**Differential roles of gestures on spatial language in neurotypical elderly adults and
individuals with focal brain injury**

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Abstract

Gestures can serve *communicative* functions by supplementing spoken expression or *restorative* functions by facilitating speech production. Speakers with speech deficits use gestures to compensate for their speech impairments. In this study, we examined gestures used by speakers with and without speech impairments and how spatial language changed when gestures were restrained. Six left-hemisphere damaged patients with speech deficits and 20 neurotypical control participants described motion events in 3 different conditions (spontaneous gesture, only speech, and only gesture). In addition to group analyses, we ran single-case analyses for each patient. Our results showed that patients used more gestures than control participants. Patients used gestures for both communicative and restorative functions whereas controls only produced gestures for communication. Single-case analyses revealed different patterns of production among patients. Overall, gesture production is multifunctional and gestures serve different functions for different populations as well as different functions within a population.

Keywords: gesture, brain injury, spatial language, speech deficits, case analysis

1. Introduction

People use spontaneous hand gestures as they speak. Iconic gestures that represent the meaning of an object or action are commonly used when communicating and thinking about spatial information because they are particularly good at depicting the visual and motor aspects of spatial events (e.g., Alibali, 2005; Beattie & Shovelton, 2002). Additionally, gestures provide a natural alternative to verbal communication, especially for people who have deficits such as aphasia (e.g., Akhavan, Göksun, & Nozari, 2018; Akbıyık, Karaduman, Göksun, & Chatterjee, 2018; Göksun, Lehet, Malykhina, & Chatterjee, 2013, 2015; Pritchard, Dipper, Morgan, & Cocks, 2015; Sekine & Rose, 2013). In this study, we focus on the functional roles of iconic gestures during spoken expression of spatial information in people with and without speech impairments.

Gesture and speech interact with one another during language production and comprehension (e.g., Kelly, Özyürek, & Maris, 2010; Kita, 2000; Kita & Özyürek, 2003). Despite this interactive nature, many theories assert that they arise from two different and interrelated representational systems (de Ruiter, 2006; Kita, 2000; Kita & Özyürek, 2003; Krauss, Chen, & Gottesman, 2000; Melinger & Levelt, 2004). This notion entails that gestures can function independently of the speech production system. Neuropsychological evidence on people with speech impairments, such as aphasia, has established that gestures compensate for underspecification in the spoken channel and can function independently of impaired speech (e.g., Akhavan et al., 2018; Akbıyık et al., 2018; de Beer et al., 2017; Göksun et al., 2013, 2015; Hogrefe, Ziegler, Weidinger, & Goldenberg, 2012, 2013a; Hogrefe, Ziegler, Wiesmayer, Weidinger, & Goldenberg,

2013b; Kemmerer, Chandrasekaran, & Tranel, 2007; Kong, Law, Wat, & Lai, 2015; Preisig et al., 2018; Sekine & Rose, 2013; Sekine, Rose, Foster, Attard, & Lanyon, 2013, but cf. Cicone, Wagner, Foldi, Zurif, & Gardner, 1979; Glosser et al., 1986). With impaired speech system, as long as conceptual knowledge and the communicative intentions are intact, the message might be split between two communication modalities (de Ruiter & de Beer, 2013). That is, communication may shift to emphasize gestures in cases of speech deficits (de Ruiter, 2006).

Supporting this view, studies report that people with aphasia (PWA) use gestures at a higher frequency than healthy adults (e.g., Feyereisen, 1983; LeMay, David, & Thomas, 1988). Although different patholinguistic profiles yielded differential patterns of gesture use by PWA (e.g., Hadar, Wenkert-Olenik, Krauss, & Soroker, 1998; Kronke, Kraft, Regenbrecht, & Obrig, 2013; Preisig et al., 2018; Rose, 2006), more severe forms of aphasia were generally associated with greater use of spontaneous co-speech gestures (Carlomagno & Cristilli, 2006; Kong, Law & Chak, 2017). However, many of these studies focused on general language use and investigated the integrity of gestures in speech by employing semi-structured interviews, free conversations, and narrating stories (e.g., Dipper, Cocks, Rowe, & Morgan, 2011; Dipper, Pritchard, Morgan, & Cocks, 2015; Lausberg, Davis, & Rothenhäuser, 2000; Rose & Douglas, 2003). Gestures are particularly helpful in communicating and thinking about spatial information (e.g., Alibali, 2005; Beattie & Shovelton, 2002). Gestures stem from visual-spatial mental imagery, and as a result, healthy adults use gestures more frequently when talking about visual-spatial information compared to non-spatial (i.e., abstract) information (Alibali, Heath, & Myers, 2001; Hadar & Butterworth, 1997; Hostetter & Alibali, 2008, 2018;

Kita & Özyürek, 2003; Krauss et al., 2000; Lavergne & Kimura, 1987; Rauscher, Krauss, & Chen, 1996). In this regard, space provides a useful context to investigate the role and the integrity of gestures in speech. To this end, the current study investigated the functions of gestures during spatial speech (i.e., descriptions of motion events) in focal brain-injured individuals who have speech impairments and neurotypical elderly adults.

Motion event descriptions are useful in assessing spatial language, including spoken and gestural expressions (e.g., Akhavan, Göksun, Nozari, 2016; Akhavan et al., 2017, 2018; Göksun et al., 2015; Karaduman, Çatak, Bahtiyar, & Göksun, 2015; Kemmerer et al., 2007; Kita & Özyürek, 2003; Kita et al., 2007). A motion event is a dynamic spatial event consisting of several components that are encoded across languages. The *path* and *manner* of motion are two of these components: path refers to the trajectory of the motion and manner refers to the way the action is performed (Talmy, 2000). For example, in the sentence “The girl is walking across the street,” walking describes the manner and across describes the path of the motion. In English, manner of motion is encoded primarily in the main verb of a sentence whereas path of motion is encoded in the preposition and can be omitted in some cases.

Neuropsychological evidence has established that individuals with speech problems use iconic co-speech gestures to compensate for spatial speech deficits when describing motion events (e.g., Akhavan et al., 2018; Göksun et al., 2013, 2015; Kemmerer et al., 2007). In a single case study of a patient with anomia (i.e. word-finding difficulty), Kemmerer et al. (2007) found that the patient replaced the intended verb referring to the manner of motion with a semantically light verb in speech (e.g., using “go” when describing the “roll down” event) and used manner-gestures to compensate for

the deficits present in the concurrent speech. Moreover, Göksun and colleagues (2013, 2015) investigated the spoken and gestural expression of locative relations (i.e., prepositions, such as “The book is on the bowl”) and motion events (manner and path) in individuals with left (LHD) and right (RHD) hemisphere focal brain damage. Although patients with LHD, as a group, were impaired in naming locative relations and the motion event components compared to neurotypical controls, they were not necessarily impaired at the individual level. Related to our study, Göksun et al. (2015) asked focal brain-injured patients and elderly controls to describe motion events (*e.g., running across*) depicted in brief videos. Patients with damage to the left anterior superior temporal gyrus (aSTG) were impaired in naming the path of the motion (*e.g., across*, encoded in the preposition in English), whereas damage to the left caudate and the adjacent white matter were impaired in naming the manner of the motion (*e.g., running*, encoded in the main verb in English). Moreover, lesions in the left aSTG correlated with higher use of path gestures. This observation suggests that the expressions of manner and path can be differentially impaired and people who have speech problems can selectively use gestures to compensate for some types of motion information. Although Göksun et al. (2015) study is important in showing the differential impairment of and gestural compensation for different motion event components (manner – path) in focal brain-injured individuals, the function(s) gesture serve during spatial expressions was not tested directly.

