LINKS BETWEEN LANGUAGE, GESTURE, AND MOTOR SKILL:

A LONGITUDINAL STUDY OF COMMUNICATION RECOVERY

IN BROCA'S APHASIA

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The undersigned, appointed by the dean of the Graduate School, have examined the

dissertation entitled

LINKS BETWEEN LANGUAGE, GESTURE, AND MOTOR SKILL:

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presented by Barbara Braddock,

a candidate for the degree of doctor of philosophy,

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INTRODUCTION

When people talk, they spontaneously gesture. During speech, hand movements often indicate size, shape, direction, and distance in co-production with descriptive vocabulary choices. Early co-developments in hand and mouth movements (Iverson & Thelen, 1999) and communicative gestures have been observed in preverbal children (Acredolo & Goodwyn, 1988); and links between gesture and speech are apparent in speakers from a variety of cultural and linguistic backgrounds (McNeill, 1992). Gesture has also been found to accompany speech in a consistent and describable manner in persons with and without language impairment (for a review, see Capone & McGregor, 2004).

Like speech, gesture can serve several functions. Some forms of gesture are conventional (e.g., waving good-bye; nodding head to indicate "yes"). Others appear to be non-conventional and largely idiosyncratic in form, and serve as a natural reflection of thought (e.g., indicating the size and shape of an item or the direction of movement). In some cases, meanings not easily encoded into speech may overflow into the accompanying gestural output. Along these lines, McNeill (1992) has suggested that since gesture conveys information not explicitly encoded in speech, it provides a unique window to view underlying thought.

The notion that gesture provides another means to examine cognitive processes is especially relevant when expressive language is impaired. To the extent that speakers are unable to use language to communicate underlying thoughts, they may use gesture to complement, substitute, or compensate for verbal communication. This may provide a

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listener with another window by which to view cognitive aspects related to the speaker's communicative intent. In some cases, gesture may present a richer or more accurate representation of the speaker's thoughts, even taking precedence over spoken language when production is difficult.

One frequently occurring and widely recognized aphasia syndrome, Broca's aphasia, is of particular interest in the study of language and gesture because it provides the opportunity to examine the relationship between the systems when expressive language is impaired. The speech of persons with Broca's aphasia is often referred to as 'nonfluent' and is marked by halting and limited verbal output characterized by incomplete and syntactically simplified sentences, reduced phrase length, awkward articulation, and disturbances in the rate, stress, pitch, and intonation of speech (Kearns, 2005; Kertesz, 1982). For example, a person with Broca's aphasia may attempt to verbalize how to use a cup by stating "cocoa… a…a…uh soup… coffee." In most persons with Broca's aphasia, auditory comprehension is functional for everyday conversation (though impaired to some degree; Kearns, 2005).

In addition, Broca's aphasia often coexists with motor and sensory impairments (e.g., to the face, hand, arm, leg) with the motor weakness or hemiparesis generally on the right side of the body. In some cases, apraxia of speech, a sensorimotor impairment that refers to the inability to select, program and/or execute voluntary, preplanned oral motor movements and/or coordinated sequences of movement necessary for production of fluent speech, co-exists with Broca's aphasia (Wertz et al., 1984). Motor weakness of the face, tongue, and soft palate is generally mild; however, motor speech weakness (known as speech dysarthria) can interact with apraxia of speech and the additive effect

of the disorders can significantly impair speech intelligibility in persons with Broca's aphasia (Kearns, 2005).

The existence of deficits in expressive language and motor functioning raises important questions with regard to the nature of gesture in persons with aphasia. For example, what is the pattern of gesture and speech co-production in adults with Broca's aphasia? And since gesture production requires motor movement, what is the relationship between gesture use and motor ability? The present longitudinal study was designed to examine language, gesture, and motor abilities in persons with Broca's aphasia over a six-month recovery period and to compare their communication patterns to those of healthy adults with no history of neurological illness (NNI).

Language and Gesture in Broca's Aphasia

A small number of investigations have examined gesture production in persons with Broca's aphasia. For instance, Cicone et al. (1979) conducted videotaped interviews of persons with aphasia and examined the frequency and types of gestures produced and the clarity of communication in gesture and spoken language. Relative to persons with Wernicke's aphasia (whose semantic processing was impaired and output was fluent) and adults with no neurological impairment, persons with Broca's aphasia produced fewer gesture units, defined as a unit of expression which might consist of a number of individual movements (e.g., moving the hand from the body and turning it over). And relative to participants with Wernicke's aphasia, persons with Broca's aphasia produced fewer maxi-gestures, or sequences of movements that linked successive gestures to one another within a gestural phrase (e.g., initiating movement of the hand out and away from

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the body, shaking it, and touching the forehead, and then bringing the hand back to rest; three gestures are linked in succession beginning with the initiation of the gesture and the hand returning to rest). Finally, representative gestures (e.g., emblems, pantomimes, numbers, and writing in the air) were more frequent in persons with Broca's aphasia relative to Wernicke's aphasia, but in both groups pantomime gestures were reduced in comparison to persons with no history of aphasia.

Further analyses revealed that when persons with Broca's aphasia did gesture, they tended to use referential gesture types- or those gestures that in some way communicated information about things in the world. Further, relative to comparison adults, persons with Broca's aphasia tended to produce a higher proportion of gesture in the absence of speech. Cicone et al's (1979) observations suggest that language and gesture undergo similar changes in aphasia. Persons with Broca's aphasia do not gesture any more fluently than they speak, and they may even use gesture to take the place of speech when output is limited.

Along the same lines, Glosser, Wiener, and Kaplan (1986) asked persons with aphasia (i.e. anomic, recovering global, and nonfluent aphasias) to converse about an experience from their past with prompts from a listener. Relative to controls with no neurological impairment, persons with aphasia were impaired in both gestural and communicative competence and the quality of their gestural communication closely resembled their verbal language patterns. Specifically, relative to controls with no neurological impairment and controls with mild aphasia, persons with moderate aphasia produced proportionally fewer of the complex semantic modifying gestures indicating uncertainty or ambiguity about the communication (e.g., palms up or circling) and fewer

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emphatic hand gestures that mark fluent speech (e.g., chops or beats).

In a related study, Pedelty (1987) analyzed and compared the communications of persons with Broca's aphasia to those of persons with Wernicke's aphasia. Participants viewed an animated color cartoon in three segments, each roughly two and a half minutes long, and narrated each segment immediately afterward. Relative to the fluent speech and gesture of adults with Wernicke's aphasia, adults with Broca's aphasia produced mostly iconic gestures in co-production with content-bearing words. Iconic gestures often accompanied stretches of inadequate speech and co-occurred with breakdowns in lexical access (e.g., paraphasias, difficulties accessing the right word).

In addition, persons with Broca's aphasia produced a higher percentage of emblem gestures (i.e., gestures that carry a standard meaning and may stand in the place of speech; a shrug for "I don't care"), but few, if any, patients with Broca's aphasia produced nonrepresentational beat gestures (i.e., rhythmic movements of the hands that often mark time with speech). This finding is not surprising given that beats tend to be associated with structural aspects of fluent speech (i.e., rhythmic stress and intonation changes), parameters that tend to be impaired in nonfluent speakers. Neither group gestured significantly more than the other did over the course of the observation. However, when gesture rate was calculated by dividing the number of gestures by the total number of words produced over the course of the observation, persons with Broca's aphasia, produced a significantly higher gesture to word ratio than did persons with Wernicke's aphasia, suggesting that they used gesture to compensate for limited verbal production.

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Finally, in some cases, gesture presented a richer or more accurate representation of the linguistic output, even taking precedence over spoken language when speech production was difficult (e.g., a person with Broca's aphasia gestured "drink" but failed to use words in conjunction with the gesture). Unlike patients with Wernicke's aphasia, gestures produced in silence accounted for a substantial proportion of the total communication corpus of persons with Broca's aphasia.

Taken together, the evidence suggests a very closely interwoven relationship between gesture production and expressive language (Cicone et al., 1979; Glosser, Wiener, & Kaplan, 1986; Pedelty, 1987). However, there is wide variation in the amount of time post-neurological event for any given participant (e.g., some participants observed less than two months after event; others observed several years post-event) both within and across studies and in the composition of the comparison group (other aphasia or healthy adults). In addition, no study has examined the relationship between expressive language and gesture longitudinally, and thus, it is not known whether and to what extent the reported patterns are stable over time or may change as expressive language functioning improves.

Gesture and Motor Skill in Broca's Aphasia

A link between impaired gesturing and motor difficulties in persons with aphasia has also been proposed. For example, Duffy & Duffy (1981) found a strong association between the severity of the aphasia and in the production of pantomime gestures (i.e. gestures produced in the absence of speech using no object; "Show me how to use a

comb"). These findings suggest that the communication disorder in aphasia may be exhibited in language, gesture, and motor modalities.

In a related study of movement sequencing, Kimura and Archibald (1974) compared participants with left vs. right brain impairment on a variety of tasks designed to assess the copying of meaningless hand movement sequences, familiar object use, and familiar gesture production (see also Schnider et al., 1997). Specifically, participants with left-brain impairment had deficits associated with aphasia, and those with right brain impairment had deficits associated with right brain dysfunction. They found that relative to adults with right brain impairment, adults with left brain impairment performed significantly worse on tasks involving the copying of meaningless hand movement sequences (e.g., close fist, thump sideways on table; fingertips and thumb together in ring, all touching forehead, hand moves out from forehead, rotating and opening wide as it moves), on traditional apraxia tasks requiring the demonstration of familiar object use (e.g., show how to use a toothbrush without the use of the real object), and in the production of familiar gestures on command (e.g., show how to wave good-bye).

Despite these documented deficits in motor ability, however, speakers with Broca's aphasia still produced spontaneous gestures (e.g., Pedelty, 1987). However, little is known about the ways in which motor impairment is reflected in the gestures of aphasic patients, particularly those gestures that require production of sequenced movements. The literature reviewed in the previous section suggests that aphasic speakers make extensive use of iconic gestures. It is important to note that gestures such as these may be quite complex, involving varied handshapes and a wide range of movement trajectories in order to supply meaning.

Thus, for example, when demonstrating how to use a key to open a locked door, a typical speaker might produce gestures referring to key insertion, key turning, key removal, as well as turning the door knob, and pushing the door open. This sequence of gestures involves three distinct handshapes (i.e. index finger touching thumb as if to hold a key; cupped handshape as if to turn the door knob, flat hand with palm facing out as if to open the door) and five distinct movement trajectories (i.e. moving hand away from body as if to insert a key; moving hand in a circular fashion as if to unlock the door with a key; moving the hand back towards the body as if to remove the key from the lock; turning the hand in a circular fashion as if to turn a door knob; pushing the hand and arm away from the body as if to open a door).

In light of the motor difficulties described above, one might expect a person with Broca's aphasia to produce less complex gesture forms; for example, opening a locked door with an empty-handed fist and a slight wrist rotation. In this case, the movement pattern is simplified and incomplete; there is one handshape (i.e. clenched fist) and only one movement trajectory (i.e. wrist rotation). Though meaning is inferred in both cases, there are marked differences in the complexity and completeness of the gesture production.

One study to date has examined iconic gesture complexity in this fashion. When Pedelty (1987) examined the number of inflections, or movement variations, in iconic gestures produced during the cartoon narration by persons with Broca's aphasia (e.g., presence and direction of movement, hand configuration and orientation, shape of the trajectory, and manner of execution for each iconic gesture), she found that the number of inflections appeared to be related to scores on a manual praxis measure, independent of

language scores. In other words, aphasic persons who were less impaired on measures of manual praxis were more likely to produce more complex iconic gestures.

More recently, Rose and Douglas (2003) asked participants with nonfluent aphasia and limb apraxia to engage in semi-structured conversation with the researcher.   They found that all participants produced a wide-range of gesture types; and those with the most severe limb apraxia produced high proportions of meaning-laden gestures (e.g., codes such as writing letters in the air and pantomime sequences of meaningful movement that are produced without speech).

Unlike Pedelty (1987) who analyzed the complexity of movement variations in iconic productions, Rose and Douglas (2003) examined the listener's ability to infer meaning from gesture in naturalistic communication. This is important distinction because it appears that persons with nonfluent aphasia and limb apraxia produce meaningful gesture in naturalistic settings, but tests of limb apraxia may not be associated with meaning-laden gesture production. On the other hand, tests of limb apraxia may be more closely aligned to performance in pantomime gesture (i.e., purposeful gesture sequences performed in the absence of speech).

In sum, language and motor impairment often coexist in aphasia (Duffy & Duffy, 1981 Kimura & Archibald, 1974; Schnider et al., 1997); however, persons with Broca's aphasia still produce gestures spontaneously when communicating (Pedelty, 1987; Rose & Douglas, 2003). While there is some indication that more complex iconic gesture production is associated with better performance on tests of manual praxis (Pedelty, 1987), traditional tests of manual praxis were not associated with production of meaning-laden gesture production in natural settings (Rose & Douglas, 2003). In addition, we do

not know whether and to what extent changes in expressive language and motor ability that occur during the course of recovery may influence gesture production in individuals with Broca's aphasia.

The Present Study

The literature reviewed above indicates that the gestures of persons with Broca's aphasia closely parallel their speech output (Cicone et al., 1979; Glosser, Wiener, & Kaplan, 1986; Pedelty, 1987); that there is a link between language and motor impairments in aphasia (Kimura & Archibald, 1974; Schnider et al. 1997); and that there may be a link between motor impairment and impaired gesture production (Pedelty, 1987). However, these studies have not systematically examined gesture in relationship to language and to motor ability. In addition, all involve varied diagnostic groups evaluated at a single timepoint. Participants tend to vary widely in the amount of time that has elapsed since symptom onset (months for some, years for others), and findings are interpreted relative to differing comparison groups. Since language abilities often exhibit measurable recovery over time in patients with aphasia (Cappa et al., 1997; Kertesz, Harlock, & Coates, 1979), a longitudinal study was designed to describe patterns of change in these systems and the extent to which gesture and motor abilities may be related to gains in expressive language. In this research described here, participants were individuals ascertained specifically with Broca's aphasia with no more than two months since time of onset; their communication patterns were examined at monthly intervals for a six-month period and compared to those of a group of healthy adults.

Predictions

Language. It was expected that participants with Broca's aphasia would improve on all measures of language production in the *speech plus gesture* and *speech only* conditions over the course of six observations. This is supported by past behavioral and neuroradiographic studies that indicated patients following cerebrovascular accident demonstrate functional compensation through a reorganization of speech processes (Kertesz, Harlock, & Coates, 1979).

When participants with Broca's aphasia were restricted from gesturing (*speech only* condition), it was expected that their speech would be qualitatively and quantitatively different from the *gesture plus speech* condition (McNeill, 1987,1992). Specifically, in the *speech only* condition, speech was expected to be effortful and contentful in the early phase of recovery (e.g., drink…used to drink…straw) and less so with recovery time (e.g., I pick up straw…put in drink. S-sip through a straw); and based on the extent of expressive language recovery, speech would become more descriptive to substitute meaning that previously may have been represented through gesture (e.g., I pick up straw. . .put in drink. Between my lips. S-Sip through a straw).

