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Spontaneous gesture and spatial language: Evidence from focal brain injury

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ABSTRACT

People often use spontaneous gestures when communicating spatial information. We investigated focal brain-injured individuals to test the hypotheses that (1) naming motion event components of manner-path (represented by verbs–prepositions in English) are impaired selectively, (2) gestures compensate for impaired naming. Patients with left or right hemisphere damage (LHD or RHD) and elderly control participants were asked to describe motion events (e.g., *running across*) depicted in brief videos. Damage to the left posterior middle frontal gyrus, left inferior frontal gyrus, and left anterior superior temporal gyrus (aSTG) produced impairments in naming paths of motion; lesions to the left caudate and adjacent white matter produced impairments in naming manners of motion. While the frequency of spontaneous gestures were low, lesions to the left aSTG significantly correlated with greater production of path gestures. These suggest that producing prepositions–verbs can be separately impaired and gesture production compensates for naming impairments when damage involves left aSTG.

1. Introduction

How do we communicate spatial information using language? What neural structures implement this type of information? We use spatial language, such as prepositions and action verbs, to describe spatial events in our environment and organize relational thinking (Chatterjee, 2001, 2008). People also use hand gestures spontaneously when they talk. Gestures, particularly *iconic* gestures are used commonly when individuals express spatial information such as giving directions or describing motion in space. These spontaneous co-speech iconic gestures that accompany verbal spatial information (Alibali, 2005) are the focus of this study.

There is growing interest in understanding the neural underpinnings of spatial language (e.g., Amorapanth, Widick, & Chatterjee, 2009; Chatterjee, 2008; Damasio et al., 2001; Kemmerer, 2006) and gesture comprehension (e.g., Dick, Goldin-Meadow, Hasson, Skipper, & Small, 2009; Dick, Goldin-Meadow, Solodkin, & Small, 2012; Holle, Gunter, Rueschemeyer, Hennenlotter, & Iacoboni, 2008; Skipper, Goldin-Meadow, Nusbaum, & Small, 2009; Willems & Hagoort, 2007; Willems, Özyürek, & Hagoort, 2007). However, little is known about the neural correlates of spontaneous gestures that naturally accompany spatial language production (but see recent papers by Marstaller & Burianova, 2015a, 2015b; Marstaller et al., 2015). In this study we test two main hypotheses. First, if spatial representations and lexical–semantic spatial information are organized similarly in the brain (Chatterjee, 2008), patients with focal brain injury to left frontal-parietal regions, known to process spatial information (e.g., Göksun, Lehet, Malykhina, & Chatterjee, 2013; Kemmerer, 2006; Kemmerer & Tranel, 2003), would have difficulty verbally describing spatial events. Second, if spatial language and spatial gestures rely on the same neural structures, then damage to areas needed for spatial language would also impair gesturing spatial events. That is, deficits of spatial knowledge would lead to deficits in both verbally and gesturally expressing spatial information. Alternatively, if spatial gestures compensate for verbal deficits without being reliant on the same neural structures, deficits in spatial language would result in a greater use of gestures.

A dynamic spatial event consists of several components that are encoded across world's languages (Talmy, 2000). The *path* and *manner* of motion describe two of these components. *Path* refers to a figure's trajectory relative to ground and *manner* refers to how the action is performed. That is, the path of motion describes an "extrinsic dynamic relation" of the movement of a figure

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relative to external landmarks and the manner of motion describes an "intrinsic dynamic relation" of the movement of figure parts relative to each other (Chatterjee, 2008). For example, in the sentence "*John is running into the room*," *running* describes the manner and *into the room* describes the path of the motion. In English, manner of motion is expressed typically by the main verb of a sentence whereas path of motion is expressed by a prepositional phrase.

In the following sections we first review the current understanding of the neural basis of spatial language, centering on dynamic spatial events. Then we discuss the relation between speech and gesture with respect to motion events before presenting the current study.

1.1. The neural correlates of spatial language: Motion events

Attention to path and manner of motion activates different neural networks (Wu, Morganti, & Chatterjee, 2008) as we demonstrated in a one-back matching task using a computer animated starfish moving with different manners and paths. In some blocks, participants attended to manner and in others to path. Within regions sensitive to motion, dorsal areas (i.e., bilateral posterior parietal and frontal areas) were preferentially activated in path conditions and relatively ventral areas (i.e., bilateral posterior inferior/middle temporal cortex) were preferentially activated in manner conditions.

The neural parsing of attention to these perceptual components of dynamic events parallels the linguistic parsing of path and manner represented by prepositions and verbs. Comprehending verbs correlates with activation in the posterior middle temporal gyrus (Kable, Kan, Wilson, Thompson-Schill, & Chatterjee, 2005; Kable, Lease-Spellmeyer, & Chatterjee, 2002; Kemmerer et al., 2008) whereas comprehending prepositions correlates with activation in the left posterior inferior parietal and prefrontal cortices (Amorapanth et al., 2009; Baciu et al., 1999; Noordzij, Neggers, Ramsey, & Postma, 2008). Neuropsychological and other imaging studies confirm the role of these areas and anatomic division of processing verbs and prepositions (Amorapanth et al., 2009; Damasio et al., 2001; Emmorey et al., 2002; Kemmerer, 2006; Göksun et al., 2013; Kemmerer, 2006; Kemmerer & Tranel, 2003; Kemmerer et al., 2012; MacSweeney et al., 2002; Tranel & Kemmerer, 2004; Tranel, Kemmerer, Adolphs, Damasio, & Damasio, 2003; Tranel, Manzel, Asp, & Kemmerer, 2008).

