



Eye gaze metrics reflect a shared motor representation for action observation and movement imagery

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ABSTRACT

Action observation (AO) and movement imagery (MI) have been reported to share similar neural networks. This study investigated the congruency between AO and MI using the eye gaze metrics, dwell time and fixation number. A simple reach–grasp–place arm movement was observed and, in a second condition, imagined where the movement was presented from the first person perspective (1PP) and the third person perspective (3PP). Dwell time and number of fixations were calculated for whole scene and regions of interest (ROIs). For whole scene, no significant differences were found in the number of fixations for condition (AO, MI) or perspective. Dwell time, however, was significantly longer in AO than MI. For ROIs, the number of fixations was significantly greater in 1PP than 3PP. The data provide support for congruence between motor simulation states but also indicate some functional differences.

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1. Introduction

Contemporary evidence from the neuroscience literature suggests that action observation (AO) and movement imagery (MI) share parts of a similar neural network (Grézes & Decety, 2001). Specifically, activation of motor cortex and ventral parts of pre-motor cortex have been reported during observation of an agent's actions (Fadiga, Fogassi, Pavesi, & Rizzolatti, 1995), as well as motor imagery (Gerardin et al., 2000). Considering that there is strong support for congruency between action execution and AO, and action execution and MI, there is limited research that demonstrates congruence between MI and AO. The simulation hypothesis (Jeannerod, 2001) suggests that intended action, MI and AO are driven by a similar, but not identical, activation of the motor system. The theory postulates that the simulation states access a shared motor representation for a given task. This mutual access suggests that the motor pathways associated with one simulated action may be enhanced via any of the other simulation states through a process of Hebbian learning (Hebb, 1949). Although the extent of the shared neural overlap is the subject of current debate (Vul, Harris, Winkelman, & Pahler, 2009), convincing evidence from brain imaging studies supports the existence of, at least a partial neural overlap between the simulation states (Decety, 1996).

The determination of the shared neural overlap in humans was preceded by the discovery of a particular subset of visuomotor

neurons in area F5 of the pre-motor cortex in macaque monkeys (Rizzolatti et al., 1988). These neurons, referred to as 'mirror neurons' were found to discharge when the macaque either observed or performed a goal-directed motor act. Using functional magnetic resonance imaging (fMRI), Iacoboni et al. (1999) highlighted their anatomical location in humans and stated that they were homologous to those of the macaque. Further, using transcranial magnetic stimulation (TMS), Fadiga et al. (1995) observed increased motor evoked potentials (MEPs) in the human motor cortex during observation of goal-directed movements, they also concluded that an action–observation matching system was present in humans.

An indirect approach that offers an objective and dynamic marker of neural activity during MI is the study of gaze behaviour (Henderson, 2003). Recording eye movements provides an unobtrusive, sensitive, real-time behavioural index of on-going visual and cognitive processing (Liversedge & Findlay, 2000). Furthermore, both fixation location and duration characteristics are thought to be indicative of the perceptual strategy used for the action/behaviour in question. Specifically, foveal fixations indicate critical task-related cues, whereas fixation duration/dwell time reflects the information-processing demands of the task. It is suggested that if an image is a reinstatement of the perceptual process then it should include similar eye movements and be constructed in a similar manner (Hebb, 1968). Brandt and Stark (1997) demonstrated this phenomenon by comparing scanpaths during visual imagery and a previously viewed static scene. Although comparable eye movements were observed there was a 20% increase in fixation duration and smaller fixation patterns. These findings were later corroborated by Laeng and Teodorescu (2002), who found visual scanpaths

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during perception to be highly correlated to those during imagery, of the same visual scene. These findings provide further support for the idea of congruence between AO and MI, with the manifestation of similar, but not identical, eye movement patterns being evidence of a shared neural network.

Further support for the concept has been provided by Spivey and Geng (2001), who recorded eye movements whilst participants listened to auditory scene descriptions whilst facing a blank screen. Participants were not aware that their eye movements were being recorded and were given no instruction to fixate on any particular area. Observers tended to make saccades in the same directions as the spatiotemporal dynamics of the described object. These findings support the theory that when people are imaging complex events, they activate the same perceptual-motor mechanisms used during observation of the event. Comparable results have been reported in motion imagery (de'Sperati & Santandrea, 2005) and motor imagery (Heremans, Helsen, & Feys, 2008) tasks.

