Demographic, neuropsychological, and speech variables that impact iconic and supplementary-to-speech gesturing in aphasia

Brielle C. Stark and Grace Oeding
Indiana University Bloomington

We model the role of demographic, neuropsychological and speech variables in characterizing iconic gesture use in speakers with aphasia, especially gestures that supplement speech and are essential for understanding the spoken message. Using backward regression modelling with cross validation in 37 speakers with aphasia, literature-derived demographic (e.g., age), neuropsychological (e.g., aphasia and anomia severity), and speech (e.g., speaking duration) variables were used to predict frequency and rate (per minute) of iconic, supplementary, and essential gesturing. We identified that nearly 60% of iconic gestures produced by speakers were supplementary to speech with 38% being essential for understanding the speech. Generally, those with more severe aphasia, anomia, and with nonfluent aphasia tended to produce fewer tokens and a slower rate of speech, and these were the speakers who produced more and a higher rate of supplementary and essential gestures. These findings underline the importance of iconic gestures to improve communication.

Keywords: gesture, aphasia, iconic, communication, language

Introduction

Aphasia, a disorder affecting expression and reception of language, often co-occurs with an increased use of manual gestures (Akhavan et al., 2018; Cocks et al., 2018; de Beer et al., 2019; Dipper et al., 2015; Stark & Cofoid, 2021). Manual gestures co-occurring with speech are common across all languages and cultures and are thought to provide benefits for both the listener and the talker (Kita, 2009). Of particular interest in aphasic gesture research are iconic gestures, which

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are semantically and temporally tightly related to speech (McNeill, 1992). An example of an iconic gesture is to use both hands to form the shape of a circle about 10 inches in diameter when describing a ball, such as, "I was playing basketball with this new ball I bought". In this example, the iconic gesture (circled hands) complements the speech because it gives some partially redundant information (i.e., we already know a ball is round) but also supplements the speech (i.e., we now know the size of the ball, which wasn't verbally mentioned).

Research has shown that speakers with aphasia tend to produce more gestures than age-matched peers, especially iconic gestures (e.g., Akhavan et al., 2018; Kong et al., 2015b; Kong et al., 2017; Özer et al., 2019), produce gestures that are closely semantically tied to speech (e.g., Cocks et al., 2011a; Pritchard et al., 2013, 2015; Sekine et al., 2013; Sekine & Rose, 2013; van Nispen et al., 2016), and may produce gestures especially in moments of word finding difficulty (Kistner et al., 2019). It should be noted that not all speakers with aphasia produce gestures that are semantically related to speech, especially individuals whose aphasia is characterized by limited access to semantic knowledge (e.g., Wernicke's aphasia) (Cicone et al., 1979; Sekine & Rose, 2013). This makes sense, given that theoretical models postulate that the semantic knowledge system is an interface shared by gesture and speech (Kita, 2010; McNeill, 1992). These theories explain why gesturing is often preserved when speech is affected and why both gesture and speech can be affected in the case of semantic impairment.

The relationship of aphasia characteristics with iconic gesturing

Of particular interest to the current study are iconic gestures which are supplementary, and the extent to which individuals with aphasia employ these types of gestures. Supplementary, iconic gestures add to, disambiguate, or replace speech (Akhavan et al., 2018; de Beer et al., 2020; Kong et al., 2015b; Kong et al., 2017; van Nispen et al., 2017). Kong et al. (2015b), in a large group of speakers with aphasia (Cantonese speakers) compared to a non-brain damaged peer group, evaluated communicative functions of gesture during three monologue narratives across eight communicative functional categories: providing additional information (giving information in addition to the language content, a type of supplementary gesture), enhancing language content (giving the same meaning to / being redundant with the language content), providing alternative means of communication (carrying meaning when no speech is present, a type of supplementary gesture), guiding and controlling speech flow (reinforcing the rhythm of the speech), reinforcing speech prosody and intonation (emphasizing meaning of speech, a type of redundant gesture), assisting lexical retrieval (facilitating word-retrieval in the presence of speech errors i.e. long pauses, interjections, word-finding behavior, and circumlocutions), assisting sentence construction (modifying syntactic structure or sentence structure), and no specific communicative function (does not demonstrate any of the above functions). In the aphasia group, Kong et al. (2015b) identified 208 iconic gestures (only three subjects did not produce any gestures), of which 22.1% were 'adding' gestures (i.e., supplementary to speech) and 74.5% were 'enhancing' (i.e., redundant with speech) gestures. Prevalence of many categories was very low (3.4% for providing alternative means to communicating, and 0% for all other communicative function types, including lexical retrieval). Speakers without brain damage tended to add information less often (10.4%) than speakers with aphasia (22.1%) and enhance information more often (84.3%) than speakers with aphasia (74.5%). Similar to the gestures produced by speakers with aphasia, the other gesture communicative function types were not often represented in the non-brain damaged speakers (0.9% providing alternative information and 4.3% assisting in lexical retrieval). Kong et al. (2015b)'s results suggest that speakers with aphasia use more iconic gestures than controls (6.4% of gestures in aphasia group were iconic vs. 3.5% in control group) and that these gestures tend to add to speech more often than iconic gestures produced by speakers without aphasia. Exploratory analysis by Kong et al. (2015b) demonstrated that speakers with more severe aphasia were those that tended to produce more gestures, and that speakers with particularly impaired naming (as measured by a lower score on a naming battery) tended to produce gestures more frequently. However, Kong et al. (2015b) did not directly evaluate the relationship of aphasia severity or anomia severity with gesture function, such as proportion of gestures that added information. A follow-up study found that speakers with fluent and non-fluent types of aphasia both tended to gesture to enhance the speech content (Kong et al. 2015a), indirectly assessing the impact of aphasia type on supplementary gesturing.

Van Nispen and colleagues (2017) evaluated gestures produced by 46 speakers with aphasia and nine non-brain-damaged speakers during semi-structured conversation, and extended the work done by Kong and colleagues by evaluating the extent to which adding gestures provided essential information, i.e., provided information that was absent in speech and was essential for understanding the message. First and foremost, all except one talker from the aphasia group produced an iconic gesture, which accounted for approximately one-fifth of all gestures produced by this group. Despite high heterogeneity in gesture production (which is demonstrated in all gesture studies, whether the speakers have aphasia or not), 28 speakers with aphasia (58%) had greater than 14% of their gestures tagged as essential for understanding their communicative message. Across all gesture types (not only limited to iconic gestures), more than 70% of gestures were redundant with speech. For only iconic gestures in the aphasia group, the mean percentage of gestures that were found to be essential was >15% (a much higher value than for any other gesture type), suggesting that iconic gestures tended to be the ones used to carry essential information. Altogether, this study demonstrated considerable use of essential gestures by speakers with aphasia compared to a non-brain damaged group. van Nispen et al. (2017) did not find a significant relationship between the proportion or number of essential gestures and aphasia severity. Similarly, they did not find a significant relationship between proportion or number of essential gestures and the Western Aphasia Battery's Information in Speech score, which is a categorical score derived by the content produced during a spontaneous narrative. Together, these results add to the results from Kong and colleagues, in that aphasia severity relates to overall number of iconic gestures produced, but perhaps not to one communicative function of iconic gestures (essentialness). van Nispen et al. (2017) did not evaluate the relationship of essential gestures with a direct measure of anomia, such as accuracy on a naming test.

