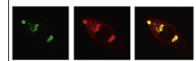


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Research Report

Semantic relation vs. surprise: The differential effects of related and unrelated co-verbal gestures on neural encoding and subsequent recognition



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ARTICLE INFO

Article history:

Accepted 9 April 2014

Available online 16 April 2014

Keywords:

Iconic gestures

Multimodal processing

Congruency

Speech associated gestures

Memory

Attention

ABSTRACT

Speech-associated gesturing leads to memory advantages for spoken sentences. However, unexpected or surprising events are also likely to be remembered. With this study we test the hypothesis that different neural mechanisms (semantic elaboration and surprise) lead to memory advantages for iconic and unrelated gestures. During fMRI-data acquisition participants were presented with video clips of an actor verbalising concrete sentences accompanied by iconic gestures (IG; e.g., *circular gesture*; sentence: “The man is sitting at the round table”), unrelated free gestures (FG; e.g., *unrelated up down movements*; same sentence) and no gestures (NG; same sentence). After scanning, recognition performance for the three conditions was tested. Videos were evaluated regarding semantic relation and surprise by a different group of participants. The semantic relationship between speech and gesture was rated higher for IG (IG>FG), whereas surprise was rated higher for FG (FG>IG). Activation of the hippocampus correlated with subsequent memory performance of both gesture conditions (IG+FG>NG). For the IG condition we found activation in the left temporal pole and middle cingulate cortex (MCC; IG>FG). In contrast, for the FG condition posterior thalamic structures (FG>IG) as well as anterior and posterior cingulate cortices were activated (FG>NG). Our behavioral and fMRI-data suggest different mechanisms for processing related and unrelated co-verbal gestures, both of them leading to enhanced memory performance. Whereas activation in MCC and left temporal pole for iconic co-verbal gestures may reflect semantic memory processes, memory enhancement for unrelated gestures relies on the surprise response, mediated by anterior/posterior cingulate cortex and thalamico-hippocampal structures.

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1. Introduction

Human speech is typically accompanied by gestures. These gestures confer advantages in comprehension, learning and memory (e.g., Cook et al., 2010, 2013; Kelly and Church, 1998;

Kelly et al., 1999; Straube et al., 2009, 2011a; Valenzano et al., 2003). For example Kelly et al. (1999) demonstrated that certain nonverbal behaviors, such as deictic and iconic gestures, help people comprehend and remember pragmatic communication. Consistent with this finding Valenzano et al. (2003) showed that

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children learn more when they watch a video containing the teacher's gestures as compared to videos without gestures. However, whether the semantic content of gestures and its relation to language are important for gesture related advantages in comprehension and memory are unknown. Only for gestures in an abstract sentence context (metaphoric gestures) it has been shown that the semantic relation between speech and gesture information is important for neural encoding and subsequent recognition (Straube et al., 2009). However, memory advantages for semantically incongruous sentences (e.g., Moss et al., 2008; Worthen et al., 2000; Worthen and Roark, 2002) and for incongruous picture information (e.g., Michelon et al., 2003; Nicolas and Worthen, 2009; Worthen and Eller, 2002), has also been reported. Thus, different mechanisms might contribute to gesture related advantages for subsequent memory. To get a better understanding of these mechanisms, we investigated the different neural processes underlying the encoding of iconic and unrelated speech–gesture information in relation to subsequent memory performance.

Iconic gestures are an important accompaniment to speech, sharing a formal relationship with the co-occurring concrete speech content (McNeill, 1992). Iconic gestures illustrate forms, shapes, events or actions of the speech content. Therefore iconic gestures directly refer to concrete features of the world, as in the sentence “The ball is round” (round hand gesture), “The cottage is located on a very high mountain” (lift of the right hand) or “The fisherman caught a huge fish” (where the gesture indicates the size of the fish). An important characteristic of iconic gestures is the reference to concrete sentence contents (By contrast, metaphoric gestures, which are also illustrative co-verbal gestures, refer to abstract speech contents, e.g., Kircher et al., 2009; Straube et al., 2011a).

