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

Demet Özer^a, Tilbe Göksun^a and Anjan Chatterjee^b

^aDepartment of Psychology, Koç University, Istanbul, Turkey; ^bDepartment of Neurology and Center for Cognitive Neuroscience, University of Pennsylvania, Philadelphia, PA, USA

ABSTRACT

Gestures might serve *communicative* functions by supplementing spoken expressions or *restorative* functions by facilitating speech production. Also, speakers with speech deficits use gestures to compensate for their speech impairments. In this study, we examined gesture use in speakers with and without speech impairments and how spoken spatial expressions changed when gestures were restrained. Six patients with speech problems and with left frontal and/or temporal lesions and 20 neurotypical controls described motion events in 3 different conditions (spontaneous gesture, only speech, and only gesture). In addition to the group analyses, we ran case analyses. Results showed that patients used more gestures compared to controls. Gestures served both communicative and restorative functions for patients whereas controls only used gestures for communicative purposes. Case analyses revealed that there were differential patterns among patients. Overall, gesture production is multifunctional and gestures serve different functions for different populations as well as within a population.

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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 speech deficits such as aphasia (e.g., Akbiyık, Karaduman, Göksun, & Chatterjee, 2018; Akhavan, Göksun, & Nozari, 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 expressions of spatial information in people with and without speech impairments.

Gesture and speech interact with one another during language production and comprehension (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, 2005). This notion entails that gestures can function independent of the speech production system. Neuropsychological evidence on people with speech impairments, such as aphasia, has established that gestures compensate for underspecifications in the spoken channel and can function independent of the impaired speech (e.g., Akbiyık et al., 2018; Akhavan 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, Wapner, Foldi, Zurif, & Gardner, 1979; Glosser, Wiener, & Kaplan, 1986). In the case of an impaired speech system, as long as the conceptual knowledge and the communicative intentions remain intact, the message to be communicated might be split between two communication modalities (de Ruiter & de Beer, 2013). That is, there can be a shift toward the gesture modality in case of a speech deficit (de Ruiter, 2006).

Supporting this view, studies have shown that people with aphasia (PWA) used gestures in a higher frequency compared to healthy adults (e.g., Feyereisen, 1983; Le May, David, & Thomas, 1988). Although different patholinguistic profiles yield differential patterns of gesture use among PWA (e.g., Hadar, Wenkert-Olenik, Krauss, & Soroker, 1998; Kroenke, Kraft, Regenbrecht, & Obrig, 2013; Preisig et al., 2018; Rose, 2006), more severe forms of aphasia were generally associated with higher use of spontaneous co-speech gestures (Carlomagno & Cristilli, 2006; Kong, Law, & Chak, 2017). However, many of these studies focused on the general language use and investigated the integrity of gestures with 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, & Rothenhäusler, 2000; Rose & Douglas, 2003). Yet, 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 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 very good 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., motion event descriptions) in focal brain-injured individuals who have speech impairments and neurotypical elderly adults.

Motion event descriptions are a good case of assessing spatial language, including spoken and gestural expressions (e.g., Akhavan, Goksun, & Nozari, 2016; Akhavan, Nozari, & Göksun, 2017, 2018; Göksun, Lehet, Malykhina, & Chatterjee, 2015; Karaduman, Çatak, Bahtiyar, & Göksun, 2015; Kemmerer et al., 2007; Kita et al., 2007; Kita & Özyürek, 2003). 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 how 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 obligatorily in the main verb of a sentence whereas the path of motion is encoded in the preposition and can be omitted in certain 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 et al. (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. Yet, it is important to note that although patients with LHD, as a group, impaired in naming locative relations and the motion event components compared to the neurotypical controls, they were not necessarily speech 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. Results showed that 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 were correlated with higher use of path gestures. This entails 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 type 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 directly tested.