A study in eight speakers with aphasia evaluated several functional categories of gestures (matching, complementary, compensatory, social cueing, and facilitating lexical retrieval), finding too that speakers with aphasia heavily relied on iconic gestures during event description and that the degree of compensation (a form of supplementing speech) varied with the extent of their language impairment (Akhavan et al., 2018). This study suggests a direct relationship with expressive language impairment and supplementary gestures (greater language impairment associating with more supplementary gestures), though the number of individuals with aphasia studied was small. A perceptual rating study conducted by Hogrefe et al. (2013) complemented this finding, revealing that some speakers with aphasia, especially when their aphasia was more severe, tended to convey more information in gesture than they did in speech.

A sample of 29 individuals with aphasia, who engaged in procedural discourse ('how to' narrative, similar to what we are evaluating in the current paper), tended to use a similar frequency and amount of iconic gestures compared with age-similar non-brain-damaged controls (Pritchard et al., 2015). Yet, speakers with aphasia tended to convey richer semantic information in their gestures, which was coupled with semantically impoverished language, thus suggesting that supplementary gesturing occurs in procedural narratives (Pritchard et al., 2015). Most speakers with aphasia included in the study had anomic aphasia ($N=16$), which is the mildest type of aphasia and is characterized by anomia (word finding difficulties) alongside preserved auditory comprehension and repetition. However, authors did not delineate the extent to which aphasia severity, or production-specific abilities, such as anomia, contributed to gesture use. Another study further implicated the role of semantic knowledge, suggesting that iconic gestures produced during word finding difficulties is what set apart an aphasia and a control group (relating to a relationship between semantic knowledge and proportion of word finding difficulties) (Cocks et al., 2013). Understanding the relationship between anomia and supplementary gestures will help to delineate whether overall aphasia severity (including impairments in repetition, comprehension, and naming), aphasia type, and anomia severity (a purely lexical production impairment) most predict use of supplementary gesturing.

Altogether, these studies make clear that speakers with aphasia produce iconic gestures readily and use gestures that supplement speech information. These studies began to characterize the speakers with aphasia who produced supplementary gestures, evaluating the type or quality of information conveyed in gesture compared to the type or quality of information conveyed in speech, as well as the relationship of neuropsychological variables (like aphasia severity) to supplementary gesturing. An obvious next step is to directly evaluate how a range of important variables (demographic, neuropsychological, speech) relate to supplementary and, further, essential gesturing in aphasia.

The relationship of demographic and speech variables with iconic gesturing in aphasia

Demographic variables that may help to characterize the speakers who use supplementary iconic gestures include age and sex. Older adults more often fail to integrate or attend to iconic gestures when decoding multimodal speech information compared with young adults (Cocks et al., 2011b; Schubotz et al., 2021) yet older and younger adults are thought to produce iconic gestures during tip-of-the-tongue states equally often (Theocharopoulou et al., 2015). There may be some difference between younger and older adults in terms of the kinds of gestures they produce and the relationship of this with task, e.g., older adults may produce less representational (or iconic) gestures during specific tasks (Arslan & Göksun, 2021; Theocharopoulou et al., 2015). One reason for this may be due to a change in working memory with age, which may impact gesture use (Arslan & Göksun, 2021). It remains unclear the extent to which age impacts supplementary gesturing, especially in relation to aging with aphasia.

Sex is another variable of interest, given that known sex differences exist in gesture production developmentally, with boys producing gesture and speech combinations later than girls (Özçalişkan & Goldin-Meadow, 2010). However, the evidence for sex differences in gesture use in adults is sparse. We investigate the relationship of sex with gesture use in the current study because studies have suggested that aphasia rates are different in men and women following stroke, though these differences are highly related to age (with women experiencing stroke and aphasia later than men) (Wallentin, 2018).

Finally, gestures tend to co-occur with speech and are intricately tied to the speech channel, such that a longer speaking sample tends to associate with a larger number of gestures (Clough & Duff, 2020). This is often why the studies cited above, evaluating gesture in aphasia, model gesture types as proportion of total gestures. However, it remains unclear the extent to which speaking duration (number of words) and fluency (words per minute) associate with supplementary gesture usage in aphasia, in particular.

Altogether, the body of work evaluating gesture use in aphasia is growing and has provided crucial data for improving theory as well as providing strategies for improving communication in individuals living with aphasia.

Study summary and hypotheses

Here, in a relatively large sample of speakers with aphasia, we extend the literature by evaluating the extent to which demographic, neuropsychological and speech variables, considered together, characterize iconic gesturing, especially gestures which are supplemental and essential, during a procedural discourse task.

H1: Neuropsychological variables, including aphasia type, severity, and anomia severity, will be related to iconic gesturing as well as supplementary and essential gesturing

We hypothesize that the total number and rate of iconic gestures produced by our speakers with aphasia will be related to aphasia type (nonfluent producing more iconic gestures), aphasia severity (those with more severe aphasia producing more iconic gestures), and anomia severity (those with more severe anomia producing more iconic gestures). Whilst the literature on supplementary and essential gesturing and its relationship with demographic, neuropsychological, and speech variables is sparse, we anticipate finding that a higher proportion of supplementary and of essential gestures is produced by those with nonfluent, more severe aphasia (including those with more severe anomia).

H2: Speech variables, including sample length, will be related to iconic gesturing

We anticipate that a longer sample, measured in tokens, will associate with more iconic gestures). We do not anticipate finding a relationship with speech variables, in that a higher number or rate of supplementary or essential gestures will not be associated with sample length or speech fluency.

H3: We will clarify the role of age and sex on iconic gesturing

Given relatively sparse evidence motivating a directional hypothesis for these variables, we will examine the impact of these demographic variables on iconic, supplementary, and essential gesturing number and rate.

Materials and methods

Participants and task

Gesture and speech data from speakers with aphasia were gathered for this study from an online database, AphasiaBank (MacWhinney et al., 2011), which archives transcribed videotaped speech samples from speakers with aphasia alongside neuropsychological and demographic information. We analyzed a specific component of the AphasiaBank protocol, which had speakers with aphasia engage in spoken discourse elicitation. For this study, we focused our analysis of gesture during a procedural narrative, which requires participants to describe how they would make a peanut butter and jelly sandwich ("the Sandwich story"). Spatial language has been shown to correlate with a higher rate of iconic gesture use (Kita & Lausberg, 2008), and because the procedural narrative involves a 'how to' objective, it produces a higher amount of spatial language, which thereby associates with a higher proportion of iconic gestures. Further, prior studies in aphasia have also evaluated procedural narratives and found high rates of iconic gesture production (Pritchard et al., 2015; Stark & Cofoid, 2022).

To acquire our analysis sample, we first evaluated each individual's video. We marked whether each procedural narrative had sufficient video and audio quality, a straight on camera angle to enable accurate gesture annotation, and sufficient visibility of the gesture space (i.e., able to see gestures for entirety of narrative). Then, we further excluded any samples in which a physical picture was provided by the experimenter to the speaker during the procedural narrative (which occurs in ~20% of the AphasiaBank sample and is largely a product of each experimental site's protocol choices). The final sample selection was determined pseudo-randomly to include an approximately equal distribution of individuals with mild and moderate-severe aphasia as well as nonfluent and fluent aphasia.

