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Abstract

The cognitive architecture and function of co-speech gesture has been the subject of a large body of research. We investigate two main questions in this field, namely, whether language and gesture are the same or two inter-related systems, and whether gestures help resolve speech problems, by examining the relationship between gesture and disfluency in neurotypical speakers. Our results support the view of separate, but inter-related systems by showing that speech problems do not necessarily cause gesture problems, and on many occasions, gestures signal an upcoming speech problem even before it surfaces in overt speech. We also show that while gestures are more common on fluent trials, speakers use both iconic and beat gestures on disfluent trials to facilitate communication, although the two gesture types support communication in different ways.

Keywords: gesture, speech production, disfluency

Introduction

People spontaneously produce gestures when they talk. It has been widely accepted that gesture and speech are semantically and temporally coordinated. However, there is mixed evidence on whether speech and gesture form a tightly integrated communication system originating from the same representational system, or whether they are two separate, but interrelated systems (Butterworth & Hadar, 1989; McNeill, 1992, 2005; Alibali, Kita, & Young, 2000; Kita, 2000; Krauss, Chen, & Gottesman 2000; Goldin-Meadow, 2003; Kita & Özyürek, 2003; de Ruiter, 2007; Hostetter & Alibali, 2008; Goldin-Meadow & Alibali, 2013; Pouw et al., 2014). McNeill (1992, 2005) argues that the coordination between speech and gesture arises from the fact that the two emerge from the same system. Others have proposed language and gesture as separate, but interdependent systems. Gesture may influence language (Krauss et al., 2000; de Ruiter, 2000), or gesture can be influenced by language (Hostetter &Alibali, 2008, 2010; Kita & Özyürek, 2003). Even in the absence of overt speech, phonological representations can influence gestures (Nozari et al., 2015).

The current study investigates the interaction between language and gesture production systems, but within a different framework than that of the previous studies. We examined the relationship between disfluency and gesture production in healthy adults to address two questions: 1) Do gesture and language reflect operations of a single system or two separate systems? 2) Does gesture support the language system? In order to better understand the relationship between gesture and speech, we also analyze the temporal relationship between speech and gesture problems.

Do gestures help language production?

One way to examine whether gestures benefit language production is to look at individuals with aphasia who have a variety of difficulties in speech production. The results are mixed. Some report that individuals with Broca's aphasia do not necessarily produce gestures to clarify their incomplete speech (Goodglass & Kaplan, 1963; Cicone et al., 1979; McNeill, 1985; Glosser et al., 1986). In contrast, others demonstrated that they produce more meaning-laden gestures when they have trouble retrieving words than when their production is fluent (Hadar et al., 1998; Lanyon & Rose, 2009; Raymer et al., 2006; Rose & Douglas, 2001; Göksun et al., 2013, 2015).

A second population for studying the benefits of gesture for language production is people who stutter. Gesture production is halted during bouts of stuttering and fluent gesture production is linked to fluent speech production (Mayberry & Jaques, 2000). This close correspondence between fluency and gesture production in this population suggests that gestures simply accompany speech and do not have a compensatory role when speech is problematic. Finally, the potential role of gestures for helping language production has been studied in healthy individuals, using gesture prevention paradigms. Performance on language production tasks usually deteriorates when gestures are prevented (Hostetter, Alibali, & Kita, 2007, but see Beattie & Coughlan, 1999). However, these paradigms require active inhibition of gestures that would have otherwise been naturally produced. Implementing such inhibition may divert attention from the main task of speaking and cause the increased error rates under circumstances when gesturing is prohibited.

In summary, investigation of the potential benefits of gesture for language production has yielded inconclusive results. Here, we propose a new approach to the same issue by exploring the relationship between disfluency and gesture in neurotypical speakers. Disfluency is an excellent tool for this purpose, because (a) it is a surefire of a glitch in the language production system, and (b) unlike overt errors that are infrequent in speech of neurotypical adults, disfluency rate is estimated to be between 6 (Bortfel et al., 2001) to 26 (FoxTree, 1995) per 100 spoken words in healthy individuals. These characteristics allow us to investigate the relationship between language and gesture in healthy adult speakers without imposing unusual demands on either language or gesture production.

Maclay and Osgood (1959) originally classified disfluency into four categories: (1) Filled pauses are verbal interruptions that do not relate to the proposition of the main message (e.g. *uh* and *um*, *er* and *ah*), (2) Silent pauses are periods of silence longer than the pauses in an equivalent fluent utterance, (3) Repeats are unmodified repetitions of a word, a part of a word, or a string of words (e.g., The girl is running around the *around the* tree). 4) Fillers and Comments that can be in the form of question asking the listener to rehearse the missing words (e.g., *what is this called?*). Disfluency can also entail corrections or repairs to produced words or phrases. Levelt (1989) divides repairs into two main categories: (1) Error repairs, where the original utterance was wrong (e.g., error = "dog", repair = "cat", or error = "cap", repair = "cat"), and (2) appropriateness repairs, where the original utterance was not wrong, but was considered by the speaker to be incomplete or ambiguous (e.g., original utterance = "the pen", repair = "the red pen"). Using a task that elicits production of sentences and gestures, we examine the relationship between these types of disfluency and gesture.

