the second column is for an image obtained from an internal point of view, as if you were looking out through your own eyes whilst performing the movement (Internal Visual Imagery). The third column is for an image obtained by feeling yourself do the movement (Kinaesthetic imagery). Try to do each item separately, independently of how you may have done other items. Complete all items from an external visual perspective and then return to the beginning of the questionnaire and complete all of the items from an internal visual perspective, and finally return to the beginning of the questionnaire and complete the items while feeling the movement. The three ratings for a given item may not in all cases be the same. For all items please have your eyes CLOSED.

Think of each of the following acts that appear on the next page, and classify the images according to the degree of clearness and vividness as shown on the RATING SCALE.

RATING SCALE. The image aroused by each item might be:

Perfectly clear and as vivid (as normal vision or feel of movement)	....	RATING 1
Clear and reasonably vivid	....	RATING 2
Moderately clear and vivid	....	RATING 3
Vague and dim	....	RATING 4
No image at all, you only "know" that you are thinking of the skill.	....	RATING 5

Item	Watching yourself performing the movement (External Visual Imagery)					Looking through your own eyes whilst performing the movement (Internal Visual Imagery)					Feeling yourself do the movement (Kinaesthetic Imagery)				
	Perfectly clear and vivid as normal vision	Clear and reasonably vivid	Moderately clear and vivid	Vague and dim	No image at all, you only know that you are thinking of the skill	Perfectly clear and vivid as normal vision	Clear and reasonably vivid	Moderately clear and vivid	Vague and dim	No image at all, you only know that you are thinking of the skill	Perfectly clear and vivid as normal feel of movement	Clear and reasonably vivid	Moderately clear and vivid	Vague and dim	No image at all, you only know that you are thinking of the skill
1.Walking	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
2.Running	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
3.Kicking a stone	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
4.Bending to pick up a coin	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
5.Running up stairs	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
6.Jumping sideways	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
7.Throwing a stone into water	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
8.Kicking a ball in the air	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
9.Running downhill	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
10.Riding a bike	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
11.Swinging on a rope	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
12.Jumping off a high wall	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5

1. Please indicate if you have a preference for using a particular visual imagery perspective on this scale (if you have no preference then circle 5):

0	1	2	3	4	5	6	7	8	9	10
Strong preference internal			Moderate preference internal		No preference		Moderate preference external			Strong preference external

2. Please indicate on the following questions the extent to which you "switched" between imagery perspectives, when completing the two visual columns of the adapted VMIQ:

a) When completing the *watching yourself do it* (External Visual Imagery) column, what perspective did you use?

0	1	2	3	4	5	6	7	8	9	10
Completely internal perspective		minimal switching to an external perspective			switched regularly			minimal switching to an internal perspective		completely external perspective

b) When completing the *looking through your own eyes* (Internal Visual Imagery) column, what perspective did you use?

0	1	2	3	4	5	6	7	8	9	10
Completely internal perspective		minimal switching to an external perspective			switched regularly			minimal switching to an internal perspective		completely external perspective

3. When completing the two visual imagery columns please specify if you used kinaesthetic imagery at the same time as the designated visual imagery perspective:

EVI

0	1	2	3	4	5	6	7	8	9	10
No kinaesthetic imagery use										high kinaesthetic imagery use

IVI

0	1	2	3	4	5	6	7	8	9	10
No kinaesthetic imagery use										high kinaesthetic imagery use

4. If you used kinaesthetic imagery at the same time as the designated visual perspective please denote (Using the numbers 3 = most often, 1 = least often) the order in which visual and kinaesthetic imagery were used