A total of $N=37$ participants were ultimately included (Table 1). Demographic information and neuropsychological data was also drawn from the database.

Table 1. Demographic, neuropsychological, and speech independent variables (aphasia types and severity groups described in-text)

	Overall (*N* = 37)
Age	
Mean (SD)	63.7 (12.1)
Median [Min, Max]	63.2 [34.4, 83.6]
Education	
Mean (SD)	14.5 (2.31)
Median [Min, Max]	14.0 [12.0, 20.0]
Missing	2 (5.4%)
Sex	
Female	15 (40.5%)
Male	22 (59.5%)
Years Since Stroke	
Mean (SD)	6.83 (5.59)
Median [Min, Max]	5.10 [0.250, 25.8]
Dominant Hand Hemiparesis or Hemiplegia	
No	9 (24.3%)
Yes	28 (75.7%)
Boston Naming Test Percentage Correct	
Mean (SD)	0.485 (0.252)
Median [Min, Max]	0.533 [0, 0.933]
Speaking Duration in Tokens	
Mean (SD)	36.2 (31.0)
Median [Min, Max]	28.0 [4.00, 142]
Words Per Minute	
Mean (SD)	58.1 (32.0)
Median [Min, Max]	49.7 [21.8, 137]
Gesture Variables	
Frequency of iconic gestures	
Mean (SD)	4.35 (3.21)
Median [Min, Max]	4.00 [0, 14.0]
Proportion of supplementary gestures	

Table 1. *(continued)*

	Overall (N=37)
Mean (SD)	0.596 (0.38)
Median [Min, Max]	0.71 [0, 1.00]
Proportion of essential gestures	
Mean (SD)	0.38 (0.33)
Median [Min, Max]	0.33 [0, 1.0]
Rate (per minute) of iconic gestures	
Mean (SD)	7.67 (5.70)
Median [Min, Max]	7.27 [0. 24,.0]
Rate (per minute) of supplementary gestures	
Mean (SD)	5.85 (5.50)
Median [Min, Max]	5.00 [0, 24.0]
Rate (per minute) of essential gestures	
Mean (SD)	3.06 (3.30)
Median [Min, Max]	2.07 [0, 12.0]

Gesture type, communicative function and iconicity

Type

This study specifically focused on iconic gestures, which are semantically tied to speech. Our definition of iconic gestures was drawn from Sekine & Rose (2013): iconic gestures should depict a concrete action, event or object. We opted to not annotate gestures that were not iconic, and other hand movements were likewise not coded (i.e., brushing hair out of face, adjusting body).

Communicative function

Because our intention was to identify how gesture improved communication, we coded iconic gestures into two primary functions: redundant or supplementary. We chose to use two categories because of issues in rater reliability across many communicative function categories noted in other studies. For example, in Kong et al. (2015b]), rater reliability (measured using Kendall tau coefficient) ranged from 0.39 (poor) to 1.0 (excellent) across communicative function categories, despite good overall rater agreement for annotating iconic gestures (0.84). In van Nispen et al. (2017), this was similarly the case, with good inter-rater reliability for labelling iconic gestures (0.75), though relatively limited reliability for labelling gesture communicative function (0.67). These studies employed multiple gesture function categories. Coupled together, the wide ranges in rater agreement and limited prevalence of certain gesture functions suggests the need to reduce gesture communicative function categories to improve rater reliability as well as data robustness when evaluating the relationship between gesture communicative function and aphasia.

For supplementary gestures only, we then employed criteria from van Nispen et al. (2017) to rate the essentialness of the gesture. Specifically, van Nispen et al. (2017) define essentialness as a gesture that conveyed information absent in speech and was essential for understanding a message. We used information from the utterance in which the gesture occurred to determine this. See Table 2 for examples. Note that eight of the same speakers (from AphasiaBank) were evaluated in both our study and the van Nispen et al. (2017) study (Elman2a, Elman03a, Elman07a, Elman14a, Scale01a, Scale05a, Scale15a, Scale19a).

Table 2. Examples of gesture communicative function

Communicative function	Example from dataset
Redundant	Speaker says "yes" with simultaneous up-down head nods
	Speaker makes spreading motion whilst saying "spread it."
Supplementary *Adds, disambiguates, or replaces speech*	Speaker pretends to hold knife and spread peanut butter on bread, whilst stating, "You put it on the bread."
	Speaker produces hand movements as if to a throw a ball and says, "two points."
Essential *Conveys information absent in speech and essential for understanding message*	Speaker points to a location on the table and says "I put the bread here."
	Speaker holds up two fingers whilst saying "I get pieces of bread."

Gesture annotation

Iconic gestures and their communicative function were annotated by author GO using ELAN (Wittenburg et al., 2006). Each annotation included a tier system in ELAN, including: speech (the speech occurring at the moment of the gesture, which was automatically imported from the CHAT transcript from AphasiaBank [MacWhinney, 2000]), communicative function (supplementary or redundant), and essentialness (only coded if gesture was marked as supplementary). Examples of gestures from the data are given in Table 3. See Figure 1 for three examples each illustrating a different type of iconicity, a description of the gesture, the way the gesture was labelled in the study, and the accompanying speech utterance.

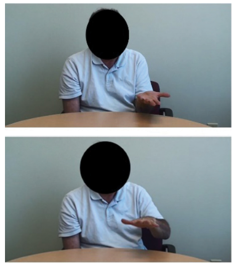
Iconicity	Handling	Object	Shape
			
Description	Talker acts as if holding an invisible sandwich. This is a "handling" gesture because talker acts as if using or holding the object, in this case, a sandwich.	Talker uses a two part gesture using one hand to represent two slices of bread. This is an "object" gesture because the talker is using his hands to represent the object (bread)	Talker draws circle with his finger to indicate the shape and location of the peanut butter jar.
Function	Supplementary and Essential	Redundant	Supplementary and Essential
Utterance	"&-uh it's hm &-uh",	"and &-um bread."	"and peanut butter right here."

Figure 1. Three examples each illustrating a different type of iconicity, a description of the gesture, the way the gesture was labelled in the study (Redundant or Supplement, and if Supplementary, if it was also Essential), and the accompanying speech utterance

Rater reliability

Author GO re-coded seven randomly selected samples to establish intra-rater agreement for iconic gestures and for supplementary gestures. There were approximately three weeks before initial coding and re-coding, and author GO did not consult prior ratings before re-rating. A research assistant, SF, performed inter-rater reliability with GO on a further ten randomly selected samples.

Gesture dependent variables

We had several dependent variables from the gesture data. First, we identified dependent gesture variables that quantified the amount of production: frequency of iconic gestures, proportion of supplementary gestures, and proportion of essential gestures. Proportions are helpful in that they take into account vast differences in length effects typically seen in aphasia, i.e., where the length of a sample greatly differs across speakers. We also identified dependent gesture variables quantifying the rate of production for each type (iconic overall, redundant, supplementary, essential), modelled per minute.

Neuropsychological variables

Aphasia severity was derived from the Aphasia Quotient (AQ) from the Western Aphasia Battery – Revised (Kertesz, 2007), a score that is computed using sub scores of Repetition, Auditory Comprehension, Naming and Word Finding, and Spontaneous Speech. An individual with an AQ of < 93.8 has clinical aphasia, and the maximum AQ score is 100.

Aphasia type was modelled dichotomously: non-fluent or fluent, as per definitions of the WAB.