We also examine the timeline of gesture interruption compared to speech interruption. Seyfeddinipur and Kita (2001) found that gesture suspension and resumption points took place before speech disfluency. They interpreted the early interruption of gestures compared to speech as a sign that speakers knew that there was a problem in speech but delayed the interruption until a repair was available.

Iconic vs. beat gestures

Co-speech gestures are classified into several categories. Two of these categories that have received attention for their role in compensating for speech problems are *iconic* and *beat* gestures. Iconic gestures are used as symbols to reenact actions (e.g., drawing a circle in the air to represent doing cartwheel) or to represent concrete objects (e.g., bending the index finger to represent a hook). Beat gestures are flicks of the hand that follow the speech prosody without the gesture conveying semantics (McNeill, 1992).

It has been suggested that producing an iconic gesture, for instance drawing a circle in the air, helps speakers produce the word (cartwheel in this case). Different hypotheses have been proposed for how iconic gestures facilitate production. Some have proposed that gesture helps lexical retrieval (Krauss, 1998), some have posited that gesturing helps packaging of conceptual information (Alibali, Kita, & Young, 2000), and some have argued that it helps create a mental image of the word's referent during lexical search (Wesp, Hesse, Keutmann, & Wheateon, 2001). Regardless of the exact mechanism, all of these accounts maintain that iconic gestures benefit language by helping the retrieval of information from the lexical-semantic system.

On the other hand, beat gestures are believed to be free of semantics and as such, are unlikely to be directly involved in retrieving information from the lexical-semantic system (Krauss & Hadar, 1999, but see Lucero, Zaharchuk, & Casasanto, 2014). Instead, they may have a communicative role by engaging the listener until the speech problem is resolved. Thus, beat gestures may "hold the conversational floor" during speech problems, similar to what has been proposed for filled pauses (e.g., Maclay and Osgood, 1959; but see Clark & Fox Tree, 2002). Given the different roles that iconic and beat gestures play, in examining the role of gesture in compensating for speech problems, we inspect these two types of gesture separately.

Predictions

Regarding our two main questions we have the following predictions. (1) If speech and gesture arise from the same system, we would expect problems in the two to co-occur. But, if gesture and speech are separate systems, at least past the conceptualization point, speech problems may emerge in the absence of gesture problems. (2) To explore the role of gesture for resolving speech problems, we posed two questions: (a) is the primary role of gestures to help when there is a problem in speech? If so, we would expect gestures to mainly arise during disfluent -- compared to fluent -- trials. (b) If gestures' primary role is not to help with speech problems, do they play any role in resolving language problems? If yes, we would expect more disfluent trials with than without gestures. Note that for (a) we divide trials primarily based on the presence or absence of gesture and then inspect which proportion of gesture trials also included a disfluency. On the other hand, in (b) we divide the trials primarily based on the presence of absence of disfluency, and then inspect which proportion of disfluent trials contained a gesture. We also analyze the temporal relationship between speech problems and gesture addresses the question of whether the two systems are highly synchronized (McNeill, 1992; Mayberry & Jaques, 2000) or whether gesture problems foreshadow speech problems (Seyfeddinipur, & Kita, 2001).

Methods

Participants

Twenty monolingual native Farsi speakers (9 females) between the ages of 18 and 30 were tested. Participants lived in Iran, were all right-handed, had normal hearing and vision. All participants gave their written consent for participation in accordance with the guidelines approved by the IRB committee of the Koç University. Two participants' data was excluded. One of these person's gestures were out of the camera frame and the other person's video recording crashed during the coding.

Materials

Participants watched 20 dynamic movie clips, depicting different motion events. Each movie lasted for 3–4 seconds. The clips were previously developed and used in English and Persian (Göksun et al., 2015; Akhavan et al., 2015). All actions were performed by a woman in an outdoor area.

Procedure

All participants were tested individually in their home environment in a silent room. They were instructed to watch each clip and then describe what they saw. No explicit instruction regarding gesture use was provided. Test stimuli were displayed on a Dell laptop in three different randomized orders across participants. Participants received no feedback throughout the testing sessions. The testing sessions were both audio- and videotaped. The camera was set in a position to capture the hands and the body of the participants but not the heads.