Gesture. On the basis of previous work (Cicone et al, 1979; Glosser, Wiener, & Kaplan, 1986; Pedelty, 1987), it was predicted that persons with Broca's aphasia would produce gestures in the *speech plus gesture* and *gesture only* conditions even if motor deficits were apparent (Kimura & Archibald, 1974; Schnider et al., 1997). Under the assumption that Broca's aphasia evolves to more fluent aphasia over time, two predictions were made. First, in line with Pedelty's (1987) findings that persons with Broca's aphasia produced relatively high ratio of gesture to words, it was predicted that

persons with Broca's aphasia would initially appear to compensate for poor expressive language abilities through increased gesture production when measured against speech (i.e. gesture to word ratio). As expressive language improved over time, this ratio was expected to decrease.

Second, in line with previous work (Cicone et al., 1979; Pedelty, 1987), it was anticipated that at the initial observations, participants with Broca's aphasia would produce a high proportion of gesture in isolation and a lower proportion of gesture in co-production with speech. The proportional use of gesture in isolation was expected to decline over time as language abilities recovered.

Under the assumption that Broca's aphasia evolves to more fluent aphasia over time, it was expected that persons with Broca's aphasia would initially produce higher proportions of iconic and emblem gestures, and that the proportion of beat gestures would increase over time. This prediction was in line with Pedelty's (1987) finding that gesture production for persons with Wernicke's and Broca's aphasia parallel their speech output (i.e., beat gestures associated with fluent Wernicke's aphasia; iconic and emblem gestures associated with nonfluent Broca's aphasia).

It was also anticipated that persons with Broca's aphasia would initially add information to their speech through gesture, and that this pattern of gesture compensation would gradually decrease as verbal language improved over time. This prediction is in line with Pedelty's (1987) finding that, in some cases, gesture added information and presented a richer or more accurate representation of the linguistic output for persons with Broca's aphasia.

Meaningful motor movements. Motor skill and coordination were expected to improve in participants with aphasia over the six-month period. Thus, it was predicted that persons with Broca's aphasia would demonstrate increased ability to 'package' meaning in gesture over time in the *gesture plus speech* and *gesture only* conditions, as indexed by the sequencing of meaningful motor movements in iconic and pantomime gesture production.

Context effects on communication. Quantitative and qualitative changes in aspects of language, gesture, and meaningful motor movement might be most apparent when persons with aphasia are communicatively 'taxed' or working at the end of their communicative competence. For instance, relative to everyday communication contexts (i.e., describing and demonstrating the use of familiar objects), it was expected that persons with Broca's aphasia would demonstrate measurable differences in language, gesture, and motor productions for contexts that tax their communicative ability (i.e., describing and demonstrating the use of unfamiliar objects).

If knowledge of the unfamiliar object is limited, persons with Broca's aphasia might produce unclear motor movements (i.e., simplified and less complex) and/or poorly formulated speech, resulting in reductions in the listener's ability to interpret meaning through gesture and/or speech. In addition, persons with Broca's aphasia might rely on overlearned communication patterns when content is unfamiliar (e.g., stating "I don't know" or shrugging the shoulders with palms up and arms extended to indicate the lack of knowledge of fail to respond altogether).

METHOD

Participants

Speech-language pathologists at Rusk Rehabilitation Center in Columbia, Missouri referred adult men with new onset of left unilateral cerebrovascular accident and resultant aphasia for participation in the study. Women with left unilateral cerebrovascular accident and resultant aphasia were excluded from the study due to previously reported post-stroke gender differences on tasks involving cognitive-communicative recovery (Martin, Franzen, & Raymond, 1996); as well as poorer physical recovery relative to men 6-months after stroke (Lai et al., 2005).

To be included in the study, participants met the following criteria: 1) speech pattern consistent with Broca's aphasia as determined on the basis of scores from the *Western Aphasia Battery (WAB*; Kertesz, 1982; subscores on the *WAB* allow for reliable classification of participants with Broca's aphasia based on fluency, comprehension, repetition, and naming); 2) right-hand dominant prior to cerebrovascular accident (CVA) with the ability to move at least one hand freely post-CVA; 3) English as the primary language; 4) no known complicating factors (e.g., dementia, alcoholism, traumatic brain injury, or prior neurological disease or injury); 5) vision and hearing normal or corrected to near normal; and 6) adult age range (see Tables 1 and 2).

Following a brief screening conducted by the researcher, eight adult men with aphasia were asked to participate in the study. Two participants were later excluded from the study because one failed to understand the *gesture only* segment of the object description task over six observation times, and the other withdrew from the study after Time 4 due to depression-like symptoms.

Six adult men with no history of neurological illness (NNI) were later matched to the participants with aphasia on the basis of age and education. Prior to conducting the primary analyses, a set of preliminary comparisons was conducted to ensure that participants with aphasia were well matched to the NNI comparison group. No reliable differences were found between the aphasia and NNI comparison group on the basis of age in years, U= 15.0, ns ($\underline{M}_{Aphasia}$= 60.67, SD= 9.58; $\underline{M}_{NNI}$= 62.0, SD= 9.12), or education in years, U=18.0, ns ($\underline{M}_{Aphasia}$= 14.0, SD= 2.19; $\underline{M}_{NNI}$= 14.0, SD= 2.19).

In light of the small sample size (N=6) and the variability of the clinical population in study, results should be considered exploratory, and are intended to map relationships between language, and gesture, and motor ability in Broca's aphasia for further exploration.   Thus, the present study serves as a guide for future research on the communication recovery patterns of persons with Broca's aphasia.

Tasks and Materials

Language and motor assessments.   Participants with Broca's aphasia completed language and motor assessments using portions of the *WAB* (Kertesz, 1982). Assessments were completed immediately prior to the first and sixth observations and required 45-60 minutes to complete. A certified speech-language pathologist administered the *WAB* following procedures outlined in the manual.

The *WAB* has been standardized on a group of 20 patients with aphasia (Kertesz, 1982; Shewan & Kertesz, 1980). It examines clinical aspects of language function in the areas of content, fluency, auditory comprehension, repetition, and naming. The scoring

yields an overall measure of the severity of the aphasia (*Aphasia Quotient; AQ*), as well as a total praxis score.

Object description task. At each scheduled observation, participants completed the object description task (Williams, 1999). For this task, a total of 48 objects typically used by manual manipulation were selected. To assess the effects of object familiarity on communication, the set was constructed to consist of 24 familiar and 24 unfamiliar objects.

Object familiarity was assessed on the basis of ratings by undergraduate students at the University of Missouri-Columbia following procedures detailed by Williams (1999). Familiar items were selected from an array of 30 actual tools or utensils typically used by adults. These items were shown to a group of 11 undergraduate students to ensure that they had high familiarity. From this initial set, 24 of 30 items that 100% of the group named were included in the experimental set. All of the undergraduate students were able to state the function of the familiar items.

Unfamiliar items were also selected from an array of 30 actual tools or utensils typically used by adults. These items were shown to a group of 11 undergraduate students to ensure that they had low familiarity. From this initial set, 24 of 30 items that 90% or more of the group failed to name were included in the experimental set. A majority of the undergraduate students (82%) were unable to state the function of the unfamiliar items.

Table 3 contains a list of the 24 familiar and 24 unfamiliar objects that have been randomly assigned to three sets. Each set contains a total of 4 practice items and 16 test

items (i.e. 2 familiar practice items, 8 familiar test items, 2 unfamiliar practice items, and 8 unfamiliar test items).

Procedure

Depending on the care setting, participants with Broca's aphasia were seen by the investigator in the hospital, clinic, or home environment on six separate occasions. The initial observation (Time 1) took place at approximately 4-8 weeks post neurological event. The five subsequent observations were scheduled at approximately 4-week intervals (Time 2: 8-12 weeks post event; Time 3: 12-16 weeks post event; Time 4: 16-20 weeks post event; Time 5: 20-24 weeks post event; Time 6: 24-28 weeks post event).

Participants with NNI were seen by the investigator in the clinic or home environment on two separate occasions approximately 4 weeks apart. Of note, in 33% of the object description transcripts reviewed, communication performance was similar between Times 1 and 2.

At each observation, participants completed the object description task in three conditions: *speech plus gesture, speech only, and gesture only.* Following the presentation of 1-2 practice items, objects (8 familiar and 8 unfamiliar test items per set) were presented in random order. Each set was presented in counterbalanced order across the six visits (For participants with Broca's aphasia: Times 1 and 4: Set 1 *gesture only*, Set 2 *speech only*; Set 3 *speech plus gesture*; Times 2 and 5: Set 2 *gesture only*, Set 3 *speech only*; Set 1 *speech plus gesture*; Times 3 and 6: Set 3 *gesture only*, Set 1 *speech only*, Set 2 *speech plus gesture;* and for participants with NNI: Time 1: Set 1 *gesture only*, Set 2 *speech only*; Set 3 *speech plus gesture*; Time 2: Set 2 *gesture only*, Set 3 *speech only*; Set 1 *speech plus gesture*).

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Participants were seen in a quiet room and seated in a chair that allowed free arm movement. The object description task lasted approximately 45 minutes and was videotaped. The video camera was set up to maximize visibility of the gesture space (a front view encompassing from the area slightly above the participant's head to slightly below the knees; cf., McNeill, 1992).

First, the object was given to the participant, who was allowed to manipulate it for up to 15 seconds. Next, the object was placed in a box, the lid was closed, and the box was placed out of view. Because objects in view often elicit pointing gestures directed toward them (e.g., Braddock & Iverson 2003, 2005; Pechmann & Deutsch, 1982), removal of the box containing the object from view presumably reduced the likelihood that participants would respond by simply pointing to the object.

In the *speech plus gesture* and *speech only* conditions, the researcher instructed the participant to "Tell me how you use this object, but don't tell me what it is." Each participant's verbal response was timed with a stopwatch. If the participant failed to provide a description of at least 15 seconds in length, the researcher prompted for further response (e.g., "Tell me what the object looks like." or "Tell me more."). No more than two additional prompts were given per object. In the *speech only* condition, participants were asked to place their hands in the pocket of an apron to prevent from gesturing. For those participants with motor weakness, the affected arm was positioned appropriately.

In the *gesture only* condition, the researcher instructed the participant to "Show me how you use this object, but do not use words." If the participant failed to demonstrate the use of the object for at least 15 seconds in length, the researcher prompted for further response (e.g., "Show me what the object looks like." or "Show me more.").

Through the use of the researcher's verbal prompt (e.g., tell or show me how to use this object), the object description task initially required participants to convey information sequentially, and thus, relied on procedural memory skills. However, if the task was too difficult, the researcher provided an additional prompt to "Tell or show me what the object looks like." This in turn provided participants with an additional opportunity to communicate about concepts such as size, shape, and spatial arrangement. In general, the task was designed to initially place a high demand upon procedural memory, which requires a good deal of visual-spatial organization and to lessen the demand if the participant was unable to perform the task. Given that gesture is a motor act, communications regarding procedural memory for a series of actions may be valuable in eliciting high levels of gesticulation.

Coding

Coding speech. All communications were coded from the videotaped object description task across the three conditions. Speech produced in the *speech plus gesture* and *speech only* conditions was transcribed verbatim and coded using a procedure outlined by *Systematic Analysis of Language Transcripts*, *Software for Analyzing English and Spanish* (*SALT*; Miller, 1984). Measures of verbal communication included: 1) total number of utterances (number of stretches of speech spanned by a single intonation contour and marked by a single primary stress and terminal juncture; Miller, 1984); 2) mean number of words in utterances (MLU; number of words divided by the total number of utterances); 3) total number of different words; and 4) intelligibility rating

(calculated as the number of completely intelligible utterances divided by the total number of intelligible and unintelligible utterances).

Coding gesture. Hand movements produced in the *speech plus gesture* and *gesture only* conditions were transcribed as gestures only when they had an identifiable beginning and a clear end. Instances of object manipulation, self-touching, and grooming movements were not coded as gestures (Pedelty, 1987). In the *speech plus gesture* condition, participants' spoken and gesture communications were coded as occurring in isolation or co-production (i.e. *speech only, gesture only, speech plus gesture*).

All gestures were further classified by type using a system adapted from previous research with adults with aphasia (Pedelty, 1987). Categories employed included: 1) standard conventional gestures (emblem, deictic, self-referential); 2) iconic gestures; and 3) beat gestures. Descriptions of each gesture type category with illustrative examples are presented in Table 4.

All communications in the *speech plus gesture* category were further analyzed according to the relative contributions of speech and gesture. All communications containing both speech and gesture were further categorized as: 1) redundant, 2) disambiguate, 3) add, 4) unintelligible, and 5) uncodable. Descriptions of each gesture-speech informational relationship with illustrative examples are presented in Table 5.

In addition, iconic gestures produced in the *speech plus gesture* condition and pantomime gestures produced in the *gesture only* condition were further coded using a system adapted from previous research (Goldin-Meadow, McNeill, & Singleton, 1996). These criteria are outlined in Table 6. All embedded movement components that were judged as meaningful and associated with object actions and/or attributes were scored.

Thus, if a participant produced a meaningful movement that captured an aspect of object motion, the movement was assumed to represent the action of the object and was scored. Similarly, if a participant produced a meaningful movement that captured an attribute of the object, the movement was assumed to represent that attribute of the object and was scored.

For example, in response to "show me how to use a knife," one participant produced a gesture with the hand moving back and forth as if to cut, then moved the hand sideways back and forth as if to slide the food away from the cutting area. These embedded movements were considered symbols for the motions (i.e. cut, slide) and thus scored as two actions. Handshape/or and movement trajectory also portrayed one of many descriptive attributes of the object. For example, in response to "show me what the object looks like," one participant produced a gesture that portrayed a physical property of the object. The participant moved both hands along a horizontal plane to indicate the length of the straight edge of the knife. In this example, the gesture was considered a symbol for the length of the knife, and thus scored as one attribute.

Reliability

To assess intercoder reliability, 9 of 42 complete speech-gesture observations (21%) were independently transcribed and coded by a second trained coder. Three different reliability procedures were utilized. First, given that gesture occurrences and the number of utterances produced were non-categorical measures, a mean percent agreement was calculated. Mean percent agreement was 91% for gesture occurrence (total N= 295; range 79%-100%), and 95% for the number of utterances (total N= 1594; range 84%-99%).

Second, for those measures that required categorical coding, the Cohen's kappa statistic was used to assess intercoder reliability for gesture type and gesture–speech informational relationship measures. Agreement between the two independent coders for gesture type (kappa=.94, observed agreements N=150); and for the gesture-speech informational relationship (kappa=.84, observed agreements N=101) was considered high.

Finally, for those measures that were calculated as a scored value, Intraclass Correlations (ICC) were computed. The correlations between two independent coders were high for MLU (ICC=.88); mean number of different words (ICC=.99); overall speech intelligibility rating (ICC=.93); and mean number of meaningful motor movements in iconic gesture productions (ICC=.96) and pantomime productions (ICC=.85).

RESULTS

Introduction

The primary aim of this research was to investigate the link between language, gesture, and motor skill in persons recovering from Broca's aphasia. The project was designed to address two broad questions: 1) What is the pattern of gesture and speech co-production in adults with Broca's aphasia? and 2) since gesture production requires motor movement, what is the relationship between gesture use and motor ability? The present longitudinal study was designed to examine language, gesture, and motor abilities in persons with Broca's aphasia over a six-month recovery period and to compare their communication patterns to those of healthy adults with no history of neurological illness (NNI).