Anomia severity was quantified using percentage correct from a confrontation naming test of objects (Boston Naming Test; BNT, Kaplan et al., 2000).

Speech variables

All transcripts were created using the Codes for the Human Analysis of Transcripts (CHAT) coding language (MacWhinney, 2000), which is a special coding language where transcribers employ codes to characterize transcribed speech (e.g., assigning a paraphasia code to an incorrect word), and where the companion analysis software CLAN (Computerized Language ANalysis; MacWhinney, 2018) automatically tags morphological and grammatical markers of speech. The transcripts were developed and coded by the respective labs involved in their collection, which was a variety of collection sites from the AphasiaBank project (MacWhinney et al., 2011).

Using the EVAL command in CLAN (Windows) version 14jul22, we extracted the following speech variables: speaking duration (in tokens) and words per minute (excluding repetitions, retracings, and unintelligible words).

Demographic information

We also explored the relationship between pre-selected demographic variables with dependent variables. Specifically, age at testing and sex. No data was available for limb apraxia (see Limitations). Data was available for hemiparesis, but we did not evaluate this further, given evidence suggesting no relation with gesture use (Kong et al., 2015b).

Analyses

To evaluate the relationship between dependent and independent variables, we employed a backward stepwise regression for each dependent variable (using AIC [Akaike information criterion] to remove variables) with 10-fold cross validation with five repeats using caret package in R. We chose backward stepwise regression given that some of the variables in our models are collinear and backward regression best takes this into account. We also chose backward regression given we have numerous predictor variables. Wherever independent variables were correlated with one another ($p < 0.05$ uncorrected), they were entered into the model as interactions (Figure 1). These interactions were: tokens and aphasia severity (AQ); tokens and aphasia type; tokens and anomia severity (BNT accuracy); tokens and words per minute; words per minute and AQ; words per minute and aphasia type; words per minute and BNT accuracy; BNT accuracy and AQ; BNT accuracy and aphasia type; and aphasia type and AQ. Outliers were explored for each dependent variable, and analyses were performed for the full dataset and for the dataset excluding outliers, if outliers were present. As such, a unique assembly of independent variables was used to predict each dependent variable.

Given a variety of analyses containing differing numbers of predictors and sample sizes, a post hoc power test was conducted to determine achieved power given alpha (0.05), sample size (outlier sample size used), number of predictors in the final model, and effect size (Cohen's f^2 computed using formula: $R^2/(1-R^2)$). Post hoc power analyses were done using G*Power 3.1.9.7.

All statistical analyses were computed using RStudio Version 1.4.1717, using R version 4.2.2.

Data availability

De-identified data used to run analyses, the coding document, and the R Markdown document, is available on our OSF page, https://osf.io/ehx7t (last access 12 January 2024). Video data, demographic information, and neuropsychological tests scores are available from AphasiaBank (aphasia.talkbank.org), upon membership (which is free) to the TalkBank project.

Results

Describing the sample of speakers

Within our sample, we had 14 individuals with Anomic aphasia (37.8%), 13 with Broca's aphasia (35.1%), five with Conduction aphasia (13.5%), four with Transcortical Motor Aphasia (10.8%) and one with Wernicke's aphasia (2.7%), thus equating to 20 speakers with a fluent type of aphasia (Anomic, Conduction, Wernicke's) and 17 speakers with a non-fluent type of aphasia (Broca's, Transcortical Motor Aphasia). Aphasia severity, as measured by the WAB Aphasia Quotient (AQ), was on average 72.7±12.9, ranging from 46.2 (severe aphasia) to 93.2 (mild aphasia).

There were five African American or Black speakers (13.5%), two Asian speakers (5.4%), and 30 White speakers (81.1%). Most were monolingual (89.1%), with two early childhood bilinguals (8.1%) and one late bilingual (2.7%). Apraxia of speech was present in 17 (45.9%), not present in 18 (48.6%), and unknown in two (5.4%). Dysarthria was present in five (13.5%), not present in 29 (78.4%) and unknown in three (8.1%). The severity of apraxia of speech and dysarthria was not available from the dataset.

Table 1 details most independent variables.

Table 3. Examples of gesture and speech

Subject	Aphasia type	Aphasia severity	Gesture function	Transcript (gesture is in bold and italics)
kurland10a	Anomic	85.1	Supplementary	make a [*indistinguishable sound*] with a corner for the kids *uses hand (flat hand shape, palm inwards, pinky down) to imitate cutting diagonally*
fridriksson09a	Anomic	90.2	Supplementary	just pred ["spread"] it on a on a trail [*unknown target word*] on the tots ["toast"] *holds left hand (flat hand shape, palm upwards) to represent bread and using right hand (flat hand shape, facing down) to represent a knife, spreads across the left hand*
kansas10a	Conduction	61.4	Supplementary	and I'd have a cough a thing *holds hands aloft, facing inwards towards each other, uses left hand (flat hand shape, palm upwards) to*

Table 3. *(continued)*

Subject	Aphasia type	Aphasia severity	Gesture function	Transcript (gesture is in bold and italics)
				represent bread and using right hand (flat hand shape, facing down) to represent a knife, spreads across the left hand
elman02a	Conduction	61.7	Supplementary	you parrots [*unknown target word*] tip [*unknown target word*] up and peel peel peel [*unknown target word*] deal *drags fingertips four times on the table making slight motions as if spreading*
elman03a	Broca	66.2	Supplementary	uh it's but it's [*pause*] it's uh *pretends to take bite of sandwich (hands are shaped as if holding a sandwich)*
elman03a	Broca	66.2	Redundant	it's a [*pause*] eat it [*laughs*] *brings fingers to mouth as if eating something*
kurland06	Not aphasic by WAB score	95.0	Redundant	and then put it together *holds hands facing inwards and touches palms together*
kansas15a	Anomic	91.5	Redundant	spread it with a knife *makes spreading motion with fist balled, as if holding a knife*

A correlation matrix between all variables is shown in Figure 2.

