Gesture in the eye of the beholder: An eye-tracking study on factors determining the attention for gestures produced by people with aphasia

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Abstract

Co-speech hand gestures are a ubiquitous form of nonverbal communication, which can express additional information that is not present in speech. Hand gestures may become more relevant when verbal production is impaired, as in speakers with post-stroke aphasia. In fact, speakers with aphasia produce more gestures than non-brain damaged speakers. Furthermore, there is evidence to suggest that speakers with aphasia produce gestures that convey information essential to understand their communication. In the present study, we addressed the question whether these gestures catch the attention of their addressees. Healthy volunteers (observers) watched short video clips while their eye movements were recorded. These video clips featured speakers with aphasia and non-brain damaged speakers describing two different scenarios (buying a sweater or having witnessed an accident). Our results show that hand gestures produced by speakers with aphasia are on average attended to longer than gestures produced by non-brain damaged speakers. This effect was significant even when we controlled for the longer duration of the gestural movements in speakers with aphasia. Further, the amount of information in speech was also correlated with gesture attention. That is gestures produced by speakers with less informative speech were attended to more frequently. In conclusion, our findings suggest that listeners reallocate their attention and focus more strongly on non-verbal information from co-speech gestures if speech comprehension becomes challenging due to the speaker's verbal production deficits. These findings support a communicative function of co-speech gestures and advocate for instructing people with aphasia to communicate things in the form of gestures that cannot be expressed verbally because interlocutors take notice of these gestures.

Keywords: aphasia; gestures; speech; eye movements; multimodal communication

Highlights

- Healthy observers watched video clips while their eye movements were recorded
- These video clips featured speakers with aphasia and non-brain damaged speakers
- Speakers in the video were using gestures to describe a vivid scenario
- Hand gestures produced by speakers with aphasia were longer attended than gestures produced by non-brain damaged speakers
- Gestures produced by speakers with less informative speech were attended to more frequently

1. Introduction

Often without noticing it, people produce hand gestures while they speak (McNeill, 1992). Although it is well documented that co-speech gestures convey meaningful information (Kendon, 2004), few studies have looked at whether gestures catch the attention of the addressee. The limited research available suggests that only few gestures get direct attention from the addressee by visual fixation (e.g. Beattie, Webster, & Ross, 2010; Gullberg & Holmqvist, 2002; Preisig et al., 2015). Does this mean that listeners miss important information conveyed by co-speech gestures? Not necessarily. Preliminary evidence in studies which have compared visual attention towards gestures in participants' stronger and weaker languages, found greater attention to gesture when processing ones' weaker language (Drijvers et al., 2019). This suggests that listeners adapt visual processing and deploy more attention to gestures if speech comprehension becomes more challenging (Drijvers et al., 2019; Zielinski & Wakefield, 2021). In the present study, we investigated whether attention paid to gestures depends on the communicative importance. To this end, we analyzed visual attention to gestures produced by speakers with aphasia, who have limited spoken language abilities.

Co-speech gestures are spontaneous hand movements that people produce while speaking (Beattie & Shovelton, 1999). These movements can express redundant (e.g., pointing while naming an object) or supplementary information to direct speech (e.g., indicating information about the size of an object, which is not conveyed in speech) (Colletta et al., 2009; McNeill, 2000; van Nispen et al., 2017). Previous research suggests that addressees integrate visual information from co-speech gestures with acoustic information to enhance speech comprehension (Beattie & Shovelton, 1999; Drijvers & Özyürek, 2017; Holle et al., 2010; Holle & Gunter, 2007; Holler et al., 2014; Schubotz et al., 2021). For example, Beattie and Shovelton (1999) showed that stories are recalled more accurately if they included meaningful co-speech gestures. More recently, it was shown that gestures enhance degraded speech comprehension

in young (Drijvers & Özyürek, 2017) and to a lesser extent also in elderly adults (Schubotz et al., 2021)

Only a few studies have investigated the amount and frequency of overt attention paid to co-speech gestures by recording visual fixations. These studies report that gestures attract only a minor portion of attention (2-7%), while the speaker's face is much more fixated (90-95%) (Beattie et al., 2010; Gullberg & Holmqvist, 2006; Preisig et al., 2015). Nonetheless, different factors seem to enhance attention for gestures, including information content and salience of the gestural movement. For example, Beattie et al. (2010) reported in an eye-tracking study that more informative gestures are fixated longer and more frequently than less informative gestures. In line with this, Cassell, McNeill, and McCullough (1999) found that gestures are attended to if they convey information that is supplementary or even contradictory to the information in speech. This suggests that gestures, which are more relevant for speech comprehension, attract more attention. This claim is further supported by the finding that the gestures will get more attention from the interlocutor if speakers increase the salience of their own gesture, e.g. when overtly looking at the gesturing hand or by suddenly stopping the gestural movement (so-called post stroke hold) (Gullberg & Kita, 2009).

To the best of our knowledge, it is still unclear whether gestures from speakers with aphasia, which are potentially more relevant for speech comprehension, attract more attention. Aphasia is an acquired language disorder that is caused by brain damage to the neural language network (Butler et al., 2014; Damasio, 1992; Dronkers et al., 2004). The disorder generally affects several language modalities (speaking, understanding speech, reading, and writing) to various degrees. Although differing in severity, most speakers with aphasia have some deficits in verbal production (Hope et al., 2021; Laine & Martin, 2013). Several theoretical models of gesture production propose that gesture and speech underlie a shared communicative intention (de Ruiter, 2000; Kita & Özyürek, 2003). For example, the Sketch Model (de Ruiter, 2000), which

