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Watching corresponding gestures facilitates learning with animations by activating human mirror-neurons: An fNIRS study

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ABSTRACT

This study investigates whether displaying gestures that correspond to the depicted movements enhances learning about non-human biological movements with dynamic visualizations compared to displaying non-corresponding gestures. Functional near-infrared spectroscopy (fNIRS) was used to assess whether both types of gestures activate the human mirror-neuron system (hMNS). Low-visuospatial-ability learners benefited from corresponding gestures only, whereas high-visuospatial-ability learners achieved good results with both types of gestures. Accordingly, only low-visuospatial-ability learners showed higher activation of the inferior-frontal cortex (part of the hMNS) for corresponding than for non-corresponding gestures. Furthermore, low-visuospatial-ability learners watching non-corresponding gestures yielded better results when their inferior-parietal cortex (another part of the hMNS) was activated. Thus, three factors predict positive learning outcomes: higher visuospatial abilities, inferior-frontal cortex activation, and inferior-parietal cortex activation. In sum, activating the hMNS seems to facilitate learning about biological movements, and stimulating the hMNS by means of corresponding gestures might be an adequate instructional strategy to support low-visuospatial-ability learners.

1. Introduction

Many contents in the Natural Sciences require the understanding of changes in space over time (e.g., Kepler's laws of planetary motion, plate tectonics, or mitosis). Dynamic visualizations can easily depict such changes and they may be particularly suited for instructional purposes if these changes do not occur in discrete steps, but rather involve continuous aspects. However, until now, research on the instructional use of dynamic visualizations has yielded rather heterogeneous results (e.g., Höffler & Leutner, 2007; Lowe, Schnotz, & Rasch, 2011; Tversky, Morrison, & Bétrancourt, 2002). Thus, in order to use dynamic visualizations effectively and to exploit their potential for learning, it is crucial to understand when and under which circumstances they are beneficial.

1.1. *Learners' visuospatial abilities*

Processing dynamic visualizations requires visuospatial abilities (cf. Hegarty, 1992). Thus, it is likely that learners' visuospatial abilities will determine how much learners profit from visualizations of depicted contents and from additional aiding visualizations (cf. Hegarty & Waller, 2005). Previous research has revealed two important findings with regard to learners' visuospatial abilities: (a) learners with higher visuospatial abilities outperform learners with lower visuospatial abilities during learning with static and dynamic visualizations (see Höffler, 2010, for a meta-analysis). Moreover, there is some evidence that (b) visuospatial abilities may moderate the effectiveness of learning with different visualization formats. For instance, higher visuospatial abilities may compensate for "poor" instructions, whereas learners with lower visuospatial abilities suffer from such instructions (cf. ability-as-compensator hypothesis; Hays, 1996; Hegarty & Kriz, 2008; Höffler, 2010; Höffler, Sumfleth, & Leutner, 2006). Thus, particularly learners with low visuospatial abilities might have a strong need for additional instructional aids and support strategies during

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learning with visualizations. In this paper we focus on the role of gestures as instructional aids.

1.2. Learning with gestures

Based on the embodied cognition approach, De Koning and Tabbers (2011) propose the use of gesture as a strategy to improve learning about movements with dynamic visualizations. Learners can either produce gestures on their own or they can watch gestures that are performed by others. With regard to the production of gestures, Hegarty, Mayer, Kriz, and Keehner (2005) showed that gestures are naturally used to communicate movements of components of mechanical devices (e.g., pulley systems). Moreover, it has already been shown that the production of gestures during learning is beneficial for acquiring knowledge about different scientific topics and for spatial problem solving (e.g., Chu & Kita, 2011; Cook & Goldin-Meadow, 2006; Scheiter, Arndt, Imhof, & Ainsworth, 2012). The beneficial effect of producing gestures might be explained by assuming the involvement of an additional modality (comprising body-based representations), that allows for an easy encoding and processing of crucial information. Recruiting additional body-based representations might be particularly helpful for learners who need additional support during learning from visualizations, such as learners with low visuospatial abilities (cf. previous section).

The same basic idea (i.e., involvement of an additional body-based modality) might also explain why watching gestures performed by others seems also to be beneficial for learning (e.g., Ayres, Marcus, Chan, & Qian, 2009; De Koning & Tabbers, 2013). For instance, Marcus, Cleary, Wong, and Ayres (2013) recently demonstrated for a procedural knot-tying task that dynamic visualizations showing hands resulted in higher instructional efficiency than similar dynamic visualizations without hands. Our study addresses the crucial issue of how the activation of body-based representations might explain the beneficial effects of watching gestures when learning about non-human biological movements with dynamic visualizations. We address the question whether watching gestures that correspond to the depicted contents are more effective for learning about movements than watching gestures that do not correspond to the depicted contents.