What function(s) do gestures serve during speech production? Gestures have communicative and speaker-internal functions. On one view, gestures’ main function is *communicative (i.e., compensatory, to communicate information)*. Speakers use gestures to complement and/or supplement spoken expressions (*The Tradeoff Hypothesis*, de

Ruiter, 2006; Melinger & Levelt, 2004). Speakers split up the to-be-communicated message into two channels of expression. For example, healthy speakers producing iconic gestures for spatial relations tend to omit the required spatial information in their speech compared to speakers who do not gesture (Melinger & Levelt, 2004). Also, PWA used gestures to express additional (i.e., non-redundant) information that was not present in their speech (Akhavan et al., 2018; Kemmerer et al., 2007). Another view suggests that gestures are not communicatively intended. Rather, they have speaker-internal functions. Gestures' main function is *facilitative* (i.e., *restorative*), helping speech production either by organizing rich visual-spatial information into the linear format required for speech (Kita, 2000; Kita & Özyürek, 2003) or by facilitating lexical retrieval (Krauss et al., 2000). One prominent theory (*The Lexical Access Hypothesis*, Krauss et al., 2000) suggests that gestures help speakers to produce speech by facilitating lexical access with cross-modal priming (Hadar & Butterworth, 1997). In line with this, many studies have reported that speakers use more gestures when producing more elusive words or in spontaneous speech compared to rehearsed speech (Chawla & Krauss, 1994; Hostetter & Hopkins, 2002; Morrel-Samuels & Krauss, 1992). Gestures may not only be used to compensate for impaired speech. PWA used gestures to cue speech production (Lanyon & Rose, 2009). Indeed, treatment plans use gestures to improve word retrieval in PWA (Attard, Rose, & Lanyon, 2013; Crosson et al., 2007; Raymer et al., 2006). Thus, gestures might either serve communicative functions by compensating for speech deficits (i.e., conveying additional information along with speech semantics) or restorative function by facilitating word retrieval. Importantly, these two functions are not mutually exclusive,

and gestures might serve multiple functions within a population or differential functions across different populations.

A recent study by Akhavan and colleagues (2018) examined the integrity and the functions of gestures during spontaneous verbal expression of motion events in Farsi-speaking PWA using the same experimental stimuli used in Göksun et al. (2015). First, they found that although PWA's speech was less informative (i.e., the accurate use of words describing any part of the target motion event), their gesture informativeness was comparable to the elderly controls. PWA used gestures for communicative and restorative functions and as social cues (i.e., communicative intent without conveying the semantics of the event to be described). In particular, in the absence of a spoken message, they used many compensatory (i.e., gestures expressing non-redundant information) gestures. There was also a negative correlation between PWA's speech informativeness and the frequency of compensatory gestures; the more impaired the participant's speech, the more they used compensatory gestures. Second, the successful resolution of word-retrieval difficulty was significantly higher when PWA used iconic gestures compared to no gestures or other types of gestures.

Although, Akhavan and colleagues (2018) suggested that gestures serve multiple functions in the presence of speech problems, it is important to note that participants were only tested in a speech condition and only co-speech spontaneous gestures were assessed. From these data it is hard to draw direct evidence for gesture-speech integrity during communication of spatial information. Indeed, one way to understand speech-gesture relations and the functions of gestures is to examine what would happen to gestural or spoken expression in the absence of one or the other. Examining the spontaneous gestural

expressions of people with speech problems (i.e., in the absence of speech) provides one probe to understand this relationship. Yet, this investigation should be complemented with an inquiry of what would happen to spoken expressions in the absence of gesture (e.g., when gesturing is hard or restricted) compared to spontaneous speech (e.g., Graham & Heywood, 1975; Hostetter, Alibali, & Kita, 2007; Özer et al., 2017).

1.1. The Current Study

Studies reviewed earlier suggested that (1) gestures are especially effective in thinking and communicating spatial information (see Alibali, 2005 for review) and motion event descriptions are a useful case of assessing spatial language (both gestural and spoken expressions; Akhavan et al., 2017, 2018; Göksun et al., 2015; Kita & Özyürek, 2003; Kita et al., 2007), (2) the expression of different motion event components (i.e., manner and path) can be selectively impaired and compensated by gestures in focal brain-injured patients (Göksun et al., 2015), and (3) PWA who had severe language impairment used gestures to compensate for speech deficits (i.e., to communicate information) and to facilitate lexical retrieval in spontaneous spatial speech (Akhavan et al., 2018).

Previous research has examined the integrity and the functions of gestures in spontaneous spatial speech of individuals who had speech problems. Yet, to draw a direct, causal, and complementary evidence regarding the integrity and the function(s) of gestures, the inquiry of what happens to gestural expressions in the absence of speech (i.e., in individuals with speech problems) should be complemented with an inquiry of what happens to spoken expressions in the absence of gestures (i.e., when gestures are restricted; Graham & Heywood, 1975; Hostetter et al., 2007; Özer et al., 2017). The current

study attempts to bridge these two lines of inquiry by investigating the gestural and spoken expressions of people with and without speech impairments in spontaneous and gesture-restricted speech. The aim is to systematically investigate speech-gesture integrity and the function(s) of gestures in individuals who have selective impairment in spatial speech.

We selected a subgroup of patients from a larger sample of the left-hemisphere focal brain-injured individuals (LHD) tested in Göksun et al. (2013, 2015). As explained earlier, although LHD individuals, as a group, were impaired in speech compared to neurotypical elderly adults, their overall speech was not always impaired at an individual level and not all the patients were aphasic. From this heterogeneous group of LHD individuals, we selected 6 participants who had selective impairment in spatial speech based on two criteria: (1) significant impairment in naming spatial relations between objects in Göksun et al. (2013) study (e.g., use of prepositions such as “in” or “on”), and motion event components of manner-path in Göksun et al. (2015) study (e.g., “run down”) in spontaneous speech as revealed by single-case statics and, (2) having a left hemisphere lesion in the frontal and/or temporal lobes.