was based on Levelt's model of verbal production (Levelt, 1981), assumes that both gesture and speech have a communicative function. This view suggests a flexible interaction between gesture and speech with one communication channel compensating for the other under certain communicative constraints. Further, the communicative function of gestures may predict that speakers and listeners with low communicative capacity, as individual with aphasia, might employ and benefit more from gestures (for a review see (Özer & Göksun, 2020)). In fact, several studies have shown that speakers with aphasia use gesture, which have communicative value, because they provide additional information that is not or cannot be expressed in concurrent speech (Goodwin, 1995, 2000; Herrmann et al., 1988; Hogrefe et al., 2012, 2013; Mol et al., 2013; Sekine et al., 2013; van Nispen et al., 2017, 2017) for a review see (Rose, 2006). Further, the compensatory use of co-speech gestures seems to be restricted to individuals, who have intact conceptual knowledge (Akhavan et al., 2018; Goksun et al., 2013; Göksun et al., 2015). However, it is unclear whether interlocutors make use of additional non-verbal information that is provided through the gestures from speakers with aphasia. Indeed, it has been found that interlocutors interpret the message of speakers with aphasia more accurately after watching video clips providing information from speech and gestures as compared to listening to audio clips providing only the speech content (de Beer Carola et al., 2017; Rose et al., 2017). This indicates that interlocutors may rely on additional non-verbal information from speakers with aphasia. However, gesture directed attention has not been studied in speakers with aphasia.

In the present study, we addressed the question whether the gestures produced by speakers with aphasia attract the attention of their addressees. For this purpose, we compared visual attention to gestures produced by speakers with aphasia to those produced by non-brain damaged participants. Healthy volunteers (observers) watched short video clips featuring speakers with aphasia and healthy non-brain damaged speakers describing two different

scenarios (buying a sweater or having witnessed an accident), while their eye movements were recorded with an infrared eye-tracker.

First, we investigated whether gestures produced by speakers with aphasia attracted more visual attention than gestures produced by non-brain damaged speakers (**Hypothesis 1, H1**). Second, we tried to determine variables, which predict visual attention for gestures produced by speakers with aphasia. To this end, we tested whether the information content of the produced speech and aphasia severity were correlated with the amount of attention paid to gestures, i.e. whether gestures from speakers with more severe verbal production impairment attract more attention (**Hypothesis 2, H2**). In a third step, we tested whether the speakers' gaze to their own gestures enhances the addressees' overt visual attention to these gestures (**Hypothesis 3, H3**). There is evidence obtained in non-brain damaged speakers suggesting that directing the eye gaze to your own gestures enhances gesture directed attention of the addressee (Gullberg & Kita, 2009), but to the best of our knowledge this has not been investigated in speakers with aphasia.

2. Methods

2.1. Video data & speaker details

This study was conducted using video stimuli recorded by Van der Meulen and colleagues (2010). These videos were originally recorded to measure the psychometric qualities of the Scenario Test (Van der Meulen et al., 2008), a test to assess daily-life communication in severe aphasia. In this study, we used videos from two subtasks (Mol et al., 2013). The task of the participants featured in our video stimuli (hereafter referred to as the video speakers) was to describe one out of two scenarios: buying a sweater or having witnessed an accident. For the former, participants had to pretend to buy a sweater. In the second scenario the video speaker was explained that they had witnessed an accident in which a car hit a person and that they had to explain to a police officer what had happened.

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For the present study, we selected videos that featured at least one iconic hand gesture, i.e. a gesture that conveys or indicates concrete meanings (McNeill, 1992), resulting in a total of 29 videos, of which 19 videos featured speakers with aphasia and 10 videos featured non-brain damaged comparison speakers. The preselected videos featured 11 speakers with aphasia (age $M = 55.82$, $SD = 14.22$, 5 female, 11 right-handed) and 10 non-brain damaged speakers (age $M = 50.80$, $SD = 11.60$, 7 female, 10 right-handed). Eight of the speakers with aphasia appeared in two videos, responding to both scenarios. All video speakers were native speakers of Dutch and provided informed consent for using their data, including video materials, for research purposes. For individual clinical characteristics of the speakers with aphasia see Table 1. Detailed information about each video stimulus including participant ID, participant group, the number of gestures, video duration, and gesture rate in terms of gestures per seconds can be found in Appendix A, table A1.

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Table 1 Details of speakers with aphasia (as also reported in Mol et al., 2013; Van der Meulen et al., 2010)

Participant ID	Gender	Age	Years of formal education	Aphasia type ¹	Time after onset (months)	Apraxia ² (0-18)	Communicative ability ³ (10-50)	Aphasia severity ⁴ Score (0-50)	Hemiplegia ⁵
1	Female	29	6	Global	2	5	10	50	-
2	Male	64	9	Global	101	8	10	50	-
3	Female	50	15	Broca	47	12	31	50	hemiparese
4	Male	69	15	Non- classifiable	73	16	19	41	hemiparese
5	Male	67	17	Global	3	18	13	45	hemiparese
6	Female	40	10	Broca	40	14	28	13	no / minimal
7	Male	71	10	Global	67	14	10	47	hemiparalyse
8	Male	52	9	Global	4	-	10	50	hemiparalyse
9	Female	66	13	Wernicke	1	14	29	48	no / minimal
10	Male	65	10	Broca	5	13	0 ⁶	26	-
11	Female	41	10	Unknown	23	18	34	42	hemiparese

¹Aphasia type was based on clinical judgement, ²Apraxia was assessed with a non-validated pantomime-to-command task in which speakers had to perform certain actions (e.g., pretend to put a key in a lock). Lower scores are indicative of more difficulties on this task, ³Communicative ability was assessed with the Amsterdam–Nijmegen Everyday Language Test (Blomert et al., 1994); ⁴Aphasia severity was assessed with the Token Test. Higher scores indicate a more severe aphasia (Graetz et al., 1991), ⁵Assessed by a physiotherapist and rehabilitation physician. ⁶This participant has a score of zero because he was unable to perform the test due his severe verbal production deficits.