Following presentation of preliminary analyses, I begin by examining aspects of communications in the familiar vs. unfamiliar object contexts at observation Times 1 and 6 within the aphasia group. This is followed by a comparison of measures of language, gesture, and meaningful motor movement in early vs. late recovery to examine patterns of communication recovery within the aphasia group. Next, I present between-group analyses using data obtained from the speech-gesture observation for the aphasia and NNI groups. In a final section, I present individual trajectories in communication recovery for the six participants with Broca's aphasia, focusing on patterns of individual variability in language recovery and gesture use.

Since distributions for all of the measures considered departed widely from normality, all descriptive data and comparisons reported below employed medians as the

measure of central tendency and average deviations as the measure of variability. All analyses were conducted by means of nonparametric statistics.

Preliminary Analyses

As described in the procedure, data were collected for the NNI group at two separate observations scheduled approximately one month apart. To rule out potential practice effects for the object description task that was administered to participants with aphasia at each monthly observation, 2 of 6 (33%) of the second speech-gesture observation for the NNI group were transcribed and coded. Communications from the NNI group's first observation were then compared to the smaller sampling taken from the second observation. Overall, performance was quite similar at the two observations in terms of number of communications in the *speech plus gesture* condition, Z=-1.34, *ns* ($\underline{Mdn}_{Time\ 1}$=64.0, AD=7.44, $\underline{Mdn}_{Time\ 2}$=59.50, AD=5.5), number of utterances in the *speech only* condition , Z=-1.43, *ns* ($\underline{Mdn}_{Time\ 1}$=65.0, AD=7.5, $\underline{Mdn}_{Time\ 2}$=54.50, AD=2.5), and number of pantomime productions in the *gesture only* condition, Z=.00, *ns* ($\underline{Mdn}_{Time\ 1}$=8.0, AD=0, $\underline{Mdn}_{Time\ 2}$=8.0, AD=0). Thus, all group analyses reported below were conducted using data from the NNI group's first observation.

Language, Gesture, and Motor Recovery Patterns within the Aphasia Group

This section focuses on the extent of communication change within the aphasia group at the initial (1-2 months post-neurological event) and final (7-8 months post-neurological event) observations. These timepoints were selected because persons with Broca's aphasia have been found to exhibit improvements in language in the initial six

months following cerebrovascular event (Cappa et al, 1997; Kertesz, Harlock, & Coates, 1979). I first examine context effects on communication within the aphasia group in the familiar and unfamiliar conditions at Time 1 and Time 6 and then present data on language, gesture, and meaningful motor change from Time 1 to Time 6.

The analyses to be reported here were designed to address a set of seven predictions regarding communication patterns within the aphasia group over time. These had to with change from the initial to the final session in communications in familiar vs. unfamiliar object contexts, verbal communication, frequency of gesture production, use of gesture with speech vs. alone, gesture type, the speech-gesture informational relationship, and the number of meaningful motor movements in gesture productions.

Context effects on communication. The first prediction had to do with potential variation in aspects of verbal language, gesture, and meaningful motor movement when persons with aphasia were communicatively 'taxed' (i.e., communicating aspects about unfamiliar objects). Specifically, it was predicted that as a group, persons with aphasia would produce unclear motor movements (i.e. simplified and less complex), poorly formulated speech, and/or rely on overlearned, stereotypical communication patterns when context was unfamiliar (e.g., fewer different words, heightened emblem gesture use, and less complex motor movements in iconic and pantomime gesture productions).

This prediction was addressed by comparing 1) number of different words produced in *speech plus gesture* and *speech only* conditions; 2) proportions of emblem gesture in *speech plus gesture* condition; 3) complexity scores for iconic gesture in the *speech plus gesture* condition; and 4) complexity scores for pantomime gesture in the *gesture only* condition.

Table 7 displays the median number and average deviation for each of the above measures in the familiar and unfamiliar contexts at Time 1 and Time 6. As evident in table, participants with aphasia produced on average fewer different words in the unfamiliar context at Time 1 and higher proportions of emblems in the unfamiliar context at Time 6, but no statistically significant differences were evident in any aspects of verbal communication, gesture, and meaningful motor movements at either Time 1 or 6. As a result, all subsequent analyses were conducted with data collapsed across the familiar and unfamiliar contexts.

Change in language over time. Language recovery within the aphasia group was examined in two sets of analyses. The first was descriptive and related to changes over time in *WAB AQ s*cores and in verbal communication measures obtained from the speech-gesture observation at Times 1 and 6. The second was prediction-driven and focused on changes over time in verbal communication between the *speech only* and *speech plus gesture* conditions.

In the first set of analyses, *WAB AQ* scores from Times 1 and 6 were compared to examine the degree of overall language recovery (see Table 1). The *WAB AQ* is an aphasia severity score that takes into account both receptive and expressive language functioning. As expected, all participants with aphasia showed a significant increase in *WAB AQ* scores from Time 1 to Time 6, $Z=-2.20$, $p=.028$ ($\underline{Mdn}_{Time\ 1}=63.2$, AD=8.95; $\underline{Mdn}_{Time\ 6}=85.4$, AD=6.23).

Observational measures of language at Times 1 and 6 were also compared to examine verbal communication recovery from the initial to the final observation. As described above, four measures of language were calculated from speech produced in the

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speech plus gesture condition: 1) number of utterances; 2) MLU in words; 3) number of different words produced; and 4) percent intelligible utterances. The decision to focus specifically on speech produced in the *speech plus gesture* condition was based on the assumption that communications in this condition would be most representative of each participant's typical language use; no restrictions were placed on communication other than "tell me how to use the object, but do not tell me what it is."

The number of utterances produced at Time 1 was somewhat lower than that at Time 6, but the difference was not statistically reliable, Z=-.32, *ns* (Mdn$_{Time\ 1}$=44.5, AD=26.72, M$_{Time\ 6}$=51.0, AD=8.44). However, as expected, relative to Time 1, there was significant improvement in expressive language ability by Time 6 in terms of increased MLUs, Z=-1.99, p=.046 (Mdn$_{Time\ 1}$=3.98, AD=1.47, Mdn$_{Time\ 6}$=6.77, AD=2.14) and greater numbers of different words, Z=-1.99, p=.046 (Mdn$_{Time\ 1}$=75.0, AD=25.56, Mdn$_{Time\ 6}$=127.5, AD=40.5). The percentage of intelligible utterances also increased from Time 1 to Time 6, but the difference was not statistically reliable, Z=-1.75, *ns* (Mdn$_{Time\ 1}$=.93, AD=.12, Mdn$_{Time\ 6}$=.97, AD=.03).

The next analysis was designed to address the prediction that when participants with aphasia were restricted from gesturing (*speech only* condition), speech would be more effortful (as indexed by shorter MLUs and fewer different words) in the early phase of recovery and would become less so with recovery time. Thus, measures of verbal communication produced in the *speech only* and *speech plus gesture* conditions at Times 1 and 6 were compared. Table 8 displays the median number and average deviation of utterances, MLU, and different words produced in the *speech plus gesture* and *speech only* conditions at Times 1 and 6 for the aphasia group.

Data indicated that the numbers of utterances produced in the two conditions were comparable at Time 1, but at Time 6, participants with aphasia on average produced fewer utterances in *speech only* than in the *speech plus gesture* condition, though the difference was not significant. At both sessions, participants with aphasia produced similar MLUs in the two conditions. In addition, at Time 1, participants with aphasia produced significantly fewer different words in the *speech only* condition. By Time 6, however, the number of different words was relatively comparable in both conditions. Thus, counter to prediction, there were few differences between the two conditions in early and late recovery, with the exception of the reliable difference in number of different words between the two conditions at Time 1.

Change in gesture over time. In this section, I present analyses related to predictions having to do with change over recovery in overall frequency of gesture use and production of gesture in isolation respectively. With regard to gesture frequency, it was expected that persons with aphasia would make greater use of gesture early in recovery, with a decrease as verbal communication improved over time. To address this prediction, overall rate of gesture was compared at Times 1 and 6. Gesture rate was calculated by dividing the number of gestures by the number of words produced in the *speech plus gesture* condition. These ratios were computed separately for each participant at Times 1 and 6. Although the median gesture rate fell substantially between Times 1 and 6, the difference was not statistically reliable, $Z=-.94$, *ns* ($\underline{Mdn}_{Time\ 1}=.11$, AD=.06, $\underline{Mdn}_{Time\ 6}=.025$, AD=.11).

With regard to the production of gesture alone, it was anticipated that participants with aphasia would produce a lower proportion of gesture in co-production with speech

and a higher proportion of gesture in isolation early in recovery. This was assessed by comparing the proportions of communications in speech with gesture vs. gesture only at Times 1 and 6. These were calculated by counting the numbers of communications in speech with gesture and in gesture only respectively and dividing each by the total number of communications.

The median proportions of communications in speech with gesture vs. in gesture only in the *speech plus gesture* condition are presented in Figure 1. As is evident, gesture was more likely to be co-produced with speech than to appear in isolation. At both timepoints, there were similar proportions of communications in speech with gesture, $Z=-1.48$, *ns* ($\underline{Mdn}_{Time\ 1}=.85$, AD=.07, $\underline{Mdn}_{Time\ 6}=.88$, AD=.09), and in gesture only, $Z=-.68$, *ns* ($\underline{Mdn}_{Time\ 1}=.15$, AD=.07, $\underline{Mdn}_{Time\ 6}=.12$, AD=.09). Thus, as a group, participants with aphasia did not produce a higher proportion of gesture in isolation when speech was most impaired in early recovery.

Next, I examined production of gesture by type to explore potential change in the types of gestures produced by persons with aphasia as they recovered more fluent language over time. Specifically, it was predicted that the proportions of emblem and iconic gestures would be relatively higher in early recovery when speech was more effortful and decline over time, and the proportion of beat gestures was expected to increase over time as speech became more fluent.

For this analysis, the mean proportions of emblem, iconic, beat, deictic, and self-representational gestures produced in the *speech plus gesture* condition were computed by dividing the number of gestures in each category by the total number of gestures

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produced. These proportions were computed separately for each participant at Times 1 and 6.

This prediction was not supported by the data. The proportion of emblem gestures increased (though not significantly) from Time 1 to Time 6, $Z=-.94$, *ns* ($\underline{Mdn}_{Time\ 1}=.34$, AD=.07, $\underline{Mdn}_{Time\ 6}=.53$, AD=.20) and the proportion of iconic gestures remained roughly unchanged, $Z=-.52$, *ns* ($\underline{Mdn}_{Time\ 1}=.30$, AD=.13, $\underline{Mdn}_{Time\ 6}=.31$, AD=.18). In addition, the proportion of beat gestures decreased from Time 1 to Time 6, $Z=-1.15$, *ns* ($\underline{Mdn}_{Time\ 1}=.27$, AD=.11, $\underline{Mdn}_{Time\ 6}=.18$, AD=.10), although the difference was not statistically significant. Proportions of deictic gestures were similar at both time points, $Z=-.37$, *ns* ($\underline{Mdn}_{Time\ 1}=.01$, AD=.02, $\underline{Mdn}_{Time\ 6}=0$, AD=.02); and there was no significant change in production of self-referential gestures, $Z=-1.84$, *ns* ($\underline{Mdn}_{Time\ 1}=.04$, AD=.02, $\underline{Mdn}_{Time\ 6}=.00$, AD=0).

To address the prediction that participants with aphasia would initially make use of gesture to add unique information to that conveyed in speech, the informational relationship conveyed in speech and gesture was examined. This was done by calculating the numbers of speech + gesture communications classified as redundant, disambiguate, and add respectively and dividing each of these by the total number of communications containing both speech and gesture. Communications classified as unintelligible (.06%) were excluded from this analysis.

Counter to prediction, the distributions of communications across the three informational categories remained relatively unchanged from Time 1 to Time 6. Thus, the proportion of communications in which gesture was redundant with speech was generally stable from Time 1 to Time 6, $Z=-.11$, *ns* ($\underline{Mdn}_{Time\ 1}=.52$, AD=.12, $\underline{Mdn}_{Time}$

$_6$=.48, AD=.07). In addition, there were no significant differences across sessions in the proportion of communications in which gesture disambiguated speech, Z=-.31, *ns* ($\underline{Mdn}_{Time\ 1}$=.06, AD=.05, $\underline{Mdn}_{Time\ 6}$=.03, AD=.09) or added information to speech, Z=-.63, *ns* ($\underline{Mdn}_{Time\ 1}$=.44, AD=.12, $\underline{Mdn}_{Time\ 6}$=.50, AD=.15).

Change in motor ability over time. Motor ability within the aphasia group was examined in two sets of analyses. The first was descriptive and related to changes over time in *WAB Praxis s*cores obtained at Times 1 and 6. The second was prediction-driven and focused on changes over time in meaningful motor movements produced in both iconic gesture (*speech plus gesture* condition) and pantomime gesture (*gesture only* condition).

In the first set of analyses, *WAB Praxis* scores from Times 1 and 6 were compared to examine the degree of skilled movement recovery (see Table 1). The *WAB Praxis* score allows for the quantification of apraxia (i.e. problems with producing sequenced movements). This comparison revealed that participants with aphasia showed a significant increase in *WAB Praxis* scores from Time 1 to Time 6, Z=-2.02, p=.043 ($\underline{Mdn}_{Time\ 1}$=9.15, AD=.94; $\underline{Mdn}_{Time\ 6}$=10.0, AD=.14). Of note, even participants with reductions in skilled movement produced gesture at Time 1, and some did so with a high frequency.

The second prediction had to do with change over recovery time in the ability to 'package' meaning in gesture. Specifically, it was anticipated that the numbers of meaningful motor movements would increase from Time 1 to Time 6 in both iconic and pantomime gestures. For this analysis, the number of meaningful motor movements in iconic gestures was determined by counting the number of meaningful phrases in each

iconic gesture that was produced in the *speech plus gesture* condition. These were computed separately for each participant separately for Time 1 and Time 6. Similarly, the number of meaningful motor movements in pantomime gesture production was determined by counting the number of meaningful phrases in pantomime gestures produced in the *gesture only* condition separately for Time 1 and Time 6.

This analysis revealed that numbers of meaningful motor movements in iconic gesture in the *speech plus gesture* condition were similar at both timepoints, Z=-1.29, *ns* ($\underline{Mdn}_{Time\ 1}$=1.2, AD=.15, $\underline{Mdn}_{Time\ 6}$=1.35, AD=.32). And relative to Time 1, participants at Time 6 produced slightly (though not significantly) higher numbers of meaningful motor movements in pantomime gesture in the *gesture only* condition, Z=-1.57, *ns* ($\underline{Mdn}_{Time\ 1}$=1.95, AD=.47, $\underline{Mdn}_{Time\ 6}$=2.85, AD=.59). Thus, counter to prediction, no significant changes over time were apparent within the aphasia group in the production of meaningful motor movements in iconic and pantomime gesture.