The current study investigated the integrity and the function(s) of gestures during expressions of motion events in speakers with and without speech impairments in spontaneous speech, in gesture-restricted speech, and in gesture-only conditions. We specifically asked (1) whether the frequency and function of gestures differ among speakers with and without speech impairments in spontaneous descriptions of motion events, and (2) how spoken expressions may change when gesture is restricted in these groups. We evaluated verbal and gestural output for two motion event components (i.e.,

path and manner), because the expression of different motion event components can be impaired selectively (Göksun et al., 2015) and each component has different activation patterns in the brain (Wu, Morganti, & Chatterjee, 2008). We examined six individuals who had focal brain injury in the left frontal and/or temporal areas and who had selective impairments in spatial speech (i.e., prepositions and motion verbs). Each patient was analyzed in depth along with group analyses. For individual level analyses, we used the corrected t-tests of case statistics (Crawford & Howell, 1998; Crawford & Garthwaite, 2002, 2005). This method provides two benefits: (1) it tests whether a single performance or a difference between performance on two tasks of a patient is reliably different from a control sample and (2) it provides a point estimate (i.e., one-tailed probability, Crawford & Garthwaite, 2006) of the rarity/abnormality of a patient's score or score difference showing the percentage of the control group that would obtain a score lower than the patient (for details, see Akhavan et al., 2018).

We predicted that, in line with the earlier findings, if gesture and speech arise from two different representational systems, gestures could be intact in the presence of impaired speech. In this case, people with speech problems would use more gestures compared to healthy controls to either compensate for the absence of required information in speech or facilitate speech production by mitigating lexical access problems. We also expected that the expression of the manner and the path of the motion can be selectively impaired among LHD individuals. Although we did not have a clear prediction regarding the specific component, we expected that individuals with speech problems would use more gestures referring to the component in which they were impaired in naming. Regarding the functions of gestures, we predicted that if gestures

mainly serve communicative functions and are used to complement and/or supplement spoken expressions, healthy controls' speech would be more informative in gesture-restriction (i.e., speech only, SO) condition compared to spontaneous speech (SG). Patients, on the other hand, would have comparable speech informativeness in SO and SG conditions due to already impaired language system. Alternatively, if gestures mainly serve restorative functions and are used to facilitate lexical retrieval, the speech informativeness would decline from SG to SO both for healthy controls and patients.

2. Methods

2.1. Participants

Six patients with left hemisphere focal lesions, resulting from stroke were recruited from the Focal Lesion Subject Database at the University of Pennsylvania (Fellows, Stark, Berg & Chatterjee, 2008). These participants were chosen from a larger sample of patients with unilateral brain lesion reported in the previous studies. Göksun and colleagues (2013, 2015) tested 16 participants with left hemisphere focal brain injury (LHD) and 14 age- and education-matched elderly neurotypicals and asked to spontaneously describe spatial relations (e.g., "The book is on the table," Göksun et al., 2013), and motion events (e.g., "The girl is running across," Göksun et al., 2015). From these 16 LHD participants tested in Göksun et al. (2013, 2015), we selected six participants based on three criteria: (1) significantly impaired naming of spatial prepositions (2013) and motion event components of path prepositions and manner verbs (2015) compared to elderly controls as revealed by individual level case analyses and, (2) having a left hemisphere lesion in the frontal and/or temporal lobes.

Participants covered a wide range of abilities in the language production and comprehension subtests of Western Aphasia Battery (WAB; Kertesz, 1982) scores (WAB-AQ of 65.3 – 94.9, $M = 88$, $SD = 11.2$). Patients had mild limb apraxia ($Range = 60 - 90$, $M = 75.5$, $SD = 11.5$) assessed by the Florida Apraxia Screening Task – Revised (FAST; Rothi & Heilman, 2014). Table 1 presents the detailed demographic information, test scores of WAB-AQ, limb apraxia scores, and the Object-Action Naming Battery percentage scores (OANB; Druks, 2000) for six patients. Figure 1 displays the lesion overlap maps of patients. All patients were native English speakers, could use at least one of their hands, and had no history of psychiatric disorders or substance use.

Table 1. Patient demographic and neuropsychological data. F, frontal; T, temporal; P, parietal; O, occipital; BG, basal ganglia; ACA, anterior cerebral artery; PA, pericallosal artery.

Patient	Sex	Age	Education (in years)	Lesion Location	Lesion Size (# of voxels)	Chronicity (in months)	WAB (AQ)	OANB (action) %	OANB (object) %	Limb Apraxia
236	M	65	18	FP	155,982	210	90.8	88	94	86.7
342	F	57	12	OT	42,144	125	93.4	94	93	66.6
360	M	58	12	T BG	38,063	118	65.3	52	28	18
363	M	74	16	F	16,845	117	91.4	96	95	76.7
493	M	68	14	ACA	22,404	101	92.1	98	95	73.3
529	F	66	12	PA F	8969	100	94.9	94	90.1	90

Figure 1. Coverage map indicating the lesion location for all six patients.

Twenty age- and education-matched healthy elderly adults (15 females; $M_{\text{age}} = 62.9$, $SD = 8.2$; $M_{\text{years of education}} = 15$, $SD = 2.5$) participated as a neurotypical control group. All participants were native English speakers, right-handed, and had no history of other neurological disorders, psychiatric disorders or substance use. All participants provided written, informed consent in accordance with the policies of the University of Pennsylvania's Institutional Review Board and received \$15/h for volunteering their time.

2.2. Tasks and Stimuli

2.2.1. Neuropsychological Tasks

Patients were administered the language production and comprehension subtests of Western Aphasia Battery (WAB; Kertesz, 1982) and Object-Action Naming Battery (OANB; Druks, 2000). The OANB contains 50 pictures of actions and 81 pictures of

objects. Patients were also administered the revised short version of Florida Apraxia Screening Task (Rothi & Heilman, 2004). In this task, participants were asked to mime actions either done with a common object (e.g., to show how to use glass to drink water) or that have a shared meaning in a culture (e.g., to show how to salute). There were 30 trials in this battery, and the individual scores show the percentage of trials in which the patient accurately performed the action.

2.2.2. *Experimental Tasks*

The experimental task consisted of thirty-nine 3-4 second dynamic movie clips, depicting different motion events with combinations of 15 different manners (hop, skip, walk, run, cartwheel, crawl, jump, twirl, march, step, climb, slide, roll, balance, and tiptoe) and 15 different paths (in front, under, through, across, downstairs, onto, over, along, upstairs, down, around, to, behind, on, in, up, and into). A woman performed all actions in outdoors (see Figure 2 for sample stimuli).

Figure 2. Sample stimuli from the experimental task. The pictures are still frames from two motion event videos: march around (left side) and run through (right side). The arrows indicate the direction of the movement.

Pretest. The final set of 39 videos was selected from a larger sample of 60 videos based on ratings of familiarity and descriptions of the action (both path and manner) by 20 native English speakers. They first watched each clip and then rated the familiarity of

the clip on a 5-point scale. After rating the familiarity, they described each action. Movie clips with an average of at least 3.5 familiarity rating and 99% naming agreement were used.

