Title: Integrity and function of gestures in aphasia

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Abstract

Background: Gestures can provide an excellent natural alternative to verbal communication in people with aphasia (PWA). However, despite numerous studies focusing on gesture production in aphasia, it is still a matter of debate whether the gesture system remains intact after language impairment, and how PWA use gestures to improve communication. A likely source for the contradicting results is that many studies were conducted on individual cases, or in heterogeneous groups of individuals with additional cognitive deficits such a conceptual impairment and comorbid conditions such as limb apraxia.

Aims: The goal of the current study was to evaluate the integrity and function of gestures in PWA in light of cognitive theories of language-gesture relationship. Since all such theories presuppose the integrity of the conceptual system, and the absence of comorbid conditions that selectively impair gesturing (i.e., limb apraxia), our sample was selected to fulfill these assumptions.

Methods & Procedures: We examined gesture production in eight PWA with preserved auditory comprehension, no comorbidities, and various degrees of expressive deficit, as well as 11 age-and education-matched controls, while they described events in 20 normed video clips. Both speech and gesture data were coded for quantitative measures of informativeness, and gestures were grouped into several functional categories (matching, complementary, compensatory, social cueing, and facilitating lexical retrieval) based on correspondence to the accompanying speech. Using rigorous group analyses, individual-case analyses, and analyses of individual differences, we provide converging evidence for the integrity and type of function(s) served by gesturing in PWA.

Outcomes & Results: Our results indicate that the gesture system can remain functional even when language production is severely impaired. Our PWA heavily relied on iconic gestures to compensate for their language impairment, and the degree of such compensation was correlated with the extent of language impairment. In addition, we found evidence that producing iconic gestures was related to higher success rates in resolving lexical retrieval difficulties.

Conclusions: When comprehension and comorbidities are controlled for, impairment of language and gesture systems are dissociable. In PWA with good comprehension, gesturing can provide an excellent means to both compensate for the impaired language and to act as a retrieval cue. Implications for cognitive theories of language-gesture relationship and therapy are discussed.

Keywords: aphasia, gesture, interface model, lexical facilitation model

Disclosure statement. The authors have no financial interest or benefit that has arisen from the direct applications of this research.

Integrity and function of gestures in aphasia

Approximately a quarter of severe stroke survivors have profound neurological deficits with long-term speech and language difficulties, known as aphasia (Ali, Lyden, & Brady, 2015; Hilari & Byng, 2009). Several studies propose that in aphasia, gesture offers a natural alternative to speech. Yet, the integrity and function of gestures in people with aphasia (PWA) are not well understood. Critically, it is not completely clear whether gesture production is affected by language impairment (e.g., Cicone, Wapner, Foldi, Zurif, & Gardner, 1979; Goodwin, 2000; Le May, David, & Thomas, 1988), and what role(s) gesture production plays in enhancing communication in individuals with language production problems (e.g., Lanyon & Rose 2009; Sekine, Rose, Foster, Attard, & Lanyon, 2013). This study addresses these two questions.

Gesture production in people with aphasia (PWA)

According to the communication hypothesis (Kendon, 2000; McNeill, 2005), speech and gesture originate from the same representational system. In this model, gesture carries a global-synthetic image of an utterance, and speech conveys the linear-segmented hierarchical linguistic structure of an utterance (McNeill, 1992; 2005; McNeill & Duncan, 2000). In the case of aphasia, this model predicts that gesture production breaks down in conjunction with speech, and the disturbance of gestures reflects type and severity of verbal deficits in aphasia (Cicone et al., 1979; Glosser, Wiener, & Kaplan, 1986).

In line with this hypothesis, Cicone et al. (1979) found that PWA with good receptive abilities, but non-fluent language production, produced fewer and simpler gestures. On the other hand, PWA with poor receptive abilities but fluent language production generated abundant and complex gestures. This pattern was interpreted as a close correspondence between speech and gesture modalities, with gesture production displaying the same characteristics as the verbal output. In the same vein, Glosser et al. (1986) reported that patients with moderate aphasia produced fewer complex and more opaque gestures than patients with mild aphasia and healthy control subjects. These findings support the degradation of gestural expression with increasing severity of language impairment.

In contrast to the aforementioned account, others have claimed that speech and gesture are generated from two separate but interrelated systems (e.g., Alibali, Kita, & Young, 2000; Goldin-Meadow, 2003; Goldin-Meadow & Alibali, 2013; Kita, 2000; Kita & Özyürek, 2003; Krauss, Chen, & Gottesman 2000; Pouw, De Nooijer, Van Gog, Zwaan, & Paas, 2014). These accounts hold that gesture production is not necessarily affected by language impairment. In fact, gesture use may even increase (in quantity, quality or both) to compensate for impaired linguistic abilities. In support of this view, several studies have shown the compensatory role of gestures in aphasia (e.g., Ahlsen, 1991; Behrmann & Penn, 1984; Beland & Ska, 1992; Herrmann, Reichle, Lucius-Hoene, Wallesch, & Johannsen-Horbach, 1988; Le May et al., 1988). For example, Behrmann and Penn (1984) found no clear relationship between gestural communication scores and the severity of aphasia, but found that PWA with non-fluent language output produced pantomimic gestures to replace their speech. In a 3-year longitudinal study of an individual with progressive aphasia, Beland and Ska (1992) observed that gesture use increased with decreasing language abilities. Also in line with these findings, Herrmann et al. (1988) reported that PWA employed more gestures than controls to either accompany their speech or compensate for their verbal deficits. Importantly, individuals with severe aphasia used more codified gestures, such as emblems than controls. The authors concluded that even people with profound language deficits could use gestural communication strategies to substitute the missing or defective verbal output.

Sekine and Rose (2013) suggested that aphasia type had an impact on gesture production. Patients with Broca's and conduction aphasia tended to produce *iconic gestures*. These are gestures that carry semantic information about an object or an action, and can co-occur with, or replace, verbal information. As such, they can be a particularly useful communication tool in PWA. Individuals with Wernicke's aphasia used more abstract gestures such as metaphoric or referential gestures. In contrast, those with anomia and transcortical motor aphasia produced fewer gestures, and they manifested a similar profile of gesture production to unimpaired speakers. By showing a specific association between the patterns of gesture production and types of aphasia, the authors suggested that as linguistic encoding fails in aphasia, individuals rely more heavily on the gesture channel. Collectively, these studies lend empirical support to the view that gestures can function independent of impaired language (e.g., de Ruiter, 2006; Hadar, Burstein, Krauss, & Soroker, 1998; Herrmann et al, 1988; Lanyon & Rose, 2009; Le May et al., 1988; Marshall et al., 2012; Raymer et al., 2006; Rose & Douglas, 2001, 2008, Rose, Douglas, & Matyas, 2002).

Function of gestures in aphasia

In the aphasia rehabilitation literature, there are two broad categories of gesture-therapy: (1) gesturing as a compensatory modality for impaired speech ("compensation"), and (2) gesturing as a cue to help produce speech ("restoration"; Rose, 2006). These two approaches roughly reflect two theoretical positions on gesture production: (1) The Interface Model (Kita & Özyürek, 2003, a hypothesis extended from Information Packaging Hypothesis by Kita, 2000), and (2) the Lexical Facilitation Model (Krauss et al., 2000, an idea originally put forth by Hadar & Butterworth, 1997). Both of these models maintain that language and gesture are separate but interconnected systems. They, however, differ on the relationship between the two systems.

Below, we review these two accounts, along with the evidence that support their predictions in aphasic production.

The Interface Model

According to the Interface Model (Kita & Özyürek, 2003), gestures arise pre-linguistically during conceptual preparation for speaking, but are influenced by language characteristics via feedback from the linguistic processing. According to this model, a message generator plans speech, while an action generator plans gesture, but both originate from an interface between spatial thinking and speech (de Ruiter, 2000; Kita & Özyürek, 2003; McNeill, 2000). The function of gestures is then to facilitate the organization of spatio-motor information into the linear format required by speech (see below for examples). However, according to this account, gestures do not directly help with word retrieval.

Several empirical findings support the Interface Model. For one, speakers produce more iconic co-speech gestures when the conceptual demands of the task increase, compatible with the view that gesturing helps in the conceptual packaging of information for easier linguistic processing. For example, making the shape of a roof with one's hand helps the speaker realize that a drawing of a house can be described as a triangle on top of a square (Hostetter, Alibali, & Kita, 2007). The key evidence in support of the Interface Model, however, comes from cross-linguistic studies showing that speakers of different languages produce different gestures for the same concept and that these gestures follow the linguistic structure of the utterances in the accompanying language. For example, English speakers produce one conflated gesture to express both manner and path for concepts expressed in a single clause (e.g., 'running up' is expressed by a gesture of moving the hand upward while simultaneously moving the index and middle fingers to signal running). In contrast, Turkish speakers tend to produce separate manner and path gestures for the same concept, which is expressed in two clauses in Turkish ('going up while running' is expressed first by an upward motion of the hand for 'going up' and then moving index and middle fingers for 'running' once the upward motion has stopped (e.g., Kita, 2000; Kita & Özyürek, 2003; McNeill, 2000; McNeill & Duncan, 2000). Akhavan, Nozari, and Göksun (2017) also found support for the Interface Model in Farsi-speaking adults by showing a correspondence between units of speech and gesture, as well as parallel ordering of speech and gesture sequences. However, the results also revealed an important limitation of this model; namely, the predominance of path gestures (i.e., gestures that reflect the trajectory of motion such as over or under) regardless of the accompanying spoken information. This was in spite of the fact that all the events in the study also included a specific manner of motion, which was included in speech, but not in gestures. In aphasia, support for the Interface Model comes from studies showing that speakers with severe aphasia tend to employ more iconic gestures (Kemmerer, Chandrasekaran, & Tranel, 2007; Marshall, Atkinson, Smulovitch, Thacker, & Woll, 2004) and these gestures are used as a strategy to convey messages using an alternative means of communication (Hogrefe, Ziegler, Weidinger, & Goldenberg, 2012; Hogrefe, Ziegler, Wiesmayer, Weidinger, & Goldenberg, 2013; Pritchard, Dipper, Morgan, & Cocks 2015; Sekine et al., 2013; Sekine & Rose, 2013; Wilkinson, Beeke, & Maxim, 2010).