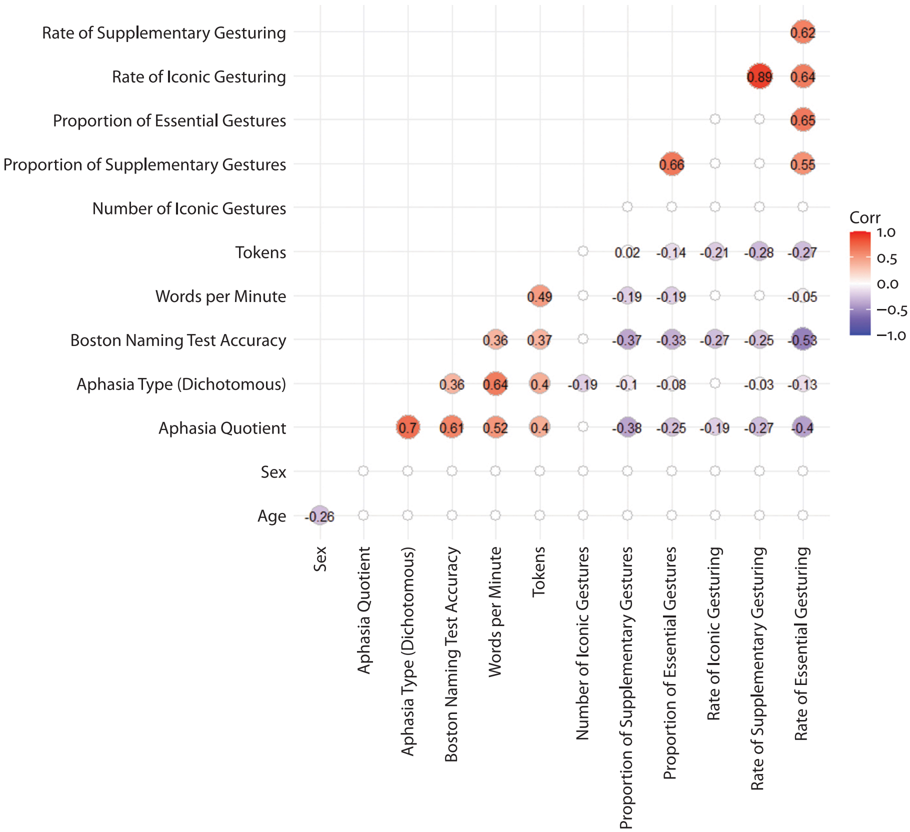


Figure 2. Correlation matrix showing demographic information, results of neuropsychological testing, speech variables, and our dependent gesture variables. Pearson's correlation r values where $p < 0.05$ (uncorrected) are shown

Rater agreement

We used intraclass correlation coefficient (ICC[2,1]) with absolute agreement to establish rater reliability, given that our variables were continuous (number of iconic and of supplementary gestures). We employed Koo & Li (2016)'s conservative criterion for reliability, where values below 0.50 indicated poor reliability, 0.50–0.75 as moderate reliability, 0.75–0.90 as good reliability, and above 0.90 as excellent reliability. For intra-rater agreement, we identified an ICC(2,1) = 0.843 (95% confidence intervals: 0.39, 0.97) for iconic gestures and ICC(2,1) = 0.92 (95% confidence intervals: 0.597, 0.99) for supplementary gestures, demonstrating strong intra-rater agreement. For inter-rater agreement, we identified an ICC(2,1) = 0.972 (95% confidence intervals: 0.89, 0.99) for iconic gestures and

ICC(2,1) = 0.943 (95% confidence intervals: 0.79, 0.99) for supplementary gestures. Therefore, average ICC values demonstrated good and excellent reliability.

Describing the dependent variables

Overall, 161 iconic gestures were coded, which equated to an average of 4.35±3.21 (med = 4) iconic gestures per participant. Four speakers produced no iconic gestures. There was a wide range of gesturing (0–14 iconic gestures per talker), as is typical in studies of gesture use, given known individual differences in gesturing (Özer & Göksun, 2020). Of these iconic gestures, 59.6% were supplementary (*SD* = 37.9, med = 71.4). Of the supplementary gestures, 37.8% (*SD* = 32.90, med = 33.3) were deemed to be essential for understanding the meaning of speech. The rate (per minute) was *M* = 7.67±5.70 (med = 7.27) for iconic gesturing, *M* = 5.85±5.50 (med = 5) for supplementary gesturing, and *M* = 3.06±3.30 (med = 2.07) for essential gesturing.

Table 1 shows the gesture dependent variables.

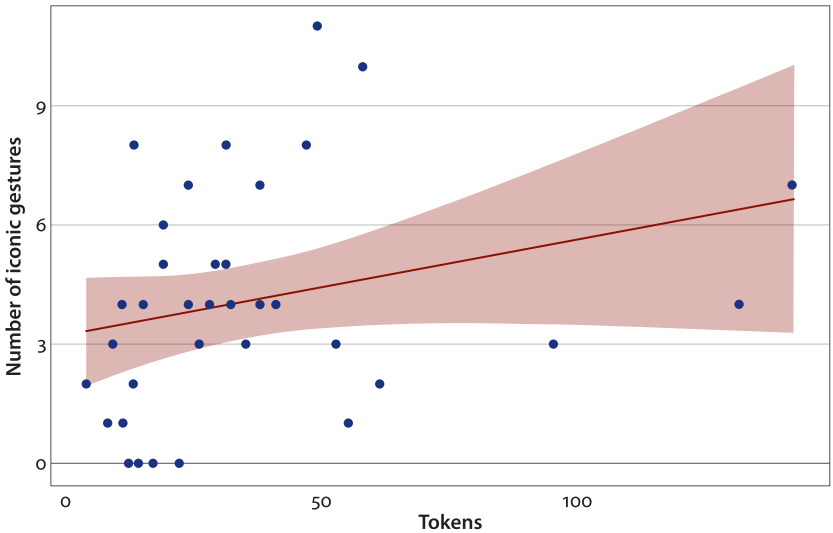
Gesture frequency and proportions

Iconic gestures

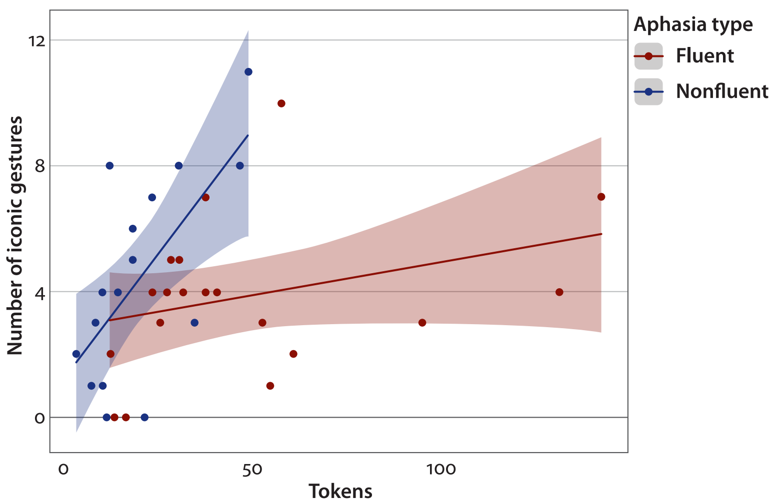
One outlier was identified for the total number of iconic gestures. For the full model, tokens ($\beta = 0.27$), and the interaction between tokens and dichotomous aphasia type (nonfluent, fluent) ($\beta = -0.12$) significantly related to number of iconic gestures (RMSE = 3.09±1.23, MAE = 2.41±0.88, $R^2 = 0.34 \pm 0.28$). A similar model was identified for the outlier-removed model, with tokens ($\beta = 0.27$) and the interaction between tokens and dichotomous aphasia type ($\beta = -0.10$) significantly related to number of iconic gestures (RMSE = 2.64±0.71, MAE = 2.13±0.60, $R^2 = 0.26 \pm 0.26$). The achieved power of the outlier-removed model was 86.82%, indicating sufficient power to identify an effect, given sample size (*N* = 36), predictors (2), large effect ($f^2 = 0.35$), and alpha probability ($\alpha = 0.05$). That is, speakers producing more tokens, and who tended to be nonfluent, produced more iconic gestures. Figure 3 demonstrates the relationship of tokens with number of iconic gestures (A), and the interaction of tokens with aphasia type on iconic gestures (B).