In summary, the data described above indicate that as a group, participants with Broca's aphasia demonstrated significant improvement in *WAB AQ* scores and on most measures of verbal communication. Although the difference was not reliable, as a group, participants with aphasia produced gesture in early recovery at a rate five times higher than in later recovery. This is likely due to substantial individual variability in gesture production, an issue to which I will return in the final section. There was no indication of higher proportional use of gesture in isolation in early vs. late recovery within the aphasia group, nor was there evidence of significant change over time in gesture type or in the informational relationship between gesture and speech in co-productions. Finally, although significant improvements were evident in *WAB Praxis*

scores, production of meaningful motor movements in iconic and pantomime gesture did not increase over time.

Group Differences in Language, Gesture, and Motor Ability

I next turn to a comparison of the data obtained from the speech-gesture observation for the aphasia and NNI groups. Group differences were examined by comparing data from the aphasia group in early recovery (i.e., at Time 1) and in later recovery (i.e., at Time 6) to data from the NNI group.[1] I begin by comparing participants with aphasia to those with NNI on measures of verbal communication. This is followed by group comparisons on measures of gesture production, as well as on meaningful motor movement in both iconic and pantomime gesture productions.

Language. Language production by the two groups was examined using the four measures of verbal communication (number of utterances, MLU in words, number of different words produced, percent of intelligible utterances) created from responses in the *gesture plus speech* condition. These data are presented in Table 9.

As is evident in the table, the aphasia group at Time 1 did not differ significantly from the NNI group in the number of utterances produced. At Time 6, however, relative to the NNI group, participants with aphasia produced significantly fewer utterances. In addition, participants with Broca's aphasia produced significantly shorter MLU in words and fewer different words at both Times 1 and 6 than did the comparison group. Participants with aphasia at Time 1 produced a significantly lower proportion of

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[1] Because analyses of communication in the familiar and unfamiliar object contexts revealed similar results for NNI participants (i.e., no significant differences on the measures considered), these analyses were conducted with data fro the NNI group collapsed across contexts.

intelligible utterances than the NNI group; and a trend was evident in the same direction at Time 6.

Gesture. To examine potential group differences in gesture production, I first present analyses having to do with the overall frequency of gesture use and production of gesture in isolation, respectively. This is followed by group comparisons on measures of gesture rate, gesture type, and informational relationship between speech and gesture.

At Time 1, participants with Broca's aphasia produced gesture at a significantly higher rate than did participants with NNI, U=4.0, p=.026 (Mdn$_{\text{Aphasia Time 1}}$=.11, AD=.06, Mdn$_{\text{NNI}}$=.03, AD=.02). Indeed, the two distributions were almost completely nonoverlapping. Five of 6 (83%) participants with aphasia at Time 1 produced gesture at or above the .03 comparison median, while all of the NNI participants produced gesture at a rate below the aphasia group's Time 1 median.

However, this comparison was not significant for the Time 6 data, U=15.0, *ns* (Mdn$_{\text{Aphasia Time 6}}$=.025, AD=.11, Mdn$_{\text{NNI}}$=.03, AD=.02). Examination of individual participants' data indicated that at Time 6, only 3 of 6 (50%) participants with aphasia produced gesture at or above the .03 comparison rate. Taken together, relative to the NNI comparison group, participants with aphasia demonstrated produced gesture at a higher rate, but resembled the comparison group by Time 6.

Second, I examined the proportions of communications produced in speech with gesture vs. in gesture only to determine the relative use of speech and gesture by participants with aphasia and those with NNI. In comparison to the NNI group, participants with aphasia at Time 1 produced a significantly lower proportion of communications in speech with gesture, U=2.5, p=.038 (Mdn$_{\text{Aphasia Time 1}}$=.85, AD=.07,

Mdn$_{NNI}$=1.0, AD=.01), and a significantly higher proportion of communications in gesture only, U=2.5, p=.038 (Mdn$_{Aphasia\ Time\ 1}$=.15, AD=.07, Mdn$_{Time\ 6}$=0, AD=.01). Although not significant at Time 6, these group differences remained apparent (speech with gesture Mdn$_{Aphasia\ Time\ 6}$=.88, AD=.09, Mdn$_{NNI}$=1.0, AD=.01; gesture only Mdn$_{Aphasia\ Time\ 6}$=.12, AD=.09, Mdn$_{NNI}$=0, AD=.01).

I next examined the types of gestures produced in the *speech plus gesture* condition by participants in the two groups. The mean proportions of emblem, iconic, beat, deictic, and self-representational gestures were calculated. The distributions of gestures across these categories are presented in Figure 2. Note that for these analyses, the NNI comparison group is smaller (N=4) than the aphasia group (N =6) due to the fact that 2 of 6 NNI participants did not produce any gestures in the *speech plus gesture* condition.

As evident in the figure, the median proportion of emblem gestures produced by participants with Broca's aphasia was almost twice as high as those for the NNI group both initially (Mdn$_{Aphasia\ Time\ 1}$=.34, AD=.07, Mdn$_{NNI}$=.19, AD=.09) and later in recovery (Mdn$_{Aphasia\ Time\ 6}$ =.43, AD=.17, Mdn$_{NNI}$=.19, AD=.09). Relative to NNI participants, participants with aphasia produced somewhat lower proportions of iconic gestures both initially (Mdn$_{Aphasia\ Time\ 1}$=.34, AD=.10, Mdn$_{NNI}$=.56, AD=.13) and later in recovery (Mdn$_{Aphasia\ Time\ 6}$ =.36, AD=.09, Mdn$_{NNI}$=.56, AD=.13), The proportion of beat gestures was higher for the aphasia group at Time 1 (Mdn$_{Aphasia\ Time\ 1}$=.27, AD=.11, Mdn$_{NNI}$=.16, AD=.13) but was similar to that for the NNI group at Time 6 (Mdn$_{Aphasia\ Time\ 6}$=.14, AD=.12, Mdn$_{NNI}$=.16, AD=.13). However, none of these comparisons was statistically reliable. Deictic and self-referential gestures were infrequent in both groups (for deictic gestures, Mdn$_{Aphasia\ Time\ 1}$=.13, AD=.02, Mdn$_{Aphasia\ Time\ 6}$=.00, AD=.02, Mdn$_{NNI}$=.01,

AD=.02; for self-referential gestures, $\underline{Mdn}_{\text{Aphasia Time 1}}$=.04, AD=.02, $\underline{Mdn}_{\text{Aphasia Time 6}}$=.00, AD=.00, $\underline{Mdn}_{\text{NNI}}$=.04, AD=.03).

Finally, I examined the informational relationship between speech and gesture in communications in which both speech and gesture contribute meaning (i.e., those in the redundant, disambiguate, and add categories) for the aphasia and NNI groups. Figure 3 displays the median proportions of communications containing both speech and gesture in each of the three informational relationship categories for the aphasia group at Times 1 and 6 and for the NNI group.

As is evident, the overall distribution of communications across categories was generally similar in the aphasia and NNI groups. Thus, participants with aphasia at Time 1 produced a higher proportion of communications in which gesture was redundant with speech, U=8.0, ns ($\underline{Mdn}_{\text{Aphasia Time 1}}$=.52, AD=.12; $\underline{Mdn}_{\text{NNI}}$=.38, AD=.10); similar proportions of communications in which gesture disambiguated from speech, U=11.5, ns ($\underline{Mdn}_{\text{Aphasia Time 1}}$=.06, AD=.05; $\underline{Mdn}_{\text{NNI}}$=.10, AD=.06); as well as a comparable proportion of communications in which gesture added information to speech, U=11.0, ns ($\underline{Mdn}_{\text{Aphasia Time 1}}$=.44, AD=.12; $\underline{Mdn}_{\text{NNI}}$=.50, AD=.09) compared to participants with NNI. However, none of these differences was statistically reliable. A similar pattern was evident in a comparison utilizing the Time 6 data for the aphasia group (redundant $\underline{Mdn}_{\text{Aphasia Time 6}}$=.48, AD=.07; $\underline{Mdn}_{\text{NNI}}$=.38, AD=.10; disambiguate $\underline{Mdn}_{\text{Aphasia Time 6}}$=.03, AD=.09; $\underline{Mdn}_{\text{NNI}}$=.10, AD=.06; add $\underline{Mdn}_{\text{Aphasia Time 6}}$=.50, AD=.15; $\underline{M}_{\text{NNI}}$=.50, SD=.09).

Meaningful motor movements. The last set of analyses focused on meaningful motor movements in iconic and pantomime gestures for participants with Broca's aphasia at Times 1 and 6 and NNI participants. Two participants with NNI did not produce

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iconic gestures in the *speech plus gesture* condition and thus were not included in the iconic analysis.

Figure 4 displays the median number of meaningful motor movements produced in iconic and pantomime gestures respectively for the aphasia group at Times 1 and 6 and the NNI group. As evident in the figure, the median numbers of meaningful motor movements in iconic gestures were relatively comparable for the NNI and aphasia groups at Time 1 ($\underline{Mdn}_{Aphasia\ Time\ 1}$=1.2, AD=.17; $\underline{Mdn}_{NNI}$=1.6, AD=.81) and Time 6 ($\underline{Mdn}_{Aphasia\ Time\ 6}$=1.4, AD=.32; $\underline{Mdn}_{NNI}$=1.6, AD=.81). In contrast, participants with aphasia at Time 1 produced significantly fewer meaningful motor movements in pantomime gestures than did the NNI comparison group, U=3.0, p=.015 ($\underline{Mdn}_{Aphasia\ Time\ 1}$=1.95, AD=.47, $\underline{Mdn}_{NNI}$=3.1, AD=.33). By Time 6, however, the median for the aphasia group approached that of the NNI group, and the difference was no longer reliable, U=16.0, *ns* ($\underline{Mdn}_{Aphasia\ Time\ 6}$=2.85, AD=.59, $\underline{Mdn}_{NNI}$=3.1, AD=.33).

In summary, comparisons between the NNI group and the aphasia group at Time 1 and Time 6 revealed significant differences on most measures of verbal communication. Participants with aphasia made significantly more frequent use of gesture and produced a significantly higher proportion of gesture in isolation than did NNI comparison participants, but only in early recovery. They made consistently greater use of emblem gestures than did the NNI group (though not significantly so), a pattern that held in early and late recovery. Further, no group differences were evident in the informational relationship between speech and gesture in co-productions in early or late recovery. And although group differences were not apparent in iconic gesture complexity, participants

with aphasia in early recovery produced significantly less complex pantomime gestures than the NNI group, but the difference was no longer evident at Time 6.

Individual Differences in Patterns of Language, Gesture, and Motor Recovery

This final section focuses on individual variability in verbal communication and gesture in the six participants with aphasia across the six observation sessions. Longitudinal data on MLU, number of different words, and gesture rate are first presented for the six individual participants. These measures were selected because their median values exhibited substantial change between the initial and final observations. I then relate data on individual differences in gesture rate at the initial session to variation in observed patterns of recovery in language.

Patterns of language and gesture production over time. Data on MLU for each participant with aphasia over the 6-month recovery period are presented in Figure 5. As is evident, there was substantial individual variability in both initial MLU and patterns of change over time. Although a general increase in MLU was apparent over the observation period, participants' trajectories fell into three clusters. Two participants (4 and 5) produced a relatively low MLU at Time 1, with MLU remaining relatively low over the 6-month observation period. Participant 1 also had a relatively low MLU at the initial session, but with a steady increase over time. For the remaining participants (2, 3, and 6), MLU was relatively high at Time 1 and increased across sessions.

Figure 6 presents individual trajectories for number of different words for the six participants with aphasia. The pattern was similar to that observed for MLU in that the number of different words generally increased over time, and participants' trajectories

again fell into three clusters. Two participants (4 and 5) produced relatively low numbers of different words at Time 1 and continued to do so for the remainder of the observation period. Participant 1 began his recovery with a relatively low number of different words produced, but made steady gains across each observation time. The remaining participants (2, 3, and 6) produced relatively high numbers of different words at time1, and continued to show increases in lexical diversity over time.

With regard to gesture rate, Figure 7 shows individual trajectories for the aphasia group participants. As is apparent in the figure, there was substantial variability in gesture production across the six sessions. Although most participants demonstrated a general downward trajectory in rate of gesture over time, two individuals (participants 4 and 5) maintained a relatively high gesture rate throughout the period of study. In contrast, three participants (1, 3, and 6) demonstrated a decrease in gesture rate over time. Participant 2 maintained a variable but relatively low rate across recovery.

Relationship between initial gesture rate and language recovery. As is apparent in Figure 7, there was a natural split in the distribution of gesture rates for the aphasia participants at Time 1. Thus, these gesture rates were ranked from highest to lowest and a median split was performed. Participants with scores above the median were assigned to the High Gesture group (HG; participants 1, 4, and 5); and those with scores below the median were included in the Low Gesture group (LG; participants 2, 3, and 6).

Examination of observational and standardized measures of language for the two subgroups of participants revealed associations between gesture rate at the initial session and overall language functioning and outcome. Thus, relative to LG participants, all of the HG participants had lower MLUs (see Figure 5) and produced fewer different words

(see Figure 6) across the six sessions. In addition, gesture rate at the initial session was negatively associated with Time 6 *WAB AQ* scores, a relationship that tended toward significance (r=-.60, p=.091; see Figure 8). Indeed, the three participants with the highest *AQ* scores at Time 6 (participants 2, 3, and 6) were all in the LG group. A similar, significant relationship held between Time 1 gesture rate and Time 6 MLU (r=-.867, p=.015; see Figure 9).

Importantly, it was not the case that LG participants, who had the best language outcomes at Time 6, were also those who were least impaired in overall language at Time 1. As evident in Table 1, initial WAB AQ scores ranged from moderately-low to moderate for participants in both the HG (range 43.4-66.4) and LG subgroups (49.6-73.8).

DISCUSSION

This research was designed to examine the relationship between language, gesture, and motor skill in adults recovering from Broca's aphasia. The study addressed two broad research questions: 1) What is the pattern of gesture and speech co-production in adults with Broca's aphasia? and 2) since gesture production requires motor movement, how is gesture use affected by impairments in motor ability?

As a group, participants with aphasia demonstrated significant improvement in verbal communication over the 6-month recovery period; and they produced gesture at a higher rate early (but not later) in recovery. However, no significant changes were apparent over recovery time for gesture type, informational relationship between gesture and speech in co-productions, and number of meaningful motor movements produced in iconic and pantomime gestures.

Although significant changes in verbal communication were evident within the aphasia group, even by Time 6 verbal language ability was still significantly poorer than that of NNI participants. In addition, the communication patterns of the aphasia group differed from those of the comparison group in a number of ways, and this was so primarily early in recovery. Specifically, gesture rate was significantly higher than that for NNI adults. The majority of gestures produced by participants with aphasia in early and late recovery were emblems, while the comparison group primarily made use of iconic gestures. When compared to the NNI group, participants with aphasia in early recovery produced a significantly higher proportion of communications in gesture only, and they also used a higher proportion of communications that were redundant with

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speech in early and late recovery than the NNI group. Further, participants with aphasia produced significantly fewer numbers of meaningful motor movements in pantomime gesture in early recovery, but no reliable differences were apparent for iconic gestures.