Coding

Speech. Participants' speech was transcribed by a native Farsi speaker (first author), and coded for disfluency. The following were coded as disfluency: a) filled pauses (e.g., *uh* and *um*, *er* and *ah*), b) repetitions (e.g., the girl is *running, running* around the tree), 3) fillers and comments (e.g., *What's the word I need ...* when used in the middle of a sentence while searching for a word), 4) appropriateness repairs when the speaker repaired an utterance to make it more complete (e.g., *the girl is running around the tree* … elaborating this by saying, *she is running very fast around the tree*).

Gesture. Gestures were coded as iconic or beat gestures. Gesture coding was done manually by the first author of the study using the ELAN software package (Brugman & Russel, 2004). Gesture abnormalities were coded as interruption (suspension of an ongoing gestural unit), repetition (immediate repetition of a gestural unit) and change (suspension of an ongoing gestural unit with an immediate initiation of a new gestural phase).

Speech-gesture relation. Parallel to the speech start-stop, gestures' re-start and interruption points were identified. The start point was coded when the hand started to move. The suspension was coded when an ongoing gestural unit was interrupted at the time of preparation or at the time of a stroke before the action was completed (holding the hand or being retracted back into its preparation position). The resume point was coded when the gesture that was at the static-hold position started a dynamic phase and was completed. Last, the time gap between the onset of a speech problem and gesture, as well as the gap between resumption of fluent speech and gesture were coded in milliseconds.

Results

A total of 356 trials were included in the analyses. Participants produced 307 iconic and 61 beat gestures, and 174 instances of disfluency. Each subject produced at least one gesture of one instance of disfluency. There were only three instances of overt errors and repairs. The rest of the disfluency cases comprised 53.4% filled pause, 27.0% appropriateness repairs, 12.6% comments, and the 7.0% repetitions. On 126 occasions, disfluency was accompanied by 105 iconic gestures and 21 beat gestures.

To test whether gesture and language reflect operations of a single system or two separate systems, we examined how often disfluent speech was accompanied by gestures that also showed a problem, as opposed to problem-free gestures. This analysis was conducted only on iconic gestures for which a problem can be objectively defined. We found that disfluent speech was accompanied by gestures that showed no problems on many occasions (45 instance or 42.9% of the time; X^2 (1, N = 105) = 2.14, p = 0.14). This finding shows that speech problems can occur without any problems in gesture, supporting the view that the two arise from different systems, at least past the conceptual level.

To investigate whether gesture can help resolve speech problems, we first asked if the primary goal of gestures was to help repair speech problems. If true, we would expect reliably more gestures when speech was disfluent, compared to when speech was fluent. Results indicated otherwise; there were significantly more gestures when speech was fluent than disfluent, (242 vs. 126; X^2 (1, N = 368) = 36.57, p < .001). These findings imply that gestures' primary function may not to resolve speech problems.

We then asked whether gesture has any role in resolving speech problems. To answer this question, we looked only at trials where there was speech disfluency. If speakers use gestures to resolve speech problems, we would expect significantly more disfluent speech trials that contain a gesture than those in without a gesture. This was the case for disfluent speech, (126 vs. 48, X^2 (1, N = 174) = 34.97, p < .001).

Next, we examined the pattern of iconic and beat gestures separately on disfluent cases. Of the 126 disfluent cases that were accompanied by gestures, 105 (i.e., 83.4%) were iconic, and the rest (16.6%) were beat gestures. Thus, speakers mainly produced iconic gestures with speech problems, X^2 (1, N = 126) = 56.0, p < .001. A closer examination of the data showed that beat gestures were produced mostly with filled pauses and comments (80.9%), and only in a few cases with repetitions and repairs. These findings show that on the majority of disfluent trials, speakers employed iconic gestures that, as reviewed earlier, have links to the lexical-semantic system. The use of beat gestures, on the other hand, was confined to cases where the nature of the disfluency implied that the speaker was cueing the listener that they are not done speaking. Together, these results suggest that while the primary role of gestures may not be to resolve problems in speech, speakers often use them when such problems arise.

In the following analysis, we examined the temporal pattern for the 126 cases of disfluent speech accompanied by the gestures, where 60 of the gestures manifested an abnormality and the other 66 gestures emerged normally at the time of the speech disfluency. First, we looked at the 60 cases when the gesture showed abnormality and coincided with the speech disfluency. We had 22 interrupted and 38 repeated gestures. Of the interrupted gestures, 91% co-occurred with filled pauses and fillers. We examined the temporal relation between the gesture interruption point and the disfluency starting point. The results revealed that gestures stopped either simultaneously or before the starting point of speech disfluency. There were significantly fewer cases, in which speech disfluency starting point preceded gesture interruption, X^2 (2, N = 20) = 23.72, p < .001 (see Table 1)

Next, we examined the temporal relationship between when speech was resumed and when gesture was resumed. Gestures were either resumed the same time as the speech was resumed (7 cases) or before speech resumption (7 cases) by an average of 237 ms. Importantly, gestures were never resumed after speech resumption.