2.2. Coding of Video data

2.2.1. Speech coding

For speakers with aphasia, we determined how much information was conveyed solely in their verbal speech signal (thus, not considering the visual speech signal in any form). For this analysis we adopted the Dutch version of the Amsterdam-Nijmegen Everyday Language Test (ANELT) for determining information in speech (Blomert et al., 1994), see Appendix B. In this scoring method, the level of communicative effectiveness is determined by the adequacy of communicating a message. The responses for every item are scored on a five-point scale to determine the comprehensibility of speech (not at all – somewhat – mediocre – sufficiently – good).

All data were coded by the first and third author of this article, both native speakers of Dutch and speech and language therapists (SLT) experienced in the diagnosis of speakers with aphasia as well as scoring and assessing the ANELT. They agreed on 12 out of 19 codes (63.2%). For the other 7 videos, the coders only differed by one point in their score. All disagreements between coders were discussed and after careful interpretation of the coding scheme both coders agreed on a final code, which was used for the statistical analyses.

2.2.2. Gesture coding

For our analysis, we used the gesture segmentation conducted by Mol et al. (2013), who used the same video stimuli. All selected video stimuli contained iconic gestures, but the range and frequency of gesture types varied between speakers. On average speakers in the selected videos produced 5.93 ($SD. = 4.47$) gestures per video. In total our video stimuli contained 172 gestures. Mol and colleagues (2013) also coded the gesture type. Please note, this information was not used for the analysis in the present study. Nonetheless, we would like to provide an overview on the characteristics of the gestures presented in our video stimuli. According to the classification conducted by Mol et al (2013), 146 out of 172 gestures in the video can be considered as iconic gestures and the remaining 26 as non-iconic gestures. Videos featuring

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speakers with aphasia contained on average 6.47 ($SD=4.27$) iconic gestures and 0.74 ($SD=1.33$) non-iconic gestures per video. Videos featuring non-brain damaged speakers included on average 2.3 ($SD=1.49$) iconic gestures and 1.2 ($SD=0.92$) non-iconic gestures. Following, Mol et al. (2013) the gestures considered as iconic include the categories outlining/molding, object/enact, deictic, and handling. All other gestures were considered non-iconic gestures.

The gesture annotation program ELAN (Wittenburg, Brugman, Russel, Klassmann, & Sloetjes, 2006) was used to code whether video speakers had attended to their own gesture. This was determined by examining whether the speakers in the video gazed at their own gesture or elsewhere. The gaze direction of the video actors was coded while the sound of the video was on. A gesture was classified as ‘gazed at their own gesture’ either if the gaze of the speaker was focused on the gesturing hands, or if the gaze of the speaker was following the gestural movement at any time. For instance, if the speaker looked down while making a gesture in front of his or her chest, or the speaker pointed in one direction and their gaze followed the direction of the pointing gesture, then the gesture was classified as ‘gazed at their own gesture’. All other cases were coded as ‘gazed elsewhere’.

The initial coding of all 172 gestures was performed by the first author. 36 randomly selected gestures (20.93%) were coded by the second author to test inter-coder agreement. Both coders are experts in the field of gesture coding. Agreement was 77.7%. Inter-coder reliability as determined by kappa ($\kappa=.60$), was moderate (Landis & Koch, 1977). Gesture coding by the first author was used for the subsequent analyses.

2.3. Eye-Tracking study

2.3.1. Observers

Fifty-seven healthy volunteers (observers) participated in the eye-tracking study. 11 observers were excluded, because the tracking ratio (the proportion of time that eye movements were recorded) was lower than 75%. In participants with a low tracking ratio, the eye tracking device cannot detect the pupils very well. This can be due to various reasons, e.g., a low contrast

between the iris and the pupil, or anatomy of the eye etc. The final dataset of the eye-tracking study included data of 46 observers (13 male, age: $M = 21.09$, $SD = 2.84$). Ethical approval was obtained by the local ethics for recruiting students from Tilburg University who received course credits for their participation. All students provided informed consent.

Observers were seated in a soundproof booth in front of a SMI 250 Hz infrared eye-tracker (RED, SensoMotoric Instruments GmbH, Teltow, Germany), at a distance of 60 to 80 cm from the screen. They were instructed to follow the videos attentively, because they had to answer content-related questions (e.g., “*What type of T-shirt did the woman want to buy?*”) after randomly selected catch trials (11 out of 29 trials). Next, the experiment started with a 9-point calibration procedure. Calibration was repeated until the gaze accuracy was sufficient (within 1.5° visual angle on x- and y-coordinates). Each trial started with the presentation of a fixation cross (duration 1 sec.). The videos were presented on a 22” computer screen. All 29 videos (average duration 16.21 secs, $SD = 12.74$ secs) were presented to every observer. The videos were presented in a semi-random order, i.e. the order in which speakers with aphasia and non-brain damaged speakers were alternating was fixed. However, the order of speakers within the subgroups was random (e.g., the first two videos were always of speakers with aphasia, and the third of a healthy speaker, but the appearance of speakers within those groups was random). See Appendix C for the specific order in which the subgroups were presented. The videos featuring speakers with aphasia had a longer duration ($M = 20.37$ sec., $SD = 13.84$ sec.), than those of non-brain damaged speakers ($M = 8.30$ sec., $SD = 4.00$ sec., $t(23.01) = -3.53$, $p = .002$, Cohen’s $d = 0.36$).

2.3.2. Data Analysis

The eye movement recordings were pre-processed with the BeGaze™ analysis software (SensoMotoric Instruments GmbH, Teltow, Germany). Separate dynamic areas of interest (AOIs) were defined for the gesture, the face, and background (see Figure 1). The AOI were dynamic that means they changed their position and size over time and always covered the

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entire hand gesture (visible part of the hands and forearm) or face of the speaker in the video. Fixation detection threshold was set at a minimal duration of 100 ms and a maximal dispersion of 100 pixels. Only fixations of the right eye were included in the analyses. After pre-processing, eye fixation data were extracted from the BeGaze™ analysis software, and behavioral data were extracted from the ELAN software, for processing with Matlab 8.0.0.783 (Mathworks Inc., Natick).