What function(s) gestures serve during speech production? Gestures have communicative, but as well as speaker-internal functions. For 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, 2005). 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, 2005). Also, PWA use gestures that express additional (i.e., non-redundant) information that was not found 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 the 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 showed 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 the impaired speech, PWA used gestures to cue speech production (Lanyon & Rose, 2009). Indeed, treatment plans incorporating the use of gestures evidenced improved 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 speech deficits (i.e., conveying additional information along with speech semantics) or restorative function by facilitating word retrieval. It is also important to note that these two functions are not mutually exclusive, and gestures might serve multiple functions within a population or differential functions for different populations.

A recent study (Akhavan et al., 2018) examined the integrity and the functions of gestures during spontaneous expressions of motion events in Farsi-speaking PWA by using the same experimental stimuli in Göksun et al. (2015). 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) than elderly controls, their gesture informativeness was comparable to the control group. However, gestures served multiple functions among PWA. They used gestures for communicative and restorative functions as well as a social cue (i.e., communicative purpose but gestures do not convey 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. Also, there was a negative correlation between PWA's speech informativeness and the frequency of compensatory gestures; the more impaired the participant's speech, the more they use 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 et al. (2018) suggested that gestures serve multiple functions in the presence of speech problems, it is important to note that participants were only tested in speech condition and gestures were co-speech spontaneous ones. 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 expressions in the absence of one or the other. Neuropsychological evidence examining the spontaneous gestural expressions of people with speech problems (i.e., in the absence of speech) provides one way to understand this relationship. Yet, this 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

of spatial information (see Alibali, 2005 for review) and motion event descriptions are a good case of assessing spatial language (both gestural and spoken expressions; Akhavan et al., 2017, 2018; Göksun et al., 2015; Kita et al., 2007; Kita & Özyürek, 2003), (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).

Earlier studies examined the integrity and the functions of gestures in the spontaneous spatial speech of individuals who had speech problems. Yet, to draw a more direct, causal and complementary evidence regarding the integrity and the function(s) of gestures, the inquiry of what would happen to gestural expressions in the absence of speech (i.e., in individuals with speech problems) should be complemented with an inquiry of what would happen 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). In light of these, the current study attempts to bridge these two lines of studies 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 the speech–gesture integrity and the function(s) of gestures in individuals who had selective impairment in spatial speech.

We selected a subgroup of patients from a larger sample of 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 of them were aphasics. 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 case statistics 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 the 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 selectively impaired (Göksun et al., 2015) and each component is related to differential activation 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 analysed in depth along with group analyses. For individual-level analyses, we used the corrected *t*-tests of case statistics (Crawford & Garthwaite, 2002, 2005; Crawford & Howell, 1998). This method provides us two benefits: (1) It tests whether a single performance or a difference between the performance on two tasks of a patient is reliably different from the 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 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 smoothing 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 that 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 GR 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 et al. (2013 and 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 and 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, 1997). 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.

Twenty age- and education-matched healthy elderly adults (15 females; $M_{age} = 62.9$, $SD = 8.2$; $M_{years\ of\ education} = 15$, $SD = 2.5$) 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 included 50 pictures of actions and 81 pictures of objects. Patients were also administered the revised short version of Florida Apraxia Screening Task (Rothi & Heilman, 1997). In this task, participants

Table 1. Patient demographic and neuropsychological data.

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

F, frontal; T, temporal; P, parietal; O, occipital; BG, basal ganglia; ACA, anterior cerebral artery; PA, pericallosal artery.