A wide range of individual variation was apparent within the aphasia group in terms of initial severity of language impairment, recovery of expressive language and motor skill, and patterns of gesture use over recovery time. There was an inverse relationship between gesture rate at the initial observation and performance on language measures at Time 6: the three participants with relatively higher gesture rates scored lower on language measures, while participants with lower gesture rates scored higher. Thus, analysis of gesture may provide information regarding who is likely to have the best communication recovery and who may have a poorer prognosis.

The idea that language and motor processes change over the course of development and in cases following cerebrovascular accident is not new to the literature. These changes have been referred to as 'dynamic neural events,' and rely on plasticity, redundancy and compensatory interactions between language and sensorimotor relationships (Bates & Dick, 2000). In particular, Broca's area appears to be overlaid in regions that mediate sensorimotor skills (i.e. sensory and/or motor control to the body; Rizzolatti & Arbib, 1998). Thus, recovery of verbal and gesture communication ability following a lesion specific to Broca's area, irrespective of the mode of expression, may depend on plasticity, redundancy and compensatory interactions between language and sensorimotor relationships. Further, improvement in one modality may affect the other in a measurable way.

Although the brain appears to be differentiated into areas that seem specific for language, other regions of the brain can 'step in' and take over when language processes are disrupted (Bates & Dick, 2000). On this view, change in language and motor processes relies on interconnections between alternative brain regions that have sensorimotor responsibilities and specific computational properties that are geared for language re-organization (i.e., speed and relative density of interconnections, neurotransmitter properties; Bates et al., 1997; Bates & Dick, 2002; Price et al., 1998). Thus, in a focal left hemispheric anterior brain lesion (i.e., CVA), shared processes that subserve language and gesture relationships may be substantially disrupted, and the task in recovery is to develop interconnections between alternative brain regions for sensorimotor and language functions.

In light of the changes in language and motor processes over recovery time observed in this study, the remainder of the discussion focuses on three general themes: a) the utility of gesture as a tool to predict language recovery following a cerebrovascular accident; b) the existence of parallel deficits in speech and gesture across recovery; and c) the potential separability of processes underlying the production of pantomime gestures and those subserving the production of iconic gestures.

Gesture as a Tool for Prediction of Language Recovery

Findings from this study are consistent with other research indicating improvement in language ability by approximately seven to eight months post-onset of aphasia (Cappa et al, 1997; Kertesz, Harlock, & Coates, 1979). As a group, participants with aphasia in

this study exhibited significant improvement on the *WAB AQ* and on most observational measures of verbal communication between times 1 and 6.

What is of particular interest in this research, however, is the relationship between language and gesture, and specifically, the pattern of gesture use as language changes over recovery. If that language and gesture are closely linked systems (McNeill, 1992, 2005), then relationships between aspects of gesture and language production should be apparent even with disruption to the systems, as in Broca's aphasia and motor impairment. The data revealed two patterns of gesture use in individuals recovering from expressive aphasia that may have prognostic value.

First, it was striking that the three participants with the lowest gesture rates in early recovery had the highest overall language scores and longer utterances at time 6; and conversely, the three participants with the highest gesture rates in early recovery had the lowest overall language scores and shorter utterances at time 6. This association between a higher gesture rate in early recovery and poorer language outcome suggests that an initial pattern of "compensation" via gesture may not be a positive prognostic indicator for language recovery. Such a pattern could be indicative of relatively greater disruption in processes that mediate language and sensorimotor skills in the region of Broca's area, but future research is clearly needed to replicate these findings with a larger sample and to elucidate mechanisms underlying the emergence of such compensatory patterns.

Second, in early recovery, participants with aphasia produced significantly more communications in gesture only than NNI participants. This finding is consistent with that of Cicone et al. (1979), who reported that persons when conversations of patients with Broca's aphasia were examined and compared to those of groups of Wernicke's

patients and control patients with no neurological illness, the proportion of communications in gesture only were higher than in either of the comparison groups (i.e. 40% of all communications were in gesture only in the Broca's aphasia group).

However, this difference disappeared as participants in the present study recovered language ability over time. By late recovery, participants with aphasia more closely resembled the comparison group and produced a higher proportion of gesture that was timed with speech. This pattern of communication recovery may suggest that participants with Broca's aphasia were compensating through gesture for their lack of verbal skills in early recovery. It may be that as interconnections between shared sensorimotor and language processes were re-established over time, participants with aphasia were more likely to produce gesture that was temporally organized with speech.

In summary, these data suggest that gesture (especially gesture rate in early stages of recovery) may be a tool for prediction of language recovery following a left hemispheric cerebrovascular accident. The degree of disruption between sensorimotor and language relationships is likely to be related to the extent to which patients go on to recover verbal language ability. Gestures that are temporally organized with speech may rely on more fully recovered connections between sensorimotor and language areas. Thus, a challenge to aphasia researchers is to validate the utility of gesture as a predictor of language recovery and to identify specific patterns of gesture use that may emerge at specific points in the recovery time that may be related to points of change in language abilities.

Previous research on speech and gesture in adults with Broca's aphasia has reported similar disruptions in both speech and gesture (Cicone et al, 1979; Glosser, Wiener, & Kaplan, 1986; Pedelty, 1987). For example, in one study, the gestures of persons with Broca's aphasia were limited mostly to high-frequency referential gestures that corresponded to high content, telegraphic speech output (Cicone et al., 1979). In addition, persons with Broca's aphasia were reported to produce a high percentage of iconic and emblem gestures but few of the nonrepresentational beat gestures that are associated with fluent speech (Pedelty, 1987).

The present findings are consistent with the view that speech and gesture break down together in Broca's aphasia. Thus, as in previous work (Pedelty, 1987), the proportion of emblem gestures was relatively high for participants with aphasia; and counter to expectation, it increased (though not significantly) from time 1 to time 6. The predominance of emblem gestures in the aphasia group throughout the six-month observation period stands in contrast to the pattern seen in the NNI group, for whom iconic gestures were most frequent. The aphasia group's continued reliance on emblem gestures may be at least partially attributed to the fact that even at time 6, their language was significantly poorer than that of comparison participants on most of the measures considered. In other words, the relatively high proportional use of emblem gestures may be reflective of the paucity of language characteristic of Broca's aphasia.

Why might aphasic persons make such extensive use of emblem gestures? Emblems are associated with a range of speech acts, and have certain social pragmatic properties (McNeill, 1992). In specific speech acts, emblems can be used to regulate or comment on

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another's behavior. For example, emblems can be used to ask another to come near by beckoning with the hand, or nodding as if to agree with another's actions. In addition, emblem gestures can reveal one's own emotional state (e.g., a head shake along with a hand pushing away may communicate "I do not like it" when words are unavailable). Emblems may also be used to greet (i.e., waving hello or good-bye), command (i.e., hand with palm out as if to say, "stop"), or even threaten (i.e., making a fist and shaking it at someone). Emblems may also be used to 'cover-up' for inadequate language when awareness of the communicative breakdown is high. Thus, emblems can potentially carry out a range of speech acts when speech is impaired.

For individuals with aphasia, emblem gestures may be particularly important because they can be used to regulate communication. For example, emblems may serve as conversational placeholders, thereby giving speakers with aphasia a strategy that is pragmatically appropriate, yet allows for extra processing time. In a sense, the speaker with aphasia may unconsciously "stall" or hold a communicative turn through the use of emblem gesture (e.g., speaker indicates "stop, wait for me," by extending the hand and palm facing out while searching for the appropriate words). Or a speaker with aphasia may shake head no, and say, "uh, no, uh, oh sit here" when speech is effortful to allow for needed processing time. In addition, as suggested above, emblems may be beneficial when speech breaks down altogether by freeing other linguistic and cognitive resources to get speech back on-line.

More extensive use of emblem gesture may also be related to difficulties with lexical retrieval and syntax that are well-documented in patients with Broca's aphasia (Kearns, 2005; Kertesz, 1982). When spoken language is difficult, emblems can

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complement or substitute meaning when words are unavailable (McNeill, 1992). For example, in Broca's aphasia, emblems can be paired with more automatic and stereotypical speech utterances when lexical retrieval is difficult (e.g., participant places index finger on thumb and extends other three fingers in the 'okay' sign and verbalizes, "that's right."). In addition, persons with Broca's aphasia may use emblems as if they are unspoken words or phrases to convey meaning (e.g., participant places index finger to mouth as if to say "quiet, too much noise.").

The data also indicated that iconic gesture accounted for about 30-40% of all gesture types produced in early and late recovery in persons with Broca's aphasia, while it accounted for over half of all gesture types produced in the NNI group. Although it was predicted that persons with aphasia would make use of iconic gestures in early recovery, they still lagged behind the control group in later recovery.

Why might aphasic persons make less extensive use of iconic gestures? Although speech content was not analyzed in the present study, it is possible that participants with aphasia provided object descriptions that contained fewer details about target objects, perhaps due to the occurrence of severe speech failures (i.e., speech fillers, speech blocks, self-corrections, re-starts, pauses, literal and semantic paraphasias, perseverative word productions). Since iconic gestures often convey information about characteristics of objects and specific actions (McNeill, 1992), reduced production of descriptive verbalizations would likely be related to less frequent occurrence of iconic gesture productions. Thus, the relatively less frequent use of iconic gestures in the aphasia group may be a general reflection of difficulty conveying information in speech.

With regard to beat gestures, the initial prediction was that persons with aphasia would produce a higher proportion of beat gestures as speech recovered (Pedelty, 1987). However, findings indicated that for the aphasia group, the proportionate production of beat gestures actually declined over recovery. At first glance, this is surprising because beat gestures are associated with the temporal structure of language, and unequal stress patterns across words of an utterance are required for these gestures to appear in adult speech (McClave, 1994, 1998). Thus, for beats to be co-produced with speech, the assumption is that language production must be recovered to the level of multi-word utterances. However, MLU was relatively low in early recovery for most participants with aphasia.

Informal inspection of the temporal patterning of beats relative to speech indicated that persons with Broca's aphasia produced some (but not all) beat occurrences in utterances that contained speech failures (i.e., with speech fillers, speech blocks, self-corrections, re-starts, pauses, literal and semantic paraphasias, perseverative word productions). Thus, some of these beat gestures may be 'atypical' in that they are not tied to fluent speech, but instead are associated with effortful speech in early recovery. This result is consistent with the general claim that gesture use increases during speech failures in participants without communication disorders (for a review, see Butterworth & Beattie, 1978; Feyereisen & Soron, 1982).

Beats that are associated with speech failures have been referred to in the literature as 'Butterworth' beats (McNeill, 1992). In contrast, a typical beat is a flick of the hand or fingers, either up and down or back and forth, and is usually produced with fluent speech (McNeill, 1992). These beat gestures add emphasis to individual words and phrases that

they accompany (e.g., marking an introduction of a new character or theme, summarizing an action, adding emphasis to co-occurring words).

Although McNeill (1992) acknowledges that atypical beats occur in aphasia, he does not classify atypical 'Butterworth' beats in the same category as those beats produced with fluent speech. In this research, analyses of the timing of 'Butterworth' beats and certain kinds of body movements such as associated head movements and body rocking in relationship to speech failures were not undertaken. In light of these findings, they may prove to be important in future research.

It is possible that the relatively more frequent use of beats by participants with aphasia may reflect a greater reliance on 'Butterworth' beats in early recovery when speech was most effortful. Further, the finding of a decrease in relative production of beats by Time 6 could be a function of 'Butterworth' beats giving way to typical beat production as language changes over time. In other words, the observed decline in beat production within the aphasia group may be indicative of a simple reduction in the relative frequency of this gesture type; rather, it may be a sign of a qualitative shift in the communicative system as language becomes less effortful speech.

A final piece of evidence for parallel deficits in speech and gesture comes from an examination of the informational relationship between speech and gesture in co-produced utterances. Although group differences did not reach conventional levels of significance, utterances in which speech and gesture were informationally redundant were relatively more frequent in the aphasia group, especially in early recovery. This may be due to the frequent speech failures that were observed among participants with aphasia in early recovery. Participants with aphasia often produced emblem head nods or headshakes

with their speech productions, such as "no", or "yeah," and thus the speech-gesture relationship was coded as redundant. At times, participants communicated "no" and shook their head when they recognized that their verbal communications were insufficient. On this analysis, the redundant informational relationship may be related to more extensive use of emblem gestures during speech failures and error recognition.

In summary, these findings are consistent with the notion of integrated processes underlying speech and gesture that control critical features of communications, irrespective of the mode of expression. Further, the finding that emblem gesture use was prevalent in the communications of participants with aphasia in both early and late recovery (while iconic was most prevalent in the NNI group) may indicate that emblem gestures perform many functions for speakers with aphasia. Emblem gestures may serve a variety of pragmatic and communication functions when produced with and without speech for persons with Broca's aphasia.

The Distinction between Iconic and Pantomime Gestures

Previous research has found that the nature of Broca's aphasia as a syndrome includes deficits in both expressive language and pantomime gesture productions (Duffy & Duffy, 1981, Kimura & Archibald, 1976). However, the literature also indicates that persons with Broca's aphasia produce meaningful gestures that accompany speech (McNeill, 1992; Pedelty, 1987; Rose & Douglas, 2003). Findings from the present study are consistent with both reports. All participants with Broca's aphasia in the present study produced gestures, even those with limb apraxia and/or motor weakness. Although participants with aphasia produced less complex pantomime gestures at time 1 relative to

the NNI group, no significant group differences were evident for meaningful motor movements in iconic gesture in early or late recovery.

A potential explanation for the lack of significant findings in iconic gesture production has to do with ceiling effects on the number of meaningful units that can be conveyed in iconic gestures. For iconic gestures, the measure of meaningful motor movements is related to the gesture stroke as defined by McNeill (1992). According to McNeill, when fluent speakers produce iconic gestures, they typically execute about one gesture stroke per spoken utterance (McNeill, 1992). A stroke is defined by McNeill as the phase that carries the gesture content (e.g., hand moves down sharply as if to roll a ball; scored as 1 gesture stroke). Thus, the number of meaningful motor movements would correspond to the number of gesture strokes, and at a rate of roughly one gesture stroke per utterance, the relatively low score would be unlikely to change over time, even in the face of language recovery.

The coding scheme for meaningful motor movements employed in this study was adapted from research that compared gestures produced in a spontaneous communication task in two conditions: *speech plus gesture* and *gesture only* (Goldin-Meadow, McNeill, & Singleton, 1996). Iconic gestures were then analyzed for their semantic contribution within a string of gestured responses. They found that participants were less likely to conjoin their gestures for semantic elements into strings in the *speech plus gesture* condition in comparison to the *gesture only* condition. These findings are similar to the present findings, in that iconic gesture in the *speech plus gesture* condition was relatively less complex than pantomime gestures in the *gesture only* condition.

Although there was little change over recovery in complexity of iconic gestures, participants with aphasia exhibited change relative to the NNI group in complexity of pantomime gestures. Thus, at Time 1, pantomime gesture complexity differed significantly between the two groups, but this was not the case at Time 6. Why might this be the case?

Pantomime gestures differ from iconic gestures in a number of ways. The most obvious difference is that pantomime gestures are produced in the absence of speech and are segmented gesture forms. They presumably arise from speech and motor processes that are likely pre-planned and conscious. In contrast, iconic gestures are generally produced with speech, are largely idiosyncratic in form, and cannot be combined into larger units. In addition, iconic gestures arise from speech and motor processes that are spontaneously produced and associated with natural contexts.