2.3. Procedure

All participants were tested individually in the laboratory or in their homes. After 2 practice trials, each participant watched a total of 39 video clips in 3 conditions (13 trials in each condition). After watching the short video clip, the experimenter asked the participants to describe what the woman did in the clip. The video clips were presented on a Mac-Book Air computer and the experimenter proceeded to the next trial when the participant was ready. All participants were asked to describe what the woman did in the video (1) spontaneously, (2) only in speech, and (3) only in gestures. In the *spontaneous gesture condition (SG)*, the experimenter did not mention or encourage gesturing during the task and only instructed the participants to describe what the woman did. In the *speech only condition (SO)*, participants were instructed to describe the video only in speech without using any gestures. In the *gesture only condition (GO)*, they were instructed only to use gestures without speech. The video clips differed in terms of the manner-path combination across these three conditions and the set of 13 trials was counterbalanced across conditions. All participants completed the three conditions in a fixed order. Spontaneous gesture condition was administered first so as not to signal participants on the use of gestures during the experiment. Then, they completed the speech only and gesture only conditions in order. All experimental sessions were videotaped for further coding. The neuropsychological tasks were administered only to patients in a separate session either before or after the experimental task.

2.3.1. Coding

A native English speaker transcribed all speech verbatim for participants' responses to each trial and the first author coded all responses (speech and gesture) manually in ELAN (Version 5.2) software package (Max Planck Institute for Psycholinguistics 2002; Brugman & Russel, 2004).

2.3.1.1. *Speech*. Speech was coded for the SG and SO conditions. First, speech for each trial was coded for the correct use of manner (i.e., how the action was performed, e.g. walk, skip) and path (i.e., the trajectory of the action, e.g. down, around). That is, the accuracy of verb (manner) and preposition (path) was coded. The accurate use of manner verbs and path prepositions with slight phonological error were coded as correct (e.g., saying “kippping” instead of “skipping”) and morphosyntactic factors did not affect the accuracy coding (e.g., “run”, “ran”, “running” and “runs” were all coded as accurate). Then, trials were categorized into four categories depending on the accurate use of manner and/or path in speech: (1) manner only, (2) path only, (3) both manner and path, and (4) none. For example, consider the event of a woman running around a tree. In this motion event, *running* is the manner of the action whereas *around* is the path of the action. In this scenario, the *manner only* response would be “she is running,” whereas the *path only* response would be “she is going around the tree.” Both *manner and path* mentioning would be a description such as “she is running around the tree.” Finally, the descriptions in which neither of the manner or path information was used such as “she is going” would be a *none* trial.

We then calculated the accurate use of manner and path information across all trials. To this end, we summed up the trials in which manner or path was used accurately

and divided it by the total number of trials. For example, we summed up *manner only* trials and both *manner and path* trials and divide by to the total number of trials for each condition (n=13) to compute the accurate use of manner in speech for each participant. This score indexes the percentage of trials in which manner or path was named accurately.

2.3.1.2. Gesture. Gestures were coded for the SG and GO conditions. It is important to note that the gestures produced in the GO condition were mostly like pantomimes. For each trial, we initially decided whether at least one gesture was performed or not. We only coded representational gestures in the form of iconic gestures (i.e., representing objects and events) and deictic gestures (i.e., pointing to an object, a person, or a location). For iconic gestures, we further categorized them into two categories: (1) dynamic and (2) static. *Dynamic iconic gestures* were the ones referring to actions whereas the *static iconic gestures* were the ones referring to objects or entities. We then coded gestures as being *target* (i.e., referring to the actions or objects that are relevant to the target motion event segment in the video) or *non-target*. For example, for the above-mentioned trial in which a woman is running around the tree, the video starts with the woman first walking to the tree to start the target action. In this trial, gestures referring to the manner (i.e., running) and/or path (i.e. around) of the target motion event would be target gestures whereas the ones referring to other actions that were irrelevant to the target action in the video (e.g., initial walking) would be non-target gestures. Although we report the descriptive statistics for the overall gesture use, we only analyzed the target iconic gestures in the current study.

For the purposes of this study, we further classified target iconic gestures into: (1) *manner only* gestures (i.e., depicting the manner of action without a path; e.g., repetitive up and down movement of middle and index fingers to represent the act of running without any circular motion to represent the path of motion, that is around), (2) *path only* gestures (i.e., depicting the trajectory of the action without a manner; e.g., index finger showing upwards doing circular movement to represent the path of the action, that is around), and (3) *conflated* gestures (i.e., depicting manner and path of the motion simultaneously; e.g., repetitive up and down movement of index and middle fingers to represent the manner of running, while simultaneously moving the hand in circular motion to represent the path, that is around). Next, we calculated the percentage of trials in which manner and/or path was gestured, for each participant. For example, we summed up the number of trials in which at least one *manner only* or *conflated* gesture was used and divided it by the number of trials in each condition (n=13) to compute the percentage of trials in which manner information was gestured.

2.3.1.3. Speech-gesture relation. For the SG condition only, we also analyzed how the expression of manner and path information was divided between verbal and gestural channels. For each trial, we coded if manner/path information was expressed (1) *only in speech*, (2) *only in gesture*, (3) *both in speech and gesture*, and (4) *none* (i.e., neither in speech nor in gesture). Related to this categorization, we labeled each target iconic gestures as being *compensatory* (i.e., non-redundant) or *matching* (i.e., redundant) (partially adapted from Kong, Law, Kwan, Lai, & Lam, 2015b). *Compensatory gestures* supplement speech (e.g., drawing a circle with the index finger to represent “around” without expressing the corresponding word in speech). *Matching gestures*, on the other

hand, are redundant gestures produced simultaneously with the corresponding referent in the speech (e.g., doing a gesture to represent “around” while expressing the corresponding referent in speech at the same time). For compensatory gestures, we decided which component (i.e., manner or path) the corresponding gesture compensated. The first categorization is practically similar to the categorization of gestures into matching vs. compensatory. For example, trials in which manner was expressed both in speech and gesture simply refer to the use of matching gestures and the trials in which manner information was only expressed in gesture and not in speech refer to the use of compensatory gestures. However, the percentage of trials does not necessarily give the exact percentage of compensatory vs. matching gestures, because more than one gesture compensating for the same manner or path information can be used within a given trial.

2.3.2. *Reliability*

To establish the reliability of our coding system, a second coder coded the 20% of each participant’s responses to each trial for both speech and gesture (n=234 trials in total, 3 trials from each participant for all conditions). For speech, the agreement between coders was 91% (n=156 speech trials) in assigning manner only, path only, manner + path, and none categories. For gesture, the agreement between coders was 88% (n=156 gesture trials) for gesture identification, 90% for gesture category (static, dynamic, or pointing), and 87% for assigning gestures as referring to manner only, path only, and manner + path. Gestures and speech that were not agreed upon were resolved through discussion and subsequent consensus of the two coders.

3. Results

3.1. Group Level Analyses

3.1.1. Speech Analyses

Figure 3 depicts the averaged distribution of trials for speech categories in neurotypical control participants and LHD patients across the SG and SO conditions.