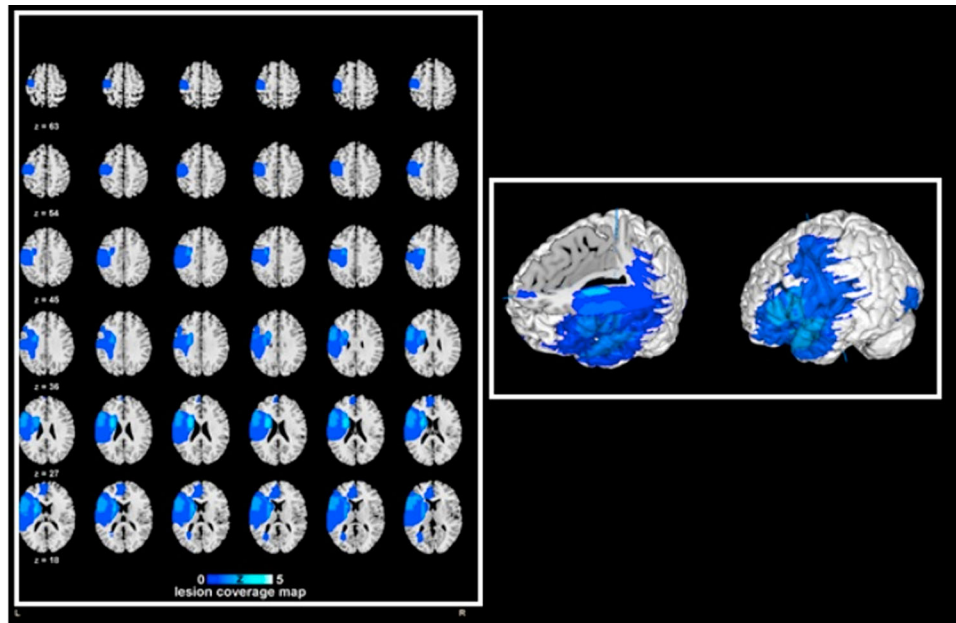


Figure 1. Coverage map indicating the lesion location for all six patients.

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 s 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).

Pretest. The final set of 39 videos were selected from a larger sample of 60 videos 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. The final movies were selected based on the agreement among the participants. 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



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.

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. There were three conditions. 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 to not 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, 2018) software package (Max Planck Institute for Psycholinguistics 2002).

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. Accurate use of manner verbs and path prepositions with slight phonological problems were coded as accurate (e.g., saying "kipping" 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 to the total number of trials. For example, we summed up *manner only* trials and both *manner and path* trials and divide it 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 a non-target gesture.

Although we reported the descriptive statistics for the overall gesture use, we only analysed 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 depicting 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 depicting the 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 moving the hand in circular motion at the same time 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 to 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 analysed 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 labelled 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. Please note that 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 the SO conditions.

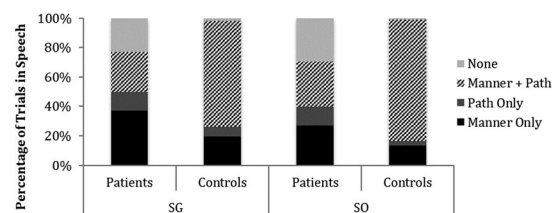


Figure 3. Stacked bars showing the averaged distribution of trials for control participants and patients in the SG and SO conditions.

We calculated the accurate use of manner and path information in speech for each participant. In the SG condition, on average, the control group used the correct manner verbs in 92% ($SD=0.09$) and the correct path prepositions in 78% ($SD=0.15$) of trials, whereas the LHD group used the correct manner verbs in 64% ($SD=0.16$) and the correct path prepositions in 40% ($SD=0.19$) of trials. In the SO condition, the controls used the correct manner verbs in 96% ($SD=0.06$) and the correct path prepositions in 86% ($SD=0.16$) of trials, whereas the LHD group produced the correct manner verbs in 58% ($SD=0.2$) and the correct path prepositions in 44% ($SD=0.22$) of trials.

In this section, we asked how speech accuracy differed across two groups (neurotypical elderly vs. LHD individuals) and two conditions (SG vs. SO). First, we asked speech accuracy differed between the controls and the LHD group and compared two by using non-parametric Mann–Whitney U test. The controls were more accurate in naming both manner verb and path preposition 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).

Second, we asked how the spoken expression of different components of motion differ in each condition for each group and compared the accurate use of manner vs. path 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 verb more accurately compared to the path preposition 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, $Z=1.9$, $p<.05$.