A further difference between iconic and pantomime gestures may have to do varied performance between communication contexts. For some persons with aphasia, the lack of the natural speaking context and demand for more abstract thought may explain their poorer performance in the pantomime (*gesture only* condition). Pantomime tasks and in other traditional tasks that are designed to measure limb apraxia (i.e., copying of meaningless hand postures, empty-handed gesture production without speech) are fairly abstract. These tasks typically require the generation of a gesture following a verbal command (e.g., "show me how to use a comb."). One must comprehend the command, then consciously represent the object's use in spatial and dynamic properties; and this process involves a good deal of cognitive abstraction (Rose & Douglas, 2003). In these instances, abstraction also involves creating a mental image of the surrounding

environment in the absence of contextual support (e.g., pretend to cut food on a plate with a knife while sitting at the table).

In contrast, when spontaneously producing an iconic gesture during conversation, the sensorimotor and language processing demands are largely unconscious because they are context-embedded (e.g., person with aphasia spontaneously gestures the direction and force of a hammer when completing a woodworking task). Thus, differences in processing between the iconic (*speech plus gesture* condition) and pantomime (*gesture only* condition) may be sufficient to explain the discrepancies in performance found between aphasia and NNI groups at time 1.

Taken together, these findings suggest that contextual demands may be an important factor in gesture production in persons with aphasia. They further suggest that clinicians who treat persons with should sample gesture along with spontaneous speech co-productions over the course of recovery, rather than simply relying on traditional measures of limb apraxia (for a complete review of gesture use in the treatment of aphasia, see Rose, 2006).

Conclusions

The present findings point to a series of issues to be addressed in future research. Because communication patterns observed in this study were not stable over recovery time, longitudinal research designs are clearly warranted. Examination of gesture over a longer course of recovery will provide a more complete picture of the communication recovery pattern in adults with Broca's aphasia.

Additionally, future research is needed to replicate the present findings with a larger sample of persons with Broca's aphasia to determine whether early assessment of gesture production can provide clinicians with information regarding who is likely to have a better communication recovery and who may have a poorer prognosis. Future research should focus on the extensive use of emblems in Broca's aphasia as it relates to pragmatic speech acts and/or information processing. Research questions should also focus on beat gestures, their relationship to fluent vs. effortful speech, and timing with fluent speech vs. speech failures.

In summary, patterns of communication in speech and gesture by patients with Broca's aphasia changed measurably over the first six months of recovery. Changes in gesture paralleled improvements in language; and there was evidence of differences in speech-gesture system organization in participants with aphasia relative to NNI comparison adults, even at the final observation. Future research with larger samples will provide a clearer picture of the mechanisms underlying the organization and production of communicative behavior in both modalities and ways in which they change over the course of recovery.

REFERENCES

Acredolo, L.P., & Goodwyn, S.W. (1988). Symbolic gesturing in normal infants. *Child Development, 59*, 450-466.

Bates, E., & Dick, F. (2000). Beyond phrenology: Brain and language in the next millennium. *Brain and Language, 71*, 18-21.

Bates, E., & Dick, F. (2002). Language, gesture, and the developing brain. *Developmental Psychobiology, 40*, 293-310.

Bates, E., Thal, D., Trauner, D., Fenson, J., Aram, D., Eisele, J., et al. (1997). From first words to grammar in children with focal brain injury. *Developmental Neuropsychology, 13,* 3, 275-343.

Braddock, B.A., & Iverson, J.M. (2003, June). *Links between gesture, speech, and motor skill in children with language impairment.* Poster presentation at the 24th Symposium on Research in Child Language Disorders, Madison, WI.

Braddock, B.A., & Iverson, J.M. (2005, manuscript in preparation). *Links between gesture, speech, and motor skill in children with language impairment.*

Butterworth, B., & Beattie, G.W. (1978). Gesture and silence as indicators of planning in speech. In R.N. Campbell & P.T. Smith (Eds.), *Recent advances in the psychology of language: Formal and experimental approaches.* New York: Harcourt Brace Jovanovich.

Cappa, S.F., Perani, D., Grassil, F., Bressi, S., Alberoni, M., Francheschi, M., Bettinardi, V., Todde, S., & Fazio, F. (1997). A PET follow-up study of recovery in stroke in acute aphasics. *Brain and Language, 56*, 55-67.

Capone, N.C., & McGregor, K.K. (2004). Gesture development: A review for clinical and research practices. *Journal of Speech, Language, and Hearing Research, 47*, 173-186.

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

Duffy, R.J., & Duffy, J.R. (1981). Three studies of deficits in pantomime expression and pantomime recognition in aphasia. *Journal of Speech and Hearing Research, 46*, 70-84.

Feyereisen, P., & Soron, X. (1982). Nonverbal communication and aphasia: A review. II. *Brain and Language, 16*, 213-236.

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

Goldin-Meadow, S., McNeill, D., & Singleton, J. (1996). Silence is liberating: Removing the handcuffs on grammatical expression in the manual modality. *Psychological Review, 103*. 1. 34-55.

Iverson, J.M., & Thelen, E. (1999). Hand, mouth, and brain: The dynamic emergence of speech and gesture. In R. Nunez & W.J. Freeman (Eds.), *Reclaiming Cognition: The Primacy of Action, Intention, and Emotion*. Thorveton: UK: Imprint Academic.

Kearns, K.P. (2005). Broca's aphasia. In L.L. LaPointe (Ed.), *Aphasia and Related Neurogenic Language Disorders, Third Edition*. New York: Thieme.

Kertesz, A. (1982). *Western Aphasia Battery (WAB)*. San Antonio, TX: Harcourt Assessment, Inc.

Kertesz, A., Harlock, W., & Coates, R. (1979). Computer tomographic localization, lesion size, and prognosis in aphasia and nonverbal impairment, *Brain and Language, 8*, 34-50.

Kimura, D., & Archibald, Y. (1974). Motor functions of the left hemisphere. *Brain, 97*, 337-350.

Lai, S.M., Duncan, P.W., Dew, P., & Keighley, J. (2005). Sex differences in stroke recovery. *Preventing Chronic Disease, 2,* 3, A13.

Martin, R.C., Franzen, M.D., & Raymond, M.J. (1996). Effects of unilateral vascular lesions and gender on visual spatial and auditory visual attention span. *Applied Neuropsychology, 3,* (3 & 4), 116-121.

McClave, E. (1994). Gestural beats: The rhythm hypothesis. *Journal of Psycholinguistic Research, 23*, 45-66.

McClave, E. (1998). Pitch and manual gestures. *Journal of Psycholinguistic Research, 27,* 69-89.

McNeill, D. (1987). So you do think gestures are nonverbal! Reply to Feyereisen (1987). *Psychological Review, 94*, 4, 499-504.

McNeill, D. (1992). *Hand and mind: What gestures reveal about thought.* Chicago, IL: University of Chicago Press.

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

Miller, J.F. (1984). *Systematic Analysis of Language Transcripts; Software for Analyzing*

English and Spanish Language Samples (SALT). Language Analysis Lab. Waisman Research Center, University of Wisconsin- Madison.

Pechman, T., & Deutsch, W. (1982). The development of verbal and nonverbal devices for reference. *Journal of Experimental Child Psychology, 34*, 330-341.

Pedelty, L.L. (1987). *Gesture in aphasia.* Unpublished doctorial dissertation, The University of Chicago.

Price, C.J., Howard, D., Patterson, K., Warburton, E.A., Friston, K.J., & Frackowiak, R.S.J. (1998). A functional neuroimaging description of two deep dyslexia patients. *Journal of Cognitive Neuroscience, 10*, 3, 303-315.

Rizzolatti, G., & Arbib, M.A. (1998). Language within our grasp. *Trends in Neuroscience, 21*, 188-194.

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

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

Schnider, A., Hanlon, R.E., Alexander, D.N., & Benson, D.F. (1997). Ideomotor apraxia: Behavioral dimensions and neuroanatomical basis. *Brain and Language, 58*,125-136.

Shewan, C.M., & Kertesz, A. (1980). Reliability and validity characteristics of the Western Aphasia Battery (WAB). *Journal of Speech and Hearing Disorders, 45*, 308-324.

Wertz, R.T., LaPointe, L.L., & Rosenbek, J.C. (1984). *Apraxia of Speech in Adults: The Disorder and Its Management*. New York: Grune & Stratton.

Williams, D. (1999). *A comparison of gesticulation in children with language impairments and children with normal development*. Unpublished doctoral dissertation, Bowling Green State University.

Table 1. Participant Information, Computerized Tomography (CT)/Magnetic Resonance Imaging (MRI) findings, *Western Aphasia Battery Aphasia Quotient (WAB* AQ), and *Western Aphasia Battery (WAB)* Praxis scores at time 1 and time 6.

	Age (years)	Education (years)	CT/ MRI findings	*WAB AQ (time 1)*	*WAB AQ (time 6)*	*WAB Praxis (time 1)*	*WAB Praxis (time 6)*
Participant 1	54	12	Left middle cerebral artery	43.4	72.6	9.3	10
Participant 2	59	16	Left frontal-parietal	64.2	89.4	9.8	10
Participant 3	78	12	Left temporal-parietal intracranial hemorrhage	49.6	90.6	7.83	10
Participant 4	64	16	Left middle cerebral artery	66.4	79.4	9	9.5
Participant 5	51	12	Left middle cerebral artery	62.2	81.4	7	10
Participant 6	58	16	Left middle cerebral artery	73.8	90.8	10	10

Note: *WAB AQ* maximum score is 100; 0-25 severe aphasia, 25-50 moderately-severe aphasia, 50-75 moderate aphasia, 75-93.8 mild aphasia (cut-off of 93.8 is used to set the definition of aphasia based on *WAB* guidelines); *WAB praxis* maximum score is 10.

Table 2. Identifying Patient Data (Adapted from Western Aphasia Battery; Kertesz, 1982)

Name: _____

Address: _____

_____

Age: _____

Birthdate: _____

Primary Language: _____

Handedness: Writing _____   Throwing _____   Cutting _____   Drawing _____
Spoon _____   Brush _____

Education (Number of Grades): _____

Occupation: _____

Neurological History

Date of onset: _____

Hemiplegia: Severe   Moderate   Mild   Recovered Side

Site of Lesion: _____

EEG: _____

CT Scan: _____

Arteriograms: _____

MRI Scan: _____

Table 3. Familiar and unfamiliar object sets

	FAMILIAR	UNFAMILIAR
SET ONE	*Padlock- practice item* *Dice- practice item* Spoon Tweezers Toothbrush Pen Button Screwdriver Rubber band Ball	*Garlic press* *Corded earplugs-practice item* Aluminum tab can opener Antifreeze hydrometer tester Golf ball cleaner Dental floss holder Grout rake Magnetic nail gripper Bias tape maker Turkey lacer
SET TWO	*Scotch tape-practice item* *Hammer-practice item* Eraser Plate Pencil Fork Comb Thumbtack Drinking straw Tape measure	*Hamburger press-practice item* *Tea ball holder-practice item* Strawberry huller Toothpaste tube squeezer Rolling knife sharpener Screen and spline installation tool Door viewer lens Ribbon shredder Sure grip jar opener Paint can opener
SET THREE	*Matches-practice items* *Quarter-practice items* Paperclip Coffee Cup Key Glove Knife Scissors Envelope Safety pin	*Egg separator-practice item* *Handwarmer -practice item* Wrapping paper cutter Ampule medicine holder Pan scraper Pill splitter Orange peeler Wax letter sealer Scalpel holder Needle threader

Table 4. Coding criteria for gesture type (taken from Pedelty, 1987)

GESTURE TYPE	DESCRIPTION	EXAMPLE
STANDARD CONVENTIONAL Emblem	Recognized by others even without accompanying speech	Waving bye-bye, or making the "OK" sign with the index finger and thumb
Deictic	Singles out a referent from other possible ones	Pointing or holding up an object to show
Self-referential	Singles out self from other persons	Pointing to self
BEAT Beat gesture	Meaningless, biphasic, up and down movements of the hands that have an emphatic function	Making a beat in the air with the hand to add stress to co-occurring words
ICONIC Iconic gesture	Depicts an action performed by or a characteristic of an object	Circular iconic gesture is produced with the word "round"

Table 5. Coding criteria for gesture-speech informational relationship (taken from Braddock and Iverson, 2005).

INFORMATIONAL RELATIONSHIP TYPE	DESCRIPTION	EXAMPLE
Redundant	Gesture provides the same information as the co-occurring speech	Participant says "yes" with simultaneous up-down head nods
Disambiguate	Gesture singles out a referent from many possible ones	Participant points to an object in the room and states "that one"
Add	Information conveyed in gesture is distinct from that in co-produced speech	Participant produces hand movements as if to a throw a ball and says, "two points" Participant produces the hand movements as if to drink from a glass and says, "wow", "oh", "yea"
Unintelligible	Gesture-speech informational relationship can not be determined given reductions in the participant's speech intelligibility	Participant verbalizes "xxx" unintelligible utterance and produces corresponding hand movements
Uncodable	Gesture-speech informational relationship can not be coded with reliability. Although the gesture may have the complexity and extent of other codeable gestures- no word or phrase is clearly associated with it	Participant moves hands side to side and says, "turn mark", but the exact referent can not be determined given the vagueness of the word choice

Table 6. Coding criteria for meaningful motor movements in iconic and pantomime gesture production (*speech plus gesture* and *gesture only* conditions respectively; adapted from Goldin-Meadow, McNeill, & Singleton, 1996).

ICONIC GESTURES	Meaningful Motor Movement Description	Meaningful Motor Movement Example
ACTION	Defined as a meaningful movement that captures an aspect of object motion, the movement will be assumed to represent the action of the object and will be scored	In response to "show me how to use a plate," participant moves arm down towards table as if to gesture placing food on a plate, and at the same time opens clasped fingers as if to drop the food on the plate. Score as 2 actions.
ATTRIBUTE	Defined as a meaningful movement that captures an attribute of the object, the movement will be assumed to represent that attribute of the object and will be scored.	In response to "show me what a plate looks like," participant gestures as if to draw a circle in the air, representing the shape of a plate. Score as 1 attribute.

Table 7. Median number and (average deviation) of different words in *speech plus gesture* and *speech only* conditions; proportion of emblem gesture in *speech plus gesture* condition; complexity scores for iconic gesture in the *speech plus gesture* condition and pantomime gesture in *the gesture only* conditions, at Time 1 and Time 6 in familiar and unfamiliar contexts for the aphasia group.