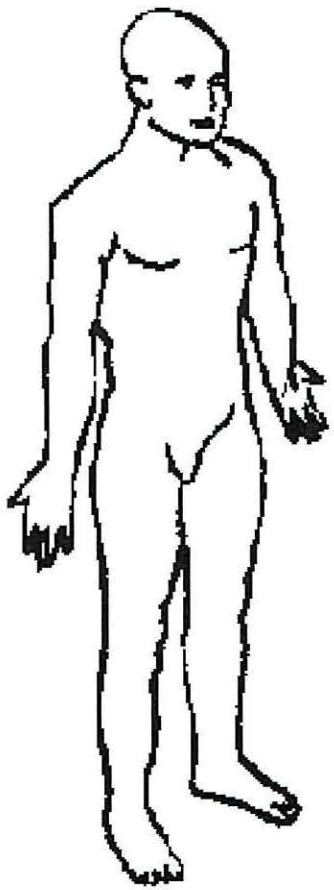
EVI

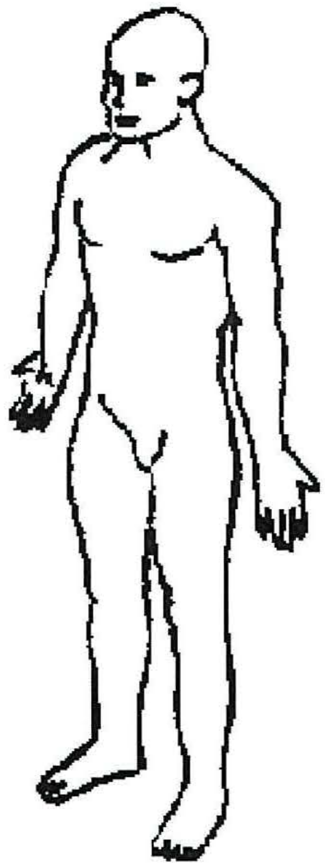
Visual and Kinaesthetic imagery at the same time ______
Visual then kinaesthetic imagery ______
Kinaesthetic then visual imagery ______

IVI

Visual and Kinaesthetic imagery at the same time ______
Visual then kinaesthetic imagery ______
Kinaesthetic then visual imagery ______

5. On <u>one</u> of the diagrams below, please draw an arrow to illustrate where you imaged from most of the time, when completing the external visual imagery column.





APPENDIX B

IMAGERY SCRIPTS

External visual imagery

You are about to imagine performing a task using external visual imagery. This is when you imagine yourself from outside as if you watching yourself performing the task. While you listen to this imagery scripts, you can have your eyes open or closed, if you wish to close them, do so now.

Take a couple of long slow relaxations to relax yourself. Focus and breathing out long and slow. From an external visual perspective, imagine seeing yourself sitting in the car with your hands on the wheel, ready to begin the race.

You see the car gathers speed as it accelerates towards the start line. As the car crosses the start line, you see the long street in front of it. Notice as the car going downhill slightly; it is travelling over a couple of horizons. As you see the car approach the S-shape bend, you see the line you want it to take. As the car approaches the bend, you see yourself break allowing the car to take the perfect line, seeing yourself turning first to your right and then to your left, so you can close the bend, and accelerating out. As the car continues around the track, you see a steep curb bend overhead. You see yourself turn first to your right and then to your left as the road drops steeply. As you watch the car accelerates, you see the car maintain the straight line, traveling as fast as you can over the bridge but staying in control. You see the car continue to accelerate through the next relatively straight section. The road is flat and you see the car maintains a good line. You noticed the white right-hand bend in the distance, and you see yourself take the line that directs the car to apex of the bend. As the car approaches the bend, you see yourself break, and accelerate the car out at full speed. You watch the car maintains the speed as it goes through the tunnel. As you come through the tunnel, you see the line to take for the short right-hand bend overhead. As you see yourself break you see the car approach the bend and accelerate out. You see yourself staring the car through series of mono bend which gradually climes the last hill. As the car reaches the top of the hill, you see it approach the last big right-hand bend. You see yourself break so that you can fully accelerate the car out of the bend, down the hill and over the finishing line.

Internal visual imagery

You are about to imagine performing a task during internal visual imagery. This is when you imagine yourself from inside looking out through your own eyes as if you were actually performing the task. While you listen to this imagery scripts, you can have your eyes open or closed, if you wish to close them, do so now.

Take a couple of long slow relaxations to relax yourself. Focus and breathing out long and slow. From an internal visual perspective, imagine sitting in the driving seat with your hands on the wheel, ready to begin the race.