Proportion of supplementary gestures

No outliers were identified. Words per minute ($\beta = 0.016$), and the interaction between words per minute and aphasia severity (AQ) ($\beta = -0.0002$), significantly related to the proportion of supplementary gestures (RMSE = 0.40±0.09, MAE = 0.34±0.08, $R^2 = 0.19 \pm 0.20$). This model did not describe a large amount



A. Iconic gesture number and tokens (sample length)



B. Iconic gesture number interacting with aphasia type and tokens

Figure 3. The well-powered, outlier-removed analysis (*n* = 36) showing the implication of tokens, and the interaction of tokens with dichotomous aphasia type, on iconic gesture number

of variance, with relatively small regression coefficients and R^2. The achieved power of the outlier-removed model was 70.49%, suggesting that this analysis was slightly underpowered and would benefit from a larger sample size, even with the medium-large effect ($f^2 = 0.23$). The model suggests that those with more severe aphasia, who also tend to produce less fluent speech (fewer words per minute), produce a higher proportion of supplementary gestures. Generally, those with less fluent speech produce a higher proportion of supplementary gestures. This finding should be interpreted with caution given power considerations.

Proportion of essential gestures

No outliers were identified. The backward regression model retained two interactions but no main effects, suggesting a limited ability to predict the proportion of essential gestures. The two interactions were aphasia type with tokens ($\beta = 0.0005$) and anomia severity (BNT accuracy) with aphasia type ($\beta = -0.22$) (RMSE = 0.35±0.08, MAE = 0.28±0.07, $R^2 = 0.11±0.12$). This model was underpowered (42.13% achieved power), given the small-medium effect ($f^2 = 0.12$). This model provides weak evidence for anomia severity, nonfluent aphasia, and a larger number of tokens in predicting a higher proportion of essential gestures.

Gesture rate per minute

Iconic

One outlier was identified. For the full dataset, a model with three variables was implicated: anomia severity (BNT accuracy) ($\beta = -7.46$), and the interactions between aphasia type and words per minute ($\beta = 0.05$) and aphasia type and tokens ($\beta = -0.04$) (RMSE = 5.80±1.49, MAE = 4.53±1.16, $R^2 = 0.27±0.25$). For the outlier-removed dataset, three variables were implicated, all of which were interactions: aphasia type with tokens ($\beta = -0.03$), aphasia type with words per minute ($\beta = 0.05$), and anomia severity (BNT accuracy) with aphasia severity (AQ) ($\beta = -0.08$) (RMSE = 5.35±1.58, MAE = 4.28±1.19, $R^2 = 0.23±0.22$). This analysis was slightly underpowered (73.98% achieved power), even with given medium-large effect ($f^2 = 0.30$), sample size, and number of predictors (3). These results implicate a role for neuropsychological variables (anomia and aphasia severity, aphasia type) as well as speech variables (tokens, words per minute) in the rate of iconic gestures per minute.

Supplementary

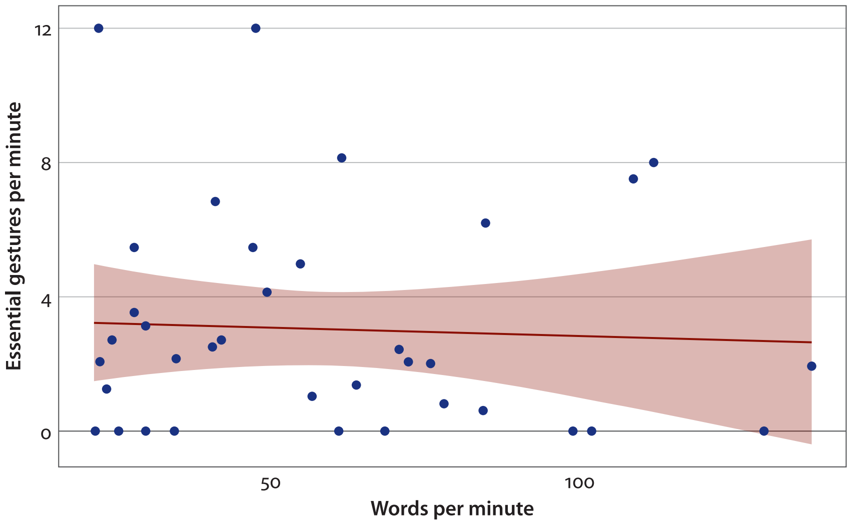
Two outliers were identified. For the full dataset, three variables were implicated: age ($\beta = 0.16$), and the interactions between aphasia type and tokens ($\beta = -0.04$) and aphasia type and words per minute ($\beta = 0.02$) (RMSE = 5.88±1.48, MAE = 4.64±1.12, $R^2 = 0.21±0.20$). Inclusion of outliers implicated a role for interactions between aphasia type and speech variables. For the outlier-removed dataset, two variables were implicated: age ($\beta = 0.11$) and aphasia severity (AQ) ($\beta = -0.10$) (RMSE = 4.24±0.92, MAE = 3.36±0.71, $R^2 = 0.12 \pm 0.14$). This analysis was underpowered (45.69% achieved power), despite the medium effect size ($f^2 = 0.14$). A cautionary interpretation is that, with increasing age and aphasia severity, a higher rate of supplementary gestures was produced (when outliers were removed).

Essential

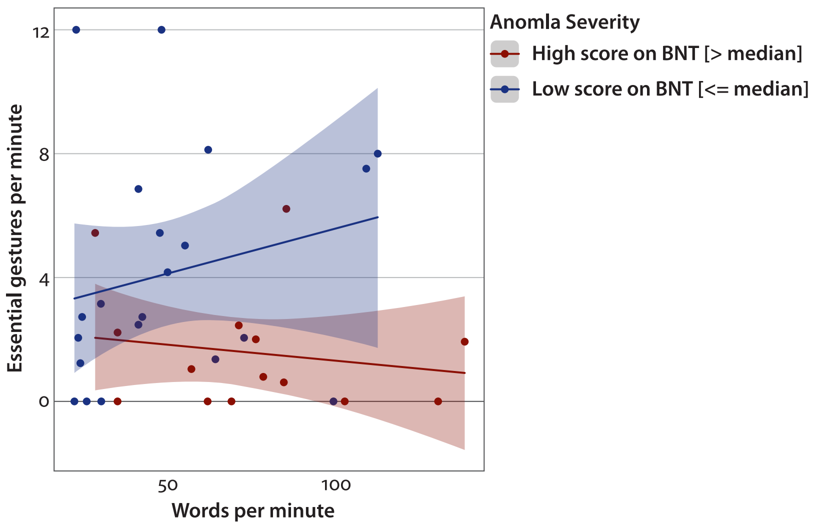
No outliers were identified. A model including two variables was implicated, including words per minute ($\beta = 0.08$) and the interaction between anomia severity (BNT accuracy) and words per minute ($\beta = -0.12$) (RMSE = 3.05±0.92, MAE = 2.43±0.71, $R^2 = 0.28 \pm 0.24$). This model was well-powered (91.21% achieved power, $f^2 = 0.39$). As such, speech fluency, and especially those with more severe anomia, produced a higher rate of essential gestures per minute. Figure 4 demonstrates the relationship of speech fluency with essential gesture rate (A), and the interaction of speech fluency with anomia severity (split dichotomously for ease of interpretation) on essential gesture rate (B).