MEASURE AND CONDITION	Familiar Context	Unfamiliar Context	Significance Level
NUMBER OF DIFFERENT WORDS **Speech Only**			
Time 1	29.0 (24.56)	31.0 (20.11)	$Z_{Time\ 1}$=-.210, *ns*
Time 6	70 (19.67)	70.5 (27.33)	$Z_{Time\ 6}$=-.105, *ns*
NUMBER OF DIFFERENT WORDS **Speech plus Gesture**			
Time 1	51.0 (11.11)	36.0 (22.77)	$Z_{Time\ 1}$=-.943, *ns*
Time 6	67.0 (24.67)	72.5 (27.56)	$Z_{Time\ 6}$=-.105, *ns*
PROPORTION OF EMBLEMS **Speech plus Gesture**			
Time 1	.22 (.09)	.45 (.15)	$Z_{Time\ 1}$=-1.57, *ns*
Time 6	.25 (.35)	.53 (20)	$Z_{Time\ 6}$=-1.21, *ns*
COMPLEXITY OF ICONICS **Speech plus Gesture**			
Time 1	1.1 (.15)	1.0 (.22)	$Z_{Time\ 1}$=-.365, *ns*
Time 6	1.13 (.14)	1.55 (.36)	$Z_{Time\ 6}$=-1.34, *ns*
COMPLEXITY OF PANTOMIMES **Gesture Only**			
Time 1	1.88 (.47)	1.95 (.45)	$Z_{Time\ 1}$=-.736, *ns*
Time 6	3.2 (.52)	2.65 (.83)	$Z_{Time\ 6}$=-1.80, *ns*

Table 8. Median number and (average deviation) of utterances, MLU, and different words produced in the *speech plus gesture* and *speech only* conditions at Time 1 and Time 6 for the aphasia group.

MEASURE	Speech Only	Speech Plus Gesture	Significance Level
NUMBER OF UTTERANCES			
Time 1	38.5 (11.67)	44.5 (26.72)	$Z_{Time\ 1}$=-.943, *ns*
Time 6	24 (3.5)	51 (8.44)	$Z_{Time\ 6}$=-.105, *ns*
MLU			
Time 1	4.03 (1.32)	3.98 (1.47)	$Z_{Time\ 1}$=-1.05, *ns*
Time 6	6.91 (2.15)	6.77 (2.14)	$Z_{Time\ 6}$=-1.15, *ns*
NUMBER OF DIFFERENT WORDS			
Time 1	50.5 (36.33)	75.0 (25.56)	$Z_{Time\ 1}$=-2.00, *p*=.046
Time 6	48.5 (4.67)	51.0 (8.44)	$Z_{Time\ 6}$=-.743, *ns*

Table 9. Median number and (average deviation) in measures of verbal communication in the Broca's aphasia group at times 1 and 6 and the NNI group.

VERBAL COMMUNICATION MEASURES	Aphasia Group	NNI Group	Significance level
Number of utterances	**Mdn $_{Time\ 1}$=44.5 (26.72)** **Mdn $_{Time\ 6}$=51.0 (8.44)**	**Mdn=64.0 (7.33)**	U$_{Time\ 1}$=8.0, p<.13 U$_{Time\ 6}$=4.5, p<.03
MLU in words	**Mdn$_{Time\ 1}$= 3.98 (1.47)** **Mdn$_{Time\ 6}$=6.77 (2.14)**	**Mdn=14.73 (1.85)**	U$_{Time\ 1}$=.00, p<.002 U$_{Time\ 6}$=.00, p<.002
Number of different words	**Mdn$_{Time\ 1}$=75.0 (25.56)** **Mdn$_{Time\ 6}$=127.5 (40.5)**	**Mdn=272.0 (25.67)**	U$_{Time\ 1}$=.00, p<.002 U$_{Time\ 6}$=.00, p<.002
Percent intelligible utterances	**Mdn$_{Time\ 1}$=.93 (.12)** **Mdn$_{Time\ 6}$=.97 (.03)**	**Mdn=1.0 (.01)**	U$_{Time\ 1}$=4.0, p<.03 U$_{Time\ 6}$=6.5, p<.07

Figure 1. Median proportion of communications in speech with gesture and gesture only at Times 1 and 6 in the Broca's aphasia group.
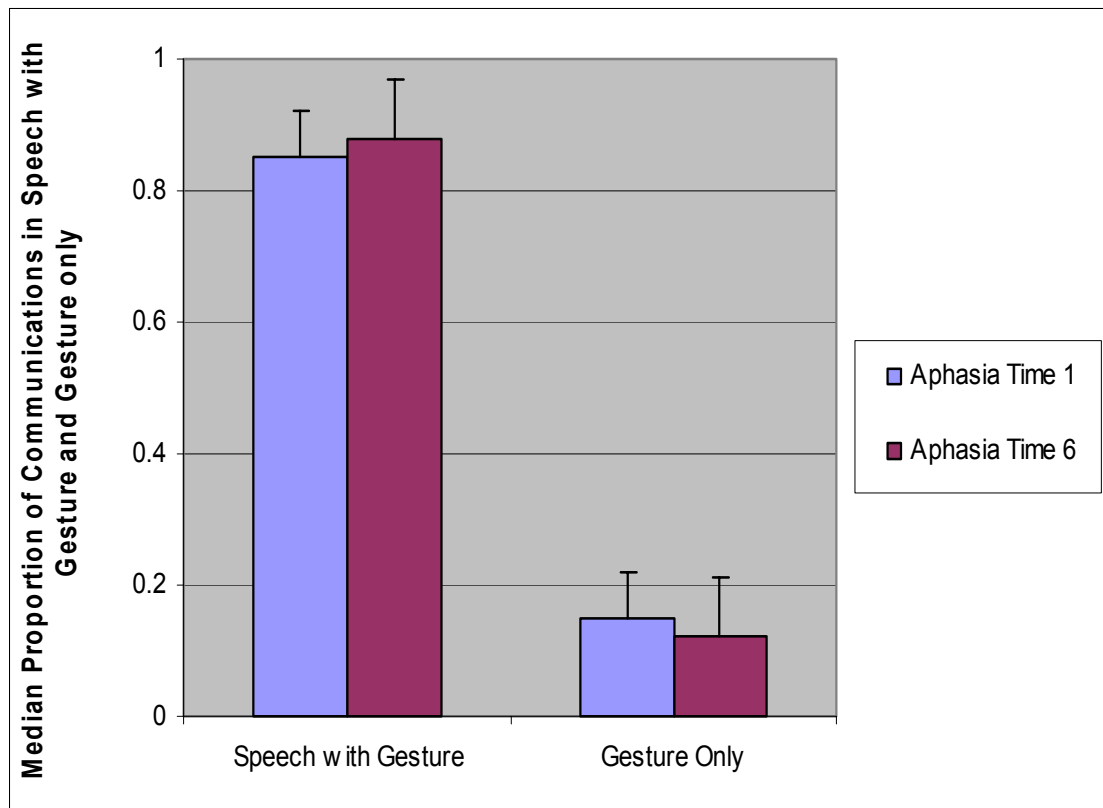
Figure 2. Median proportion of gesture types produced by participants with Broca's aphasia at Times 1 and 6 and participants with no neurological impairment (NNI).
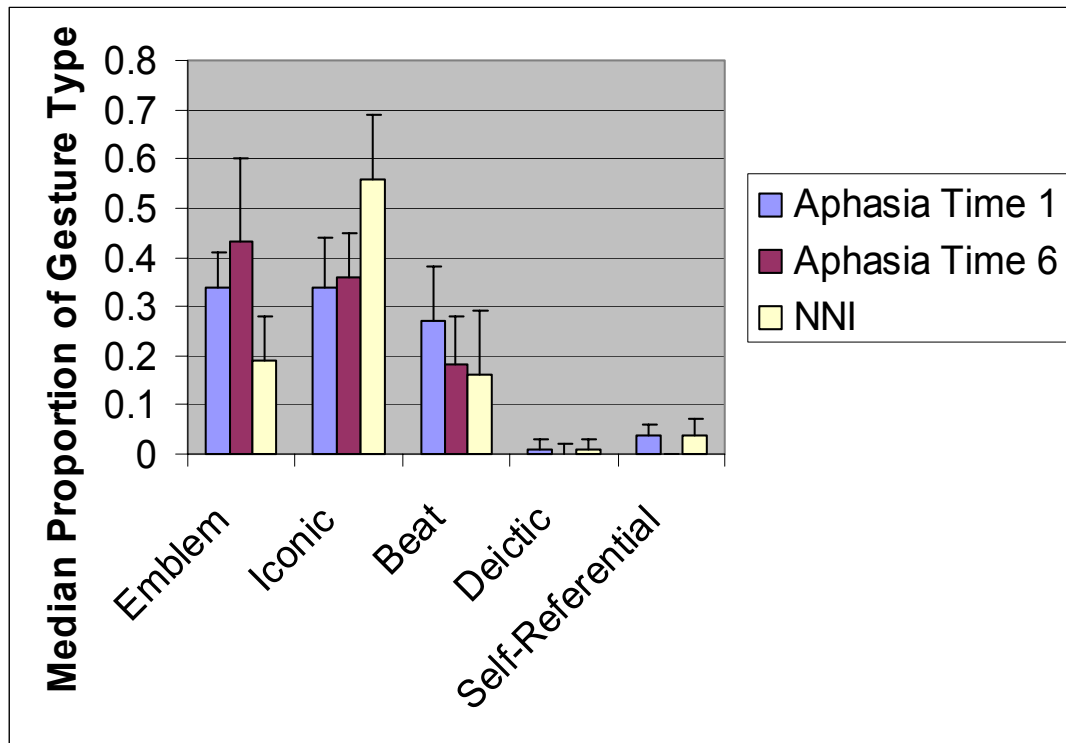
Figure 3. Median proportion of utterances in both speech and gesture containing only meaningful speech-gesture informational relationships (redundant, disambiguate, add) produced by participants with Broca's aphasia at Times 1 and 6 and relative to those with no neurological illness (NNI).
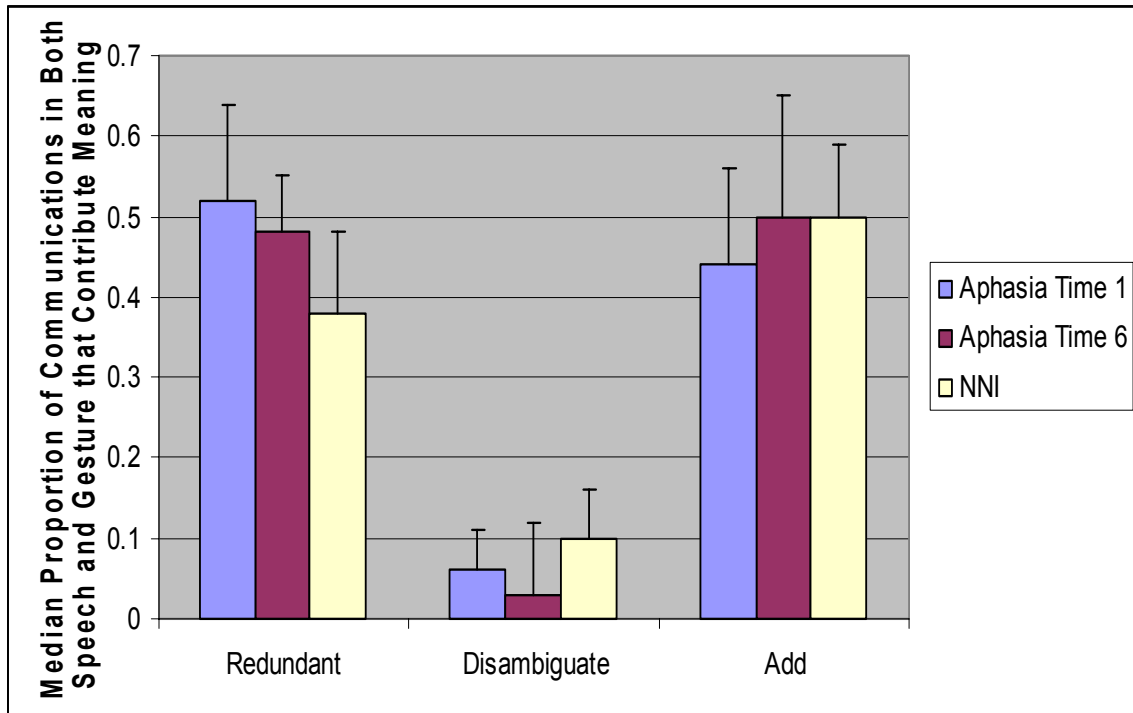
Figure 4. Median number of meaningful motor movements produced in iconic and pantomime gestures for participants with aphasia at Times 1 and 6 and for the NNI group.
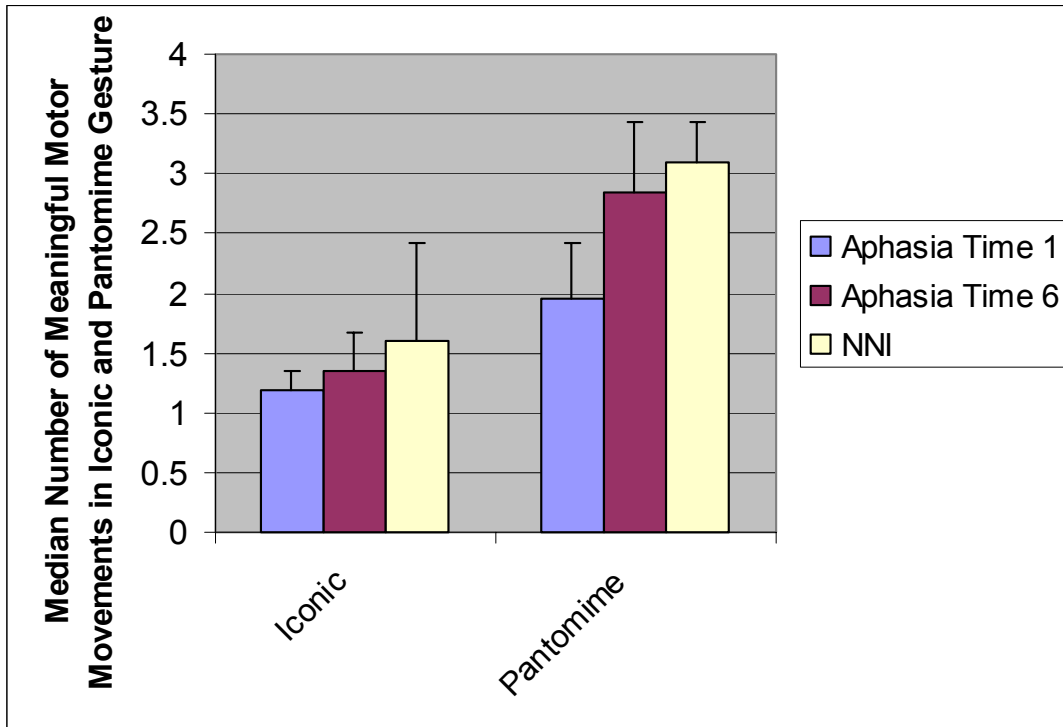
Figure 5. Mean length of utterance in words for participants with Broca's aphasia at each observation.
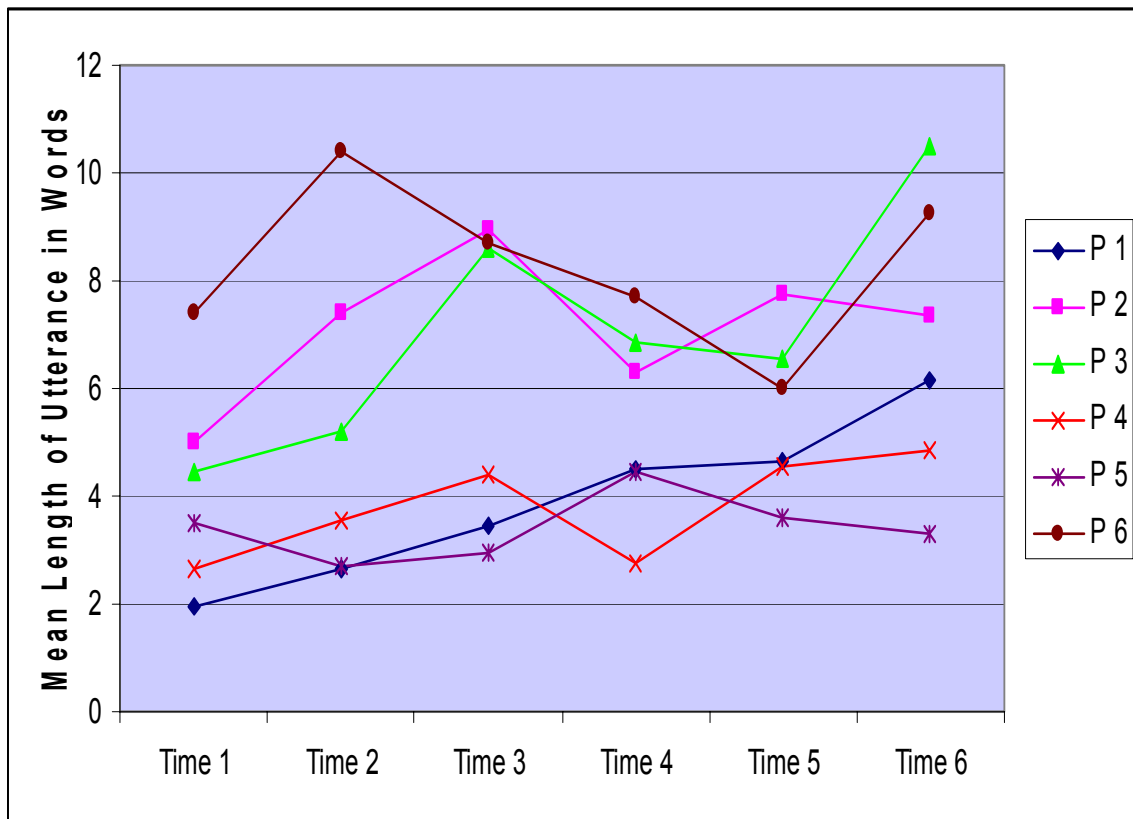
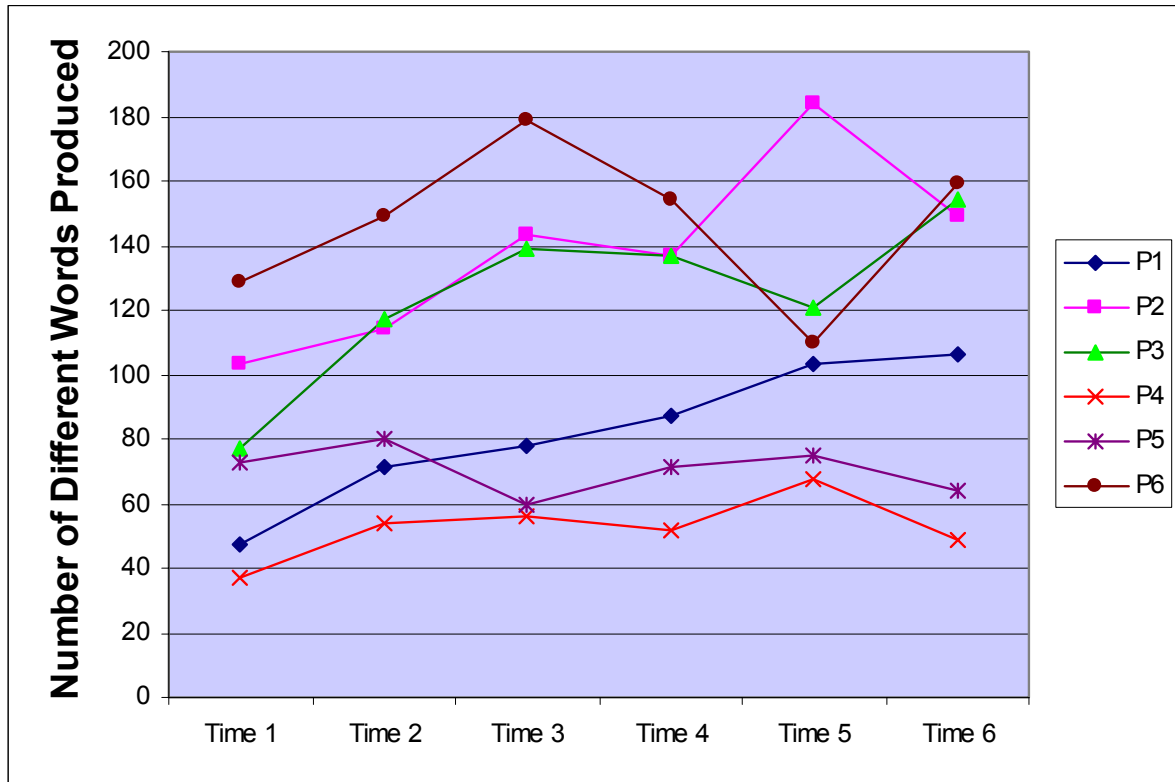Figure 6. Number of different words produced by individual participants with Broca's aphasia at each observation.