As the car accelerates, it gathers speed. As you come over the hill, you can see the start line in front of you. Crossing the start line, you see the long street in front of the car. Notice as the front of the car is going downhill slightly; it is travelling over a couple of horizons. As you approach the S-shape bend head, you see the line you want to take. As the car approaches the bend, you break to take the perfect line, turning first your right and then quickly to your left, taking close to the bend, and accelerating after the bend. As the car continues around the track, you see steep curb bend in front of you. You turn first to your right and then to your left as the road drops steeply. As the car accelerates out, you maintain the straight line, traveling as fast as you can over the bridge but staying in control. You keep it accelerating through the next relatively straight section. The road is flat and the car maintains a good line. You noticed the white right-hand bend in the distance, and you take the line that directs the car to apex of the bend. As the car approaches the bend, you break, and accelerate out at full speed. The car maintains the speed as it enters the tunnel. As you come through the tunnel, you see the line to take for the short right-hand bend ahead. You break as you approach the bend and accelerate out. You stare through series of mono bend which gradually climes the last hill. As the car reaches the top, you see the last big right-hand bend approaching. You break into it so that you can fully accelerate the car out of the bend, down the hill and over the finishing line.

Internal visual imagery and kinesthetic imagery

You are about to imagine performing a task using internal visual imagery and kinesthetic imagery. This is when you imagine yourself from inside looking out through your own eyes while feeling the movements as if you were actually performing the task. When you listen to this imagery scripts, you can have your eyes open or closed, if you wish to close them, do so now.

Take a couple of long slow breaths to relax yourself. Focus and breath in and out long and slowly. From an internal visual perspective, imagine sitting in the driving seat with your hands on the wheel, you feel that your body is relaxed but alert, and ready to begin the race.

As the car accelerates, it gathers speed; you feel the pressure through your right leg and foot to the accelerator pedal. As you come over the hill, you can see the start line in front of you. Crossing the start line, you see the long road in front of the car. Notice as the front of the car is going downhill slightly; it is traveling over a couple of horizons. As you approach the S-shape bend head, you see the line you want to take. As the car approaches the bend, you break to take the perfect line. As you break you feel your upper body move forward slightly, and hands tightening their grasp on the wheel, as you take the right then left hand turn, you feel your body moving with the turns, and you accelerate out of the bend. As the car continues around the track, you see steep curb bend in front of you. You could feel the light force through your arms to the wheel; you quickly turn the wheel first to your right and then to your left as the road drops steeply. As the car accelerates out, you maintain the straight line, traveling as fast as you can over the bridge but staying in control. You are relax but alert to the road conditions. You keep the car accelerating through the next relatively straight section; you feel the pressure through your right leg and foot onto the accelerator pedal. The road is flat and the car maintains a good line. You noticed the white right-hand bend in the distance, and you take the line that directs the car to apex of the bend. As the car approaches the bend, you break, and feel your body move into the bend, and you accelerate out at full speed. The car maintains the speed as it enters the tunnel. As you come through the tunnel, you see the line to take for the short right-hand bend ahead. You break as you approach the bend and accelerate out. You stare through a series of mono bends which gradually climb the last hill. As the car reaches the top, you see the last big right-hand bend approaching. As you break into the bend you feel your body move with the bend, and then the pressure on the accelerator pedal as you fully accelerate the car out of the bend, down the hill and over the finishing line.

APPENDIX C

POST-EXPERIMENTAL QUESTIONNAIRES

Study 1 EVI group post-experimental questionnaire

Participant Number...........

1. To what extent were you able to adhere to the imagery script that you were asked to use?

0	1	2	3	4	5	6	7	8	9	10
Not at all										Very much so

2. Did you switch between imagery perspectives and use the non-required perspective?

0	1	2	3	4	5	6	7	8	9	10
Not at all										Very much so

3. To what extent did you switch between and use both imagery perspectives?

0	1	2	3	4	5	6	7	8	9	10
Not at all										Very much so

4. Please rate the ease/difficulty with which you were able to image the visual content of the scripts.

0	1	2	3	4	5	6	7	8	9	10
Very difficult to see										Very easy to see

5. How easy was it for you to create the images?

0	1	2	3	4	5	6	7	8	9	10
Very difficult to create										Very easy to create

6. How detailed were the images that you were able to create?

0	1	2	3	4	5	6	7	8	9	10
Not at all detailed										Extremely detailed

7. How vivid (i.e. clear and lifelike) were the images you created?

0	1	2	3	4	5	6	7	8	9	10
Not at all clear										Extremely clear

8. How easy was it for you to maintain the images once you had created them?

0 1 2 3 4 5 6 7 8 9 10

Very difficult to maintain — Very easy to maintain

9. To what extent could you control the images once you had created them?

0 1 2 3 4 5 6 7 8 9 10

Not at all — Very much so

10. To what extent did you feel that the imagery treatment helped your self-confidence to perform well in the task?

0 1 2 3 4 5 6 7 8 9 10

Not at all — Very much so

11. To what extent did you feel that the imagery treatment helped your motivation to perform well in the task?

0 1 2 3 4 5 6 7 8 9 10

Not at all — Very much so

12. To what extent did you feel that the imagery treatment prepared you for the task?

0 1 2 3 4 5 6 7 8 9 10

Not at all — Very much so

13. To what extent did you experience any kinaesthetic imagery (imagery relating to the feeling of the movements) during your attempts?