The Lexical Facilitation Model

According to the Lexical Facilitation Model (Krauss et al., 2000), the primary function of producing iconic gestures is to facilitate word production. Iconic gestures arise from non-propositional representations of the concept, feed into the phonological encoder, and help retrieve the word-form (Krauss et al., 2000). Note that this notion contrasts with the Interface Model, which proposes an interaction between gesture and language at the higher levels (i.e., semantic conceptualization and formulation), as opposed to lower levels (i.e., phonological encoding). In support for the close interaction between gesture and phonological forms, Nozari, Göksun, Thompson-Schill, and Chatterjee (2015) showed that participants who thought of two gestures as having phonologically-similar labels (twist and twirl) confused the two gestures in their pantomimes more than participants who produced the same two gestures but thought of them as having phonologically-dissimilar labels (unscrew, twirl). The close ties between gestures and phonological forms is critical in the Lexical Facilitation Model, because it proposes that the primary function of iconic gestures is not to convey information to a listener, but to facilitate the speaker-internal process of word form retrieval (de Ruiter & de Beer, 2013).

Specific support for the role of gestures as facilitating word production comes from studies in which neurotypical participants' speech deteriorated when they were prohibited from using co-speech gestures in their descriptions (Frick-Horbury, & Guttentag 1998; Hostetter et al., 2007; but see Beattie & Coughlan, 1999). While a negative impact of obliterating gestures on word retrieval is compatible with a role of gestures in facilitating word production, this finding may instead reflect an increased demand for inhibiting gestures that naturally accompany speech. Language production requires cognitive control resources such as inhibitory control (Nozari, Arnold, & Thompson-Schill, 2014; Nozari & Novick, in press; Nozari & Thompson-Schill, 2015), thus allocation of such resources to other processes like inhibiting gestures, can interfere with production. Studies in aphasia suggest that gestures may not simply compensate for the impaired speech, but also cue speech production (Lanyon & Rose, 2009). Indeed, treatments that include a gestural component have improved word retrieval in aphasia (Attard, Rose, & Lanyon, 2013; Crosson et al., 2007; Raymer et al., 2006). However, the independent contribution of gesture to the treatment effect is difficult to determine. When gesture is treated in isolation, effects have not generalized to speech (Marshall et al., 2012), and gesturing at the time of difficulty with lexical retrieval may not always be helpful (e.g., Cocks, Dipper, Middleton, & Morgan, 2015).

Summary of the past work and motivation for the current study

The findings reviewed above show that much work has explored the relationship between language and gesture in aphasia. However, the inconsistencies in the findings make it difficult to draw definite conclusions about the integrity and function of gestures in the presence of impaired speech: while some studies have found significant impairment of gestures, others have reported intact or increased gesturing in PWA. It thus remains unclear whether language and gesture impairment go hand in hand or not. Similarly, many functions have been proposed for gestures in individuals with language impairment. Some, such as compensation for defective speech (e.g., Le May et al., 1988) and aiding sentence re-construction (i.e., gestures used when a speaker attempts modification of syntactic structure; Alibali, Kita, & Young, 2000) are better aligned with the Interface Model. Others, such as assisting lexical retrieval (Mayberry & Jacuqes, 2000) are more compatible with the Lexical Facilitation Model. Importantly, these two models need not be mutually exclusive. But to better interpret the results, the source of the discrepancies must be examined more carefully. Four sources can be readily identified: the first is the variability in patient profiles. Aphasia is a diverse syndrome, and PWA vary considerably in their cognitive abilities, including semantic comprehension, lexical access, phonological encoding, and the integrity of the cognitive paths underlying these functions (Nozari & Dell, 2013). Many studies reviewed above were single-case studies or studies of heterogeneous groups of PWA which may explain the discrepancies in the findings (but see Sekine, & Rose, 2013; Sekine et al., 2013).

The second possible source of discrepancy is the coexistence of independent disorders that cause gesture impairment, most prominently limb apraxia. Limb apraxia is a wide-spectrum higher order motor disorder that can occur at different levels (Leiguarda & Marsden, 2000). It mostly affects pantomime production, tool knowledge or skilled movements (e.g., cutting with scissors), whereas the ability to produce co-speech representational gestures such as displaying spatial relations between two objects (e.g., putting an apple inside a bowl) can vary (Göksun, Lehet, Malykhania, & Chatterjee, 2013). Although some studies have found a link between limb apraxia and the spontaneous use of gestures (Borod, Fitzpatrick, Helm-Estabrooks, & Goodglass, 1989; Hogrefe et al., 2012; Feyereisen, Barter, Goossens, & Clerebaut, 1988), the processes underlying co-speech gesture production and pantomime production have been shown to be largely separable both in neurotypical individuals and in PWA (e.g., Bartolo, Cubelli, Della Sala, & Drie, 2003; Goldin-Meadow, So, Özyürek, & Mylander, 2008; Lausberg, Davis, & Rothenhausler, 2000; Lausberg, Zaidel, Cruz, & Ptito, 2007; Rose & Douglas, 2003). Thus, it is likely that limb apraxia occurs as a comorbidity in certain PWA (e.g., Borod et al., 1989; for a review see Leiguarda & Marsden, 2000), and impaired gesturing that could result from the coexisting limb apraxia is mistakenly attributed to language impairment.

The third potential source of discrepancy is the variability in conversational demands of the task. Semi-structured interviews, free conversations, and narrative story telling are common methods used in studies examining co-speech gestures (e.g., Dipper, Cocks, Rowe, & Morgan, 2011; Dipper et al., 2015; Kemmerer et al., 2007; Lausberg et al., 2000; Rose & Douglas, 2003). While these tasks have a special role in examining spontaneous behavior of PWA, their results are difficult to interpret across individuals and studies, because (a) it is difficult to control the influence of a partner in semi-structured interviews and free conversations (Hogrefe et al., 2013), and (b) narratives place a significant demand on general cognitive skills (i.e. attention and memory), which may also vary significantly among PWA (Duinmeijer, de Jong, & Scheper, 2012).

Finally, the fourth source of discrepancy is the different analytic techniques used in different studies. Most of the previous studies have focused on the differences in the frequency of gesture use, rather than examining detailed functions of gestures and the corresponding speech (Feyereisen, 1983; Göksun et al., 2013; Göksun, Lehet, Malykhania, & Chatterjee, 2015; Hadar et al., 1998; Kemmerer et al., 2007; Lanyon & Pedelty, 1987; Rose 2009; Sekine et al., 2013; but see Mol, Krahmer, & van de Sandt-Koenderman, 2013). Without a careful analysis of the function of gestures, it is impossible to determine whether they serve a communicative purpose or not, and if they do what this purpose is. For example, gestures may be used to convey part of the message that was not expressed verbally, or they may be used to signal to the conversational partner that the speaker is having difficulty in verbal communication.

The current study revisits the question of the relationship between gesture and language impairment using a design that employs a more homogenous group of PWA and a more rigorously-controlled design and analysis plan. Specifically, the experimental group comprised eight PWA with good auditory comprehension (to ensure at least relatively preserved semantic knowledge which all theoretical accounts agree is important for gesture production). There was, however, no restriction in terms of the degree of fluency and aphasia severity, and individuals with mild to severe aphasia were included to ensure that the effects were not driven by severity. In addition, we assessed limb apraxia independently using a pantomime paradigm that tested object use, a gesture type fundamentally different from the co-speech gestures elicited by our experimental paradigm. Only the PWA without limb apraxia were included in order to rule out gesture impairment due to a comorbid condition. For the experimental stimuli, we used short (3-

4 second) clips, depicting different motion events. The set of clips were previously developed and standardized for familiarity in a study of English-speaking PWA (Göksun et al., 2015), and have been used in several cross-linguistic studies in Farsi (Akhavan, Göksun, & Nozari, 2016; Akhavan, Nozari, & Göksun, 2017) and Turkish (Karaduman, Çatak, Bahtiyar, & Göksun, 2015). In analyzing the results, we used group analyses, case-by-case comparison of PWA vs. a control group, and correlational analyses between language and gesture within the PWA group.

Using these procedures, we were able to answer two main questions: (1) is language production impairment necessarily accompanied by gesture impairment? And (2) what is the function of gestures in PWA with good comprehension but impaired production abilities?

