A Novel Eye-Tracking Method to Assess Attention Allocation in Individuals with and without
Aphasia Using a Dual-Task Paradigm

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ABSTRACT

Numerous authors report that people with aphasia have greater difficulty allocating attention than people without neurological disorders. Studying how attention deficits contribute to language deficits is important. However, existing methods for indexing attention allocation in people with aphasia pose serious methodological challenges. Eye-tracking methods have great potential to address such challenges. We developed and assessed the validity of a new dual-task method incorporating eye tracking to assess attention allocation.

Twenty-six adults with aphasia and 33 control participants completed auditory sentence comprehension and visual search tasks. To test whether the new method validly indexes well-documented patterns in attention allocation, demands were manipulated by varying task complexity in single- and dual-task conditions. Differences in attention allocation were indexed via eye-tracking measures.

For all participants significant increases in attention allocation demands were observed from single- to dual-task conditions and from simple to complex stimuli. Individuals with aphasia had greater difficulty allocating attention with greater task demands. Relationships between eye-tracking indices of comprehension during single and dual tasks and standardized testing were examined.

Results support the validity of the novel eye-tracking method for assessing attention allocation in people with and without aphasia. Clinical and research implications are discussed.

1. Introduction

1.1 Relevance of Attention Allocation to Aphasia

People with aphasia frequently have not only language impairments but also difficulties properly allocating attention resources required for language processing. Attention is a limited resource that can only be allocated to a finite number of tasks (Kahneman, 1973). Attention allocation, the process of allotting attention to a given task in the face of competing tasks and complex or multiple stimuli to be processed, is of particular concern in people with aphasia. Attention limitations are generally considered to contribute to language comprehension deficits (Hula & McNeil, 2008; LaPointe & Erickson, 1991; McNeil et al., 2004, 2005; Murray, Holland, & Beeson, 1997; Robin & Rizzo, 1988). An increase in task demands requires more attention resources (Murray, 1999); that is, it requires greater cognitive effort, and taxes a finite capacity. Furthermore, the efficiency of attention allocation depends on an individual's ability to assess task demands (Murray, 1999; Robin & Rizzo, 1988). If demands exceed resources, comprehension deficits occur or become more severe.

Understanding impairments in attention allocation in people with aphasia is important in terms of theoretical implications as well as implications for clinical assessment and treatment. Attention allocation deficits, when not recognized and accounted for during assessment, may lead to invalid indexing of language abilities. Attention allocation deficits may negatively affect not only language comprehension but also learning, and thus rehabilitation potential, in individuals with aphasia (Helm-Estabrooks, 2002). It is therefore crucial for clinicians and researchers to understand the interaction between attention allocation and language comprehension, be alert to different types of attention impairments, assess non-linguistic

attention deficits in addition to language impairments, and create appropriate treatment plans involving attention allocation.

Valid measures of attention allocation are vital to further elucidation of the relationship between attention and language deficits in aphasia. Unfortunately, there are serious methodological challenges associated with indexing attention allocation in people with aphasia. New methods constructively addressing those challenges are needed. In this light, online eye-tracking methods hold great promise. The goal of this study was to develop and assess the construct validity of a new dual-task method to assess attention allocation during auditory linguistic processing using eye tracking. We tested whether the new method would replicate patterns of results similar to those obtained using more traditional dual-task methods for indexing attention allocation.

1.2 Methods for Studying Attention

Dual-task experiments have been used widely to explore the relationship between language and attention. Results of previous studies indicate that increased attention demands of dual-task conditions tend to impact language comprehension (Blackwell & Bates, 1995; Granier, Robin, Shapiro, Peach, and Zimba, 2000; King & Hux, 1996; LaPointe & Erickson, 1991; McNeil, Matthews, Hula, Doyle, & Fossett, 2006; McNeil et al., 2005; Murray, Holland, & Beeson, 1997; Tseng, McNeil, & Milenkovic, 1993) and production (Hula, McNeil, & Sung, 2007; Murray, 2000) in people with and without aphasia.

Although there is great variation in specific aspects of dual-task methods designed to study attention allocation, there are two basic methodological approaches across studies: comparisons of performance in single- versus dual-task conditions and simple (or easy) versus complex (or difficult) conditions. In a dual-task experiment, participants are asked to complete a

task under two conditions, in isolation and simultaneously with a secondary task. When the two tasks are performed at once, decrements in performance on one task reflect the processing load imposed by the second task. Reduced accuracy and slower reaction times during the dual-task condition are interpreted to reflect resource allocation problems or limited capacity resources due to increased task demands. People without aphasia tend to exhibit a decrease in performance on dual tasks when compared to single tasks in terms of accuracy and response time (Blackwell & Bates, 1995; Granier et al., 2000; Hula, McNeil, & Sung, 2007; McNeil et al., 2004, 2005; Tseng et al., 1993). In studies including individuals with and without aphasia, those with aphasia tended to demonstrate greater decrements in performance compared to control participants on dual tasks (King & Hux, 1996; LaPointe & Erickson, 1991; Murray, 2000, 2012; Murray, Holland, & Beeson, 1997, 1998). Notable exceptions to these findings are detailed in a study by McNeil et al. (2006) that included only participants with aphasia, in which no dual-task effects were observed and a study by Tseng et al. (1993), in which control participants exhibited a stronger dual-task interference effect than participants with aphasia. The latter was interpreted as a result of greater flexibility in allocation of attention resources according to task demands in individuals without aphasia.