0 1 2 3 4 5 6 7 8 9 10

Not at all — Very much so

14. How suitable did you think the imagery script was for the task you had to perform?

0 1 2 3 4 5 6 7 8 9 10

Not suitable — Very suitable

15. Based on the most amount of physical effort you have ever put into driving, how would you rate your effort during the 10 trials?

0 1 2 3 4 5 6 7 8 9 10

No effort — Most effort

at all ever

16. Based on the most amount of mental effort you have ever put into driving, how would you rate your effort during the 10 trials?

0	1	2	3	4	5	6	7	8	9	10
No effort at all										Most effort ever

17. When you were imaging from an external perspective, where in relation to your body and/or the car were you imaging from for the majority of the time? Please provide as much detail as possible.

18. Were there any other strategies which you employed at any time during the experiment? Please provide as much detail as possible.

Thank you very much for your participation.

Study 1 and study 2 IVI group post-experimental questionnaire

Participant Number………..

1. To what extent were you able to adhere to the imagery script that you were asked to use?

0	1	2	3	4	5	6	7	8	9	10
Not at all										Very much so

2. Did you switch between imagery perspectives and use the non-required perspective?

0	1	2	3	4	5	6	7	8	9	10
Not at all										Very much so

3. To what extent did you switch between and use both imagery perspectives?

0	1	2	3	4	5	6	7	8	9	10
Not at all										Very much so

4. Please rate the ease/difficulty with which you were able to image the visual content of the scripts.

0	1	2	3	4	5	6	7	8	9	10
Very difficult to see										Very easy to see

5. How easy was it for you to create the images?

0	1	2	3	4	5	6	7	8	9	10
Very difficult to create										Very easy to create

6. How detailed were the images that you were able to create?

0	1	2	3	4	5	6	7	8	9	10
Not at all detailed										Extremely detailed

7. How vivid (i.e. clear and lifelike) were the images you created?

0	1	2	3	4	5	6	7	8	9	10
Not at all clear										Extremely clear

8. How easy was it for you to maintain the images once you had created them?

0	1	2	3	4	5	6	7	8	9	10
Very difficult to maintain										Very easy to maintain

9. To what extent could you control the images once you had created them?

0 1 2 3 4 5 6 7 8 9 10

Not at all — Very much so

10. To what extent did you feel that the imagery treatment helped your self-confidence to perform well in the task?

0 1 2 3 4 5 6 7 8 9 10

Not at all — Very much so

11. To what extent did you feel that the imagery treatment helped your motivation to perform well in the task?

0 1 2 3 4 5 6 7 8 9 10

Not at all — Very much so

12. To what extent did you feel that the imagery treatment prepared you for the task?

0 1 2 3 4 5 6 7 8 9 10

Not at all — Very much so

13. To what extent did you experience any kinaesthetic imagery (imagery relating to the feeling of the movements) during your attempts?

0 1 2 3 4 5 6 7 8 9 10

Not at all — Very much so

14. How suitable did you think the imagery script was for the task you had to perform?

0 1 2 3 4 5 6 7 8 9 10

Not suitable — Very suitable

15. Based on the most amount of physical effort you have ever put into driving, how would you rate your effort during the 10 trials?

0 1 2 3 4 5 6 7 8 9 10

No effort at all — Most effort ever

16. Based on the most amount of mental effort you have ever put into driving, how would you rate your effort during the 10 trials?

0	1	2	3	4	5	6	7	8	9	10
No effort at all										Most effort ever

17. Were there any other strategies which you employed at any time during the experiment? Please provide as much detail as possible.

Thank you very much for your participation.

Study 2 KIN and IVI group post-experimental questionnaire

Participant Number………..