Methods

Participants

Eight right-handed native Farsi speakers with chronic aphasia resulting from left hemisphere stroke were recruited from the Tabasom Stroke Rehabilitation center in Tehran, Iran, who met the following criteria: (1) Good auditory comprehension in understanding and following commands in everyday speech as screened by a trained clinician in the rehabilitation center, as well as on sequential command test of the Farsi version of the Bedside Western Aphasia Battery (M = 8.13 (Max = 10), SD = 1.66; B-WAB; Nilipour, Pourshahbaz, & Ghoreyshi, 2014) and (2) mild or no limb apraxia pertaining to a score of 85 and above (M = 93.46 (Max = 100), SD = 7.53) on the Limb Apraxia Battery adapted for Persian (Nilipour, 2005). For limb apraxia task, participants were asked to mime the use of 20 common objects, for example, they were shown a picture of a toothbrush and were asked to mime the action of brushing their teeth. Importantly, the eight participants covered a wide range of severity (WAB-AQ of 42.5 - 95.8; M = 60.6, SD = 18.77), and comprised of both Broca's aphasics (non-fluent and agrammatical) and anomics (more fluent and grammatical but with word finding difficulties). None of the participants had received therapeutic interventions that specifically targeted the use of gestures at any point after their stroke. Table 1 presents the demographics, as well as WAB-AQ and limb apraxia scores for the eight PWA.

In addition, eleven age- and education-matched elderly healthy adults (M_{age} = 58.18, SD = 10.67; $M_{years\ of\ education}$ = 12.27, SD = 4.63) participated as a control group. None of the participants had a history of other neurological disorders, psychiatric disorders, substance abuse, or uncorrected vision and hearing problems. All subjects gave informed consent to participate in the study in accordance with the policies of the Koç University Institutional Review Board.

Table 1. Background information on the eight PWA. WAB-AQ was calculated using the Farsi version of Bedside Aphasia Battery (B-WAB). Limb apraxia score was derived from Apraxia Battery for Adults.

Patient	**Aphasia Type**	**Gender**	**Age**	**Education (yrs.)**	**Months post stoke**	**WAB (AQ)**	**Limb Apraxia score**
P1	Broca's	F	50	12	69	56.7	100
P3	Broca's	M	64	Home-schooled	45	47.5	85.7
P4	Anomic	M	62	16	44	80.8	100
P5	Broca's	F	27	12	49	42.5	88.5
P6	Anomic	M	56	16	33	50.8	100
P8	Broca's	M	72	16	51	64.2	93.1
P10	Broca's	M	73	12	28	46.7	89.4
P14	Anomic	M	43	16	22	95.8	100

Task and Stimuli

Materials

Participants watched 20 dynamic 3-4 second movie clips, depicting different motion events with combinations of 10 manners (hop, skip, walk, run, cartwheel, crawl, jump, twirl, march, step) and 9 paths (between, to (towards), out of, under, over, in front of, around, across, into). All actions were performed by a female in an outdoor area (see Figure 1 for sample stimuli, and Appendix A for a full list of the actions in the 20 video clips). These materials were previously standardized in English (Göksun et al., 2015) and tested on 20 neurotypical Farsi speakers to ensure their linguistic and cultural suitability (Akhavan et al., 2017). Motion events have been used in the literature to elicit natural gesture use (e.g., Dipper et al., 2015; Göksun et al., 2013, 2015; Kemmerer et al., 2007; Kita & Özyürek, 2003). There are several advantages to using motion events: (a) many such events contain both path and manner information that can promote gesturing. (b) Unlike emblems, most gestures arising from motion events are not specific to a certain culture or language, allowing for cross-cultural studies. (c) Also, unlike emblems which are represented by arbitrary symbols, motion gestures do not have to be learned, as they imitate the core characteristics of the motion to be described. This latter characteristic alleviates concerns regarding gesture impairment due to the potential loss of learned knowledge after brain damage. Together, these three properties made the current set of materials well suited for studying gestures in an impaired population belonging to a culture in which gesture studies have been sparse.

Figure 1. Sample stimuli from the experimental task. The pictures are still frames (changed to black and white for print) from two motion events: jump over the bench (left side) and walk across the street (right side). The arrows indicate the direction of the person's movement.

Procedure

All participants were tested individually in the clinic at Tabasom Stroke Rehabilitation center in Tehran, Iran. First, Neuropsychological tests (WAB and then Apraxia tests) were administered. Then, patients watched the video clips. This part of the session was video- and audiotaped for offline coding of speech and gestures. Participants were instructed to watch each clip and then describe what they saw to the examiner. No explicit instruction regarding gesture use was provided. Before the test trials, two practice trials were administered to make sure that participants could follow the instructions. Test stimuli were displayed on a Dell laptop in three different randomized orders across participants. The entire session including the clinical assessment and the experimental testing took around 2 hours.

Coding

All responses (speech and gestures) were transcribed and coded by a native Farsi speaker (first author), and a subset of the data was double-coded by a second coder for reliability (see below). Gesture coding was done manually by the same person using the ELAN software package (Brugman, Russel, & Nijmegen, 2004).

Informativeness of Speech and Gestures

Speech and gestures were coded separately. Participants' speech on each trial was transcribed, and accurate and non-repetitive words were coded as informative. "Accurate" referred to words that were semantically suitable for describing part of the target event. For example, "girl" and "woman" were both accepted as accurate for describing the young female performing the actions, but "man" or "this" were not counted as accurate words to describe the agent of the action. The same was true for words describing other parts of the sentence, such as path and manner of motion. Morphosyntactic factors did not affect the accuracy coding. For example, “crawl”, “crawls” and “crawling” were all coded as accurate (see Appendix B for a detailed example). Speech informativeness was then calculated as the duration of informative speech over total speech time on each trial which also included errors and repetitions, and silent and filled pauses. We used duration instead of the number of informative words because nonfluency, which is a prominent feature of many aphasic syndromes (e.g., Nozari & Faroqi-Shah, 2017), is better captured by coding durations. For instance, two participants may both produce “girl crawls into booth”, but one speaks it fluently in 5 seconds, while the other inserts long pauses between words, taking a minute to complete the sentence. A measure that counts the number of words would score the two participants the same, but a duration measure correctly scores the first participant higher.

To keep the coding of speech and gesture consistent, we used a metric for gesture coding that was similar in spirit to the one used for coding the informativeness of speech. Informative gestures were non-repetitive gestures that carried semantic information relevant to the target event. An uninformative gesture would constitute moving hands randomly or miming irrelevant events. Gesture informativeness was then calculated as the duration of informative gestures over total gesture duration on each trial (see Appendix B for an example).

Functions of Gestures

Gestures complementing or replacing speech. This category, partially adapted from Kong, Law, Wat, and Lai (2015), includes three functions that address how communication of meaning is split between linguistic expressions and gestures.: *(a) matching gestures* refer to gestures that were produced along with a corresponding utterance such as mimicking the action of cartwheeling with the hand while producing the word. (b) *complementary gestures* refer to production of a part of semantic information in a gesture that completes a verbal description. For example, when the speaker says, “She walked like this” and complements her speech with a gesture indicating the manner of walking. (c) *Compensatory gestures* refer to cases where gesture supplants speech, for example when the speaker draws a circle with the index finger to represent ‘around’ without producing the corresponding word. These three classes of iconic gestures show a gradual move from gesture being redundant to gesture being critical in conveying semantic information to the listener. If gesturing serves a crucial communicative purpose in aphasia, we would expect to see a high rate of compensatory gestures in this population. Moreover, a negative relationship would be expected between the rate of compensatory gestures and the informativeness of speech: the more impoverished the speech, the greater the rate of compensation through gesture.

Gestures as social cues. Another class of gestures is those that also serve a communicative purpose but do not convey the semantics of the event to be described. Examples include when the speakers raise the hands palm-up to indicate uncertainty or having nothing to say. This class of gestures provides a potential alternative to the previous three types of gestures where gesturing is used to communicate meaning directly. If individuals primarily use gestures in one capacity or another, we would expect a negative correlation between gesture use to convey meaning and gesture use to cue uncertainty.

Gesturing to help word retrieval. Finally, we investigated whether there is a correlation between producing meaning-laden gestures and facilitation of word retrieval. To this end, we used a subset of the trials in which PWA had word retrieval difficulty, and determined whether this difficulty was resolved or not. Word retrieval difficulty was defined as cases where PWA visibly struggled with the production of the next word. In fluent speech, words are retrieved at a rate of 1-3 words per second (Butterworth, 1989,1992; Levelt, 1989). We coded gaps of 1500 ms or more between the two words along with signs of struggle (filled pauses, frustrated comments such as “ah, can’t say it”, attempts at self-corrections, as well as repetitions of the last word or words) as cases associated with word retrieval difficulty. Each case was also coded for a binary outcome: the struggle either ended in the speaker finding the correct word (resolved), or it did not (unresolved). We then compared the proportion of resolved trials that contained an iconic gesture with those that contained no gesture or non-iconic gestures. If producing iconic gestures facilitates word retrieval, there should be significantly more iconic gestures on trials in which word retrieval difficulty was resolved.