Figure 1. Illustration of the Areas of interest (AOI). This series of video frames shows the trajectory of the AOIs gesture and face during a co-speech gesture. Please note that the AOIs were dynamic that means they changed their position and size over time and always covered the entire hand gesture (visible part of the hands and forearm) or face of the speaker in the video. The AOI face includes the entire violet area including the transparent and opaque part. The central part of the AOI is opaque to protect the speaker's anonymity.

Afterwards, we defined for the time window that comprised the stroke phase of every presented gesture, whether the gesture was fixated by a given observer (fixation = 1, no fixation = 0). For fixated gestures, we calculated the observer's fixation time in ms. Based on this we defined two variables of gesture attention: *Fixation frequency* and *Fixation duration*. Fixation frequency was calculated as the proportion of fixated gestures per video, i.e. the number of fixated gestures divided by the total number of gestures in a particular video. Fixation duration was calculated as the average length of gesture fixation per video. These variables were used to address each of our hypotheses. Parametric tests (*t tests* and *multiple linear regression*) were

used for normally distributed data (Royston, 1982), non-parametric tests (*Mann Whitney U-Test*, *Wilcoxon Sign Rank Test*, and *partial Spearman rank correlations*) for not normally distributed data. To account for differences in gesture use, we computed *Gesture frequency*, i.e. the number of gestures, and *Gesture duration*, i.e. the average duration of gestural movements (stroke phase), for each video. These variables were entered as control variables in our multiple regression and partial correlation analyses. Further, bivariate spearman rank correlations were computed between different variables of interest (see table 3). The variables Fixation frequency, Fixation duration, Gesture frequency, Gesture duration, and ANELT video score were computed at the level of individual videos. Therefore, correlations between these variables were computed at the level of individual video stimuli. The variables Aphasia Severity, Apraxia severity, and Time after stroke are speaker specific variables. Therefore, correlations between these variables were computed at the level of individual speakers. To compute the correlations between video and speaker related variables, video related variables from speakers, who contributed two video stimuli (see section 2.1 video data & speaker details), were averaged per speaker.

3. Results

3.1. The influence of video speaker on attention for gestures

Fixation frequency: Our results show that the frequency of the fixated gestures, i.e. the proportion of gestures that participants fixated, did not differ between videos featuring speakers with aphasia and non-brain damaged speakers (aphasia: 0.32 ± 0.04 ; non-brain damaged: 0.22 ± 0.04 , mean $\pm$ SEM, *Shapiro-Wilk Test of Normality* $p = .110$, independent sample t test $t(15.76) = 1.189$, $p = .252$, Cohen's $d = 0.49$), see Figure 2A. Note that gesture frequency was significantly higher for videos featuring speakers with aphasia than videos featuring non-brain damaged speakers (aphasia: 7.21 ± 0.92 ; non-brain damaged: 3.5 ± 0.34 , mean $\pm$ SEM, *Shapiro-Wilk Test of Normality* both groups $p < .001$, *Mann Whitney U-Test*, $Z = 2.587$, $p = .001$, $d =$

0.48). However, fixation frequency was not correlated with the gesture frequency (aphasia: $\rho = .11$, $p = .643$; non-brain damaged: $\rho = .10$, $p = .773$), see Figure 2B.

Fixation duration: We found that the average duration of gesture fixation was significantly longer for videos showing speakers with aphasia than videos showing non-brain damaged speakers (aphasia: $243.67\text{ms} \pm 10.68\text{ms}$; non-brain damaged: $164.65\text{ms} \pm 15.37\text{ms}$, mean $\pm$ SEM, *Shapiro-Wilk Test of Normality* $p = .305$, independent sample t test $t(12) = 2.66$, $p = .021$, $d = 1.23$), see Figure 2C. Note that gesture duration was longer in speakers with aphasia than in non-brain damaged speakers (aphasia: $1266\text{ms} \pm 81\text{ms}$; non-brain damaged: $738\text{ms} \pm 51\text{ms}$, *Shapiro-Wilk Test* $p = .252$ independent sample t test $t(23.40) = 3.973$, $p < .001$, $d = 1.40$). To evaluate whether the longer fixation duration in speakers with aphasia depended on the longer duration of their gestural movements, we conducted a multiple regression analysis including the factors Speaker type (aphasia; non-brain damaged) and Gesture Duration and the dependent variable Fixation duration. The results of the regression analysis (multiple linear model, $R^2 = 0.43$, $F(3,23) = 5.883$, $p = .004$, see Table 2) indicate that both predictors (Speaker type and Gesture duration) explain a significant amount of variance in the dependent variable Fixation duration (Speaker type: $\beta = 236.77$, $t(23) = 3.120$, $p = .005$; Gesture duration: $\beta = 0.204$, $t(23) = 2.609$, $p = .016$). Gestures from speakers with aphasia and gestures with a longer duration were on average longer fixated. Further, a comparison of the sizes of beta estimates shows that the effect of Speaker type is larger than the effect of Gesture Duration. Moreover, our regression model revealed a significant interaction for Speaker type x Gesture duration ($\beta = -0.210$, $t(23) = -2.459$, $p = .022$), this effect may be explained by a statistical trend for a correlation between the Fixation duration and Gesture duration in the non-brain damaged speakers ($\rho = .58$, $p = .108$). In non-brain damaged speakers, gestures with a longer duration tended to be fixated for a longer time. There was no comparable pattern in speakers with aphasia (see Table 2 and Figure 2D).