From a Neuroscience perspective, specific brain structures have been identified that are used to observe, understand and imitate the actions of others by mapping the observed movements to movements of the own body. These structures constitute the so-called human mirror-neuron system (hMNS) and comprise cortical areas of both the inferior frontal and inferior parietal lobe (brodmann area 6, 40, 44, 45; Fogassi & Ferrari, 2011; Rizzolatti & Craighero, 2004). A current hypothesis in the literature on instructional animations, which has received considerable attention recently, states that the stimulation and involvement of the hMNS might be crucial for successful learning about continuous processes with dynamic visualizations (e.g., Ayres et al., 2009; Van Gog, Paas, Marcus, Ayres, & Sweller, 2009). The hMNS is typically activated by human movements, but may be more generally used to also represent other biological or even non-biological movements, if the observer can anthropomorphize those movements, that is, map them on his/her own body (cf., De Koning & Tabbers, 2011; Engel, Burke, Fiehler, Bien, & Rösler, 2008).

To address the questions of whether and when the hMNS will be activated during learning with dynamic visualizations and whether such activation is truly beneficial for learning, we used a neurophysiological method in the present study. Answering these questions is particularly interesting due to their potential implications for instructional strategies. For instance, one effective instructional strategy to activate the hMNS during learning about continuous processes might be to show learners not only the processes to-be-learned, but also human gestures illustrating the to-be-learned dynamics in order to trigger an anthropomorphized encoding, that is, a mapping between the to-be-learned content and body-based representations (e.g., the mapping between a hoisting crane and a human arm, cf., De Koning & Tabbers, 2011). In line with this reasoning, Pine, Reeves, Howlett, and Fletcher (2013) recently showed that participants could name objects faster when enacting a gesture that corresponded to an object (e.g., flat open hand for airplane and closed fist for microphone) than with a gesture that did not correspond to the object (e.g., flat open hand for microphone and closed fist for airplane). In our study, we wanted to investigate similar mapping processes between human gestures and non-human movements. During learning about movements, gestures that easily map onto the to-be-learned dynamics (i.e., *corresponding gestures*) should activate more strongly the hMNS and should be more beneficial for learning than gestures that cannot easily be mapped onto the to-be-learned dynamics (i.e., *non-corresponding gestures*).

For investigating this hypothesis, we tried to identify content domains comprising non-human movements that can nevertheless be easily anthropomorphized and are likely to benefit from such mapping processes. In particular, we wanted to study a content domain that satisfies the following three constraints: (a) the domain is derived from the natural sciences, (b) the domain does not directly comprise human movements or movements very similar to human movements (such as movements of apes or other mammals with limbs similar to those of humans), and (c) the domain comprises biological movements and thereby allows for an anthropomorphized encoding, so that learners are able to map the to-be-learned dynamics onto body-based representations of their own human movements. A domain that satisfies these constraints and that has been commonly used in research on instructional dynamic visualizations is the locomotion behavior of fish (e.g., Gerjets et al., 2010; Imhof, Scheiter, Edelmann, & Gerjets, 2012; Imhof, Scheiter, & Gerjets, 2011; Jarodzka, Scheiter, Gerjets, & van Gog, 2010; Kühl, Scheiter, Gerjets, & Gemballa, 2011). A mapping of the human body onto the fish body (e.g., mapping the hands onto the pectoral fins or mapping the fingers onto the fin rays) is possible, but – due to differences in anatomy – not trivial and more complex than mapping parts of more similar anatomical bodies (e.g., the fingers of a human onto the fingers of an ape). Different types of fish locomotion patterns were used as content domain in the current study.

1.3. Research questions and hypotheses

Until now, to the best of our knowledge, there is no direct test of the assumption that learners' ability to recruit their hMNS during processing dynamic visualizations may influence the instructional effectiveness of these visualizations. Moreover, it still has not been investigated whether gestures that correspond to non-human movements induce hMNS activation and whether this activation will foster learning about the non-human movements. We addressed the research question whether the hMNS is activated during viewing corresponding gestures compared to non-corresponding ones and whether viewing corresponding gestures facilitates learning about movements better than viewing non-corresponding gestures. To measure hMNS activity we used functional near-infrared spectroscopy (fNIRS), which is a non-intrusive optical imaging method to gather data about cortical activation in humans (e.g., Ehlis, Schneider, Dressler, & Fallgatter, 2014; Schneider et al., 2014; Tupak et al., 2012). While the method's spatial resolution is limited as compared to functional magnetic resonance imaging (fMRI), specific advantages make fNIRS