We first asked how speech accuracy differed across the groups (neurotypical elderly vs. LHD individuals). Using a non-parametric Mann-Whitney U test, we found that the controls were more accurate in naming both manner verbs and path prepositions compared to the LHD group in the SG ($Z = 2.7, p < .05$ and $Z = 3.2, p < .001$, respectively) and in the SO conditions ($Z = 3.8, p < .001$ and $Z = 3.3, p = .001$, respectively; see Figure 4).

Figure 3. Stacked bars showing the averaged distribution of trials for control participants and patients in the SG and SO conditions.

Figure 4. Percentage of trials in which manner and path was expressed accurately in speech across SG and SO conditions for controls and patients.

Second, we compared the accurate naming of different motion event components (manner vs. path) in each condition for each group by using paired samples t-test for the controls and non-parametric Wilcoxon signed rank test for the LHD group. The controls named the manner verbs more accurately compared to the path prepositions both in the SG, $t(19) = 4.07, p = .01$, and in the SO conditions, $t(19) = 2.82, p < .05$ ¹. Like the controls, LHD group also named the manner verb more accurately compared to the path preposition in the SG, $Z = 2.2, p < .05$, and in the SO conditions, $Z = 1.9, p < .05$.

Third, we asked how the accurate use of manner and path differ across the SG and the SO conditions for each group and compared two conditions using paired samples t-test for the controls and non-parametric Wilcoxon signed rank test for the LHD group. The controls named the manner verbs similarly across the SG and the SO conditions, $t(19) = 1.81, p > .05$. Yet, they named the path prepositions more accurately in the SO

¹ We also ran non-parametric tests for the controls. The non-parametric Wilcoxon signed rank tests revealed the same results as the paired samples t-tests. The controls used manner verbs more accurately compared to path prepositions in the SG ($Z = -3.18, p < .05$) and in the SO conditions, $Z = -2.71, p < .05$.

compared to the SG condition, $t(19) = 2.18, p < .05^2$. The LHD group, on the other hand, used the path prepositions similarly across the SG and the SO condition ($Z = .27, p > .05$), whereas they used manner verbs less accurately in the SO than in the SG condition, $Z = 1.9, p < .05$.

Last, we asked how the change in the accurate use of manner/path from the SG to the SO differed between the controls and the LHD group and compared these two groups using non-parametric Mann-Whitney U test. The change in the accurate use of manner verb and path preposition from the SG to the SO condition was similar in the controls and the LHD group, $Z = -1.52, p > .05$ and $Z = -.49, p > .05$, respectively.

3.1.2. Gesture Analyses

For gestures, we analyzed the SG and the GO conditions. In the SG condition, the controls produced 41 representational gestures in total with a mean of 2.05 ($SD = 3.6$). On average, 83% of these co-speech gestures were iconic gestures and the rest were deictic gestures (i.e., pointing). Sixty-six percent of those gestures were target gestures referring to the path and/or manner (i.e., dynamic iconic gestures) or the object (i.e., static iconic gestures) of the described action in the motion event videos. Half of the controls ($N = 10$) did not produce any target iconic gestures in the SG condition. The LHD group, on the other hand, produced 39 representational gestures in total with a mean of 6.5 ($SD = 6.6$), in which 67% of them were iconic gestures and 33% of them were pointing

² For the controls, we also ran non-parametric Wilcoxon signed rank test that revealed the same results as the paired samples t-test. The controls used path prepositions more accurately in the SO compared to the SG condition ($Z = -2.27, p < .05$), whereas they used manner verbs similarly across two conditions, $Z = -1.80, p > .05$.

gestures. Out of 39 gestures, 67% of them were target gestures. Two patients (236 and 493) did not produce any target iconic gestures.

In the GO condition, one control participant was discarded because of technical problems with video recording. The remaining 19 control participants used 296 target iconic gestures in total with a mean of 15.6 ($SD = 3.6$) and patients used 92 target iconic gestures with a mean of 15.3 ($SD = 6.2$). Figure 5 depicts the distribution of the total number of target iconic gestures based on their referents (i.e., manner only, path only, conflated, and static iconic gestures) for the SG and the GO conditions. An inspection of Figure 5 reveals that although the controls could produce conflated gestures on command, as evident in the abundant use of them in the GO condition, they did not produce conflated gestures (path + manner) during the SG condition. Most of the target iconic gestures used by control participants were path only gestures in the SG condition.

Figure 5. Stacked bars showing the distribution of target iconic gestures.

Participants produced pantomime-like gestures on command in the GO condition. The frequency of gestures was inherently higher in the GO condition compared to the SG condition in which gestures were produced spontaneously. That is why we did not

compare gestures across both conditions and only analyzed gesture use within each condition.

First, using non-parametric Mann-Whitney U tests, we compared the controls and the LHD group for the total number of gestures they produced, manner gestures and path gestures produced in the SG condition. Two groups produced a similar number of total target iconic gestures during the SG condition, $Z = 1.6, p > .05$. The LHD group used more manner gestures than the controls, $Z = 2.7, p < .05$, whereas the use of path gestures was similar across both groups, $Z = .75, p > .05$ (see Figure 6). Second, we compared manner and path gestures within each group by using paired samples t-test for the controls and non-parametric Wilcoxon signed ranked test for the LHD group. The controls gestured manner information more often than path information in the SG condition, $t(19) = 3.2, p < .05^3$. The LHD group, however, gestured manner and path information similarly in the SG condition, $Z = 1.5, p > .05$.

Then, we analyzed gesture production in the GO condition. The controls and the LHD group produced comparable numbers of total target iconic gestures in the GO condition, $Z = .16, p > .05$. However, the LHD group gestured the manner information less than controls, $Z = 13.5, p < .05$, whereas the gestural expression of path information was similar across groups, $Z = .07, p > .05$ (see Figure 6).

³ The non-parametric Wilcoxon signed ranked test for the controls revealed the same results. The controls used more manner gestures than path gestures in the SG condition, $Z = -2.54, p < .05$.

Figure 6. The percentage of trials in which manner/ path was gestured at least once across SG and GO conditions for controls and patients.

3.1.3. Speech-Gesture Relation Analyses

Figure 7 presents how manner or path information was expressed in spoken and gestural channels and depicts the distribution of trials in the SG condition. We compared the controls and the LHD group for each category of trials using non-parametric Mann-Whitney U tests: percentage of trials in which manner/path was expressed (1) only in speech, (2) neither in speech nor in gestures (i.e., not expressed) and, (3) both in speech and in gestures. Yet, we did not run group-level comparisons for the trials in which the target manner/path information was expressed only in gestures because they occurred so rarely in our sample, especially in the controls.

The controls expressed manner and path information only in speech more than the LHD group, $Z = 3.12, p < .05$ and $Z = 2.88, p < .05$, respectively. The LHD group did not express manner and path information in speech nor in gestures more frequently than the controls, $Z = 2.64, p < .05$ and $Z = 3.01, p < .05$. However, the percentages of trials in

which the target manner and path was expressed both in speech and in gestures were similar across two groups, $Z = 1.73, p > .05$ and $Z = .40, p > .05$.

Figure 7. The percentage of trials in which manner/path was expressed only in speech, only in gesture, both in speech and gesture concurrently or none of them during the SG condition.

