



The neural substrates for the different modalities of movement imagery



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ABSTRACT

Research highlights that internal visual, external visual and kinesthetic imagery differentially effect motor performance (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 (one item from the VMIQ-2) using internal visual imagery, external visual imagery, kinesthetic 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 activated occipital, parietal and frontal brain areas (i.e., the dorsal stream) while external visual imagery activated occipital ventral stream areas and kinesthetic imagery activated caudate and cerebellum areas. These results provide the first central evidence for the visual perspectives and modalities delineated in the VMIQ-2, and, initial biological validity for the VMIQ-2. However, given that only one item from the VMIQ-2 was employed, future fMRI research needs to explore all items to further examine these contentions.

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1. Introduction

Research has 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 Thompson & Kosslyn, 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 some types of 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

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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 some evidence for shared processes between visually perceived stimuli, visually imagined stimuli and action execution (McCormick, Casner, & 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 the ventral stream (originating in areas V1 and V2 of the occipital lobe and extending into the temporal lobe; often referred to as the what pathway) and vision for action is proposed to use the dorsal stream (originating in areas V1 and V2 of the occipital lobe and extending into the parietal lobe; often referred to as the where pathway). Although this linear hierarchical pathway model has been challenged (Rizzolatti & Matelli, 2003; de Haan & 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 kinesthetic 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 where 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, Roberts, Hardy, Jiang, & Edwards, 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; Suchan et al., 2002). 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, Wright, & Cantwell, 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 vice 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 conceptualizations 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 kinesthetic imagery. While several other fMRI studies (e.g., Guillot et al., 2008) are clear to make distinctions between imagery modalities (i.e., visual and kinesthetic), 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 (see Callow & Roberts, 2010 for further detail). An fMRI study comparing the two visual perspectives to determine the differences versus overlaps in activity will help aid our understanding mechanisms by which performance can be moderated following imagery.

Consequently, 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 kinesthetic 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 behaviour to the same imagined action, and no papers have aimed to consider which parts of the brain show common activation for all of the different imagery behaviours. 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 cerebellar and basal ganglia activation for the kinesthetic imagery (replicating Guillot et al., 2009).

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