1. To what extent were you able to adhere to the imagery script that you were asked to use?

0 1 2 3 4 5 6 7 8 9 10

Not at all | Very much so

2. Did you switch between imagery perspectives and use the non-required perspective?

0 1 2 3 4 5 6 7 8 9 10

Not at all | Very much so

3. To what extent did you switch between and use both imagery perspectives?

0 1 2 3 4 5 6 7 8 9 10

Not at all | Very much so

4. Please rate the ease/difficulty with which you were able to image the visual content of the scripts.

0 1 2 3 4 5 6 7 8 9 10

Very difficult to see | Very easy to see

5. To what extent did you experience any kinaesthetic imagery (imagery relating to the feeling of the movements) during your attempts?

0 1 2 3 4 5 6 7 8 9 10

Not at all | Very much so

6. How easy was it for you to create the visual images?

0 1 2 3 4 5 6 7 8 9 10

Very difficult to create | Very easy to create

7. How easy was it for you to create the feelings of the movement?

0 1 2 3 4 5 6 7 8 9 10

Very difficult to create | Very easy to create

8. How detailed were the visual images that you were able to create?

0 1 2 3 4 5 6 7 8 9 10

Not at all detailed | Extremely detailed

9. How detailed were the feelings of the movement that you were able to create?

0 1 2 3 4 5 6 7 8 9 10

Not at all detailed | Extremely detailed

10. How vivid (i.e. clear and lifelike) were the visual images you created?

0 1 2 3 4 5 6 7 8 9 10

Not at all clear | Extremely clear

11. How vivid (i.e. clear and lifelike) were the feelings of the movement you created?

0 1 2 3 4 5 6 7 8 9 10

Not at all clear | Extremely clear

12. How easy was it for you to maintain the visual images once you had created them?

0 1 2 3 4 5 6 7 8 9 10

Very difficult to maintain | Very easy to maintain

13. How easy was it for you to maintain the feelings of the movement once you had created them?

0 1 2 3 4 5 6 7 8 9 10

Very difficult to maintain | Very easy to maintain

14. To what extent could you control the visual images once you had created them?

0 1 2 3 4 5 6 7 8 9 10

Not at all | Very much so

15. To what extent could you control the feelings of the movement once you had created them?

0 1 2 3 4 5 6 7 8 9 10

Not at all | Very much so

16. To what extent did you feel that the imagery treatment helped your self-confidence to perform well in the task?

0 1 2 3 4 5 6 7 8 9 10

Not at all | Very much so

17. To what extent did you feel that the imagery treatment helped your motivation to perform well in the task?

0 1 2 3 4 5 6 7 8 9 10

Not at all | Very much so

18. To what extent did you feel that the imagery treatment prepared you for the task?

0 1 2 3 4 5 6 7 8 9 10

Not at all | Very much so

19. How suitable did you think the imagery script was for the task you had to perform?

0 1 2 3 4 5 6 7 8 9 10

Not suitable | Very suitable

20. Based on the most amount of physical effort you have ever put into driving, how would you rate your effort during the 10 trials?

0 1 2 3 4 5 6 7 8 9 10

No effort at all — Most effort ever

21. Based on the most amount of mental effort you have ever put into driving, how would you rate your effort during the 10 trials?

0	1	2	3	4	5	6	7	8	9	10
No effort at all										Most effort ever

22. Were there any other strategies which you employed at any time during the experiment? Please provide as much detail as possible.

Thank you very much for your participation.

Study 1 and study 2 control group post-experimental questionnaire

Participant number..............

1. To what extent were you able to adhere to the maths problem that you were asked to perform prior to the driving task?

0	1	2	3	4	5	6	7	8	9	10
Not at all										Very much so

2. To what extent did you feel that the maths problems you performed helped your self-confidence to perform well in the driving task?

0	1	2	3	4	5	6	7	8	9	10
Not at all										Very much so

3. To what extent did you feel that the maths problems helped your motivation to perform well in the driving task?

0	1	2	3	4	5	6	7	8	9	10
Not at all										Very much so

4. To what extent did you feel that the maths problems prepared you for the driving task?

0	1	2	3	4	5	6	7	8	9	10
Not at all										Very much so

5. How suitable did you think the maths problems were for the driving task you performed?

0	1	2	3	4	5	6	7	8	9	10
Not at all										Very much so

6. Based on the most amount of physical effort you have ever put into driving, how would you rate your effort during the 10 trials?

0	1	2	3	4	5	6	7	8	9	10
No effort at all										Most effort ever

7. Based on the most amount of mental effort you have ever put into driving, how would you rate your effort during the 10 trials?