Out of 10 control participants who produced at least one target iconic gesture throughout the SG condition, only one of them used a gesture compensating for path information. Except for this participant, all of the target gestures used by control participants matched. Among the LHD group, four patients who produced at least one target gesture during the SG condition used 15 compensatory gestures in total, with a mean of 3.75 ($SD = 3.56$). Among these 15 gestures, 7 of them were manner only gestures, 1 was a path only gesture and the rest were conflated gestures, compensating for both manner and path information.

3.2. Individual Case Analyses

Along with group-level analyses, we used the corrected t-tests proposed by Crawford and Garthwaite (2002, 2005) to analyze speech and gesture at an individual level (for details, see Akhavan et al., 2018). Table 2 presents single-case analyses for the

accurate use of manner and path in speech within the SG and the SO conditions, along with the percent change in the accurate use of manner and path information from the SG to the SO condition. Table 3 shows the single-case analyses for gesture use within the SG and the GO conditions. We did not carry out single-case analyses for the use of compensatory gestures because controls' average score was 0 for manner compensatory gestures and was close to zero (.03) for path compensatory gestures. We only reported single-case descriptive data for compensatory gestures. In this section, we reported the results of each case analyses.

Table 2. Single case-statistics for patients for speech. The first two sections (SG and SO) compare the percentage of trials in which manner/path was named accurately for each patient against controls' average scores. The last section (Change in Speech%) compares the percent change in the accurate use of manner/path in speech from the SG to the SO condition against the difference observed in the control participants. The reported *p* values are the one-tailed probabilities for SG and SO sections, and two-tailed probabilities for Change in Speech% section. The t-test formula used by Crawford and Garthwaite (2005) for difference score comparison incorporates the mean and the standard deviation of two tasks as well as the correlation between them for controls. In this regard, we did not report the averaged difference scores for groups.

Subject	<i>Spontaneous Gesture (SG)</i>						<i>Speech Only (SO)</i>						<i>Change in Speech%</i>			
	Manner%	<i>t</i>	<i>p</i>	Path%	<i>t</i>	<i>P</i>	Manner%	<i>t</i>	<i>p</i>	Path%	<i>t</i>	<i>p</i>	<i>t</i> (Manner)	<i>p</i>	<i>t</i> (Path)	<i>p</i>
236	38	-5.8	< .001	23	-3.6	< .05	46	-8.4	< .001	23	-3.8	< .05	-1.6	.14	-.31	.78
342	69	-2.5	< .05	54	-1.6	.06	62	-5.5	< .001	46	-2.4	< .05	-2.1	.05	-.93	.36
360	54	-4.1	< .001	31	-3.1	< .05	31	-10	< .001	15	-4.3	< .05	-4.4	< .001	-1.3	.18
363	69	-2.5	< .05	15	-4.1	< .001	46	-8.1	< .001	54	-1.9	< .05	-3.9	< .05	-2.3	< .05
493	85	-.8	.23	54	-1.6	.07	77	-3.1	< .05	46	-2.4	< .05	-1.6	.13	-.93	.36
529	69	-2.5	< .05	61	-1.1	.14	85	-1.8	< .05	77	-0.5	.29	-.48	.64	-.59	.46
Patients																
Group Average	64			40			58			44						
SD	.16			.19			.2			.22						
Median	69			42			53			46						
Controls																
Group Average	92			78			96			86						
SD	.09			.15			.06			.16						
Median	92			77			100			92						

Table 3. Single case-statistics for patients for gesture. This table presents the total target iconic gesture use and the percentage of trials in which manner/path information was gestured at least once in the SG and the GO conditions.

Subject	<i>Spontaneous Gesture (SG)</i>									<i>Gesture Only (GO)</i>								
	Total Gestures	<i>t</i>	<i>p</i>	Manner%	<i>t</i>	<i>p</i>	Path%	<i>t</i>	<i>p</i>	Total Gestures	<i>t</i>	<i>p</i>	Manner%	<i>t</i>	<i>p</i>	Path%	<i>t</i>	<i>p</i>
236	0	-.60	.56	0	-.3	.7	0	-.7	.50	20	1.2	.12	85	-.23	.41	85	-.07	.47
342	8	2.9	< .05	23	4.1	< .05	15	.8	.44	21	1.5	.08	46	-.97	.17	46	-.03	.49
360	6	2.1	< .05	46	8.6	< .001	23	1.6	.13	5	-2.9	< .05	23	-1.4	.08	23	-.09	.46
363	10	3.7	< .05	23	4.1	< .05	15	-.8	.44	14	-.43	.34	85	-.23	.41	92	.09	.47
493	0	-.6	.56	0	-.3	.7	0	-.7	.50	12	-.97	.17	77	-.38	.35	46	-.03	.49
529	2	.3	.78	08	1.2	.26	08	-1	.92	77	1.2	.12	1	.06	.48	54	-.01	.49
<i>Patients</i>																		
Group Average	4.3			17			10			15.3			69			56		
SD	4.3			.18			.09			6.25			3.74			3.39		
Median	4			15			11			17			81			50		
<i>Controls</i>																		
Group Average	1.3			02			07			15.6			97			59		
SD	2.2			.05			.10			3.59			.51			3.76		
Median	0			0			0			14			1			69		

Patient 236 was impaired in naming both manners ($ps < .001$) and paths ($ps < .05$) in the SG and the SO conditions compared to neurotypical controls. When restrained from gesturing, Patient 236's accuracy in naming manner information increased whereas the accuracy of naming path information was stable. However, this difference in speech accuracy was not reliably different from controls (all $ps > .05$). In the GO condition, he performed comparable to the neurotypical control participants. He used similar number of target iconic gestures as controls and was able to express both manner and path information with gestures when explicitly asked to do so (all $ps > .05$). Yet, he did not use any target iconic gestures during the SG condition.

Patient 342 was impaired in naming manner ($p < .05$ and $p < .001$) and path ($p = .06$ and $p < .05$) in both the SG and the GO conditions, respectively (the use of path preposition in the SG condition was marginally significant). Although her accuracy in speech decreased from the SG to the SO condition, this decrease was reliably different from controls only for manner information. She was selectively impaired in naming manner information when gesture use was restricted ($p = .05$). In the GO condition, she performed similarly to the neurotypical control participants in the use of total target iconic gestures and the gestural expressions of manner and path information (all $ps > .05$). In the SG condition, she used 8 target iconic gestures, which was reliably more than controls ($p < .05$) and this difference mainly came from manner-referring gestures. She gestured manner information reliably more than controls ($p < .05$). Among 8 gestures she used in the SG condition, 2 of them were compensatory; one compensating for manner information and the other for path information.