Heremans et al. (2008) examined the physical execution and visual motor imagery of a cyclical aiming task using eye movement registration. Their results showed that 89% of participants made task-related eye movements during imagery with the eyes open and 84% did so during imagery with eyes closed. Furthermore, both the number and amplitude of the eye movements during imagery closely resembled those of eye movements made during the physical execution of the task. These data suggest that the coupling between neural patterns for eye and hand movements remains intact when hand movements are either imagined or physically executed. In a follow up study, Heremans et al. (2011) reported that eye movements during MI assisted movement accuracy but did not affect the temporal parameters of the action. In partial support of these findings, Gueugneau, Crognier, and Papaxanthis (2008) report that while the temporal congruency between action execution and MI is not affected by the presence, or absence, of eye movement, the presence of saccades has a facilitation effect on the movement duration in both action execution and MI. It would appear that eye movement data could be used as an objective technique to evaluate motor imagery ability and improve the effectiveness of an imagery intervention. In the current paper, we extended this previous work by examining whether the congruency in eye movement metrics reported between action execution and motor imagery (Heremans et al., 2008), exists between AO and MI of a reach-grasp-place movement.

To progress these ideas and concepts, this paper also reports an examination of visual perspective influences on AO and MI congruence. The influence of perspective on imagery remains unclear (Morris, Spittle, & Watt, 2005), and it is an area that has remained relatively unexplored. Visual perspective typically describes the viewpoint of an action but can also include the agent of the behaviour being viewed, i.e., self or other. First person perspective (1PP) is associated with the agent (self or other) performing the action. In contrast, third person perspective (3PP) is associated with the agent, in this case other, rather than self or other, being observed when performing the action (Holmes & Calmels, 2008). While not identical, common areas of cortical activation have been reported in 1PP and 3PP (Ruby & Decety, 2001). Using positron emission tomography (PET), Ruby and Decety (2001) reported that neural function during mental imagery was differentiated by perspective. Using TMS, Fourkas, Avenanti, Urgesi, and Aglioti (2006) observed increases in MEPs during visual imagery of finger abduction from both a 1PP and a 3PP, with larger MEPs recorded in the 1PP. In contrast, when MI is employed for observational learning, the sports psychology literature suggests imagery from a 3PP is most effective (White & Hardy, 1995); novice athletes initially use imagery from a 3PP to make approximations of the desired movement, progressing to 1PP imagery when the basic skill is acquired.

The present paper had two aims. First, we examined the similarity of eye movements between AO and MI, with the specific aim of determining whether congruency, in this metric, exists between the simulation states. Second, we examine the effect of visual perspective on the congruency of eye movements between AO and MI. Based on previous research using eye movement metrics, it was predicted that there would be significant congruency between AO and MI (Gueugneau et al., 2008; Heremans et al., 2008, 2011). Due to the ambiguity of previous findings we made no predictions regarding the effect of visual perspective on the congruency of eye movements between the two conditions.

2. Materials and methods

2.1. Participants

A sample of 26 participants were recruited for the study, however, four participants were excluded from the analysis because of luminance errors, and three made no task related eye movements. These exclusion rates are consistent with previous studies (Heremans et al., 2009; Rodionov, Zislin, & Elidan, 2004). The 19 remaining participants (age: 37.89 ± 9.5 years, 10 females) all had normal or corrected to normal vision and were assessed using the Edinburgh Handedness Inventory; all participants were right handed (mean laterality index: 94.41 ± 8.41) (Oldfield, 1971). Participants were informed that the study aimed to investigate memory function in tasks of varying complexity. The local institutional ethics committee approved the study and participants provided written informed consent prior to the study.

2.2. Apparatus

Eye movements were recorded using the Applied Science Laboratories (ASL) Mobile Eye system (Bedford, Massachusetts). The system uses a method known as 'dark pupil tracking', which uses the relationship between the pupil and a reflection from the cornea to calculate point of gaze in relation to an external scene camera. The system computes the relationship between the pupil and cornea to locate gaze within a scene at a sampling rate of 30 Hz. The equipment has a system accuracy of 0.5° of visual angle, a resolution of 0.10° of visual angle, and a visual range of 50° horizontal and 40° vertical. An experimenter, located behind the participant to minimize distraction, controlled the equipment.

2.3. Task and design

Participants were sat at a desk, situated in a black booth, facing an 81.3 cm LCD screen (Logik, L32DIGB20) positioned 87 cm away. Participants were asked to place their hands, face down, on top of the desk immediately in front of them. The experiment involved performing a repeated ($2 \times$) block, which was separated by a 60 s rest and a calibration check (see Fig. 1). Each block comprised four tasks ($2 \times$ AO and $2 \times$ MI) and all tasks involved the same goal-directed action, manipulated by perspective (1PP or 3PP). In AO, participants viewed a 5 s video (repeated continuously five times) of a model returning a cup to its saucer. In MI, the screen was black and participants were requested to imagine the observed action for the same time as AO (i.e., 25 s). Each MI task was always preceded by the congruent AO task; temporal and spatial accuracy were emphasized. A 15 s rest (looking at a black screen) was given to a random sample ($N = 9$) of the participants following final calibration. Collection of eye movements during this time permitted comparison of eye movements performed during MI and those associated with associated with non-specific gaze. To maintain ecological validity the video clips were presented in colour, how-

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