Table 2. Summary of the regression analysis

	<i>beta</i>	<i>SE</i>	<i>t-value</i>	<i>p</i>
Constant	13.776	61.06	0.226	0.823
Speaker type	236.77	75.8805	3.12	0.005
Gesture duration	0.205	0.078	2.609	0.016
Speaker type x Gesture Duration	-0.21	0.085	-2.459	0.028

Note: $R^2_{\text{adjusted}} = 0.360$, $p = 0.004$

Since the video topics were restricted to two scenarios, we controlled whether the gaze behavior of the observers changes over time. For this purpose, we compared the fixation frequency and the fixation duration in the first and the second half of the experiment. Our results show that neither fixation frequency (1st half: 0.39 ± 0.04 ; 2nd half: 0.40 ± 0.04 , mean $\pm$ SEM, *Shapiro-Wilk Test of Normality* $p = .467$, paired sample t test $t(26) = -0.430$, $p = .671$, Cohen's $d = -0.05$) nor the fixation duration (1st half: $223.75\text{ms} \pm 13.68\text{ms}$; 2nd half: $215.38\text{ms} \pm 13.21\text{ms}$, mean $\pm$ SEM, *Shapiro-Wilk Test of Normality* $p = .111$, paired sample t test $t(24) = 1.027$, $p = .314$, Cohen's $d = 0.12$) differed between the first and the second half of the experiment.

Figure 2. The influence of video speaker (aphasia; non-brain damaged) on attention for gestures. In blue, data from videos including speakers with aphasia, in red data from videos including non-brain damaged speakers. (A) There was no difference in gesture fixation frequency between videos of speakers with aphasia and non-brain damaged speakers. (B) Gesture fixation frequency was not correlated with gesture frequency per video. (C) On average gestures produced by speakers with aphasia were fixated longer than gestures produced by non-brain damaged speakers. (D) In speakers with aphasia, Gesture fixation duration did not correlate with Gesture duration. In non-brain damaged speakers, longer gestures by healthy speakers tended to be fixated longer than shorter gestures ($\rho = .58$, $p = .108$). $*p < .05$.

3.2. The influence of speech comprehensibility and aphasia severity on attention for gesture

Next, we assessed how attention for gestures is related to speech comprehensibility (ANELT score), aphasia severity (Token Test), and apraxia severity (pantomime-to-command task).

3.2.1. Speech comprehensibility

Fixation frequency: We found a negative correlation between the information in speech (ANELT video test score) and frequency of gesture fixation ($\rho = -.65$, $p = .002$). Gestures of speakers with aphasia whose speech was less comprehensible were fixated on more frequently (see Figure 3A). This relationship could not be explained by gesture frequency (partial correlation of Fixation frequency and Information in speech, controlling for Gesture frequency, $\rho_{\text{partial}} = -.66$, $p = .003$). One impressive qualitative example for this relationship is provided by the two speakers with aphasia, who showed the highest gesture frequency (Speaker A: 20 gestures; Speaker B: 19 gestures), but a considerable difference in their gesture fixation frequency (Proportion of fixated gestures: Speaker A: 0.12; Speaker B: 0.57) (see Figure 2D). The gestures produced by Speaker A, who obtained a ANELT score of 4 (the message is comprehensible, but incomplete), were less frequently fixated than the gestures produced by Speaker B, who obtained a ANELT score of 1 (verbal production is completely incomprehensible)

Fixation duration: We observed a positive correlation between the average duration of gesture fixation and Information in speech ($\rho = .55$, $p = .017$). We observed that gestures of speakers with aphasia who produced more comprehensible speech were fixated on longer (Figure 3B). This relationship could not be explained by gesture duration (partial correlation between Fixation duration and Information in speech, controlling for Gesture duration, $\rho_{\text{partial}} = .57$, $p = .018$).

3.2.2. Aphasia severity

Fixation frequency: Aphasia severity (Token Test error rate) correlated positively with the gesture fixation frequency ($\rho = .69, p = .019$) suggesting that gestures of more severely affected speakers got fixated more frequently.

Fixation duration: Aphasia severity did not correlate with the average duration of gesture fixation ($\rho = -.02, p > .05$).

3.2.3. Apraxia severity

Fixation frequency: There was statistical trend for a negative correlation of apraxia severity (assessed with a non-validated pantomime-to-command task) with the gesture fixation frequency ($\rho = -.62, p = .058$) suggesting that gestures of more severely affected speakers got fixated more frequently.

Fixation duration: Apraxia severity did not correlate with the average duration of gesture fixation ($\rho = -.30, p > .05$), see Table 3 for all correlation outcomes.

Figure 3. The influence of speech comprehensibility on attention for gesture (A) We found a negative correlation between speech comprehensibility (ANELT video scoring) and gesture fixation frequency. This suggests that gestures from speakers with less comprehensible speech were fixated more frequently. (B) In contrast, we observed a positive correlation between the ANELT score and the average fixation duration suggesting that the average gesture duration was longer if speech was more comprehensible.

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Table 3: Bivariate spearman rank correlations between the variables of interest.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
<u>Eye gaze</u>								
(1) Fixation frequency	1							
(2) Fixation duration	-0.45 ⁺	1						
<u>Gestures</u>								
(3) Gesture frequency	0.11	-0.27	1					
(4) Gesture duration	0.36	0.00	-0.03	1				
<u>Speakers with aphasia</u>								
(5) Speech comprehensibility (ANELT score per Video)	-0.65**	0.55*	-0.34	-0.19	1			
(6) Aphasia severity (Token Test error rate)	0.69*	-0.02	-0.03	0.19	-0.40	1		
(7) ¹ Apraxia severity	-0.62 ⁺	-0.30	0.15	-0.01	0.34	-0.59 ⁺	1	
(8) Time after onset (months)	-0.40	0.22	-0.43	-0.56 ⁺	0.24	-0.11	-0.07	1

Variables 1-5 (N = 19 videos): Variables 6-8 (N = 11 speakers); + p < .1; * p < .05; ** p < .01, ¹Apraxia was assessed with a non-validated pantomime-to-command task in which speakers had to perform certain actions (e.g., pretend to put a key in a lock)

3.3. *The influence of the speakers' gaze to their own gestures*

Fixation frequency: First, we analyzed the gesture fixation frequency at the level of individual gestures pooled across speaker types (aphasia; non-brain damaged). As expected, we found that the proportion of gestures that were fixated on was higher for gestures which were gazed at by the speaker (Speaker's gaze on gesture: 0.35 ± 0.03 ; Speaker's gaze elsewhere: 0.25 ± 0.02 , mean $\pm$ SEM, Shapiro-Wilk Test of Normality $p < .001$, *Mann Whitney U-Test*, $Z = 2.18$, $p = .029$, $d = 0.16$).