Discussion

In a population of speakers with aphasia, we evaluated the frequency and rate of iconic gesturing, whether the iconic gesture was supplementary to speech and, if so, whether that supplementary gesture was essential for understanding the meaning being conveyed. We evaluated the contribution of literature-driven demographic, neuropsychological, and speech variables to better understand personal factors associated with these gesture variables. To summarize briefly, two models were well-powered, and implicated a role for tokens and interaction of tokens with aphasia type (specifically, nonfluent) in describing the number of iconic gestures produced, and a role for words per minute and the interaction of words per minute with anomia severity (specifically, more severe anomia) in describing the rate of essential gestures produced. The other four models (iconic gesturing rate, proportion of supplementary gestures, supplementary gesture rate, and proportion of essential gestures) were underpowered to varying degrees, and the Discussion that follows should be interpreted as such. The Discussion, below, is largely organized by hypothesis.



A. Essential gesture rate and words per minute



B. Essential gesture rate interacts with WPM anomia severity

Figure 4. The well-powered analysis ($n = 37$) showing the implication of words per minute, and the interaction of words per minute with anomia severity (modeled as high/low group based on median split for easier visualization), on essential gesture rate

Our findings related to the extent to which persons with aphasia use supplementary and essential iconic gestures complement results from van Nispen et al. (2017) identifying that speakers with aphasia produce supplementary gestures during speaking, and that ~38% of these are essential gestures required to convey meaning. van Nispen et al. (2017) also used data from AphasiaBank, and as such, there was some overlap in the speakers between our two studies (specifically, eight speakers, as mentioned in the Methods). We identified that the average percentage of essential gestures (in the Sandwich task) for these individuals was ~42%, whereas van Nispen et al. (2017) identified that the average percentage of essential gestures (in the Interview and autobiographical tasks, and across gesture types though largely these were iconic) was ~33%. The average essential gesture percentage for our entire cohort was 38% and theirs was 21.8%. That is, for the shared eight speakers between studies, both studies found that these speakers produced a higher proportion of essential gestures compared to the group average. This suggests convergent validity for our two studies, signifying that, even while we evaluated gestures produced during different tasks, and even when we focused exclusively on iconic gestures, coding parameters and general findings converged. A comparison of our two studies suggests that individuals who make more essential gestures in one task may also do so in other tasks.

H1: Neuropsychological variables will be related to iconic gesturing as well as supplementary and essential gesturing

We hypothesized that the total number and rate of iconic gestures produced by our speakers with aphasia would be related to aphasia type (nonfluent producing more iconic gestures), aphasia severity (those with more severe aphasia producing more iconic gestures), and anomia severity (those with more severe anomia producing more iconic gestures). Generally, the results support these hypotheses, especially in relation to total iconic gestures and essential gesturing rate, which were the well-powered analyses.

Kong et al. (2015a) found that aphasia severity was related to gesture (they evaluated six forms of gestures, including iconic), where speakers with more severe aphasia tended to use more gestures during discourse tasks. We did not identify this trend for iconic gestures. Instead, our well-powered analysis identified that tokens, and the interaction of tokens and aphasia type, were associated with the frequency of iconic gestures: individuals who produced fewer tokens, and who tended to be considered nonfluent, produced the most iconic gestures. Kong et al. (2015a) evaluated three discourse tasks: monologue of narrating an important event in their life, storytelling of two highly familiar stories after presentation of picture cards, and procedural description of making a ham and egg sandwich (with photos of the ingredients remaining in sight during the task). That is, a portion of their task was similar to our own, in that they also evaluated a procedural narrative. Therefore, we may not have found a relationship between aphasia severity and iconic gesture number due to differences related to tasks, or because we only evaluated iconic gestures and not other types of gestures (e.g., deictic).

Kong et al. (2015a) suggests that the correlation between gesture use and aphasia severity provides support for the Sketch model of gesture use (see de Ruiter, 2000), which may be supported by our finding about aphasia severity's relationship with supplementary gesture rate. Briefly, the Sketch model suggests that speakers with more severe aphasia rely on the gestural modality to assist communication because speech is difficult. See de Ruiter & de Beer (2013) for a more elaborate description of the Sketch model phenomenon. It should be noted that an impairment in overall conceptualization (i.e., semantic knowledge) may impair use of gesture as well as speech, given that most models accept that gesture and language draw from this shared resource, but this argument is beyond the scope of the present study (given we do not have detailed information on semantic knowledge, see Limitations). We believe it highly unlikely that we had any individuals with such a substantial conceptualization impairment (having no individuals scoring 0% on the naming task), so it's unlikely we had individuals who were severely compromised in their semantic access.

Our results highlight the role of aphasia type and anomia in explaining variance related to supplementary and essential iconic gesture use. van Nispen et al. (2017) did not find a relationship of aphasia severity with production of essential gestures, and we likewise did not identify a relationship of aphasia severity with essential gesturing. Yet, we did identify two interactions with aphasia type (tokens; anomia severity) that impacted the proportion of essential gesturing, suggesting that it is perhaps aphasia type (nonfluent), and the high prevalence of anomia in this group, that is more related to essential gesturing. Note, though, that this analysis was underpowered, which dampens conclusions related to the importance of these factors on essential gesturing amount. van Nispen et al. (2017) explored essential gestures and their relationship with information content of speech (a standard scale from a battery), finding no significant correlation. However, they did not directly evaluate anomia, and here, we find that anomia severity interacted with aphasia type in explaining the proportion of essential gestures made (though this was an underpowered analysis), was a main effect impacting the rate of iconic gesturing (a slightly underpowered analysis), and interacted with words per minute to influence rate of essential gesturing (a highly powered analysis). A recent theory, the gesture-for-conceptualization hypothesis, combines the ideas of action imagery and language and may help to explain this finding (Kita et al., 2017). The gesture-for-conceptualization hypothesis suggests that co-speech gestures affect speaking (and thinking) in four ways: gestures activate, manipulate, package, and explore spatio-motoric information. Viewed through the lens of aphasia, this theory suggests that gesture may provide benefits to speakers with aphasia in that gestures may help to communicate information especially during tasks that are spatio-motoric because the framework supposes that gestures are generated from the same system that generates practical actions (action imagery). The task evaluated here ("how to make a sandwich") is highly spatial, eliciting words like "spread," "open," "eat," "make," and "cut" (Fromm et al., 2013). According to the gesture-for-conceptualization framework, producing gestures increases the activation level of spatio-motoric information during speaking, which may be particularly useful for speakers with aphasia who have impairments in accessing spatio-motoric language information (e.g., difficulty producing semantically heavy, action-related objects and verbs). Our results indicated that it was the speakers with the most severe anomia that tended to produce more essential gestures, and higher rates of iconic and essential gestures. Framing that within the gesture-for-conceptualization framework, one might interpret the 'increase in activation level of spatio-motoric information' to not necessarily mean the production of the correct word (given that this does not always occur when a gesture is produced, e.g., Pritchard et al., 2013), but instead, the production of the correct concept (via gesture, in this case) that supplements the lacking linguistic information.