Reliability

The first author coded the entire data set. To establish reliability for speech, a second native Farsi speaker independently coded 18% of randomly-selected trials from the PWA and control data. The agreement between coders was 97% in measuring the informativeness of speech for the control group and 96% for PWA. To ensure the reliability for gesture coding, a second person coded 18% of participants’ randomly-selected gestures. The agreement between coders for the control group was 92% for gesture informativeness, and 91% for gesture function assignments (matching, complementary, compensatory, social cues). The agreement on PWA’s coding was 89% for gesture informativeness, 88% for assigning gesture function (matching, complementary, compensatory, social cues) and 93% for identifying the cases where gesture helped word retrieval. Any coding disagreements were resolved through discussion and subsequent consensus.

Results

Speech. The eleven control participants produced 218 full sentences in response to the events in the video clips (M = 19.81, SD = 0.40). Two trials were missed due to the technical errors. The eight PWA produced 87 event-relevant utterances (M = 10.88, SD = 6.05) on 152 trials (8 trials with no responses, or responses irrelevant to the event, such as “I don’t know” were excluded). As typical for people with Broca’s aphasia, P1, P3, P5, P8, and P10 produced effortful and telegraphic speech, consisting mainly of nouns and verbs, and impoverished in function words. Farsi verbs often consist of a noun + a light auxiliary verb, e.g., ley ley kardan (hop + doing = hopping [on one leg]). The simplest form is the past tense third person singular, i.e., ley ley kard, which drops the “/æn/” in the infinitive without taking additional morphemes that mark the first and second person singular or the plural forms. Thus, the majority of verbs produced were past tense third person singular. Farsi does not have definite articles (e.g., no equivalent to “the”), but uses prepositions such as “from” and “to” more frequently than English. For example, “crossing the street” is expressed as “<u>*az*</u> khiaban rad shodan” (*lit: from* street crossing). These prepositions were often missing in the utterances produced by people with Broca’s aphasia. Below are the two examples:

(1) Target sentence: Dokhtar dore derakht jasto khiz kard. (*lit: Girl around tree skip did;* The girl skipped around the tree).

Example utterance from Broca’s participant (P1): Derakht [pause] park [pause] raft[1]. (*lit: Tree [pause] park [pause] went;* Tree [pause] park [pause] went)

(2) Target sentence: Dokhtar ley ley konan az sakhteman biroon amad. (*lit: Girl hop hop doing from building out came;* The girl hopped out of the building).

Example utterance from Broca’s participant (P5): Khoone [pause] biroon amad. (*lit: House [pause] out came*; House [pause] came out).

On the other hand, people with anomia (P4, P6, and P14) in our sample spoke in longer and often grammatical sentences that missed critical content words (see examples 3 and 4 below):

[1] Farsi is a pro-drop language, so the absence of subject is not ungrammatical.

(3) Target sentence: Dokhtar beyne sotoonha rah raft (*lit: Girl between poles path went;* The girl walked between the poles).

Example utterance from Anomic participant (P4): Oomad inja, be soorate in oomad, intori raft. (*lit: Came here, of manner this came, this like went;* She came here, came here like this, went away like this.)

(4) Target sentence: Dokhtar az rooye nimkat parid (*lit: Girl from over bench jumped;* The girl jumped over the bench).

Example utterance from Anomic participant (P6): Bala mire ba'd mipare intori. (*lit: Up goes, then jumps like this;* She goes up and then jumps like this).

Gesture. Controls had a total of 108 gestures in 218 trials (M = 9.82, SD = 10.22). PWA produced a total of 366 gestures in 152 trials (M = 45.75, SD = 16.81). On average 72.4% of PWA's gestures were identified as iconic, 25.7% as beat gestures, and 1.91% as deictic. The controls' gestures compromised 81.9% iconic, and 11.1% beat gestures.

The Informativeness of Speech and Gesture

To quantify the informativeness of speech and gestures in our participants, we calculated the informativeness index described in the Methods for each PWA, as well as each of our 11 neurotypical control participants (see Table 2). In a group-level analysis using the non-parametric Mann-Whitney U test, speech informativeness was significantly higher in the control group compared to the PWA group (z= 3.64, p <0.001). Critically, however, the informativeness of gesture did not reliably differ between the two groups (z= 1.30, p = .20), suggesting that impairment in speech was not mirrored by impairment in gesture at the group level. To further probe the status of the gesture system at the level of individuals, we compared these indices for each PWA to the average of controls using the corrected t-test (below) proposed by Crawford and Howell (1998),

$$t=\frac{Xi-X}{s\sqrt{\frac{n+1}{n}}}$$

where *Xi* is a PWA's score, *X* is the mean score of the control sample, *s* is the standard deviation of the control sample, and *n* is the size of the control sample. The advantage of this method over the traditional t-test is that it treats the mean and standard deviation of the control sample as sample statistics instead of population parameters, which is more appropriate for small control sample sizes, and avoids Type I error. An additional advantage of this test is that the p value provides a point estimate for where the patient score falls compared to the population. For example, P1 in Table has an index of informative gesture equal to 68. A two-tailed test returns a p-value of 0.77. Since we are interested in a deficit here, we care about the percentage of population who may have a *lower* index of gesture informativeness than P1. Thus, we care about the one-tailed probability that the patient's score might be lower than the population. This probability (0.38) can be translated to ~38% of the population would have a lower index of gesture informativeness than P1. This is a fairly high percentage; thus, we can conclude that P1 is unlikely to have a deficit in this regard.

Table 2 shows the full results of the individual-case analyses for both speech and gesture informativeness. Not surprisingly, all PWA had significantly lower scores on speech informativeness than the controls. Critically, however, none of the eight PWA had reliably lower indices of gesture informativeness compared to control participants. This finding shows that the gesture system can remain fairly functional despite the language breakdown in PWA, suggesting a separation between deficits of the language and the gesture systems.

Table 2. Single case statistics for speech and gesture informativeness in PWA and controls.

Participant	**Informative speech %**	**t**	**2-tailed probability**	**Estimated % of normal population falling below individual's score**	**Total number of gestures**	**Informative gesture %**	**t**	**2-tailed probability**	**Estimated % of normal population falling below individual's score**
P1	46	-10.0	<.001	<.001	70	68	-0.31	.77	38.3
P3	12	-17.4	<.001	<.001	48	39	-1.42	.19	9.34
P4	27	-14.1	<.001	<.001	67	66	-0.38	.71	35.5
P5	22	-15.2	<.001	<.001	42	42	-1.30	.22	11.1
P6	25	-14.6	<.001	<.001	50	85	0.35	.74	63.2
P8	25	-14.6	<.001	<.001	21	87	0.42	.68	65.9
P10	0	-20.1	<.001	<.001	21	62	-0.54	.6	30.2
P14	72	-4.35	.001	.07	47	75	-0.04	.97	48.5
PWA									
Group Avg.	28.6				45.8	65.5			
SD	21.9				18.1	17.8			
Median	25				47.5	66.6			
Range	72				49	48			
CONTROL									
Group Avg.	92				12	76			
SD	4.4				10.8	25			
Median	92.8				9	80.9			
Range	13.6				34	87			

Table 3. Percentages of different gesture functions in PWA and controls, along with individual statistics. Matching and complementary gestures were marked as NA for P10, because his speech informativeness index was 0 (Table 2), eliminating opportunities for matching and complementary gestures. Because the SD for compensatory gestures in the control group was 0 and the Crawford & Howell's (1998) formula does not work with a zero denominator, a small positive SD (1%) was used for the calculation of t and p values for single-case statistics of compensatory gestures. Note that the total % of gestures in this table does not add up to 100% because of the final category, namely gestures that help word retrieval, which are discussed in a later section.

ID	**Matching %**	**t (p value)**	**Complementary %**	**t (p value)**	**Compensatory %**	**t (p value)**	**Social Cuing %**	**t (p value)**
P1	17	-1.59 (.14)	1	-0.58 (.57)	22	21.1 (<.001)	42	1.82 (.10)
P3	8	-1.90 (.09)	0	-0.62 (.028)	19	18.2 (<.001)	56	2.76 (.02)
P4	1	-2.14 (.06)	7	-0.39 (.71)	39	37.3 (<.001)	46	2.09 (.06)
P5	2	-2.11 (.06)	0	-0.62 (.028)	36	34.5 (<.001)	57	2.83 (.02)
P6	8	-1.90 (.09)	4	-0.49 (.64)	56	53.6 (<.001)	24	0.61 (.56)
P8	29	-1.18 (.27)	0	-0.62 (.028)	24	30.0 (<.001)	43	1.89 (.09)
P10	NA	NA	NA	NA	62	59.4 (<.001)	38	1.56 (.15)
P14	56	-0.24 (.81)	4	-0.62 (.028)	0	0 (1)	35	1.35 (.21)
PWA								
Group Avg.	17.3		2.29		32.3		42.6	
SD	19.6		2.75		20.3		10.9	
Median	8		0.5		30		44.5	
Range	28		7		34		33	
CONTROL								
Group Avg.	63		19		0		15	
SD	27.7		29.6		0		14.2	
Median	66.8		8.8		0		14.3	
Range	100		100		0		40	

Functions of Gestures

The dissociation between speech and gesture impairment demonstrated by the previous analysis suggests that speech and gesture arise from different systems, but, as shown in previous research the two systems most likely interact at some level. The following analyses investigate the nature of this interaction in PWA.

