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The human execution/observation matching system investigated with a complex everyday task: A functional near-infrared spectroscopy (fNIRS) study

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ABSTRACT

The investigation of brain areas involved in the human *execution/observation matching system (EOM)* has been limited to restricted motor actions when using common neuroimaging techniques such as functional magnetic resonance imaging (fMRI). A method which overcomes this limitation is functional near-infrared spectroscopy (fNIRS). In the present study, we explored the cerebral responses underlying action execution and observation during a complex everyday task. We measured brain activation of 39 participants during the performance of object-related reaching, grasping and displacing movements, namely setting and clearing a table, and observation of the same task from different perspectives. Observation of the table-setting task activated parts of a network matching those activated during execution of the task. Specifically, observation from an egocentric perspective led to a higher activation in the inferior parietal cortex than observation from an allocentric perspective, implicating that the viewpoint also influences the *EOM* during the observation of complex everyday tasks. Together these findings suggest that fNIRS is able to overcome the restrictions of common imaging methods by investigating the *EOM* with a naturalistic task.

1. Introduction

Social life requires that we understand other people's behavior. This capacity has been associated with action simulation processes in the so-called *execution/observation matching system (EOM)* of the human brain [10]. Current theories suggest that whenever an observed action is matched onto this system, representations of our own actions serve as internal models that can provide information about actual movements and probable future events [30]. Brain areas involved in this system are not only active when we perform an action, but also when we see another person performing the same action. The *EOM* has been predominantly found in the inferior frontal cortex (inferior frontal gyrus and premotor cortex), in the posterior superior temporal sulcus (STS), and in posterior parietal regions using fMRI [9,14], as well as in the primary motor cortex using transcranial magnetic stimulation (TMS) [8].

fMRI is the most dominant imaging technique used to investigate human brain function. Similar to positron emission tomography (PET), fMRI requires the subject to lie in a narrow bore, allowing only restricted body movements and decomposed sub-actions (e.g., wrist movement and finger tapping). Thus, previous studies on action execution and observation have been limited to finger movements or closely spaced hand and arm movements [9,14,15,23]. In comparison, most everyday actions and interactions are characterized by complex and often spatially expansive movements composed of continuous and distinct sub-actions. For example, everyday life actions, like setting a dinner table, consist of distinct object-related reaching, grasping and displacing movements with high spatial and temporal degrees of freedom. Using fMRI, these everyday actions are hardly investigable due to the confined space in the fMRI bore. Therefore, fMRI provides limited ecological validity to investigate the *EOM* during execution and observation of daily actions.

In the past years, functional near-infrared spectroscopy (fNIRS) has been established as a highly flexible brain imaging technique.

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This non-invasive optical method is robust against movement artifacts and allows functional brain measurements during many ordinary human activities. For example, fNIRS is capable of measuring cortical activity while subjects execute knot-tying tasks [17] or even walk on a treadmill [18]. Furthermore, an experimental fNIRS setting is, in comparison to fMRI, less unpleasant and exhausting (e.g., no noise and unconstraint sitting position). These aspects of fNIRS result in increased compliance of participants and make this technique appropriate for use with patients, e.g., psychiatric patients [7] and children [27]. Regarding the motor system, fNIRS has been successfully applied to measure activity in motor areas elicited by the execution of finger and arm movements [11,21], simple grasping movements [24] and the observation of hand movements [25]. A recent fNIRS study measured activation in motor areas during observation and imitation of hand actions elicited by a virtual environment [13]. It remains an open question whether this method is able to identify areas of the *EOM* during execution and passive observation of complex everyday tasks.

Neuroimaging studies on the *EOM* often use an egocentric perspective for the observation conditions, i.e., the observer takes the view point of the actor [e.g., 2,9]. However, during everyday interactions with others, we normally have an allocentric viewpoint of our partner's actions, i.e., the observer faces the actor. The effect of the observer's viewpoint on neural activity in the left motor cortex has been recently investigated by means of TMS [1]. For the observation of simple right-handed actions, neural activity in the left motor cortex was stronger for an egocentric viewpoint than for an allocentric viewpoint. Similarly, an fMRI study [15] detected a stronger activation in the left sensory-motor cortex for an egocentric than it did for an allocentric perspective during the observation of simple hand and foot actions. It has still to be clarified, whether the effect of the observer's viewpoint can be revealed in *EOM* areas during the observation of complex everyday tasks.