Together, these findings are consistent with Chatterjee's (2008) suggestion that spatial perception and language have an analogous organizational structure within the brain. That is, the left hemisphere contains a perceptual to verbal gradient, in which perceptual nodes serve as points of entry for their lexical correspondences that are shifted toward peri-Sylvian cortex (Chatterjee, 2008).

Here we examine the neural segregation of path and manner of motion by testing focal brain injured individuals' production of motion event sentences using voxel-based lesion symptom mapping (VLSM) analysis. In VLSM patients are not classified based on lesion site, clinical diagnosis or behavioral performance. The inferential strengths of lesion methods offer an important constraint on neural hypotheses generated by functional neuroimaging methods (Chatterjee, 2005; Fellows et al., 2005).

1.2. Gesture as a compensatory strategy for impaired speech

Speech and gesture form a tightly integrated communication system; either part of one system or two highly interrelated systems (Alibali, Kita, & Young, 2000; Goldin-Meadow, 2003; Kita & Özyürek, 2003; McNeill, 1992; McNeill, 2005; for opposing views see Krauss, Chen, & Gottesman, 2000). Although most theories agree that spontaneous gesture production relates to speech production, the proposed nature of this relationship differs (e.g., Alibali, 2005; Butterworth & Hadar, 1989; De Ruiter, 2007; Hostetter & Alibali, 2008; Kita, 2000; Kita & Özyürek, 2003; McNeill, 1992, 2005). Some argue that speech and gesture originate from the same representational system, in which gesture carries a global-synthetic image of an utterance and speech carries the linear-segmented hierarchical linguistic structure of an utterance (McNeill, 1992, 2005) or that gestures are generated during subprocesses of speech production (Butterworth & Hadar, 1989).

Others claim that speech and gesture are generated by two separate but interrelated systems (e.g., Alibali et al., 2000; Kita, 2000; Kita & Özyürek, 2003; Krauss et al., 2000). For example, Krauss' *Lexical Gesture Process Model* proposes that gestures are generated from spatial imagery in working memory. These gestures prime lexical items, increase their activation, and facilitate their access to speech (Krauss et al., 2000). In this model, gestures are formed before speech processes occur. Another view, the *Interface Model* suggests that speech and gesture are generated by two separate, but bidirectionally related systems. A message generator plans speech whereas an action generator plans gesture, originating from an interface representation between spatial thinking and speech (Kita & Özyürek, 2003). This model is also compatible with the *information-packaging hypothesis,* which argues that gestures help speakers to organize and package spatial information into units that are compatible with the speech (Kita, 2000).

Evidence for the Interface Model comes from cross-linguistic studies of gesture production. For instance, when an English speaker expresses a "roll down" event, the one-clause sentence (e.g., he *rolled down*) accompanies a gesture that conflates path and manner information (e.g., index finger makes circles while moving down). In contrast, Turkish or Japanese speakers express the same event in two clauses (e.g., he descended as he rolled) and use two separate gestures for path and manner (e.g., one for moving down and the other for circular movement). Nevertheless, when English speakers use two separate clauses for manner and path of motion, their gestures are similar to those of Turkish speakers (Kita et al., 2007). These findings suggest that spontaneous gestures are synchronized with speech and influenced by the form of sentences used, regardless of the surface properties a particular language (Kita et al., 2007; Kita & Özyürek, 2003). Additionally, healthy people often gesture when they communicate spatial information verbally (Alibali, 2005; Alibali, Heath, & Myers, 2001; Feyereisen & Havard, 1999).

Only recently neurocognitive research has started to investigate the neural correlations of co-speech gestures, suggesting that co-speech gestures and speech processing probably engage overlapping areas in the left inferior frontal gyrus (BA 45), superior temporal sulcus, and posterior middle temporal gyrus (Dick et al., 2009, 2012; Holle et al., 2008; Willems & Hagoort, 2007; Willems et al., 2007; Willems, Özyürek, & Hagoort, 2009). In two recent studies, Marstaller and Burianova (2015a, 2015b) examined neural underpinnings of co-speech gestures. One was an fMRI study, showing that co-speech gesture production engaged areas that were associated with language production such as left inferior frontal gyrus, anterior superior temporal gyrus, bilateral posterior superior temporal sulcus, left hippocampus, parahippocampus, ventral and dorsal premotor areas, and primary motor cortex (Marstaller et al., 2015a).

Neuropsychological evidence of neural correlates of gesture production comes from studies with aphasic patients (e.g., Ahlsen, 1991; Cicone, Wapner, Foldi, Zurif, & Gardner, 1979; Cocks, Dipper, Middleton, & Morgan, 2011; Cocks, Sautin, Kita, Morgan, & Zlotowitz, 2009; Dipper, Cocks, Rowe, & Morgan, 2011; Feyereisen, 1983; Friederici, 1981, 1982; Glosser, Wiener, & Kaplan, 1986; Hadar, Burstein, Krauss, & Soroker, 1998; Kemmerer, Chandrasekaran, & Tranel, 2007; Le May, David, &