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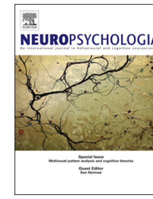

The role of beat gesture and pitch accent in semantic processing: An ERP study

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ABSTRACT

The present study investigated whether and how beat gesture (small baton-like hand movements used to emphasize information in speech) influences semantic processing as well as its interaction with pitch accent during speech comprehension. Event-related potentials were recorded as participants watched videos of a person gesturing and speaking simultaneously. The critical words in the spoken sentences were accompanied by a beat gesture, a control hand movement, or no hand movement, and were expressed either with or without pitch accent. We found that both beat gesture and control hand movement induced smaller negativities in the N400 time window than when no hand movement was presented. The reduced N400s indicate that both beat gesture and control movement facilitated the semantic integration of the critical word into the sentence context. In addition, the words accompanied by beat gesture elicited smaller negativities in the N400 time window than those accompanied by control hand movement over right posterior electrodes, suggesting that beat gesture has a unique role for enhancing semantic processing during speech comprehension. Finally, no interaction was observed between beat gesture and pitch accent, indicating that they affect semantic processing independently.

1. Introduction

Successful face-to-face communication requires integration of information from multiple sensory modalities. People derive meaning not only from speech, but also from visual cues such as lip movements, facial expression, body posture, and hand gestures. An important question then is how a listener combines information from auditory (e.g., speech) and visual channel (e.g., gesture) to comprehend a message.

To date, most studies on the speech and gesture integration have focused on representational gestures, which depict a concrete or abstract semantic meaning with the shape or motion of the hand/s. Behavioral studies demonstrated that speech comprehension is enhanced by accompanying representational gestures (Beattie & Shovelton, 1999; Holler, Shovelton, & Beattie, 2009; Kelly, Barr, Church, & Lynch, 1999; but see Kelly & Goldsmith, 2004; Krauss, Dushay, Chen, & Rauscher, 1995 for conflict findings). Evidence from neuroimaging studies suggests that the left inferior frontal gyrus (Willems, Özyürek, & Hagoort, 2007, 2009) and the left posterior temporal lobe (Holle, Gunter, Rüschemeyer, Hennenlotter, & Iacoboni, 2008; Holle, Obleser, Rueschemeyer, & Gunter, 2010) are crucially involved in the integration of the semantic information provided by representational gesture and speech. Several event-related potential (ERP) studies reported that semantically incongruent gesture–speech pairings elicited larger N400 amplitudes than congruent pairings (Cornejo et al., 2009; Holle & Gunter, 2007; Kelly, Kravitz, & Hopkins, 2004; Özyürek, Willems, Kita, & Hagoort, 2007; Wu & Coulson, 2005). In general, the N400 amplitude is larger when it is more difficult to integrate the semantic meaning of a word into previous context than when it is easier (Kutas & Hillyard,1980). Thus, these ERP data suggest that people integrate semantic information from representational gestures into speech. Furthermore, Kelly, Creigh, and Bartolotti (2009) demonstrated that when participants were presented with gesture and speech, they automatically integrated the two modalities even when that integration was not required in the task given to the participants. In sum, existing evidence shows that gesture and speech are automatically integrated during language comprehension.

Speakers not only produce representational gestures, but also beat gestures in communication. A beat gesture is a rapid movement of the hand, usually up and down, produced with the rhythm of the concurrent speech (McNeill, 1992). It does not convey semantic content (Alibali, Heath, & Myers, 2001). It indexes the significance of its accompanying word or phrase and is often used to highlight new or contrastive information (McNeill, 1992). Although beat gesture is a common type of gestures in communication (McNeill, 1992), it has received much less attention in the literature than representational gestures, presumably because

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beat gesture does not convey any semantic meaning in itself. The present study aimed to examine how seeing a beat influence listeners' processing of the accompanying speech.

To our knowledge, there is so far only one fMRI study and two ERP studies that investigated how the brain integrates beat gesture with speech during language comprehension. In the fMRI study, Hubbard, Wilson, Callan, and Dapretto (2009) found greater activation in non-primary auditory cortex (e.g., bilateral posterior superior temporal gyrus) when speech was accompanied by beat gestures than when speech was presented alone. They also found stronger activations in left superior temporal gyrus/sulcus when speech was accompanied by beat gestures than when speech was accompanied by nonsense hand movements (i.e., non-iconic American Sign Language movements unknown to participants). The authors concluded that these brain areas are crucial for the integration of beat gesture and speech. The ERP study by Holle et al. (2012) demonstrated that beat gesture had an impact on syntactic analysis. This study focused on the P600 component, a positive-going deflection of the ERP peaking around 600 ms after the onset of the critical word. A larger P600 is often elicited by less preferred syntactic structures in ambiguous sentences (Osterhout & Holcomb, 1992). Holle et al. (2012) showed that the P600 effect disappeared when the subject (e.g., *the men*) of the non-preferred syntactic structure (OSV structure: *The woman$_{[object]}$ the men$_{[subject]}$ have greeted.*) was accompanied by a beat gesture. This suggests that the visual emphasis provided by beat gestures increased the plausibility of the non-preferred syntactic structure. The other ERP study by Biau and Soto-Faraco (2013) showed that beat gesture had an impact on speech processing at the sensory/phonological level. In this study, words accompanied by beat gesture elicited a positive shift at an early sensory stage as well as an enhanced P2, compared to words accompanied by no hand movement. The authors concluded that beat gestures facilitate early speech analysis by allocating listeners' attention towards important information. Taken together, these studies have shown that seeing beat gesture has an effect on speech processing.