The present study aimed to examine whether fNIRS is a valid approach for investigating the involvement of the *EOM* during execution and observation of complex everyday tasks. Furthermore, we aimed to determine if fNIRS is capable of discriminating between an allocentric perspective and an egocentric perspective when monitoring activation in response to action observation.

We measured brain activity in the left hemisphere of subjects that performed a table-setting task with their right arm and observed videos of another person performing the same task, recorded from either an allocentric or an egocentric perspective. Firstly, we expected to reveal areas that are activated during both action execution and action observation of the table-setting task. This would imply that fNIRS is capable of identifying activation of *EOM* areas relevant for complex everyday actions. Secondly, since we investigated left hemispheric activation during the observation of right-handed actions, we expected higher activation for observation from an *egocentric* perspective than for observation from an *allocentric* perspective in *EOM* areas. Such a result would indicate that fNIRS is able to differentiate between an egocentric viewpoint and an allocentric viewpoint when investigating the involvement of the *EOM* during observation of everyday tasks.

2. Methods

2.1. Subjects

A group of 39 subjects (25 women, 14 men; mean age 21.8 years; range 19–30 years) participated in this study after written informed consent was obtained. All subjects were right-handed, as assessed with the Edinburgh Handedness Questionnaire [20], and had normal or corrected-to-normal vision. None of the subjects had a known history of any neurological disorder or current psychiatric disorder. The study was approved by the Ethics Committee of the University of Würzburg.

2.2. Experimental design

Subjects executed and observed a table-setting task which required object-related reaching, grasping and displacing movements: while sitting at a table, which was covered with a black tablecloth, subjects were asked to arrange plastic dishware (plate, cup, bowl, spoon and knife) for setting and clearing the table and to observe these actions. The subject sat in a comfortable chair facing a monitor (17 in., screen refresh rate of 70 Hz) at a fixed distance of 1 m in a normally illuminated room.

Subjects participated in three experimental conditions:

(1) execution (EXE): performance of the table-setting task with the right arm,
(2) observation from egocentric perspective (OBS_{ego}, Fig. 1A): observation of table-setting task from an egocentric perspective, i.e., body- and hand-orientation of the actor facing out from the observer,
(3) observation from allocentric perspective (OBS_{allo}, Fig. 1A): observation of the table-setting task in an allocentric perspective, i.e., body- and hand-orientation of the actor facing toward the observer.

At the beginning of the experiment, the dishware was stacked at the lower right edge of the table in front of the subject. During EXE, subjects were instructed to grasp and move each of the five dishes separately (order not specified) and to arrange the dishes on the table as they normally use in daily routine. During the next EXE, subjects were asked to grasp each of the five dishes separately, and to move them back to the lower right edge of the table. In every block of EXE subjects performed five movements, resulting in a movement sequence lasting about 12 s. The movement had to be executed as smoothly as possible without any delays in arranging the tableware so that the five movements were of similar length and had the same timing and duration as the movements in the video recordings of the OBS conditions (five movements in 12 s). To ensure this, each subject practiced the performance of the table-setting tasks before the fNIRS measurement began. In the rare case that subjects were not finished with all movements within the 12 s, they had to stop when seeing "pause" on the screen. Subjects were instructed to keep the left arm relaxed on their lap. All executed and observed actions were performed with the right hand to control for the influence of the hand/arm side. Subjects were instructed to move the head and torso as little as possible during the entire experimental session.

During the observation conditions (OBS_{ego} and OBS_{allo}), subjects observed video clips of a person's arm, from egocentric and allocentric positions, performing the table-setting task. Therefore, we used four different videos: (1) setting the table and (2) clearing the table recorded from an egocentric perspective (OBS_{ego}) and an allocentric perspective (OBS_{allo}). Attention was paid to keep the same properties for brightness and contrast for all of the video clips, as well as for EXE. Within each observation condition, subjects observed movements with five dishware objects. Timing and duration of the movements were similar to the EXE conditions. During the observation conditions, the dishware for EXE remained either in the set or cleared position.

We used a pseudo-randomized block design (Fig. 1A). Randomization was restricted since the first EXE consisted of moving the dishware to set the table, and the next EXE consisted of returning the dishware to its original position. For each condition, the task interval was 12 s. Each condition was repeated eight times. A resting interval of 12 s was inserted between the task intervals of