Figure 7. Rate of gesture (gesture to word ratio) produced in the *speech plus gesture* condition) for Participants (P) 1, 2, 3, 4, 5, and 6 at Times 1, 2, 3, 4, 5, and 6 in the aphasia group.
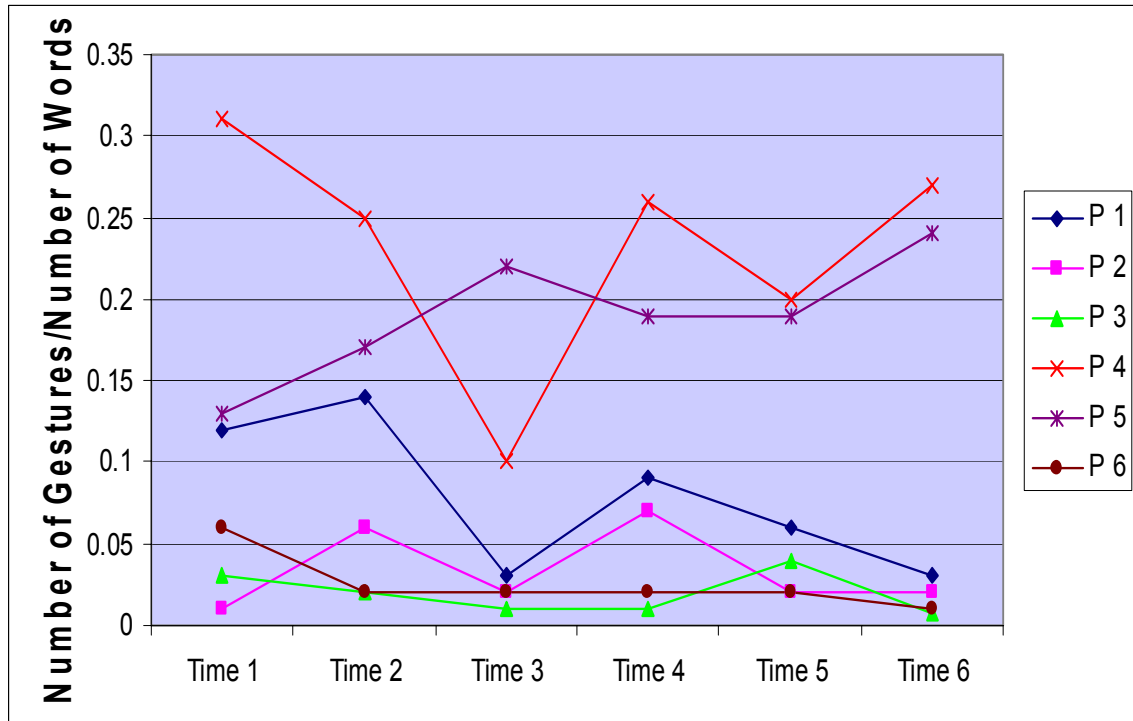
Figure 8. Scatterplot of gesture rate at Time 1 by *Western Aphasia Battery Aphasia Quotient (WAB AQ*) scores at Time 6 for participants with aphasia.
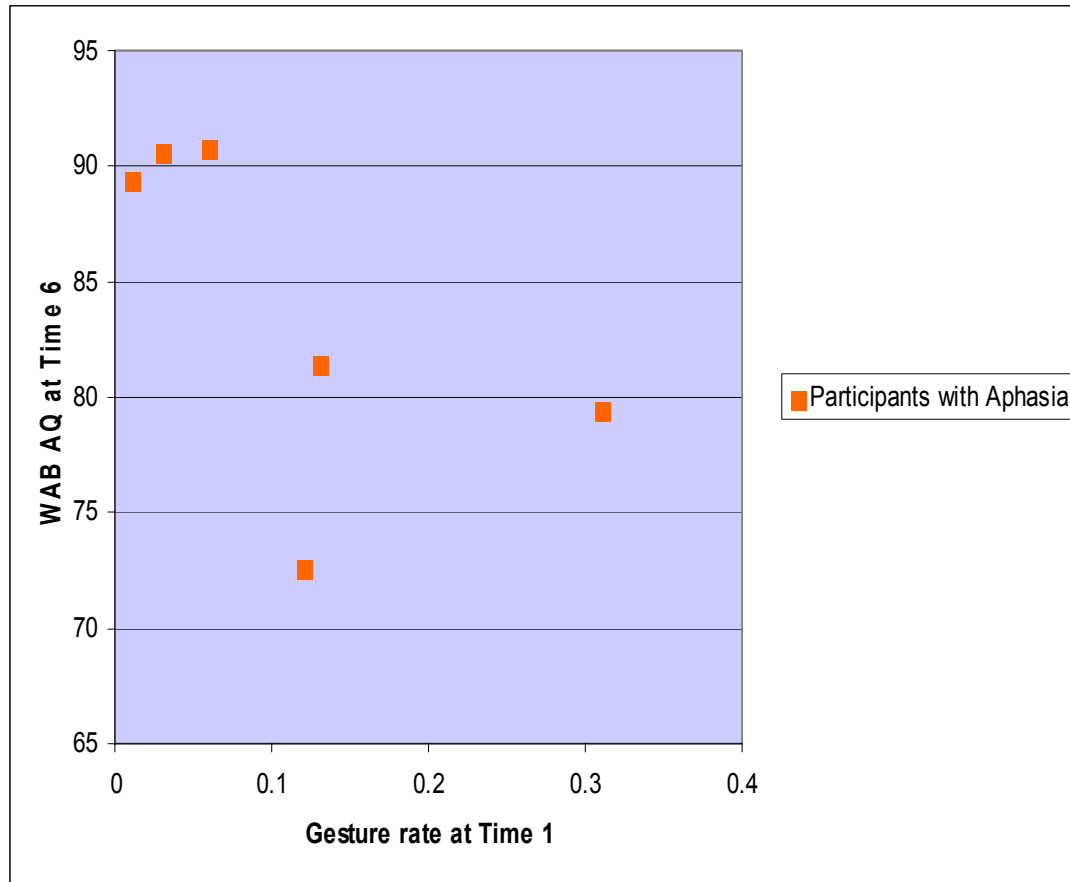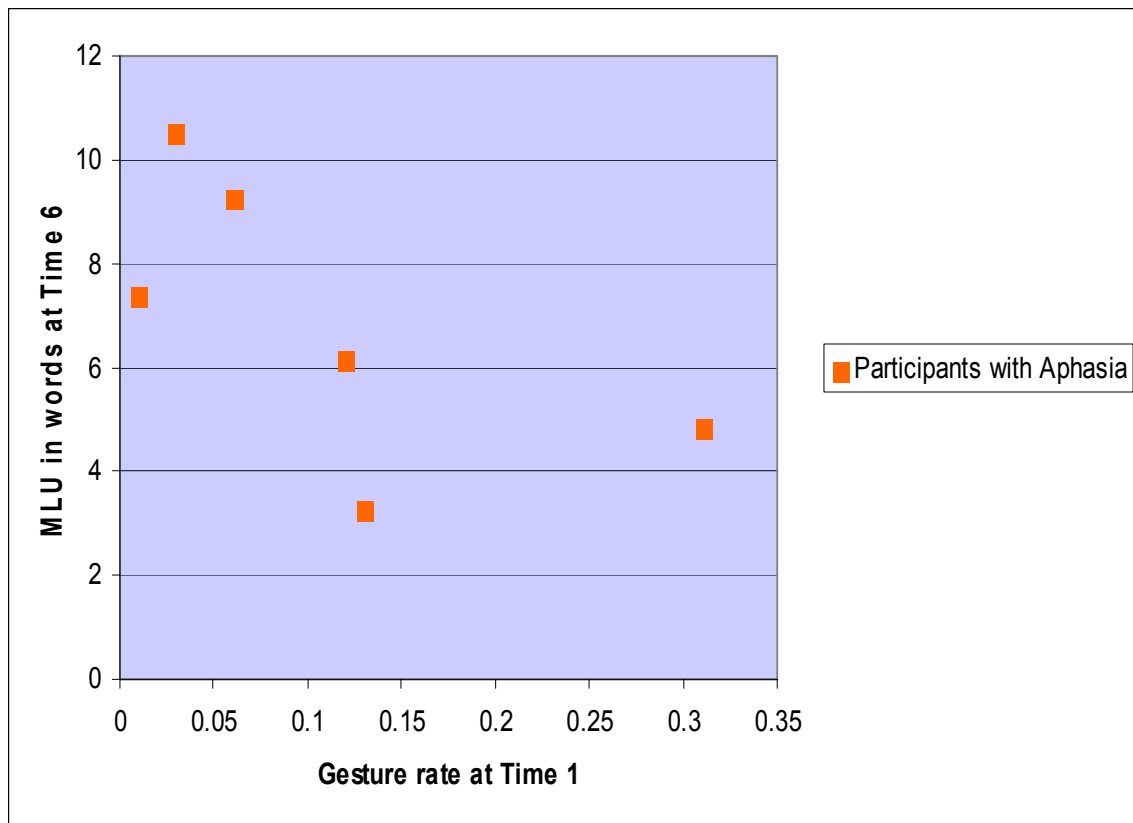
Figure 9. Scatterplot of gesture rate at Time 1 by MLU in words at Time 6 for participants with aphasia.

VITA

Barbara Braddock is a speech-language pathologist with many years of experience working with persons with neurogenic communication disorders in rehabilitation settings. She completed undergraduate and graduate studies in Communication Sciences and Disorders at the University of Missouri-Columbia in 1985 and 1986. Following a period of time, she returned to the University of Missouri-Columbia to complete studies in the area of Developmental Psychology through the Department of Psychological Sciences. She has studied with Dr. Jana Iverson. Her research interests are in the area of gesture production in atypical language populations. She has accepted a position as Assistant Professor at the University of Virginia in Charlottesville, Virginia.