Patient 360 was impaired in naming manners ($ps > .001$) and paths ($ps > .05$) in both SG and SO conditions. Although his accuracy in speech decreased when restrained from gesturing, this decrease was reliably different from controls only for manner information. He was selectively impaired in naming manner verbs when gesture use was restricted ($p < .001$). He used reliably fewer target iconic gestures in the GO condition ($p < .05$) but he could use gestures when asked to do so and performed comparable to neurotypical control participants in the gestural expression of manner and path information in the GO condition ($ps > .05$). In the SG condition, he produced 6 target iconic gestures, which was significantly more frequent than controls' usage ($p < .05$). However, this difference mainly came from manner-referring gestures; he gestured manner information in more trials than controls ($p < .001$). Among 6 gestures he used, there was 4 compensatory gestures; 2 gestures compensating for manner information and the other 2 were conflated gestures compensating for both manner and path information.

Patient 363 was impaired in naming both manners ($p < .05$ and $p < .001$) and paths ($p < .001$ and $p < .05$) in the SG and the GO conditions, respectively. When restricted from gesturing, his accuracy in naming manner information decreased ($p < .001$) whereas accuracy in naming paths increased ($p < .05$) reliably more compared to neurotypical control participants. In the GO condition, he performed similar to the controls and exhibited no impairment in the gestural expression of manner and path information (all $ps > .05$). During the SG condition, he used 10 target iconic gestures, which was reliably more often than control participants ($p < .05$). He gestured manner information in significantly more trials than controls ($p < .05$). Among these 10 spontaneous target gestures, 8 of them were compensatory. Three of them were used in

the same trial and compensated for the same manner information. Four of them were conflated gestures produced in another trial and compensated for both manner and path information. The last one was again a conflated gesture compensating only path information.

Patient 493 was impaired in naming both manner and path information only in the SO condition ($ps < .05$), but not in the SG condition ($ps > .05$). Although his accuracy in naming manner and path information decreased from the SG to the SO condition, this decrease was not reliably different from what has been observed in control participants ($ps > .05$). In the GO condition, he performed comparable to the control participants (all $ps > .05$). Although he could use gestures on command and express manner and path information with gestures when asked to do so (as evident in the GO condition), he did not use any target iconic gestures during the SG condition.

Patient 529 was only impaired in naming manners ($ps < .05$) but not paths ($ps > .05$) in both the SG and the SO conditions. She used both manner and path information more accurately in speech when restricted from gesturing; however, this increase was not reliably different from what was observed in control participants ($ps > .05$). In the GO condition, she performed comparable to the neurotypical control participants (all $ps > .05$). She used 2 target iconic gestures during the SG condition; however, it was not reliably different from control participants. There was also no reliable difference in the gestural expression of manner and path information across trials between controls and patient 529 (all $ps > .05$). Among 2 gestures, one was compensatory for manner information.

4. Discussion

The aim of the present study was to examine the relationship between speech and gesture and the function(s) gestures serve during communication. To understand the integrity and the functions of gestures, we asked whether gesture production differed between neurotypical elderly adults and focal brain-injured individuals with speech deficits and how restricting gestures affected speech across these two groups. Space provides a good context for the inquiry of the mechanism and functions of speech, and motion event descriptions are a good case for assessing spatial language (Akhavan et al., 2018; Alibali, 2005; Beattie & Shovelton, 1999; Göksun et al., 2015; Kita & Özyürek, 2003). We focused on the spoken and gestural expressions of two components: *manner* and *path* of motion (Talmy, 2000). The perception and expressions of manner and path can be selectively impaired and people who have speech deficits can selectively use gestures to compensate for some components of motion (Göksun et al., 2015; Kemmerer et al., 2007). To test whether there is differential impairment and gestural compensation for one of the motion event components, we analyzed data separately for the expression of manner and path information. We hypothesized that (1) if speech and gesture arise from two separate representational systems (de Ruiter, 2006; Kita & Özyürek, 2000; Krauss et al., 2000) and gestures compensate for speech under-specifications and/or impairments, individuals with speech problems (i.e., LHD group) would use more gestures compared to controls, (2) there can be differential impairment for the naming of manner vs. path information and LHD group would use more gestures expressing the component that they were impaired in naming, and (3) if gestures' main function is to complement spoken expressions (i.e., *communicative* function, e.g., de Ruiter, 2006; Melinger & Levelt, 2004), the controls' speech would be more informative when gestures

were restricted (i.e., in the SO compared to the SG). The LHD group, on the other hand, would have comparable speech informativeness across two conditions; they would not be able to increase their naming accuracy because of already impaired speech and, (4) if gestures' main function is to facilitate lexical retrieval (i.e., *restorative* function, e.g., Krauss et al., 2000; Rose, 2006), we expected to see a decline in the speech informativeness when gesture were restricted (i.e., from the SG to the SO) for both the controls and the LHD group. However, gesture restriction might hinder speech informativeness more in the LHD group compared to the controls because inhibiting one's own gestures might be more detrimental for word production in the LHD group.

Overall, we found that (1) the LHD group performed worse than the controls in naming manners and paths of the motion events, (2) both groups named manner verbs more accurately compared to path prepositions, (3) the LHD group used more manner gestures compared to the controls, and (4) gesture restriction affected both groups in different ways for different motion event components such that the controls named path preposition more when they could not use gestures whereas the LHD group used manner verb less when they could not use gestures (i.e., in the SO compared to the SG). However, results found in group-level analyses did not apply to all patients, as evident in the single-case analyses.

The group level analyses showed that the LHD group was impaired in naming manner verbs and path prepositions in each condition compared to the controls. Although the number of total target iconic gestures was comparable across two groups, the LHD group used more manner gestures compared to the controls. This study is partially in line with previous studies showing the higher frequency of representational gesture use

among people with speech deficits such as aphasia (e.g., Akhavan et al., 2018; Göksun et al., 2013, 2015; Lanyon & Rose, 2009; Sekine et al., 2013). This finding provides further supporting evidence for the view that speech and gesture arise from different yet interrelated representational systems and thus, gesture system can be intact in the presence of speech problems (e.g., de Ruiter, 2006; Kita, 2000; Kita & Özyürek, 2003). However, the increased gesture production in the LHD group was only for manner gestures. Indeed, the LHD group was impaired in naming manner verbs, but not path prepositions when gestures were restricted (from the SG to the SO). These two findings suggest that the LHD individuals with speech deficits used iconic gestures for *restorative* functions to facilitate the retrieval of correct lexical items, especially for the manner of motion. This finding supports the Lexical Access Model and is in line with previous evidence showing that PWA use more gestures during word retrieval difficulties and the resolution of these word retrieval difficulties was higher when an iconic gesture was present (Akhavan et al., 2018; Lanyon & Rose, 2009). Additionally, encouraged use of iconic gestures increased PWA's accuracy in naming objects and patients with word retrieval difficulties (Rose & Douglas, 2001). Yet, in our sample we also demonstrated that during the SG condition, LHD individuals used many compensatory gestures that expressed additional information not found in their speech and most of these gestures referred to the manner of motion. LHD individuals who had deficits in naming manner verbs expressed this information in their gestures. This pattern suggests that the LHD individuals also used gestures for *communicative* purposes, to compensate for breakdowns in spoken channel. In line with this observation, van Nispen and colleagues (2017) found that a fifth of PWA's representational gestures (mainly composed of

pointing, iconic, and emblematic gesture) were “essential” gestures conveying necessary information not found in speech. Additionally, gestures used by PWA were found to disambiguate the interpretation of the message and increased the comprehensibility of PWA’s overall communication (de Beer et al., 2017; van Nispen, Sekine, & Rose, 2015). Thus, the use of compensatory gestures expressing non-redundant information along with matching gestures facilitating lexical retrieval suggest that the role of gesture is not singular, at least for people with speech deficits. Indeed, the idea that gestures serve multiple functions has been established among neurotypical speakers as well (Driskell & Radtke, 2003). The role of gestures is multi-faceted and speakers with word retrieval difficulties might use gestures both for restorative and communicative reasons.