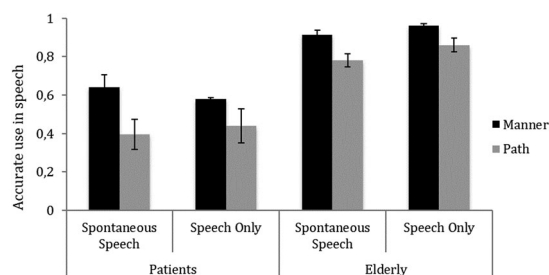


Figure 4. Percentage of trials in which manner and path was expressed accurately in speech across SG and SO conditions for controls and patients.

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 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 verb comparable across the SG and the SO conditions, $t(19)=1.81$, $p>.05$. Yet, they named the path preposition more accurately in the SO compared to the SG condition, $t(19)=2.18$, $p<.05$. The LHD group, on the other hand, used the path preposition comparably across the SG and the SO condition ($Z=.27$, $p>.05$), whereas they used manner verb less accurately in the SO compared to 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 by 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 comparable between 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 analysed 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 per cent 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 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 gestures, path only gestures, conflated gestures, and static iconic gestures) for the SG and the GO conditions. The 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 any conflated gestures (path + manner) during the SG condition and most target iconic gestures used by control participants were path only gestures in the SG condition.

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 two conditions and only analysed gesture use within each condition.

First, we analysed gesture use in the SG condition. First, we compared the controls and the LHD group for the total number of gestures, manner gestures and path gestures produced in the SG condition and used non-parametric Mann–Whitney U tests. Two groups produced comparable numbers of total target iconic gestures during the SG condition, $Z = 1.6$, $p > .05$. The LHD group used more manner gestures compared to the controls, $Z = 2.7$, $p < .05$, whereas, the use of path gestures was comparable across two groups, $Z = .75$, $p > .05$ (see Figure 6). Second, we compared manner and path gestures for 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 compared to path in the SG condition, $t(19) = 3.2$, $p < .05$.² The LHD group, however, gestured manner and path information comparably in the SG condition, $Z = 1.5$, $p > .05$.

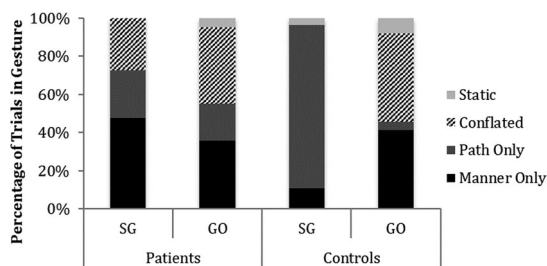


Figure 5. Stacked bars showing the distribution of target iconic gestures.

Then, we analysed 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 compared to controls, $Z = 13.5$, $p < .05$, whereas the gestural expression of path information was comparable across groups, $Z = .07$, $p > .05$ (see Figure 6).

3.1.3. Speech–gesture relation analyses

Figure 7 presents how the expression of manner or path information was divided between 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 by 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 neither in speech nor in gestures more frequently compared to 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 comparable across two groups, $Z = 1.73$, $p > .05$ and $Z = .40$, $p > .05$.

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

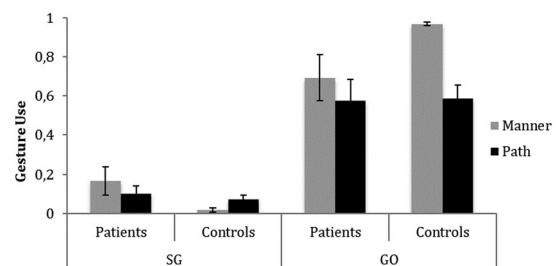


Figure 6. The percentage of trials in which manner/ path was gestured at least once across SG and GO conditions for controls and patients.