Gestures complementing or replacing speech. Table 3 presents the percentage of matching, complementary, and compensatory gestures in PWA and the control sample. The control group showed the highest proportion of gestures in the matching cluster (63%) followed by the complementary cluster (19%) and virtually no gestures in the compensatory category. This pattern was quite different from PWA who, as a group, showed the highest proportion in the compensatory cluster (~32%), followed by matching (~17%) and complementary (~2%) clusters. At the group level, PWA generated significantly fewer matching gestures than controls ($z = 2.49$, $p = 0.013$). Note that since PWA produce less speech, the opportunities for producing matching gestures is considerably reduced in this population, which explains the lower proportion of such gestures compared to controls. PWA, however, did not reliably differ from controls in their production of complementary gestures ($z = 1.63$, $p = 0.10$), and critically, produced significantly more compensatory gestures compared to controls ($z = 3.39$, $p = 0.001$).

Next, we tested each PWA's gesture production in these three clusters in comparison to controls using the Crawford and Howell's (1998) modified t-test. Table 3 reports the t statistics and corresponding p values for these tests. Due to the large variability found in matching and complementary gestures in the control sample, PWA's gestures in these two clusters, for the most part, did not differ reliably from controls, although the tendency for producing fewer gestures in these clusters was apparent in a few participants. Critically, however, every patient, except for P14 showed a reliably higher percentage of compensatory gestures than the controls. Moreover, the percentage of compensatory gestures was reliably and negatively correlated with speech informativeness (*r* = -0.74, *p* = 0.037; Figure 2). Together, these findings show that iconic gestures are used to compensate for speech deficits in aphasia.

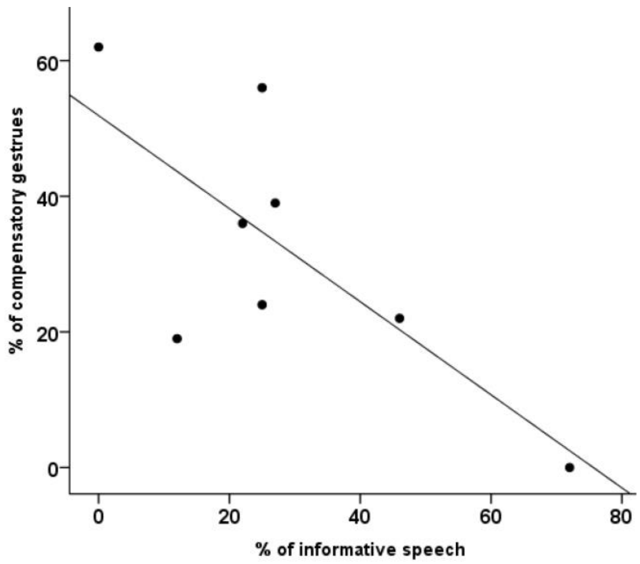

Figure 2. The correlation between speech informativeness and production of compensatory gestures in the eight PWA.

Gestures as social cues. As a group, PWA used a greater proportion of gestures as social cues (~43%) compared to controls (15%). This difference was significant at the group level ($z = 3.09$, $p = 0.002$) and for a few individuals (Table 3). Importantly, there was a strong negative correlation between gesture informativeness and the proportion of gestures used as social cues ($r = -0.82$, $p = 0.013$, Figure 3), indicating that participants with more impoverished gestures used gesturing more as social cues.

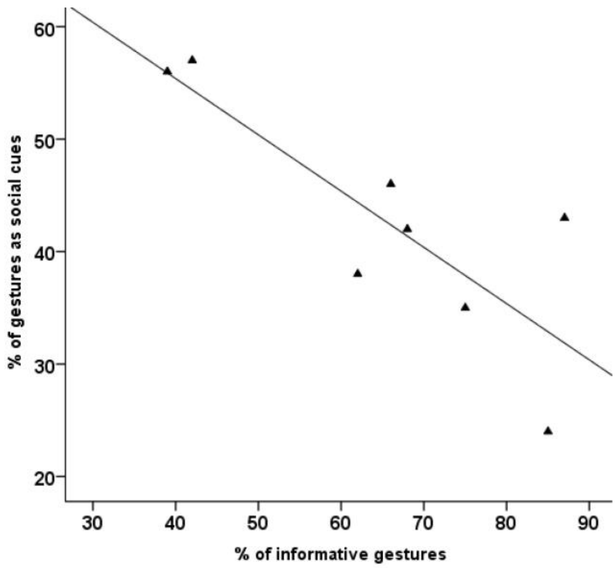

Figure 3. The correlation between gesture informativeness and the use of gesture as social cues in the eight PWA.

Gesturing to help word retrieval. Finally, we turn to the question of whether using iconic gestures may help in word retrieval. A total of 330 cases of word retrieval difficulty was identified across the eight PWA. Of these, 41 were ultimately resolved, while the other 289 remained unresolved. Of the 41 resolved cases, 36 (88%) were accompanied by iconic gestures corresponding to the to-be-retrieved lexical item, while in the remaining five either no gesture was produced or other types of gestures were produced. Of the 289 unresolved cases, 163 (56%) were accompanied by iconic gestures while the rest comprised no gestures or other gesture types. In a within-subject comparison, we compared the proportion of resolved trials with iconic gestures to the proportion of unresolved trials with iconic gestures (Figure 4) using the non-parametric Wilcoxon signed rank test. The results suggested that when iconic gestures were produced, a significantly higher proportion of trials with word retrieval difficulty were resolved, compared to when no gesture or other gesture types were produced (z = 2.37, p = 0.018). This result suggests a correlation between the production of iconic gestures and successful word retrieval.

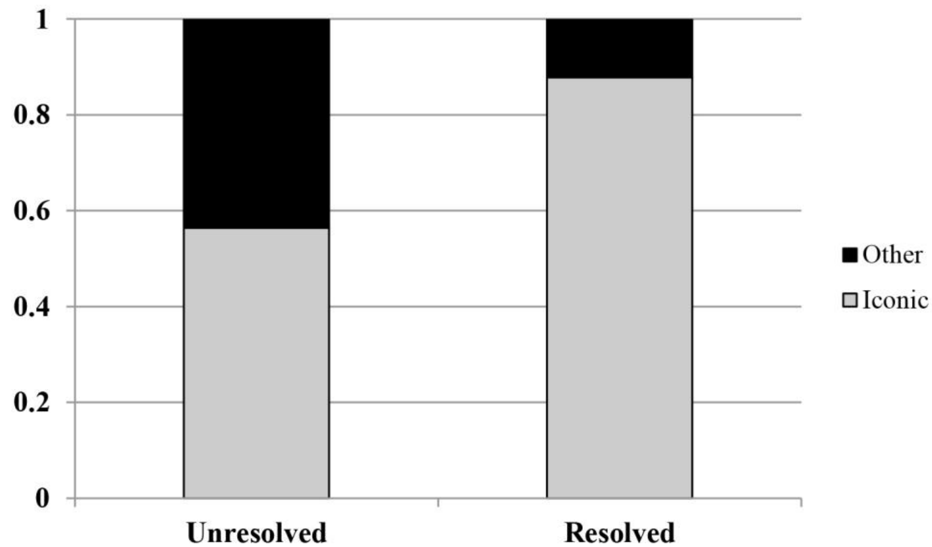

Figure 4. Stack bars showing the distribution of trials with iconic gestures compared to those with no gestures or other gesture types (folded into "other") on trials with word retrieval difficulty that was either resolved or not. The right bar shows that >80% of trials in which word retrieval difficulty was resolved contained iconic gestures. The left bar provides a control, showing that this effect is not simply due to greater prevalence of iconic gestures; when the participants were unable to resolve the word retrieval difficulty (perhaps because the representations were lost or too inaccessible), distribution of iconic vs. other gestures was about 50/50.

Discussion

We found that all eight PWA, independent of their aphasia severity, used gestures in their description of motion events, and that gesture use in this group did not differ from neurotypical adults. Moreover, we showed that PWA used their gesture system in several capacities to increase the efficacy of communication. These included compensating for lost speech with gestures, using gestures to resolve lexical retrieval difficulties, and in some cases, employing gestures as social cues for the interlocutor. Below, we discuss the implications of the findings for theories of language and gesture relationship, as well as therapeutic approaches in aphasia.

Theoretical implications

Gesture theories differ in whether language and gesture should be viewed as one (e.g., McNeill 2005; McNeill & Duncan, 2000) or two systems (e.g., Kita & Özyürek, 2003; Krauss et al., 2000). Moreover, there is debate among the latter theories on the exact relationship between language and gesture. To test the hypotheses of the two models, it is important to emphasize the intactness of the conceptual system, as all the aforementioned theories assert that damage to concepts should affect both language and gesture systems. The debate is whether gesturing is impaired in individuals with language impairment and spared conceptual representations. The current study targeted PWA who met these criteria.

Our results showed that although PWA's speech was significantly less informative than that of non-aphasic control speakers, their gestures were not. This finding is consistent with studies reporting intact gestures in PWA, despite the language impairment (e.g., Goodwin, 1995, 2000; Herrmann et al., 1988; Rousseaux, Daveluy, & Kozlowski, 2010; Wilkinson et al., 2010). These results, however, contradict a few other studies who have suggested that language and gesture impairment go hand in hand (Cicone et al. 1979; Glosser et al.,1986; Mol et al.,2013). Importantly all these studies in the latter group include PWA with comprehension deficits, which point to potential problems in conceptual processing of the message. If a message cannot be constructed, it naturally cannot be communicated by verbal or other modalities of communication. An additional problem was the presence of limb apraxia in some participants, which, as argued in earlier sections, is a comorbid condition in aphasia, but is not part of the aphasic syndrome per se. Taken together, these findings indicate that when conceptual representations are relatively intact, and comorbid conditions such as limb apraxia are ruled out, the gesture system may function effectively, even when language is severely impaired. This finding supports a post-conceptual separation of language and gesture systems.