0	1	2	3	4	5	6	7	8	9	10

No effort at all | Most effort ever

8. Were there any other strategies which you employed at any time throughout the experiment? Please provide as much detail as possible.

Thank you very much for your participation.

Study 3 post-experimental questionnaire

Participant Number

1. To what extent were you able to adhere to internal visual imagery when in the scanner?

1 2 3 4 5 6 7 8 9 10
not at all greatly

2. To what extent were you able to adhere to external visual imagery when in the scanner?

1 2 3 4 5 6 7 8 9 10
not at all greatly

3. To what extent were you able to adhere to kinaesthetic imagery when in the scanner?

1 2 3 4 5 6 7 8 9 10
not at all greatly

4. Did you switch between internal visual imagery, external visual imagery and kinaesthetic imagery when you were performing imagery in the scanner?

1 2 3 4 5 6 7 8 9 10
not at all always

5. To what extent did you experience any kinaesthetic (feeling) during internal visual imagery?

1 2 3 4 5 6 7 8 9 10
not at all greatly

6. To what extent did you experience any kinaesthetic (feeling) during external visual imagery?

1 2 3 4 5 6 7 8 9 10
not at all greatly

7. To what extent did you use any internal visual imagery during kinaesthetic imagery?

1 2 3 4 5 6 7 8 9 10
not at all greatly

8. To what extent did you use any external visual imagery during kinaesthetic imagery?

1 2 3 4 5 6 7 8 9 10
not at all greatly

9. In the rest period, were you able to keep your eyes focussed on the fixation cross?

1 2 3 4 5 6 7 8 9 10
not at all greatly

Study 4 post-experimental questionnaire

Participant Number

1. To what extent were you able to adhere to internal visual imagery when in the scanner?

0 1 2 3 4 5 6 7 8 9 10
not at all somewhat greatly

2. To what extent were you able to adhere to external visual imagery when in the scanner?

0 1 2 3 4 5 6 7 8 9 10
not at all somewhat greatly

3. To what extent were you able to adhere to kinaesthetic imagery when in the scanner?

0 1 2 3 4 5 6 7 8 9 10
not at all somewhat greatly

4. To what extent were you able to adhere to internal visual imagery and kinaesthetic imagery when in the scanner?

0 1 2 3 4 5 6 7 8 9 10
not at all somewhat greatly

5. When you were asked to do a specific type of imagery, did you switch to any of the other types of imagery?

0 1 2 3 4 5 6 7 8 9 10
not at all somewhat greatly

6. To what extent did you experience any kinaesthetic (feeling) during internal visual imagery?

0 1 2 3 4 5 6 7 8 9 10
not at all somewhat greatly

7. To what extent did you experience any kinaesthetic (feeling) during external visual imagery?

0 1 2 3 4 5 6 7 8 9 10
not at all somewhat greatly

8. To what extent did you use any internal visual imagery during kinaesthetic imagery?

0 1 2 3 4 5 6 7 8 9 10
not at all somewhat greatly

9. To what extent did you use any external visual imagery during kinaesthetic imagery?

0 1 2 3 4 5 6 7 8 9 10
not at all somewhat greatly

10. In the rest period, were you able to keep your eyes focussed on the fixation cross?

0 1 2 3 4 5 6 7 8 9 10
not at all somewhat greatly

APPENDIX D

EXPERIMENT INSTRUCTIONS

Study 1 and study 2 instructions to participants in control group

Part one

You are about to undertake the first of two driving tasks using the driving simulator. The first task will be using the Suzuka circuit. The aim of this first part of the task is to develop your driving skills. You will be using a Citron C4 2.0 VTS Coupe with automatic gear transmission. In order to keep the situation as real life as possible, please use you right foot for both the accelerator and the brake.

You are aiming to complete the circuit in as fast a time as possible. Try and ensure that you are taking the best line to drive the car around the circuit, making as few errors as possible. It is important that you learn how to control the car.

Part two

The second part of the experiment will use the Eiger Nordward track and the same car as before. You will be given five practice attempts to get used to the track layout. Following this, you will have a short break. You will then be asked to complete the track five times driving as fast as you possibly can whilst maintaining control. You will be given a short break between each task. Finally, you will be asked to listen to an imagery script of the task before completing the task five more times as fast as you possibly can and then complete a short questionnaire. Testing will then be complete.