H2: Speech variables will be related to iconic gesturing

For the two well-powered analyses examining iconic gesture number and essential gesture rate, speech variables were found to be main effects. In the case of iconic gesture number, a greater sample length (measured in tokens) associated with a higher number of iconic gestures. This has been shown previously in many studies, both in typical individuals and those with aphasia, as described in the Introduction. It should also be noted that in no analysis was a main effect of speech variables the only variable of interest. In the case of the two well-powered analyses, the speech variable was a main effect but also significantly interacted with a neuropsychological variable. For example, nonfluent individuals, who produced fewer tokens overall, produced more iconic gestures and those individuals experience greater anomia who had a higher speaking rate also tended to produce a higher essential gesturing rate. Words per minute was a main effect in describing the rate of essential gesturing, with a more clear picture developing with the interaction of words per minute with severe anomia on essential gesturing rate. That is, those individuals experience greater anomia who had a higher speaking rate also tended to produce a higher essential gesturing rate. To our knowledge, this is a relatively novel finding, suggesting a complex interaction of neuropsychological with speech variables in describing essential gesture rate.

Speech variables like tokens and words per minute are intimately tied to neuropsychological characteristics, and often involved in the primary classification of aphasia. For example, those individuals considered to have a nonfluent type of aphasia by definition produce fewer tokens and a slower speech rate than those with a fluent type of aphasia. That is, speech variables are part of the core definition of certain aphasia classifications. It is therefore not surprising that we found speech variable interactions with key neuropsychological variables in explaining gesture variance. Speech variables, alone, do not appear to be wholly responsible for describing the gesture phenomena evaluated here. Therefore, a major takeaway is that both neuropsychological and speech variables appear to be important descriptors of iconic, supplementary, and essential gesturing, and should be evaluated in more diverse and larger samples in the future.

H3: Explore the role of age and sex on iconic gesturing

Age was implicated as a main effect only for rate of supplementary gesturing, with older adults producing more supplementary gestures. Given the paucity of research on the impact of aging on gesture use, and its function/relationship to speech, this is key information for future studies to take into account. However, this analysis was underpowered, and the finding may be spurious and should be interpreted cautiously. Sex was not implicated in any of the analyses. While we did have a decent age range, and a relatively even sex distribution, our results do not suggest a large role for either of these demographic variables in explaining the gesture variables of interest.

Clinical implications

We identified that, on average, nearly 60% of iconic gestures produced by speakers with aphasia were supplementary to speech, and of those, a further 38% were essential to understanding the speech's message. This lines up with the finding from van Nispen et al. 2017, who analyzed a different task, but still found that >20% of all gestures produced by speakers with aphasia were essential. Our findings emphasize the importance of professionals and communication partners paying attention to the information conveyed in gesture by speakers with aphasia (especially those with more severe aphasia, severe anomia, and those with nonfluent aphasia), as well as the importance of integrating gesture into assessment and treatment. For example, we recently published recommendations for improving the efficacy and quality of gesture research in aphasia by emphasizing several key methodological actions, including making sure that the gesture space (i.e., above the waist) is fully visible during telehealth sessions and research sessions (Stark et al., 2021). This ensures that multimodal communication can be accurately used by the listener (e.g., researcher, speech therapist) as well as be a part of the assessment of communicative ability/competence. Additionally, new assessments are being created that explicitly evaluate a person with aphasia's gesturing capacities, improving one's ability to accurately and reliably collect this information (Caute et al., 2021; Hogrefe et al., 2019). A clear future direction is integration of reliable and valid gesture assessments into typical language/communication screenings and batteries for aphasia. Relating to treatment, gesture to improve word finding and communication has been posited as a possible treatment in therapy for people with aphasia and other communicative disorders (Caute et al., 2013; Lanyon & Rose, 2009; Marshall et al., 2012; Roper et al., 2016). However, our ongoing work has identified that most speech therapists face barriers in using gesture as a treatment target or leverage gesture during treament to improve other aspects of communication, suggesting a rift between best practice and current practice (Roper et al., 2022).

Limitations and future directions

We acknowledge that the present study has several limitations. Several factors that might play a role in speakers with aphasia's use of gestures could not be taken into account in the present study due to using AphasiaBank, where data was pre-collected. This included data on limb apraxia, and more detailed data on semantic knowledge. Work by Hogrefe and colleagues suggests that the impact of limb apraxia may be larger than the impact of language impairment on spontaneous gesturing in aphasia, and future work should focus on the inclusion of limb apraxia data (Hogrefe et al., 2012).

A limitation of note is the number of gestures produced by participants in the present study. An average of 4.35±3.21 (med = 4; range 0–14) iconic gestures per participant, with four speakers producing no iconic gestures. While this variation is typical in gesture studies, the limited number of total gestures likely dampens the confidence with which some of the findings in this study should be interpreted. This small number may have related to the small R^2 of some models, indicating small effect sizes. Small R^2 should also be interpreted as perhaps requiring more and better predictors to improve the amount of variance explained in the gesture variables of interest.

Another limitation was being slightly underpowered in two analyses (iconic gestures per minute, at 73.98% achieved power; and proportion of supplementary gestures, at 70.49% achieved power) and very underpowered in two analyses (supplementary gestures per minute, at 45.69% achieved power; and proportion of essential gestures, at 42.13% achieved power). This suggests that our sample size was insufficient to answer the research questions related to proportions of essential gestures and supplementary gesture rate with high confidence and accuracy. Underpowered analyses increase the risk of false negatives (type 2 errors) as well as false positives (type 1 errors) and should be interpreted with caution.

On the other hand, we are more confident in our slightly underpowered models (iconic gesture rate, proportion of supplementary gestures). The high power accompanying essential gesture rate (91.21%) and number of iconic gestures (86.82%) increase confidence in the implications of sample length (in tokens), and the presence of nonfluent aphasia, on increased use of iconic gestures during spontaneous language, and on the impact of greater speech fluency and more severe anomia on enhancing the rate of essential gestures. Future research should aim to replicate our findings in a different, and ideally larger, sample of individuals with aphasia. Additionally, transdiagnostic research (examining, for example, gesturing in individuals with anomia, or reduced speech fluency, who do not have aphasia) would be ideal for building the evidence base. Individuals with traumatic brain injury often have anomia, but not severe enough that they would test as having aphasia on standardized assessment batteries. If the same pattern shown here – that a greater degree of anomia related to a higher rate of essential gestures per minute – was shown in a sample of individuals with traumatic brain injury, this would build overall confidence in the relationship of essential gesturing with anomia as a symptom, rather than anomia as a manifestation of a specific disorder (e.g., aphasia).

Conclusions

Overall, this study extends the literature by modelling variables that characterize supplementary and essential iconic gesturing, and underlines the importance of considering neuropsychological variables like aphasia severity, aphasia type, and anomia severity in mediating gesture use during discourse in aphasia. This study's well-powered findings supported a role for both neuropsychological and speech variables in describing iconic gesture use and essential gesturing rate in individuals with aphasia during a procedural narrative. Oher analyses provide preliminary evidence, also supporting neuropsychological and speech variables in describing iconic gesture rate, supplementary gesture use and rate, and essential gesture use, though these studies require replication and expansion due to being underpowered. Generally, models had small to medium R^2, suggesting inclusion of more variables, such as motor planning variables (e.g., limb apraxia), to comprehensively characterize iconic gesturing in individuals with aphasia.

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Declaration of interest

The authors report there are no competing interests to declare.

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Address for correspondence

Brielle C. Stark
Speech, Language and Hearing Sciences Department
Indiana University Health Sciences Building
2631 E Discovery Parkway
Bloomington, IN 47404
USA

bcstark@iu.edu
https://orcid.org/0000-0002-7001-8324

Co-author information

Grace Oeding
Speech, Language and Hearing Sciences Department
Indiana University Health Sciences Building

goeding@iu.edu

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