Our results regarding the function of gestures help further adjudicate between the two dominant theories of gesture production compatible with separate, but related language and gesture systems. The Interface Model (Kita & Özyürek, 2003) views gestures as connecting with the speech at the conceptual level to help unpack a concept. Thus, this account maintains that gestures should be used to facilitate the communication of concepts to the listener[2]. In other words, this account predicts a compensatory role for gestures in conveying the message when speech is impaired. The prediction was confirmed in our study: seven out of eight PWA reliably used more iconic gestures than healthy controls to convey semantic information; the exception was the participant with the mildest speech impairment (i.e., who conveyed the same information orally). Additional evidence for the compensatory role of gestures in impaired speech was provided by a strong negative correlation between the informativeness of speech and the production of compensatory gestures; the more impaired the participant's speech, the more the use of compensatory gestures. Together, these findings are in keeping with the predictions of the Interface Model, and studies that have also found the function of gestures to be complementing speech (e.g., Dipper et al., 2015; Göksun et al., 2013, 2015).

The Lexical Facilitation Model, on the other hand, views the gesture system as connecting with the language production system at lower levels, i.e., at the level of phonological

[2] The Interface Model also posits that gesturing helps with syntactic packaging. Since the majority of PWA in our sample were Broca's and produced agrammatic utterances, this prediction is not examined.

encoding. While the predictions of this model are not mutually exclusive with those of the Interface Model, they are different in spirit: the Interface Model predicts an interaction at the conceptual level, which may affect production down to syntactic planning. The Lexical Facilitation Model predicts a direct effect on word retrieval. If this model is correct, we would expect iconic gestures to help PWA produce words that they have difficulty retrieving. In keeping with this prediction, we found that a higher proportion of word production difficulties ended in successful retrieval in the presence of iconic gestures, compared to no gestures or other gesture types. It must be noted, however, that establishing a causal link between gesture production and word production is difficult. A plausible alternative interpretation of this result is that words that have stronger representations in the aphasic system give rise to more iconic gestures. Either way, this finding supports a close correspondence between producing individual words and corresponding gestures (see also Nozari et al., 2015), and adds to the indirect evidence in support of the Lexical Facilitation Model which reported a link between iconic gestures and verbal fluency (Butterworth & Beattie, 1978; Morrel-Samuels & Krauss, 1992).

In summary, we identified two critical functions for gestures that provided support for both the Interface Model and the Lexical Facilitation Model. More broadly, these results are compatible with an account that allows for an interaction between language and gesture systems at multiple levels, from conceptual planning down to more concrete operations such as lexical retrieval and phonological encoding.

Finally, we also investigated the use of gestures as social cues. Two findings were of note: Several participants produced significantly or marginally more gestures as social cues than the control group (Table 3), and there was a general trade-off between the use of gestures as informative cues (i.e., to convey semantic information) and as social cues. These two findings suggest that social gestures are commonly used by PWA and may contain important information about the state of the gesture system or the individual's communication strategy. For example, the trade-off between informative and social gestures might indicate that the individual has trouble retrieving the informative gesture, or it might indicate that s/he is adopting the strategy to use gestures in order to hold the conversational ground, as opposed to convey information. While the current task naturally elicited a rich set of co-speech gestures, a more thorough investigation of the role of gestures as social cues requires tasks that include active conversational partners.

Implications for aphasia therapy

As discussed in the Introduction, there are two capacities in which gesturing could potentially help PWA communicate. They can either compensate for absent speech ("compensation") or help the speaker retrieve the necessary words ("restoration"; Rose, 2006). Several studies have reported positive outcomes for compensation therapy with gestures (see Rose, 2006 for a summary). However, these studies vary substantially in several critical dimensions such as aphasia type, number of participants, type and duration of training, presence of absence of a control group, and the dependent measures used to assess improvement. Our results provide strong evidence that at least in PWA with good comprehension abilities, the compensation method has a high likelihood of success since such individuals readily use gestures to compensate for linguistic difficulties. For example, therapy can encourage PWA to routinely engage in producing iconic gestures when speaking. This strategy should help the individual to quickly switch to manual gesturing when encountered with a word retrieval difficulty in order to maintain the flow of information. In addition, encouraging the use of iconic gestures may benefit the PWA who predominantly use gestures as social cues. While social cueing is helpful for holding the conversational ground, it is not conducive to conveying the intended message. Thus, the switch may increase the informational content of communication in such individuals.

More contentious is the restorative function of gestures in restoring language. The original report of improved speech with gesture therapy was provided by Skelly, Schinsky, Smith, and Fust (1974) who trained PWA with new gestural symbols paired with words. Later case studies of individuals trained with pure gesture therapy, naming therapy, and combined gesture-naming therapy, however, did not find additional benefits for including gestures in naming therapy (Boo & Rose, 2011; Rose & Douglas, 2008; Rose et al., 2002). A recent review of 23 group studies (mostly single case designs) concluded that gesture therapy alone did not have a significant impact on oral production, but combined gesture-language therapy was successful in over half of the studied population, although it is still disputed whether gains from such therapies are significantly larger than language therapy alone (Rose et al., 2013).

Our results suggest a positive correlation between producing iconic gestures and successfully retrieving a word. This correlation could suggest that strengthening the relationship between gestures and words may facilitate word retrieval. However, this view would also predict no special advantage for gesture therapy per se, as the advantage is in strengthening the link between gestures and lexical items. Such advantage is only expected (a) when the speaker has preserved conceptual representations leading to a natural production of gestures, and (b) when the speaker produce gestures at the time of attempting lexical retrieval, so that gesture can act as a multi-modal cue. The existing literature suggests that these two conditions were often not met in studies that evaluated the efficacy of combined gesture-language therapy.

Conclusion

To summarize, using a relatively homogeneous group of PWA with good comprehension and various degrees of production difficulty, we showed that the gesture system can remain functional in spite of damage to the language production system, and that gestures can be used by such individuals to both compensate for impaired speech and to facilitate word production. This subgroup of PWA shows the greatest promise in benefitting from gesture-based therapeutic approaches. Even some simple strategies such as shifting their gestures from social cueing towards more meaning-laden gestures may be hugely beneficial in increasing the informational value of communication in this population.

Acknowledgement

We would like to thank the staff and patients at the Tabasom Stroke Rehabilitation center for helping us in the recruiting process. We also thank everyone in the Language and Cognition Lab at Koç University for their helpful comments on this research, and Aylin Küntay for her constructive feedback on the findings.

References

Ahlsen, E. (1991). Body communication as compensation for speech in a Wernicke's aphasic A longitudinal study. *Journal of Communication Disorders, 24*(1), 1-12.

Akhavan, N., Goksun, T., & Nozari, N. (2016). Disfluency production in speech and gesture. In A. Papafragou, D. Grodner, D. Mirman, & J.C. Trueswell (Eds.), *Proceedings of the 38th Annual Conference of the Cognitive Science Society* (pp. 716-721). Austin, TX: Cognitive Science Society.

Akhavan, N., Nozari, N., & Göksun, T. (2017). Expression of motion events in Farsi. *Language, Cognition and Neuroscience,* doi: 10.1080/23273798.2016.1276607

Ali, M., Lyden, P., & Brady, M. (2015). Aphasia and dysarthria in acute stroke: recovery and functional outcome. *International Journal of Stroke*, *10*(3), 400-406.

Alibali, M. W., Kita, S., & Young, A. J. (2000). Gesture and the process of speech production: We think, therefore we gesture. *Language and Cognitive Processes, 15*(6), 593-613.

Attard, M. C., Rose, M. L., & Lanyon, L. (2013). The comparative effects of Multi-Modality Aphasia Therapy and Constraint-Induced Aphasia Therapy-Plus for severe chronic Broca's aphasia: An in-depth pilot study. *Aphasiology*, *27*(1), 80-111.

Bartolo, A., Cubelli, R., Della Sala, S., & Drei, S. (2003). Pantomimes are special gestures which rely on working memory. *Brain and Cognition*, *53*(3), 483-494.

Beattie, G. & Coughlan J. (1999). An experimental investigation of the role of iconic gestures in lexical access using the tip-of-the-tongue phenomenon. *British Journal of Psychology*, *90*, 1, 35-56.

Behrmann, M., & Penn, C. (1984). Non-verbal communication of aphasic patients. *British Journal of Disorders of Communication*, *19*(2): 155-168.

Beland, R., & Ska, B. (1992). Interaction between verbal and gestural language in progressive aphasia: A longitudinal case study. *Brain and Language*, *43*(3): 355-385.

Boo, M., & Rose, M. L. (2011). The efficacy of repetition, semantic, and gesture treatments for verb retrieval and use in Broca's aphasia. *Aphasiology*, *25*(2), 154-175.

Borod, J. C., Fitzpatrick, P. M., Helm-Estabrooks, N., & Goodglass, H. (1989). The relationship between limb apraxia and the spontaneous use of communicative gesture in aphasia. *Brain and Cognition*, *10*(1), 121-131.

