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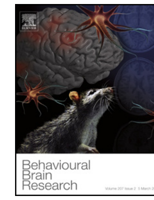

Research report

Observed manipulation of novel tools leads to mu rhythm suppression over sensory-motor cortices

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HIGHLIGHTS

- Observational learning of tool manipulation leads to mu rhythm modulation.
- Similar modulation is seen for visual exploration of tools.
- Mu rhythm modulation takes place over sensory-motor cortices.
- The effect is seen within 200 ms after tool picture presentation.

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ABSTRACT

Tool stimuli can be analyzed based on their affordance, that is, their visual structure hinting at possible interaction points. Additionally, familiar tools can initiate the retrieval of stored object–action associations, providing the basis for a meaningful object use. The mu rhythm within the electroencephalographic alpha band is associated with sensory-motor processing and was shown to be modulated during the sight of familiar tool stimuli, suggesting motor cortex activation based on either affordance processing or access to stored conceptual object–action associations. The current study aimed to investigate the impact of such associations, acquired by observation of manipulation, in a training study controlling for inherent object affordances and previous individual differences in object-related experience. Participants observed the manipulation of a set of novel tool objects and visually explored a second set of novel tools for which only functional information was provided. In contrast to non-trained objects, observed objects modulated the mu rhythm over left sensory-motor cortex within 200 ms after training. Additionally, both observed and visually explored objects modulated mu rhythm over right sensory-motor cortex in the same time window to some extent, with the effect being stronger for the latter. This result suggests that motor cortex activation in visual processing of tools can result from observation of tool manipulation. However, mu rhythm modulation, albeit with a different and less clear left-lateralized pattern, is also seen when the tools were only made visually familiar and when information was restricted to the tools function.

1. Introduction

Tools represent a special class of object as they are defined by the way one interacts with them, and the purpose they serve. Hence, when seeing manipulable tools, information about potential action interaction points, or “affordances” [1], is extracted. Furthermore, familiar tools can initiate the retrieval of stored information about associations between the object, an object-related action and an action goal, which is based on previous object interaction experience [2]. Several functional neuroimaging studies have found activations of a frontoparietal network by the sight of familiar

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tools, most likely representing the stored motor action representation associated with the tool (for review, see [3–6]). Furthermore, behavioral studies have shown that the mere sight of tools can prime, or "potentiate", motor responses to object parts, affording an action through motor facilitation, therefore supporting the idea of the automatic extraction of affordances when seeing manipulable objects. Together, these findings suggest that action information can be an integral part of object representations.

One potential mechanism for this is described in the Two Action Systems Model [2], which proposes that the action system is separable into two functionally and anatomically distinguishable units, a Structural System and a Functional System. The Structural System is devoted to perform an online analysis of visual object structures for a rapid interaction and is proposed to be not exclusively cognitive. During repeated and skilled interaction with objects, a Functional System extracts the characteristics of an action that remain constant across object-directed interactions, hence providing the basis for the formation of conceptual object representations. During manual object interaction the extracted functional knowledge and object-associated actions thus become integral parts of conceptual representations, which do, however, comprise different types of knowledge about an object in different modalities. A key component for the evolution of human tool use behavior is the capacity to learn through the observation of others performing an action [7]. This therefore suggests that the formation of mental representations of tools is not only bound to direct interactive experience with the object, but can also result from indirect experience through the observation of others' interactions with the object. It has been shown that certain neurons in area F5 of the monkey cortex, called "mirror neurons", discharge during the observation of others performing object-related actions [8–10], a property that has been proposed to represent a direct matching mechanism by which the observed motor action is mapped onto the observer's internal motor representations [11,12].