In spontaneous speech, control participants mainly used path-referring gestures, almost all of which were matching gestures (i.e., referring to the same information found in speech). When they were restrained from gesturing, they used path information more accurately in speech compared to the spontaneous condition. This observation provides evidence corroborating earlier studies showing that healthy speakers mainly use gestures for *communicative* functions to supplement information expressed in speech, particularly for the path of motion (Kong et al., 2015b; Melinger & Levelt, 2004). For example, Kong and colleagues (2015b) found that the majority of content-carrying gestures (i.e., representational gestures) used by healthy speakers were matching gestures that expressed the same information found in speech and used mainly to enhance spoken message content. In a previous study, we also found that healthy young speakers use more spatial language when gesture use is restricted (Özer et al., 2017). The group level analyses showed that the neurotypical adults primarily used gestures for communicative

reasons for the path of the motion, whereas the LHD individuals with speech deficits used gestures for both communicative and restorative functions for the manner of motion.

All participants named manner verbs more accurately compared to path prepositions in each condition. The path of motion is expressed in the preposition in English and can be omitted in certain cases whereas the manner of motion is expressed obligatorily in the main verb. Although our stimuli (i.e., motion event videos) were piloted to make sure that both components were salient enough to name, the participants omitted path prepositions in some trials, resulting in the higher accuracy in naming for manner verbs. There was also a differential gestural compensation for manner vs. path of the motion between the controls and the LHD group. First, we found that although the LHD group was impaired in naming both manner verbs and path prepositions, they mainly used gestures to compensate for manner verbs, suggesting a selective compensatory mechanism for manners of motion. This observation is line with earlier evidence suggesting selective impairments in the expression and the gestural compensation of different motion event components (Göksun et al., 2015). Second, the controls mainly used path gestures in the SG and used more path prepositions when restricted from gesturing. Yet, the controls performed near at ceiling level for naming manner verbs (the average was 92%) whereas the naming accuracy for path prepositions was 78% in the SG condition. This pattern suggests that controls omitted path prepositions from the speech and expressed paths of motion with gestures. Since manner verbs are obligatorily expressed in the main verb and the controls had no difficulty in naming them, there was no room for improvement in naming manner verbs from the SG to the SO.

Even though the group level analyses demonstrated differential use of gestures between patients and controls, patients in our study did not gesture indiscriminately. Rather, there were notable patterns from the single-case analyses. Three patients (236, 493, and 529) did not produce more gestures than the neurotypical controls and did not compensate speech deficits with gestures. Patients 236 and 493 did not gesture at all, whereas patient 529 used only 2 iconic gestures, which was not reliably more than control participants. However, the lack of spontaneous gesture use among these patients was not because of motor problems that could interfere with their gestural ability. In the gesture only condition, these patients produced similar number of gestures for manner and path information to the controls. Yet, these patients exhibited different patterns. One (patient 236) was impaired in naming both manners and paths in both spontaneous and gesture-restricted speech, one (patient 493) did not display any impairment in spontaneous speech but was only impaired in gesture-restricted speech, and the last one was selectively impaired in naming manner verbs (patient 529). Since they did not spontaneously use gestures, gesture restriction did not affect their speech accuracy. Their lesions comprised of the left frontal regions as well as pericallosal regions in the distribution of the anterior cerebral arteries.

The other three patients (342, 360, and 363) exhibited similar profiles to each other and displayed the same pattern found in the group level analyses. These patients were impaired in naming both manner and path information in speech and used more manner-referring gestures than the control participants. However, when they could not use gestures, they were more impaired in producing manner verbs. The lesions of those patients who compensated speech with gestures involved the left frontal, temporal,

occipito-temporal areas as well as basal ganglia. This finding is consistent with an earlier study with the same patients. Göksun and colleagues (2015) found that left hemisphere injured patients who had lesions to the left superior temporal gyrus produced more spatial gestures to compensate for their deficits in speech.

Previous research suggests that PWA might exhibit different patterns in gesture use (Hadar et al., 1998; Lanyon & Rose, 2009; Rose & Douglas, 2001). For example, Lanyon and Rose (2009) showed that in their study only 5 PWA (out of 18) used more iconic gestures during word retrieval difficulties than when they fluently spoke whereas 13 PWA used comparable number of gestures during fluent and non-fluent speech. Patients who used more gestures to facilitate speech production were the ones with phonological problems, both at the encoding and the access stages, as well as with relatively intact semantics and mild-to-moderate aphasia. It has also been established that some PWA do not use any gestures during spontaneous discourse (Kong et al., 2015a).

In the current study, we did not investigate the specific deficits these patients might have at different stages of speech production (e.g., phonological problems, word retrieval difficulties, semantic deficits). In-depth analysis of patients' profiles and speech impairment patterns might help elucidate which specific problems in speech production leads to the compensatory use of gestures and if different patients with different speech profiles use gestures for different purposes. The case analyses reported here are limited by the narrow range of baseline assessments. Future studies can test how the integrity and the functions of gestures differ for different patholinguistic profiles. Moreover, a caveat of the current study is that the gesture restriction might pose an extra difficulty for individuals with speech deficits. To our knowledge, this is the first study employing the

gesture restriction in people with speech deficits. Yet, the impact of inhibiting one's own gestures and the intactness of the cognitive resources implicated in these processes were not directly tested in the current study.

Our findings also have implications for therapies and treatments of word retrieval impairments. The use of gestures during verbal treatment enhances both noun and verb retrieval in PWA (e.g., Raymer et al., 2006; Rose & Douglas, 2001). Many studies also reported positive results for therapies that involved compensations with gestures (Rose, 2006). Rose and colleagues (2013) reported that gesture therapy alone did not aid speech production, but a combination of gesture and speech therapy would be beneficial for PWA. We suggest that when people have impairments, particularly when talking about actions, encouraging them to gesture can help them retrieve words or communicate information that would not otherwise appear in the verbal modality. Thus, for these individuals gesturing has the benefits to enhance their communicative abilities.

In conclusion, the findings of the present study do not unequivocally support the restorative or the communicative functions of gestures, which hold that the role of gestures is singularly to facilitate speech production or communicate meaning. Rather, our results show that gesture production is multifunctional and gestures might serve different functions for different populations as well as within the same population.

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Declaration of Interest

The authors report no conflict of interests.

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