Butterworth, B. (1989). Lexical access in speech production. In *Lexical representation and process* (pp. 108-135). MIT Press.

Butterworth, B. (1992). Disorders of phonological encoding. *Cognition*, *42*(1), 261-286.

Butterworth, B., & Beattie, G. (1978). Gesture and silence as indicators of planning speech. In R. Campbell & P. Smith (Eds.), *Recent Advances in the Psychology of Language* (pp. 347–360). New York: Plenum.

Brugman, H., Russel, A., & Nijmegen, X. (2004). Annotating Multi-media/Multi-modal Resources with ELAN. In *LREC*.

Cicone, M., Wapner, W., Foldi, N., Zurif, E., & Gardner, H. (1979). The relation between gesture and language in aphasic communication. *Brain and Language, 8*(3), 324-349.

Crawford, J. R., & Garthwaite, P. H. (2007). Using regression equations built from summary data in the neuropsychological assessment of the individual case. *Neuropsychology*, *21*(5), 611.

Cocks, N., Dipper, L., Middleton, R., & Morgan, G. (2015). What can iconic gestures tell us about the language system? A case of conduction aphasia. *International Journal of Language & Communication Disorders*, 1-14.

Crosson, B., Fabrizio, K. S., Singletary, F., Cato, M. A., Wierenga, C. E., Parkinson, R. B., ... & Leon, S. (2007). Treatment of naming in nonfluent aphasia through manipulation of intention and attention: A phase 1 comparison of two novel treatments. *Journal of the International Neuropsychological Society*, *13*(04), 582-594.

de Ruiter, J. P. (2000). The production of gesture and speech. *Language and Gesture*, *2*, 284.

de Ruiter, J. P. (2006). Can gesticulation help aphasic people speak, or rather, communicate?. *Advances in Speech Language Pathology*, *8*(2), 124-127.

de Ruiter, J. P., & de Beer, C. (2013). A critical evaluation of models of gesture and speech production for understanding gesture in aphasia. *Aphasiology*, *27*(9), 1015-1030.

Dipper, L., Cocks, N., Rowe, M., & Morgan, G. (2011). What can co-speech gestures in aphasia tell us about the relationship between language and gesture?: A single case study of a participant with conduction aphasia. *Gesture*, *11*(2), 123-147.

Dipper, L., Pritchard, M., Morgan, G., & Cocks, N. (2015). The language–gesture connection: Evidence from aphasia. *Clinical Linguistics & Phonetics*, *29*(8-10), 748-763.

Duinmeijer, I., de Jong, J., & Scheper, A. (2012). Narrative abilities, memory and attention in children with a specific language impairment. *International Journal of Language & Communication Disorders*, *47*(5), 542-555.

Feyereisen, P. (1983). Manual activity during speaking in aphasic subjects. *International Journal of Psychology*, *18*, 545–556.

Feyereisen, P., Barter, D., Goossens, M., & Clerebaut, N. (1988). Gestures and speech in referential communication by aphasic subjects: channel use and efficiency. *Aphasiology*, *2*(1), 21-31.

Frick-Horbury, D., & Guttentag, R. E. (1998). The effects of restricting hand gesture production on lexical retrieval and free recall. *The American Journal of Psychology*, *111*(1), 43.

Glosser, G., Wiener, M., & Kaplan, E. (1986). Communicative gestures in aphasia. *Brain and Language*, *27*(2), 345-359.

Goldin-Meadow, S. (2003). *Hearing gesture: How our hands help us think*. Cambridge, MA: Belknap Press of Harvard University Press.

Goldin-Meadow, S., & Alibali, M. W. (2013). Gesture's role in speaking, learning, and creating language. *Annual Review of Psychology*, *64*, 257.

Goldin-Meadow, S., So, W. C., Özyürek, A., & Mylander, C. (2008). The natural order of events: How speakers of different languages represent events nonverbally. *Proceedings of the National Academy of Sciences*, *105(27)*, 9163 - 9168.

Goodwin, C. (1995). Co-constructing meaning in conversations with an aphasic man. *Research in Language and Social Interaction*, *28*(3), 233–260.

Goodwin, C. (2000). Gesture, aphasia, and interaction. In D. McNeill (Ed.), *Language and gesture* (pp. 84–98). Cambridge: Cambridge University Press.

Göksun, T., Lehet, M., Malykhina, K., & Chatterjee, A. (2013). Naming and gesturing spatial relations: Evidence from focal brain-injured individuals. *Neuropsychologia*, *51*(8), 1518-1527.

Göksun, T., Lehet, M., Malykhina, K., & Chatterjee, A. (2015). Spontaneous gesture and spatial language: Evidence from focal brain injury. *Brain and Language*, *150*, 1-13.

Hadar, U., & Butterworth, B. (1997). Iconic gestures, imagery, and word retrieval in speech. *Semiotica*, *115*(1-2), 147-172.

Hadar, U., Burstein, A., Krauss, R., & Soroker, N. (1998). Ideational gestures and speech in brain-damaged subjects. *Language and Cognitive Processes*, *13*(1), 59-76.

Herrmann, M., Reichle, T., Lucius-Hoene, G., Wallesch, C.-W., & Johannsen-Horbach, H. (1988). Nonverbal communication as a compensative strategy for severely nonfluent aphasics-A quantitative approach. *Brain and Language*, *33*(1), 41–54.

Hilari, K., & Byng, S. (2009). Health-related quality of life in people with severe aphasia. *International Journal of Language & Communication Disorders*, *44*(2), 193-205.

Hogrefe, K., Ziegler, W., Weidinger, N., & Goldenberg, G. (2012). Non-verbal communication in severe aphasia: Influence of aphasia, apraxia, or semantic processing? *Cortex*, *48*, 952–962.

Hogrefe, K., Ziegler, W., Wiesmayer, S., Weidinger, N., & Goldenberg, G. (2013). The actual and potential use of gestures for communication in aphasia. *Aphasiology*, *27*(9), 1070-1089.

Hostetter, A. B., Alibali, M. W., & Kita, S. (2007). Does sitting on your hands make you bite your tongue? The effects of gesture prohibition on speech during motor descriptions. In *Proceedings of the 29th annual meeting of the Cognitive Science Society* (pp. 1097-1102). Mawhah, NJ: Erlbaum.

Karaduman, A. N., Çatak, E. N., Bahtiyar. S., Göksun, T., (2015). *The role of gestures in describing motion in English and Turkish*. Poster presented at the International Conference on Psychological Science, Amsterdam, Netherlands.

Kemmerer, D., Chandrasekaran, B., & Tranel, D. (2007). A case of impaired verbalization but preserved gesticulation of motion events. *Cognitive Neuropsychology*, *24*(1), 70-114.

Kendon, A. (2000). Language and gesture: Unity or duality. *Language and Gesture*, (2).

Kong, A. P. H., Law, S. P., Wat, W. K. C., & Lai, C. (2015). Co-verbal gestures among speakers with aphasia: Influence of aphasia severity, linguistic and semantic skills, and hemiplegia on gesture employment in oral discourse. *Journal of Communication Disorders*, *56*, 88-102.

Kita, S. (2000). How representational gestures help speaking. In D. McNeill (Ed.), *Language and gesture* (pp. 162-185). Cambridge: Cambridge University Press.

Kita, S., & Özyürek, A. (2003). What does cross-linguistic variation in semantic coordination of speech and gesture reveal?: Evidence for an interface representation of spatial thinking and speaking. *Journal of Memory and Language*, *48*(1), 16-32.

Krauss, R. M., Chen, Y., & Gottesman, R. F. (2000). Lexical gestures and lexical access: A process model. In D. McNeill (Ed.), *Language and Gesture* (pp. 261-283). Cambridge: Cambridge University Press.

Lanyon, L., & Rose, M. L. (2009). Do the hands have it? The facilitation effects of arm and hand gesture on word retrieval in aphasia. *Aphasiology*, *23*, 809–822.

Lausberg, H., Davis, M., & Rothenhäusler, A. (2000). Hemispheric specialization in spontaneous gesticulation in a patient with callosal disconnection. *Neuropsychologia*, *38*(12), 1654-1663.

Lausberg, H., Zaidel, E., Cruz, R. F., & Ptito, A. (2007). Speech-independent production of communicative gestures: Evidence from patients with complete callosal disconnection. *Neuropsychologia*, *45*(13), 3092-3104.

Leiguarda, R. C., & Marsden, C. D. (2000). Limb apraxias. *Brain*, *123*(5), 860-879.

Le May, A., David, R., & Thomas, A. P. (1988). The use of spontaneous gesture by aphasic patients. *Aphasiology*, 2(2), 137–145.

Levelt, W. J. M. (1989). *Speaking: From intention to articulation*. Cambridge, MA: MIT Press.

Marshall, J., Atkinson, J., Smulovitch, E., Thacker, A., & Woll, B. (2004). Aphasia in a user of British Sign Language: Dissociation between sign and gesture. *Cognitive Neuropsychology*, *21*(5), 537-554.

Marshall, J., Best, W., Cocks, N., Cruice, M., Pring, T., Bulcock, G., ... & Caute, A. (2012). Gesture and naming therapy for people with severe aphasia: A group study. *Journal of Speech, Language, and Hearing Research*, *55*(3), 726-738.