In a second step, we computed gesture fixation frequency for each gaze direction at the level of individual videos. Pairwise post-hoc comparisons revealed no differences in gesture fixation frequency between different speaker types (aphasia; non-brain damaged) for different gaze directions (aphasia Gaze on gesture: 0.34 ± 0.06 ; non-brain damaged Gaze on gesture: 0.19 ± 0.09 ; aphasia Gaze elsewhere: 0.29 ± 0.04 ; non-brain damaged Gaze elsewhere: 0.24 ± 0.09 , *Wilcoxon Sign Rank Test*, all p-values holm-corrected $> .65$).

Note that we found no difference between speakers with aphasia and non-brain damaged speakers in how often they gazed at their own gestures in the videos (proportion of gazed gesture in speakers with aphasia: 0.34 ± 0.05 ; non-brain damaged: 0.41 ± 0.07 , *Shapiro-Wilk Test* $p = .061$ independent sample t test $t(13.33) = -0.512$, $p = .617$, $d = 0.23$). The relative high rate of gestures that were fixated by the speaker might be explained by the pre-selection of videos that feature iconic gestures, because speakers merely highlight iconic gestures with their eye gaze (Streeck, 1993).

Fixation duration: Again, we first analyzed the average fixation duration at the level of individual gestures pooled across speaker types. In contrast to our analyses for fixation frequency, gaze direction had no impact on the gesture fixation duration. Gestures that were gazed at by the speaker were not fixated longer than gesture during which the speaker was gazing elsewhere (Gaze on gesture: $82.03\text{ms} \pm 9.70\text{ms}$; Gaze elsewhere: $57.55\text{ms} \pm 5.06\text{ms}$,

Shapiro-Wilk Test of Normality $p < .001$, *Mann Whitney U-Test*, $Z = 1.43$, $p = .152$, $d = 0.10$).

As before, we computed the fixation duration for each gaze direction at the level of individual videos. Pairwise post-hoc comparisons revealed no differences in the average gesture fixation duration between different speaker types (aphasia; non-brain damaged) for different gaze directions (aphasia $\text{Gaze on gesture: } 78.10 \text{ ms} \pm 16.91 \text{ ms}$; non-brain damaged $\text{Gaze on gesture: } 31.44 \text{ ms} \pm 18.43 \text{ ms}$; aphasia $\text{Gaze elsewhere: } 64.30 \text{ ms} \pm 8.99 \text{ ms}$; non-brain damaged $\text{Gaze elsewhere: } 49.92 \text{ ms} \pm 19.21 \text{ ms}$., *Wilcoxon Sign Rank Test*, all $p\text{-values}_{\text{holm-corrected}} > .25$)

4. Discussion

The present study investigated whether gestures attract more attention if they have a higher communicative relevance because they are produced by speakers with aphasia, who have impaired verbal production. For this purpose, we recorded eye movements of healthy observers, while they were watching short video clips featuring speakers with aphasia and non-brain damaged speakers describing either a shopping or a car accident scenario. We found that hand gestures produced by speakers with aphasia were on average longer attended than gestures produced by non-brain damaged speakers. This effect was still present after accounting for the longer gesture duration in speakers with aphasia. Our findings support the notion that communicative importance guides attention for gesture. In the sections below, we discuss and interpret these results in the context of the current literature.

4.1. Observers fixate longer on gestures produced by speakers with aphasia

Our results show that gestures produced by speakers with aphasia were fixated for a longer time. This supports our hypothesis (H1) that gestures produced by speakers with aphasia attract more attention than gestures produced by non-brain damaged speakers. Please note that, speakers with aphasia usually produce more gestures per 100 words than non-brain damaged speakers (de Beer et al., 2019; McNeill, 1992; Preisig et al., 2018; Sekine et al., 2013). Consistent with previous studies, speakers with aphasia in our videos also showed a higher

gesture frequency and a longer duration of the gestural movements. However, we found no correlation between gesture frequency and the proportion of the fixated gestures in our videos. Moreover, the results of the regression analysis showed that both speaker type and gesture duration predicted the gesture fixation duration. Further, our analysis revealed a significant interaction between speaker type and gesture duration. However, the interaction was driven by a statistical trend for a correlation between the fixation duration and gesture duration in the non-brain damaged speakers. Observers tended to fixate longer gestures produced by non-brain damaged speakers for a longer time. We found no evidence for a similar relationship in speakers with aphasia (see Figure 2D). This implies that attention to gestures in speakers with aphasia may not only be the result of an enhanced gesture frequency and longer gesture duration, but also depends on communicative importance. The gestures produced by speakers with aphasia may be attended to longer because they are more important in order to disambiguate the impaired verbal output. In line with theoretical models (de Ruiter, 2000; Kita & Özyürek, 2003), our findings suggest that addressees adapt their listening strategies under challenging listening conditions. If one communication channel is disrupted, as the verbal channel in speakers with aphasia, listeners reallocate their attention and focus more strongly on another communication channel, i.e. co-speech gestures. This finding advocates for a communicative function of co-speech gestures and it implies that the extra effort that speakers with aphasia put into gesture is worthwhile, as interlocutors seem to notice their gestures. We would like to emphasize that this finding may not generalize to speakers, who produce only non-iconic gestures, because the video stimuli were preselected such that they contained at least one iconic gesture.