Given the relatively small number of studies on the integration of beat gesture and speech in the brain, several research questions remain unclear. First, little is known on whether beat gesture has an impact on speech processing at the semantic level. Although beat gesture does not convey any semantic information, it may affect semantic processing by indexing the saliency of its accompanying word (McNeill, 1992; Holle et al., 2012; Biau & Soto-Faraco, 2013). Previous evidence shows that linguistic devices that are used to highlight information (e.g., question context: Wang, Hagoort, & Yang, 2009; pitch accent: Swerts, Krahmer, & Avesani, 2002, Krahmer & Swerts, 2007; syntactic structure: Cowles, Kluender, Kutas, & Polinsky, 2007) can modulate semantic processing. For instance, a smaller N400 was found when information was marked to be focus than when it was not, suggesting that focused information was easier to be integrated into context compared to non-focused information (Wang et al. 2009; Wang, Bastiaansen, Yang, & Hagoort, 2011). Furthermore, in an fMRI study, Kristensen, Wang, Petersson, & Hagoort (2012) showed that words expressed with pitch accent activated a fronto-parietal attention network to a larger degree than words expressed without pitch accent. Also, semantically violating words activated left inferior frontal gyrus (which is sensitive to semantic violations) only when they were expressed with pitch accent. The authors concluded that accented information receives more attentional resources and more elaborate semantic processing relative to unaccented information. Therefore, it is rational to expect that beat gesture, as a visual cue to highlight information, will also have an effect on semantic processing.

Another open question is that if beat gesture could facilitate semantic processing of concurrent speech, what would be the underlying mechanism. One possibility is that the presence of beat gesture, or any other hand movements increases the general attention level and enable deeper processing of the concurrent speech than when no hand movement is present. A second possibility is that beat gesture has a unique role in modulating semantic processing due to its conventional use to emphasize information in communication. That is, rather than simply capturing attention as a visual signal, beat gesture serves as a special communication signal (Grice, 1975). This implies that other, non-communicative visual signals (such as non-sense hand movements) should not facilitate semantic processing, or at least not as much as beat gesture. Of course, the two possibilities are not mutually exclusive. Beat gesture may facilitate semantic processing through both a general attention capture mechanism and its unique role in emphasizing information in face-to-face communication.

In addition, although beat gesture and pitch accent are closely related in time and function (Leonard & Cummins, 2010; Krahmer & Swerts, 2007), little is known about whether they modulate the semantic processing of speech interactively or independently. Krahmer and Swerts (2007) found that the production of beat gesture enhanced the acoustic prominence of the simultaneously produced speech, and in return, seeing beat gesture increased the perceived prominence of the gesture-accompanied word. Thus, beat gesture and pitch accent may facilitate semantic processing interactively. Beat gesture may only affect semantic processing of a word when the word is expressed with pitch accent. When beat gesture is presented without pitch accent, it may not facilitate semantic processing or may even increase the difficulty of semantic processing due to a violation of the expectation on the co-occurrence of beat gesture and pitch accent. Alternatively, the effect of beat gesture and pitch accent on semantic processing of speech words may be independent of each other, because beat gesture and pitch accent highlight information via different modalities and both of them are prominent cues to highlight the saliency of information expressed in speech.

To sum up, the present study aimed to address three research questions: (1) Does beat gesture facilitate semantic processing of its accompanying word? (2) If beat gesture facilitates semantic processing, is this effect specific to beat gesture, or do other non-beat-like hand movements have the same effect? (3) Do beat gesture and pitch accent affect semantic processing interactively or independently? To answer these questions, we presented participants with short video clips containing spoken sentences. A critical word in each sentence was accompanied by a beat gesture, a control movement, or no hand movement. The control movement was produced by the same hand, at the same starting and ending location, with the same rhythmic properties, but with a non-beat-like moving trajectory as the beat gesture. We pretested the emphasis function and the likelihood of daily use of the beat gesture and the control movement. The critical word was either accented or not. The ERP responses to the critical words in the different conditions were compared. Specifically, the N400 effect, which reflects the difficultly of semantic integration (for a review see Kutas & Federmeier, 2011), was measured.

We made the following predictions. First, if beat gesture reduces the difficulty of a word's semantic processing, there should be a smaller N400 when a word is accompanied by a beat gesture than when it is not. Secondly, if beat gesture has a unique role in facilitating semantic processing due to its conventional use as a communicative signal (which were manifested in the pretest), there should be a smaller N400 when a word is accompanied by beat gesture than when it is accompanied by control movement. Third, if beat gesture and pitch accent affect semantic processing interactively, words accompanied by a beat gesture will only elicit smaller N400s than the words accompanied with no hand movement when they are expressed with pitch accent. When pitch accent is