Mayberry, R. I., & Jaques, J. (2000). Gesture production during stuttered speech: Insights into the nature of gesture-speech integration. In D. McNeill (Ed.), *Language and gesture* (pp. 199–214). New York: Cambridge University Press.

McNeill, D. (1992). *Hand and Mind: What Gestures Reveal about Thought*. Chicago: University of Chicago Press.

McNeill, D. (2005). *Gesture and Thought*. Chicago: University of Chicago Press.

McNeill, D., & Duncan, S. D. (2000). Growth points in thinking-for-speaking. In D. McNeill (Ed.), *Language and gesture* (pp. 141-161). Cambridge: Cambridge University Press.

Mol, L., Krahmer, E., & van de Sandt-Koenderman, M. (2013). Gesturing by speakers with aphasia: How does it compare? *Journal of Speech*, *Language and Hearing Research*, *56*(4), 1224–1236.

Morrel-Samuels, P., & Krauss, R. M. (1992). Word familiarity predicts temporal asynchrony of hand gestures and speech. *Journal of Experimental Psychology, 18*(3), 615–622.

Nilipour, R. (2005). Apraxia Test. Unpublished manuscript.

Nilipour, R., Pourshahbaz, A., & Ghoreyshi, Z. S. (2014). Reliability and validity of bedside version of Persian WAB (P-WAB-1). *Basic and Clinical Neuroscience*, *5*(4), 253.

Nozari, N., Arnold, J. E., & Thompson-Schill, S. L. (2014). The effects of anodal stimulation of the left prefrontal cortex on sentence production. *Brain stimulation*, *7*(6), 784-792.

Nozari, N., & Dell, G. S. (2013). How damaged brains repeat words: A computational approach. *Brain and Language*, *126*(3), 327-337.

Nozari, N., & Faroqi-Shah, Y. (2017). Investigating the origin of nonfluency in aphasia: A path modeling approach to neuropsychology. *Cortex*, *95*, 119-135.

Nozari, N., Göksun, T., Thompson-Schill, S. L., & Chatterjee, A. (2015). Phonological similarity affects production of gestures, even in the absence of overt speech. *Frontiers in Psychology*, *6*.

Nozari, N., & Novick, J. (in press). Monitoring and control in language production. *Current Directions in Psychological Science.* doi: 10. 1177/0963721417702419

Nozari, N., & Thompson-Schill, S.L. (2015). Left Ventrolateral Prefrontal Cortex in Processing of Words and Sentences. In G. Hickok & S.L. Small (Eds.), *The Neurobiology of Language* (pp. 569-588). Waltham, MA: Academic Press.

Pedelty, L. L. (1987). *Gesture in aphasia* (Doctoral dissertation, University of Chicago, Department of Behavioral Sciences, Committee on Cognition and Communication).

Pritchard, M., Dipper, L., Morgan, G., & Cocks, N. (2015). Language and iconic gesture use in procedural discourse by speakers with aphasia. *Aphasiology*, *29*(7), 826-844.

Pouw, W. T., De Nooijer, J. A., Van Gog, T., Zwaan, R. A., & Paas, F. (2014). Toward a more embedded/extended perspective on the cognitive function of gestures. *Frontiers in Psychology*, *5*.

Raymer, A., Singletary, F., Rodriguez, A., Ciampitti, M., Heilman, K., & Rhoti, L. (2006). Effects of gesture-verbal treatment for noun and verb retrieval in aphasia. *Journal of International Neuropsychological Society, 12*, 867–882.

Rousseaux, M., Daveluy, W., & Kozlowski, O. (2010). Communication in conversation in stroke patients. *Journal of Neurology*, *257*(7), 1099-1107.

Rose, M. L. (2006). The utility of arm and hand gestures in the treatment of aphasia. *Advances in Speech Language Pathology*, *8*(2), 92-109.

Rose, M., & Douglas, J. (2001). The differential facilitatory effects of gesture and visualisation processes on object naming in aphasia. *Aphasiology*, *15*(10-11), 977-990.

Rose, M., & Douglas, J. (2008). Treating semantic deficits in aphasia with gesture and verbal methods. *Aphasiology*, *22*(1), 1-22.

Rose, M., & Douglas, J. (2003). Limb apraxia, pantomime, and lexical gesture in aphasic speakers: Preliminary findings. *Aphasiology, 17*(5), 453–464.

Rose, M., Douglas, J., & Matyas, T. (2002). The comparative effectiveness of gesture and verbal treatments for a specific phonologic naming impairment. *Aphasiology*, *16*(10-11), 1001-1030.

Rose, M. L., Raymer, A. M., Lanyon, L. E., & Attard, M. C. (2013). A systematic review of gesture treatments for post-stroke aphasia. *Aphasiology*, *27*(9), 1090-1127.

Sekine, K., & Rose, M. L. (2013). The relationship of aphasia type and gesture production in people with aphasia. *American Journal of Speech-Language Pathology*, *22*(4), 662-672.

Sekine, K., Rose, M. L., Foster, A. M., Attard, M. C., & Lanyon, L. E. (2013). Gesture production patterns in aphasic discourse: In-depth description and preliminary predictions. *Aphasiology*, *27*(9), 1031-1049.

Skelly, M., Schinsky, L., Smith, R. W., & Fust, R. S. (1974). American Indian sign (Amerind) as a facilitator of verbalization for the oral verbal apraxic. *Journal of Speech and Hearing Disorders*, *39*(4), 445-456.

Wilkinson, R., Beeke, S., & Maxim, J. (2010). Formulating actions and events with limited linguistic resources: Enactment and iconicity in agrammatic aphasic talk. *Research on Language and Social Interaction*,*43*(1), 57-84.

Appendix A

The list of actions performed in the 20 video clips in the current study. Note that participants had flexibility in how they described the event. All semantically plausible sentences were accepted as the correct response.

English description	Farsi description
1. Tiptoe in front of the tree	جلوی درخت نوک پا راه رفتن
2. Crawl into phone booth	به داخل باجه تلفن خزیدن
3. Walk between the poles	بین ستونها راه رفتن
4. Skip into the phone booth	به داخل باجه تلفن جستن
5. Skip between the poles	بین ستون ها جست و خیز کردن
6. Hop around the tree	دور درخت لی لی کردن
7. Crawl in front of the tree	جلوی درخت خزیدن
8. Jump jack out of the building	از ساختمان پروانه زنان خارج شدن
9. Hop to the door	به سمت در لی لی کردن
10. Run in front of tree	جلوی درخت دویدن
11. Jump over the bench	از روی نیمکت پریدن
12. Step over the bench	روی نیمکت قدم گذاشتن
13. Crawl under the sign	زیرتابلو خزیدن
14. Hop across the street	لی لی کنان از خیابان رد شدن
15. Hop out of the building	لی لی کنان از ساختمان خارج شدن
16. Jumping jack between the poles	بین ستونها پروانه زدن
17. Skip around the tree	دوردرخت جست و خیز کردن
18. Twirl around the tree	دورخود زنان دور درخت چرخیدن
19. Hop in front of the tree	جلوی درخت لی لی کردن

20. March in front of the tree جلوی درخت راه پیمایی کردن

Appendix B

An example of the dual speech-gesture coding for the target sentence: “She hopped out of the building.”. The highlighted cells mark utterances/gestures that were coded as informative. See text for explanations on how “informative” was defined.

<table>
<tr><td>Speech</td><td>[the]* girl</td><td>u-u-um</td><td>[the]* house</td><td colspan="2">what is… uhhh… um</td><td>[experimenter encourages the participant to continue]</td><td>hopping</td><td colspan="3">[silence]</td><td>[the]* street</td><td>Oh god…</td></tr>
<tr><td>Speech duration</td><td>1760</td><td>1050</td><td>640</td><td colspan="2">7230</td><td>[excluded]</td><td>2160</td><td colspan="3">3200</td><td>1610</td><td>1930</td></tr>
<tr><td>Gesture</td><td colspan="3">Draws the outlines of a house in the air with index finger</td><td>Makes circular motions with hand</td><td>Pushes hand away from self to mark “going out/away”</td><td colspan="3">Gestures hopping by moving hand up and down</td><td>Stops and repeats the hopping gesture</td><td>[no gesture]</td><td>Random flicks of hand</td><td>[no gesture]</td></tr>
<tr><td>Gesture duration</td><td colspan="3">3450</td><td>3640</td><td>3575</td><td colspan="3">4850</td><td>1220</td><td>[excluded]</td><td>1610</td><td>[excluded]</td></tr>
</table>

* There is no definite article in Farsi, so the bare noun may imply isolated noun production or implicit noun phrase production.

The shaded cells are coded as “informative”. The non-shaded cells are coded as “non-informative”, and include irrelevant utterances and gestures, as well as repetitions, fillers and silent pauses. If the experimenter interjected (occasionally necessary to encourage the participant to continue), the duration of the interjection was excluded. Because gesturing is not mandatory, the intervals when the participant made no gestures with the hands were also excluded from the analyses. In the example above, the measure of informativeness for speech is calculated as (1760+640+2160+1610)/(1760+1050+640+7230+2160+3200+1610+1930)=0.32 (32%). The measure of informativeness of gesture is (3450+3575+4850)/(3450+3640+3575+4850+1220+1610)=0.64 (64%).