4.2. Less informative speech relates to more attention for gesture

Our results also support H2 by showing that the severity of speakers' verbal production deficit was correlated with the attention deployed to their gestures. More specifically, gestures from speakers with aphasia who produce less informative speech and who showed more severe

aphasia were attended to more frequently. This indicates that listeners search more frequently for additional information conveyed by gestures if they are confronted with a speaker who is less comprehensible. At the same time, the gestures of speakers who could produce more informative speech were attend to for a longer time. This is no contradiction; gestures may be only fixated on longer if the information provided in gestures can be integrated with information coming from the speech signal to disambiguate the content of the utterance. If gesture-speech integration becomes more difficult due to more severe verbal production deficits or co-occurring apraxia of the speaker, the observers may quicker shift their gaze away to search for additional information elsewhere. Consistent with the idea that the gesture benefit depends on the ability to integrate gestures and speech, Drijvers and colleagues (2019) found that visual attention to gestures predicted gestural benefit during degraded speech comprehension only in native, but not non-native listeners. It is conceivable that this is because only native listeners could integrate degraded speech and co-speech gestures. In summary, these findings suggest that the more important a gesture is for communication the more attention it will receive. This finding adds to the claim that co-speech gestures have a higher communicative importance for speakers with aphasia (Rose, 2006; Rose et al., 2017). One limitation of the present study is that we did not assess speech comprehension on trial-by-trial basis. This means that each observer could have comprehended different spoken information from each video stimuli. In this study, we found a relation between a global measure of speech informativeness and attention to gestures, hence future studies may test the link between speech comprehension and visual attention for gestures more directly. For example, by asking the observers to rate the speech informativeness after watching the video. Further, previous studies indicate that the co-occurrence of apraxia, an impairment of the ability to perform skilled, purposive limb movements (Ochipa & Gonzalez Rothi, 2000) can influence the comprehensibility of the gestures (Feyereisen et al., 1988; Hogrefe et al., 2017). Thus, it is conceivable that limb apraxia

influences gesture directed attention. In the present study, we found only a statistical trend between the apraxia score of the speakers and the frequency of gesture fixation. However, the generalizability of this result may be limited because the obtained apraxia scores were based on non-validated pantomime-to-command task. Moreover, the variability of individual apraxia scores in our sample was low. This suggests that further research is needed to gain more insights about the role of apraxia in gesture directed attention.

4.3. Speaker's attention for their own gestures influences the observer's attention for them

Finally, we found that the speakers' gaze towards their own gestures increased observers' attention to these gestures. This finding supports H3 and is line with previous research in this domain (Gullberg & Kita, 2009). We did not find a difference between speakers with aphasia and non-brain damaged speakers in the effect of their own gaze on the observer's attention for their gestures. Further, we found no difference between speakers with aphasia and non-brain damaged speakers in how often they fixated on their own gesture in our videos.

4.4. Clinical implications

Gestures from non-brain damaged individuals attract only a minor portion of attention (Beattie et al., 2010; Gullberg & Holmqvist, 2006; Preisig et al., 2015). In the current study, we showed that gestures made by speakers with aphasia receive considerably more attention from observers. In speech and language therapy, persons with moderate to severe aphasia often learn to make use of *Total Communication*, i.e. the use of all available communication channels (speech, writing, facial expressions, gestures etc.) (Pierce et al., 2019). For example, speakers with aphasia may be instructed to produce gestures more frequently or to use specific types of meaningful gestures to convey the intended meaning when the expression in speech fails. Further, gesture therapy may stimulate word retrieval (Krauss & Hadar, 1999; Rauscher et al.,

1996), but see also the following references, which question the benefit of hand gestures for word retrieval (Kısa et al., 2021; Lanyon & Rose, 2009).

Several studies have shown that gestures from speakers with aphasia can be comprehensible. These gestures convey information that could not be expressed in speech and thus help non-brain damaged interlocutors to identify the intended meaning (de Beer et al., 2017; Mol et al., 2013; Rose et al., 2017; van Nispen et al., 2017). However, partners and relatives of speakers with aphasia often do not pay attention to the non-verbal communicative attempts made by speakers with aphasia and focus solely on verbal communication. Therefore, recent treatment programs have been developed in which relatives of speakers with aphasia are trained to become more aware of the speakers' nonverbal communication repertoire. An examples of this type of intervention is SPPARC (Supporting Partners of People with Aphasia in Relationships and Conversation) (Lock et al., 2020). However, interventions like SPPARC are not yet commonly applied in speech and language therapy. Too often, SLTs focus only on improving the communication of the person with aphasia. The results of our study support the view that SLTs working with person with aphasia should help both communication partners. Nevertheless, gestures produced by speakers with aphasia are often harder to interpret than those produced by non-brain damaged speakers (Duffy et al., 1984; Hogrefe et al., 2013; Mol et al., 2013; van Nispen et al., 2017). One reason for this is that certain gesture types are unique to persons with aphasia, e.g. some speakers with aphasia sometimes try to 'draw' objects in the air (van Nispen et al., 2016). That's why attempts have been made to practice certain gestures using a computer gesture therapy tool (GeST) (Marshall et al., 2013). The results show that the comprehensibility of the trained gestures improves. However, the effects were small and did not generalize to untrained gestures.

While our study showed that interlocutors pay more attention to the gestures by speakers with aphasia, we did not investigate to what extent the additional information in gestures supported

speech comprehension. Future research should therefore examine whether a training of communication partners would enhance gesture directed attention and thereby the communicative effectiveness of speakers with aphasia. In such a training, interlocutors of speakers with aphasia could learn ways to unravel the meaning of speakers with aphasia's gestures and receive information on the type of gestures made by persons with aphasia.