Electroencephalography (EEG) studies investigating sensory-motor processing in humans have analyzed the mu rhythm, which refers to oscillatory brain activity in the alpha and beta band (8–12 Hz and ~20 Hz), in electrodes placed over the sensory-motor cortices. Event-related desynchronization (ERD) of the oscillatory neuronal firing that underlies the mu rhythm can, for example, be found during movement execution (e.g., [13–15]) but also during the observation of movements (e.g., [16,17]) and movement imagery (e.g., [18]). These properties of the mu rhythm show that the motor system can also be engaged in the absence of active action execution, and some researchers argue that this activity partly represents an index of the mirror neuron system [19]. Furthermore, findings on the suppression of the mu rhythm during object-related in contrast to meaningless actions have been interpreted as activation of goal-directed motor programs related to the mirror neuron system [16]. Interestingly, the simple viewing of tool stimuli, even without the demand to interact, can also lead to mu rhythm suppression between 140 ms and 300 ms after stimulus presentation [20], possibly reflecting the automatic access to object-associated actions. Further support for this comes from early event-related potentials (ERPs) during the processing of tools for which sources were described in the left postcentral gyrus and bilateral premotor cortex. However, so far it is not clear if the modulation of the mu rhythm during the sight of tool stimuli relates to simple visual affordance processing, or to experience-dependent object–action associations that can be acquired during observation of object manipulation. As mu suppression has been found both for action execution and for the sight of known objects [13–15,20], it seems likely that active object experience plays a role in the activation of motor cortex during visual object processing. While mu suppression was also seen for the observation of meaningful actions [16,17,21], it is not clear what effect the observation of object interactions has on the formation of object–action associations. The mirror neuron hypothesis [8–10] and related simulationist theories [22] posit that direct motor experience may not be necessary to form such associations, but rather observation of object-related motor actions may be sufficient. However, this is a topic that is still hotly debated.

A major problem with using familiar tools in experiments addressing experience effects is that interindividual differences in previous knowledge cannot be controlled for. Recently, several training studies have used novel objects to overcome this problem (e.g., [23–26]). In these studies, subjects systematically received different types of object-related experience. Even though the object-related knowledge gained cannot be compared to existing conceptual representations, training studies can lead to important insights, providing a model for the mechanisms involved in the emergence of new object representations. One such study found that early activation over sensory-motor and occipito-parietal brain regions during object processing only occurred in the condition in which object-related movements had been previously trained through pantomimed actions, as compared to training with non-functional actions that were not relevant to the object being seen [25]. The authors here concluded that object processing can be altered with respect to the specific sensory-motor interactions with objects during knowledge acquisition.

In the current study, novel, tool-like objects ([23] similar to the ones used by Weisberg et al. [24]) were used to investigate whether observing the manipulation of objects had a differential impact on neural correlates of object–action associations, as reflected in the sensory-motor mu rhythm, when compared to the mere learning about object function, but without seeing the object being used. Each participant in the present study received three sessions of object-related training over 3 days. For one set of objects, participants observed an experimenter manipulating the invented, unfamiliar tools during training (observation of manipulation training objects, OBS). For another set of invented and unfamiliar tool objects, participants were informed about the tools' function but only visually explored the object (visual training objects, VIS). Finally, a third object set served as an untrained control set (not trained objects, NO). Before and after training, participants performed a visual matching task during which photographs of all tools were shown and brain activity was measured with EEG.

We expected a post training modulation of ERD of activity in the sensory-motor mu rhythm depending on the specific training experience with the objects. More specifically, we predicted that the processing of objects that had been observed to be manipulated (OBS) would lead to a larger mu rhythm suppression as compared to objects that had not been seen to be manipulated (VIS and NO).

2. Materials and methods

2.1. Participants

Twenty-one right-handed students (11 women, mean age 25.33, *SD* = 3.71, range = 20–34) with normal or corrected-to-normal vision participated in the study. No participant had a history of neurological or psychiatric diseases. All were informed about the testing procedure and signed a written consent. Participants received either course credit or financial reimbursement. The study was approved by the Ethics Committee of the Medical Faculty at Ruhr University Bochum, Germany.

2.2. Overall procedure

Using a children construction toy (K'nex™), similar to the studies in [23,24], 36 novel objects were constructed. Participants