Table 1: The timeline of speech disfluency start point and gesture interruption point

	Percentage	**Average time gap (in ms)**
Speech disfluency precedes gesture interruption	5.0%	893.33
Gesture interruption precedes speech disfluency	40.0%	380
Speech disfluency and gesture interruption occur simultaneously	55.0%	0

It should be noted that out of 38 cases of gesture repetition, 95% co-occurred with repetition type of disfluency or appropriateness repairs. Further, the repeated units of the gesture occurred either simultaneously or before the repeated or repaired section of the speech (average of 104 ms gap), (20 vs. 14, X^2 (1, N = 34) = 1.06, p = 0.30). There were only 2 cases where speech repetition preceded gesture repetition. In sum, the analysis of both interrupted and repeated gestures showed that in the majority of cases, changes in the gesture occurred before or simultaneously with problems in the speech.

Recall that among the 126 cases of gestures accompanying disfluent speech, 45 of the gestures were iconic and problem-free. These iconic gestures preceded their semantically targeted speech with the average of 1036 ms gap. Finally, out of 126, the remaining 21 were beat gestures, where 70.3% were produced before the starting point of the speech disfluency. The rest were simultaneously produced with speech disfluency.

Discussion

To our knowledge, this is the first controlled study examining the speech and gesture interaction in the light of disfluency in neurotypical adult speakers. We first asked if language and gestures come from the same of separate -- but related -- systems. Our results supported the latter: on many occasions when there was a problem in speech, gestures showed no trace of the problem. This finding is incompatible theories that propose a tight co-expression of gesture and speech (McNeill, 1992, 2005), and is better aligned with separate but interrelated models of speech and gesture (Krauss et al., 2000; de Ruiter, 2000; Hostetter & Alibali, 2008, 2010; Kita & Özyürek, 2003).

We then turned to a question that has been a focus of many past studies: Do gestures have a supporting role for speech production? This questions has been addressed by examining various populations (e.g., individuals with aphasia, individuals who stutter), but the results have been mixed. The only investigation of this question in neurotypical adults have been through the use of the gesture inhibition paradigm, which poses unusual cognitive demands on the speaker, making the interpretation of the results difficult. By examining the relationship between disfluency during normal speech production, we were able to address this issue from two angles: we first showed that the main role of gesture was *not* to remedy speech problems: gestures were reliably more prevalent on the fluent than disfluent sentences. Without independently assessing the fluency of speech, it is not possible to predict the exact link between gesture and fluency from correlational data. However, from this data, we can conclude that when speakers did encounter problems, they showed evidence of using gestures to help resolve speech problems: significantly more disfluent trials were with than without gesture. Moreover, the majority of these gestures were iconic gestures that are linked to lexical-semantic system. Thus, it is likely that speakers used these gestures to increase the activation of that system and to facilitate lexical retrieval (see also Cook, Yip, & Goldin-Meadow, 2012).

Another explanation could be that gesturing may lighten the verbal working memory (VWM) load (Goldin-Meadow et al., 2001). Speakers were better able to remember verbal items when they gestured during intervening speech than when they did not. Additional evidence in support of this hypothesis showed that speakers with lower VWM capacities produce gesture more often than those having higher VWM capacities (Gillespie et al., 2014).

Although beat gestures were not the most common type of gestures to accompany disfluent speech, they accompanied some of the trials with filled pauses and comments. These are cases where speakers most clearly signal to the listener that the speech problems are temporary and that speech will be soon resumed. As such, beat gestures, while they may not play a direct role in supporting lexical retrieval (e.g., Lucero et al., 2014), seem to play a social role in communication. This finding explains the prevalence of such gestures during speech (e.g., Beattie & Coughlan, 1999), in the absence of semantic meaning (see also Krauss & Hadar, 1999, Lucero, Zaharchuk, & Casasanto, 2014).

Finally, we examined the temporal relationship between speech and gestures, and found that in most cases gesture interruption of repetition preceded or coincided with the onset of the speech problem. Critically, there were only two instances where gesture problem manifested after the speech problem. These findings imply that speech and gestures are not always temporally synchronized as suggested (McNeill, 1992, 2005; Mayberry et al., 2000) Moreover, it suggests that the two systems are closely connected, such that speech problems can be reflected in gestures even before they surface in speech.

Collectively, these results support a model of separate, but interrelated systems for speech and gesture. In addition, it sheds light on the functional role of gestures: while not specialized for resolving overt problems in speech, both iconic and beat gestures are used by speakers when speech shows problems, although in different capacities.

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