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Review

The neural basis of hand gesture comprehension: A meta-analysis of functional magnetic resonance imaging studies

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ABSTRACT

Gestures play an important role in face-to-face communication and have been increasingly studied via functional magnetic resonance imaging. Although a large amount of data has been provided to describe the neural substrates of gesture comprehension, these findings have never been quantitatively summarized and the conclusion is still unclear. This activation likelihood estimation meta-analysis investigated the brain networks underpinning gesture comprehension while considering the impact of gesture type (co-speech gestures vs. speech-independent gestures) and task demand (implicit vs. explicit) on the brain activation of gesture comprehension. The meta-analysis of 31 papers showed that as hand actions, gestures involve a perceptual-motor network important for action recognition. As meaningful symbols, gestures involve a semantic network for conceptual processing. Finally, during face-to-face interactions, gestures involve a network for social emotive processes. Our finding also indicated that gesture type and task demand influence the involvement of the brain networks during gesture comprehension. The results highlight the complexity of gesture comprehension, and suggest that future research is necessary to clarify the dynamic interactions among these networks.

Contents

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1. Introduction

Hand gestures play an important role in conveying meaning, and its comprehension has attracted researchers from fields of psychology and neuroscience (for reviews, see Andric and Small, 2012; Gentilucci and Corballis, 2006; Goldin-Meadow, 2010; Goldin-Meadow and Alibali, 2013; Willems and Hagoort, 2007). However, the investigation has been challenging because of the complexity of gestures: the meaning of gestures can depend on speech (e.g., iconic and metaphoric gestures) or can be independent of speech (e.g., emblems), and hand gestures can describe concrete meanings (e.g., iconic gestures) or abstract meanings (e.g., metaphoric gestures) (e.g., Montgomery et al., 2007; Straube et al., 2010; 2013; Villarreal et al., 2008), and social or non-social meanings (e.g., Saggar et al., 2014). Furthermore, the processing of gestures has also been studied using varying amounts of task demands on the participants, such as passive viewing of gesture videos (e.g., Andric et al., 2013; Dick et al., 2014; Holle et al., 2010; Flaisch et al., 2009; Lotze et al., 2009; Straube et al., 2010), making judgments about gestures (e.g., Ferri et al., 2014; Holle et al., 2008; Josse et al., 2012; Prochnow et al., 2013), and even performing irrelevant tasks (e.g., Green et al., 2009; Kircher et al., 2009; Straube et al., 2012). These variables have made it hard to explore the neural substrates for gesture comprehension.

While previous research has studied gesture processing at a behavioral level (for a review, see Hostetter, 2011), the development of fMRI technique has enabled scientists to explore the neural basis of different aspects of gesture comprehension. For instance, studies that have looked into the brain activation indicate that the left inferior frontal gyrus (IFG) (*P. opercularis*), bilateral IFG (*P. triangularis*), bilateral ventral and dorsal premotor cortex (PMv and PMd), left posterior middle temporal gyrus (pMTG), bilateral superior temporal gyrus (STG) are involved in gesture comprehension (for a review, see Andric and Small, 2012).

Nevertheless, one needs to be careful when drawing conclusions about the neural substrates underpinning gesture comprehension from neuroimaging studies using a descriptive approach. This is because, first most of the fMRI results come from comparisons between gesture conditions and baseline conditions, and the task demands and the baseline conditions often vary across experiments. Second, the statistical power of these studies is relatively low due to small sample sizes (e.g., 15–30 participants in one study) (Eickhoff and Bzdok, 2013). Third, the fMRI technique records neuronal activity indirectly through the regional increases of blood–oxygen-level-dependent (BOLD) signal that is potentially confounded by biological, technical, and methodological factors (e.g., Birn et al., 2006; Heeger and Ress, 2002; Zeng et al., 2014). For example, Heeger and Ress (2002) suggested that several factors could influence the relationship between the BOLD signal and neuronal activity, including fMRI acquisition technique, the behavioral and stimulation protocols, the fMRI data-analysis methods, and how the neuronal activity itself is measured. Birn et al. (2006) suggested that respiration variations, such as breathing rate or depth, and movement of the chest during respiration could induce changes of BOLD signal. All of these factors can make the obtained findings from a single fMRI study less reliable. Fourth, the considerable financial effort of each neuroimaging study discourages the replication of previous studies as well as the combination of several experiments within one paper, and this in turn makes these fMRI findings quite isolated (Eickhoff and Bzdok, 2013). Thus, it is difficult to get an accurate view about the brain areas involved in a certain aspect of gesture comprehension.

To address the above issues, the current study provides an overview of the brain areas involved in gesture comprehension using a quantitative approach. In fMRI research about gesture processing, people use different terms to describe the processes when participants view gestures. For instance, some studies used "gesture perception" and "gesture recognition" interchangeably (Villarreal et al., 2008; Gallagher and Frith, 2004), while other studies used the term "gesture perception", because the results showed activation in brain areas involved in action perception, such as the superior temporal sulcus, occipital areas, and inferior temporal gyrus (e.g., Dick et al., 2009). Nevertheless, these studies also mentioned that during gesture perception (e.g., passively watching videos of speech accompanied by natural co-speech gestures), participants attempt to find meaning not only in speech but also in gestures (e.g., Dick et al., 2009). Other researchers suggested that gesture perception and decoding are involved in gesture comprehension (e.g., Lindenberg et al., 2012). For instance, Lindenberg et al. (2012) used gesture expression and reception tasks, and the results suggest that a fronto-parietal network for action recognition (e.g., IFG, PMv, and IPL) is involved in gesture perception, whereas areas (e.g., left MTG) and emotional and intentional areas (anterior cingulate and medial prefrontal cortex) may be more involved in gesture decoding.

In the current meta-analysis, we focused on gesture comprehension, which involve both gesture perception and decoding. This is because the gestures investigated in all the fMRI studies can express some semantic information. In addition, many tasks used in these studies focused on the explicit comprehension of gestures (e.g., Holle et al., 2008; Josse et al., 2012; Lindenberg et al., 2012; Prochnow et al., 2013). Studies using tasks such as passive viewing or color detection investigated the implicit comprehension of speech and/or gestures and avoided interaction between activity related to stimulus comprehension and instruction-related activity (e.g., Green et al., 2009; Holle et al., 2010).

The current study used activation likelihood estimation (ALE, Eickhoff et al., 2009), a coordinate-based meta-analysis method that identifies the convergence of the reported peak coordinates across experiments and can help answer questions regarding where in the brain the included foci cluster more tightly than that in a random association of experiments (Turkeltaub et al., 2002). ALE can effectively synthesize a large number of fMRI data while overcoming the limitations of individual experiments (Eickhoff et al., 2009), and it has been widely used in meta-analysis studies that aim to provide maps of brain structures involved in human cognitive processes (e.g., Hétu et al., 2013; Molenberghs et al., 2012; Watson et al., 2013).

Previous findings have shown that some variables can influence the brain activity during the process of gesture comprehension. One important factor is gesture type. Iconic, metaphoric, and beat