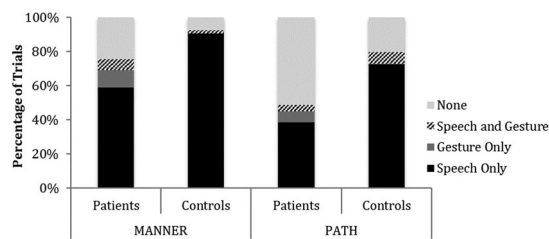


Figure 7. The percentage of trials in which manner/path was expressed only in speech, only in gesture, both in speech and gesture concurrently or none of them during the SG condition.

for path information. Except this, all of the target gestures used by control participants were matching. 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 analyse speech and gesture at the individual level (for details, see Akhavan et al., 2018). Table 2 presents individual-level analyses for the accurate use of manner and path in speech within the SG and the SO conditions, along with the per cent change in the accurate use of manner and path information from the SG to the SO condition. Table 3 shows the

individual level analyses for gesture use within the SG and the GO conditions. We did not carry out individual-level analyses for the use of compensatory gestures because controls' average against which patients' scores were compared were 0 for manner compensatory gestures and were close to zero (.03) for path compensatory gestures. Thus, we reported individual level descriptive data for compensatory gestures. In this section, we reported the results of individual-level analyses case-by-case.

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 comparable number of target iconic gestures as controls and was able to express 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

Table 2. Case-statistics for patients.

Subject	Spontaneous gesture						Speech only						Change in speech%			
	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						

Note: 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. 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.

Table 3. Single case-statistics for patients.

Subject	Spontaneous gesture						Gesture only					
	Total gestures	t	p	Manner%	t	p	Path%	t	p	Manner%	t	p
236	0	-.60	.56	0	-.3	.7	0	-.7	.50	20	1.2	.12
342	8	2.9	<.05	23	4.1	<.05	15	.8	.44	21	1.5	.08
360	6	2.1	<.05	46	8.6	<.001	23	1.6	.13	5	-2.9	<.05
363	10	3.7	<.05	23	4.1	<.05	15	-.8	.44	14	-.43	.34
493	0	-.6	.56	0	-.3	.7	0	-.7	.50	12	-.97	.17
529	2	.3	.78	08	1.2	.26	08	-.1	.92	77	1.2	.12
Patients												
Group average	4.3			17			10			15.3		
SD	4.3			.18			.09			6.25		
Median	4			15			11			17		
Controls												
Group average	1.3			02			07			15.6		
SD	2.2			.05			.10			3.59		
Median	0			0			0			14		

Note: 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.

manner information. She was selectively impaired in naming manner information when gesture use was restricted ($p = .05$). In the GO condition, she performed comparable to the neurotypical control participants in the use of total target iconic gestures and the gestural expression 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 in 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 ($p < .001$). Although he used reliably fewer target iconic gestures in the GO condition ($p < .05$), 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 than what controls used ($p < .05$). However, this difference mainly came from manner-referring gestures; he gestured manner information in more trials compared to 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 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 has been 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, only 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 gesture, we asked whether gesture production differs between neurotypical elderly adults and focal brain-injured individuals with speech problems and how restricting gestures affects 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; 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 speech problems can selectively use gestures to compensate for some components of motion (Göksun et al., 2015; Wu et al., 2008). To test whether there is differential impairment and gestural compensation for one of the motion event components, we analysed 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, 2003; 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 the 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, (3) if gestures' main function is to complement spoken expressions (i.e., *communicative* function, e.g., de Ruiter, 2006; Melinger & Levelt, 2005), 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 due to 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 the word production for the LHD group.