The neural basis of co-verbal gesture processing is being investigated by an increasing number of functional magnetic resonance imaging (fMRI) studies (Dick et al., 2009; Green et al., 2009; Holle et al., 2008, 2010; Kircher et al., 2009; Nagels et al., 2013; Skipper et al., 2007, 2009; Straube et al., 2011a, 2012, 2013c; Willems et al., 2007, 2009). For the processing of iconic co-verbal gestures the left posterior temporal cortex seems to be especially relevant (Green et al., 2009; Holle et al., 2008, 2010; Straube et al., 2011a, 2013b), whereas left inferior frontal and parietal brain activations were reported for mismatches between unrelated concrete speech and iconic gesture information (Green et al., 2009; Willems et al., 2007). For the processing of metaphoric co-verbal gestures both inferior frontal as well as posterior temporal activations seem to be relevant (Kircher et al., 2009; Straube et al., 2009, 2011a, 2013a, 2013b). Whereas these studies always compared different gesture conditions, studies that investigate the neural correlates of memory processes for speech and gesture utterances are rare. For iconic and emblematic gestures and corresponding sentences it was found that body orientation of the actor affects memory processes in hippocampal and medial frontal brain regions (Straube et al., 2011b). For metaphoric co-verbal gestures left lateral posterior temporal and inferior frontal as well as bilateral hippocampal brain regions are involved in successful encoding processes for speech and gesture (Straube et al., 2009). Other than these findings the effect of related vs. unrelated speech–gesture

information on neural memory encoding processes for iconic gestures is unknown. Straube et al. (2009) showed activation of the left occipito-temporo-cerebellar region, the right inferior frontal cortex and the bilateral medial temporal lobe for the successful encoding of unrelated gesture information in the context of abstract speech. However, with reference to the differences of iconic and metaphoric co-verbal gestures reported above (Straube et al., 2011a), manipulation of congruency in iconic gestures most likely led to different neural encoding processes in relation to subsequent recognition.

In general we would expect gesture related advantages in comprehension and memory encoding only in semantic related speech and gesture pairs (as basically supported for metaphorical gestures, Straube et al., 2009). However, in our recent fMRI-study about iconic gesture integration we found even a slightly higher hit-rate for unrelated in contrast to related iconic gestures (Green et al., 2009). Such an in-congruency effect on memory has repeatedly been found, for example, in semantically incongruous sentences (e.g., Moss et al., 2008; Worthen et al., 2000; Worthen and Roark, 2002) and for incongruous picture information (e.g., Michelon et al., 2003; Nicolas and Worthen, 2009; Worthen and Eller, 2002), which were better recalled subsequently than ordinary ones. This paradoxical effect, the so-called “bizarreness effect” (Hirshman et al., 1989; McDaniel et al., 1995; Moss et al., 2008; Nicolas and Marchal, 1998; Nicolas and Worthen, 2009; Riefer and Rouder, 1992; Worthen and Wood, 2001; Worthen and Roark, 2002; Worthen and Deschamps, 2008) may result from a surprise response due to violated expectations, which enhances the contextual cues that help in subsequent recognition (surprise hypothesis, Hirshman et al., 1989; Michelon et al., 2003). The surprise may be part of an orienting response that includes arousal, captured attention and memory formation (see Shulman et al., 2009; Sokolov, 1963). Thus, the surprise hypothesis predicts an emotional response for incongruous items (Michelon et al., 2003; Strange et al., 2000), which should not occur in congruous items. For utterances with congruent speech and gesture information we expect that deeper elaboration of the presented material is related to enhanced memory performance (Staresina et al., 2009; Straube et al., 2009). As alternative to the semantic elaboration theory recent studies have related schema activation to enhancing effects of congruently learned associations (e.g., McKenzie and Eichenbaum, 2011; McKenzie et al., 2013; van Kesteren et al., 2012, 2013; Wang et al., 2012). In accordance with this theory an activated schema leads to faster incorporation of congruent information into neocortical networks, including the medial prefrontal cortex. Oppositely, the processing of unexpected or surprising events are suggested to rather relate to processing in the medial temporal lobe, particularly the hippocampus (van Kesteren et al., 2012, 2013). Nevertheless, we assumed that the memory effect of unrelated gestures relies on different mechanisms than the encoding of iconic gestures in context of related concrete speech, which is therefore the focus of the current study.

To get a better understanding of these mechanisms, we investigated the different neural processes underlying the encoding of iconic and unrelated speech–gesture information in relation to subsequent memory performance. We performed a rating of the speech–gesture video-clips with regard to the semantic relationship as well as surprise (rating study) to

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