4.5. Conclusion

In sum, we found that gestures produced by speakers with aphasia attract more direct visual attention than gestures from non-brain damaged speakers. This suggests that listeners search for additional non-verbal information in gestures if speech comprehension is challenging due to the speaker's verbal production deficits. This work could have implications for aphasia therapy. Our results advocate for instructing people with aphasia to communicate things in the form of gestures that cannot be expressed verbally because interlocutors take notice of their gestures.

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Appendix A: Video stimuli

Table A1

Video ID	Participant ID	Group	Number of gestures per video	Duation [secs]	Gesture rate [secs]
s-12-t	1	PWA	9	11.22	0.8
s-24-o	2	PWA	7	18.35	0.38
s-24-t	2	PWA	2	8.27	0.24
g-26-o	3	PWA	4	23.2	0.17
g-26-t	3	PWA	4	8.85	0.45
s-36-o	4	PWA	5	39.57	0.13
s-41-o	5	PWA	7	27.45	0.26
s-41-t	5	PWA	3	10.31	0.29
g-60-o	6	PWA	10	27.13	0.37
g-60-t	6	PWA	1	4.72	0.21
s-65-o	7	PWA	8	14.56	0.55
s-65-t	7	PWA	9	11.65	0.77
s-80-o	8	PWA	20	45.88	0.44
s-80-t	8	PWA	7	28.33	0.25
s-94-o	9	PWA	6	46.02	0.13
s-94-t	9	PWA	5	14.45	0.35
s-111-o	10	PWA	6	15.44	0.39
g-125-o	11	PWA	19	41.34	0.46
g-125-t	11	PWA	5	24.22	0.21
PPN2-o	12	NBDP	2	8.73	0.23
PPN3-o	13	NBDP	3	12.37	0.24
PPN4-t	14	NBDP	5	8.44	0.59
PPN8-t	15	NBDP	4	13.98	0.29
PPN9-o	16	NBDP	7	14.48	0.48
PPN10-o	17	NBDP	4	5.92	0.68
PPN11-o	18	NBDP	2	4.17	0.48
PPN12-t	19	NBDP	2	5.2	0.38
PPN15-o	20	NBDP	1	6.09	0.16
PPN17-o	21	NBDP	5	11.73	0.43

Note. PWA = Person with aphasia; NBDP = Non-brain damaged participants

Appendix B: Speech coding

Table B1 Classification of information conveyed in speech on a scale from 1-5, based on the ANELT (Blomert, Koster, & Kean, 1995)¹ with dutch examples per scenario [english translation].

Score	Definition	Example sweater ²	Example accident ³
1. Not at all	Fully incomprehensible. No production of words, or only irrelevant words or sounds e.g. “and, and”	“zo he” [like, yeah]	“Ik weet weer de” [I know, again the]
2. Somewhat	There is somewhat comprehensible verbal production. For instance demonstrative pronouns (combined with pointing) and onomatopei.	“die, die, die” [this, this, this]	“tatu tatu tatu” [Weeeoo, weeeo, weehoooh] “hier en hier en hup” [Here and here and hop]
3. Mediocre	The message shows semantic relation to the target. However, it is incomplete. This score encompasses semantic parafasias (e.g. “bus” instead of car). For the accident scenario this means communication of only one relevant preposition.	“(T-)shirt”/ “overhemd” [(t-)shirt]/ “blouse” [blouse]/ “kopen” [buy]/ “Hebben” [have’] / “Nodig” [need] “even kopen alstublieft” [just buy please] “ik wil een eh, ik wil zo een” [I want a ehm, I want one like]	“us” [bus] / “wandelaar” [walker] / “gevallen” [fell] / “auto” [car]/ “fiets” [bike] / “ongeluk” [accident]/ “botsing” [crash] / “doorgereden” [drove]/ “slachtoffer” [victim] “bulance” [(am)bulance] “ehm auto, ehm roodje” [ehm car, ehm, rove – neologism] “die ene is weg, die andere is blijven liggen” [this one is gone, the other is laying here]
4. Sufficiently	The message is comprehensible, though incomplete. For the accident scenario at least two prepositions are communicated, though the link between these prepositions is not clear (e.g. “bike and ehm accident”)	“trui” [“sweater”]	“fiets en ehm auto” [bike and ehm car/ “Botsing en ehm slachtoffer” [crash and ehm victim] “fiets met ehm auto, en de auto en ehm werd uit, weg, ehm door” [bike

			<i>and ehm car and ehm was out, away ehm through]</i>
5. Good	All prepositions are named and a listener is able to understand the utterance correctly without seeing the video.	“(Ik wil een) trui kopen” [(I want to) buy a sweater/ “Ik zoek een trui” [I (am) looking for a sweater]/ “Ik wil een trui hebben”[I want a sweater]/ “Ik heb een trui nodig” [I need a sweater]	“Fietser aangereden door een auto” [biker hit by car]/ “De auto heeft deze meneer aangereden” [the car hit this man]

¹Prepositions for sweater scenario: Sweater; (to) buy(ing) / look(ing) for / (I) need / (I) want

²Prepositions for accident scenario: car; accident / (was) hit ; bicycle / man / mister / boy

Appendix C: Eye-tracking study

Table C1 Order in which the videos of the subgroups were presented to the observers (within those subgroups the order was random).

Order of the video	Subgroup featuring in the video
1	speakers with aphasia
2	speakers with aphasia
3	Healthy speakers
4	speakers with aphasia
5	Healthy speakers
6	speakers with aphasia
7	Healthy speakers
8	speakers with aphasia
9	speakers with aphasia
10	Healthy speakers
11	speakers with aphasia
12	Healthy speakers
13	speakers with aphasia
14	Healthy speakers
15	speakers with aphasia
16	speakers with aphasia
17	speakers with aphasia
18	Healthy speakers
19	speakers with aphasia
20	speakers with aphasia
21	speakers with aphasia
22	Healthy speakers
23	speakers with aphasia
24	speakers with aphasia
25	Healthy speakers
26	speakers with aphasia
27	Healthy speakers
28	speakers with aphasia
29	speakers with aphasia