Overall, we found that (1) the LHD group used more manner gestures compared to the controls and (2) gesture restriction affected two 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 individual level 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 problems 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; the LHD group used path gestures comparably with the controls. Indeed, the LHD group was also impaired in naming manner verb, but not path preposition when gestures were restricted (from the SG to the SO). These two lines of evidence suggest that the LHD individuals with speech problems used iconic gestures for *restorative* functions; to facilitate the retrieval of correct lexical items, especially for the manner of motion. This finding provides supporting evidence for 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). Also, the encouraged use of iconic gestures increased PWA's accuracy in naming objects and patients with word retrieval difficulties, especially at the phonological level benefited most from the facilitating effects of iconic gestures (Rose & Douglas, 2001). Yet, during the SG condition, LHD individuals used many compensatory gestures that express additional information not found in speech and most of these gestures were referring to the

manner of motion. LHD individuals who had problems in naming the correct manner verb expressed this information in their gestures. This suggests that the LHD individuals also used gestures for *communicative* purposes, to compensate for breakdowns in spoken channel. In line with this, van Nispen, van de Sandt-Koenderman, Sekine, Krahmer, and Rose (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, Ferré, & Tutton, 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 problems. Indeed, the idea that gestures serve multiple functions has been established among neurotypical speakers as well (Driskell & Radtke, 2003). The role of gestures is multifaceted and speakers with word retrieval difficulties might use gestures both for restorative and communicative reasons.

What about neurotypical control participants? 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 provides corroborating evidence for earlier studies showing that healthy speakers mainly use gestures for *communicative* functions to supplement information expressed in speech, particularly for the path of motion in our data (Kong, Law, Kwan, et al., 2015b; Melinger & Levelt, 2005). For example, Kong, Law, Kwan, et al. (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 problems used gestures for both communicative and restorative functions for the manner of motion.

Why there was a differential gestural compensation for the 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 the manner of motion. This is line with earlier studies suggesting selective impairments in the perception, expression and the gestural compensation of different motion event components (e.g., Göksun et al., 2015; Wu et al., 2008). Second, the neurotypical controls used gestures to compensate mainly for the path of the motion. As noted earlier, the path is expressed in the preposition in English and can be omitted in certain cases whereas the manner is expressed obligatorily in the main verb. Although we chose the stimuli with a pretest to make sure that both of the components were salient enough to name; the neurotypical adults preferred to omit the path of the motion in certain cases.

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 as was evident in individual-level 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 activity. In the gesture only condition, these patients produced comparable number of gestures for manner and path information. 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 verb (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 verb. The lesions of those patients who compensated speech with gestures involved left frontal, temporal, occipito-temporal areas as well as basal ganglia. This finding is consistent with an earlier study with the same patients. Göksun et al. (2015) found that left hemisphere injured patients who had lesions to the left superior temporal gyrus produced more spatial gestures to compensate for their problems 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, Law, Wat, et al., 2015a).

In the current study, we did not investigate the specific problems these patients might have at different stages of speech production. In-depth analysis of patients' profiles and speech impairment patterns might help us 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 in the current study are limited by the narrow range of baseline assessments. Future studies can test how the integrity and the functions of gesture differ for different pathologic profiles. Moreover, a caveat of the current study is that the gesture restriction might pose an

extra difficulty for individuals with speech problems. To our knowledge, this is the first study employing the gesture restriction paradigm in people with speech problems. Yet, the impact of inhibiting one's own gestures and the intactness of the cognitive resources implicated in these processes are 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). In a recent review, Rose, Raymer, Lanyon, and Attard (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 retrieving words or communicating information that would not 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.

Notes

1. We also ran non-parametric tests for the controls. The non-parametric Wilcoxon signed rank tests revealed the same results as for the paired samples *t*-tests. The controls used manner verb more accurately compared to the LHD group in the SG ($Z = -3.18, p < .05$) and in the SO conditions, $Z = -2.71, p < .05$. The controls used the path preposition more accurately in the SO compared to the SG condition ($Z = -2.27, p < .05$), whereas they used the path preposition comparably across two conditions, $Z = -1.80, p > .05$.
2. The non-parametric Wilcoxon signed ranked test for the controls revealed the same results. The controls used more manner gestures compared to path gestures in the SG condition, $Z = -2.54, p < .05$.

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