Study 1 and study 2 instructions to participants in imagery group

Part one

You are about to undertake the first of two driving tasks using the driving simulator. The first task will be using the Suzuka circuit. The aim of this first part of the task is to develop your driving skills. You will be using a Citron C4 2.0 VTS Coupe with automatic gear transmission. In order to keep the situation as real life as possible, please use you right foot for both the accelerator and the brake.

You are aiming to complete the circuit in as fast a time as possible. Try and ensure that you are taking the best line to drive the car around the circuit, making as few errors as possible. It is important that you learn how to control the car.

Part two

The second part of the experiment will use the Eiger Nordward track and the same car as before. You will be given five practice attempts to get used to the track layout. Following this, you will have a short break. You will then be asked to complete the track five times driving as fast as you possibly can whilst maintaining control. You will be given a short break between each task. Finally, you will be asked to listen to an imagery script of the task before completing the task five more times as fast as you possibly can and then complete a short questionnaire. Testing will then be complete.

APPENDIX E

MR SAFETY SCREENING QUESTIONNAIRE

To be completed by ANYONE entering the Magnet Room.
Shaded boxes need to be filled in by participants undergoing a scan only.

Name	BANGOR BRAIN IMAGING UNIT no. (Staff Use Only)
Phone number	Date of Birth
Email address	Weight (kg)

MR scanning uses strong magnetic fields. For your own safety and the safety of others it is **very important** that you do not go into the Scanner Room with any metal in or on your body or clothing.

Please answer the following questions carefully and ask if anything is not clear.

All information is held in the strictest confidence.

Circle one answer for each question.

1. Do you have a pacemaker or artificial heart valve?
Y/N
2. Do you have aneurysm clips (clips put around blood vessels during surgery)?
Y/N
3. Do you have any implants in your body? (e.g., replacement joints, drug pumps, metal pins, plates, coronary stents, breast implants etc.)
Y/N
4. Have you ever had any metal fragments in your eyes?
Y/N
5. Have you ever worked with metal (e.g., grinding, machining, welding) without eye protection?
Y/N
6. Do you have any metal or shrapnel fragments anywhere in your body?
Y/N
7. Do have an indwelling catheter in your body?
Y/N
8. Have you ever had an operation on your head, spine, or chest?
Y/N
9. Have you ever had any surgery (if yes, please give brief details)?
Y/N
Details ____
10. Do you have any implanted electrical devices (e.g., hearing aid, cochlea implant, nerve stimulator)?
Y/N

11. Have you ever had an MRI scan before?
Y/N
12. Do you wear dentures, a dental plate, or a brace (not fillings)?
Y/N
13. Do you have any transdermal patches? (skin patches)
Y/N
14. Do you have any tattoos or body piercings?
Y/N
15. Is there any possibility that you could be pregnant?
Y/N
16. Are you susceptible to claustrophobia?
Y/N
17. Do you have hypertension (high blood pressure) sufficient to require medication?
Y/N
18. If Yes to 17 above, has your hypertension been adequately treated by medication?
Y/N
19. Have you had or do you have any heart problems?
Y/N
20. Do you have an impaired ability to perspire?
Y/N
21. Do you have reduced thermal regulatory capabilities or an increased sensitivity to raised body temperature?
Y/N
22. Do you suffer from any other medical condition that might be relevant? (e.g., epilepsy, diabetes, asthma)?
Y/N
Details ____

- I confirm that before entering the Magnet Room, I will:
    - remove all metal including coins, keys, lighters, body-piercings, jewellery, watches, wigs/hairpieces, clothing with zips and/or metal buttons, false teeth, hearing aids etc.;
    - remove all cosmetics;
    - remove all prostheses (e.g., prosthetic limbs);
    - turn off and remove mobile phones;
    - ensure that I am not wearing damp clothing
    - conform with the operator's instructions in regard to the above

- I confirm that the above information is accurate to the best of my knowledge. I have read and understood this form and the information sheet and have had the opportunity to ask questions regarding their contents and the MRI procedure that I am about to undergo.
- I acknowledge that BANGOR BRAIN IMAGING UNIT has taken reasonable precautions to screen for potential difficulties and is not liable for any event that might result from incorrect answers to the above.

Signature	Date
Verified by (BANGOR BRAIN IMAGING UNIT Staff Member) Name Signature	Date