Theoretical accounts for decrements in reaction time and accuracy during dual tasks include models of capacity limitation and the central bottleneck model (Hula & McNeil, 2008; Kurland, 2011; Murray, 1999). According to the limited capacity account, attention is a limited processing resource that is flexibly allocated to varying task demands. When task demands exceed capacity resources, performance decreases, as is often observed when comparing single- to dual-task processing. The central bottleneck model (Pashler, 1994) attributes dual-task performance decrements to a limited ability to process more than one task simultaneously due to

a central processing limit. Thus, dual-task processing deficits result from response selection rather than capacity limitation. See Hula and McNeil (2008) for a detailed discussion of models of attention and the role of attention in language processing.

A variety of linguistic and nonlinguistic tasks have been used to demonstrate the effect of attention impairment on linguistic abilities during dual tasks. Examples are an auditory sustained attention task and card sorting (LaPointe & Erickson, 1991); semantic category judgment and tone discrimination (Murray et al, 1997); word-picture matching and speaker identification (King & Hux, 1996); grammatical judgment and visual digit recall (Blackwell & Bates, 1995); lexical processing and tone perception (Hula et al., 2007); and sentence comprehension and motor tracking (Granier et al., 2000). Also the effects of two simultaneously presented linguistic tasks have been studied to explore resource allocation, including semantic category judgment and lexical decision (Murray et al., 1997), and lexical processing and semantic category judgment (Hula et al., 2007).

As noted above, dual-task experiments also include manipulations of task complexity. For example, Tseng et al. (1993) modified the probability of occurrence of phonetic and semantic target stimuli while participants identified semantic targets, phonetic targets, or both; Blackwell and Bates (1995) modified the length of digit sequences to be recognized while participants judged grammaticality of sentences; McNeil et al. (2004, 2005, 2006) manipulated the complexity of stories to be remembered and for later retelling while participants carried out a manual tracking task. When complexity is increased, decreases in speed and accuracy tend to be observed in people with and without aphasia; these decrements, too, are attributed to an attention resource shortage or allocation inefficiency. The dual-task paradigm is widely accepted as a means of assessing changes in performance in language comprehension when attention demands

are manipulated (Hula & McNeil, 2008). Although valuable insights have been gained from dual-task studies, there are challenges to dual-task designs that potentially affect the validity of results.

1.3 Using Eye Tracking to Address Challenges Associated with Dual-Task Experiments

One key challenge reflected in published dual-task research to date is that studies involving people with aphasia have typically been based on data from small samples, with only few reported studies (Murray et al., 1997, 1998) exceeding nine participants with aphasia. Studies with larger sample sizes are needed in order to draw conclusions with greater confidence about attention allocation in individuals with aphasia.

Also challenging the validity of dual-task methods, especially for use with people with aphasia, are potential confounds associated with response requirements that may impact participants' performance. Examples of response execution in dual-task conditions to date include: (a) selecting and pressing a computer keyboard key (Murray et al., 1997, 1998, Tseng et al., 1993), (b) speaking (King & Hux, 1996), (c) gesturing or raising ones' hand when hearing a target word (LaPointe & Erickson, 1991), and (d) continuous manipulation of a joystick or computer mouse during motor tracking (Granier et al., 2000; McNeil et al., 2005, 2006). Requisite eye-hand coordination, visual-spatial orientation, motor planning, and fine motor skills, are commonly affected by brain injury. Poor performance may be incorrectly assumed to be a result of impaired attention allocation. Confounds associated with motor planning and accurate response execution affect all traditional assessments but are especially problematic in dual tasks in which participants are required to coordinate response execution to two tasks at the same time. For example, Murray et al. (1997) found that dual-task performance in individuals with posterior brain lesions was affected because they exhibited difficulty following dual-task

instructions. Similarly, Hula excluded results of eight of 20 language-normal participants because they did not correctly follow dual-task instructions.

Eye-tracking methods have potential to help avoid several of these challenges associated with traditional dual-task designs. Participants may simply look at visual displays while a remote eye-tracking system records eye-movement data. No verbal or written responses, no device manipulation, no conscious planning of responses, or verbal prompting by the examiner are required (Hallowell, Wertz, & Kruse, 2002). Thus, confounding response factors associated with impaired eye-hand coordination, visual-spatial orientation, motor planning, and response execution can be avoided, increasing the validity of cognitive-linguistic assessments, and further, allowing the inclusion of individuals with a wide range of severity levels into structured assessments.

1.4 Eye Tracking as a Promising Tool for Studying Attention Allocation in Aphasia

The fact that eye tracking is increasingly popular, affordable, accessible, and user-friendly bodes well for developing research-based methods for eventual clinical application (Hallowell, 2012). The use of eye tracking in cognitive-linguistic experiments is based on the assumption that viewers tend to look at objects or images that they are thinking about. Fixation duration is assumed to reflect the time to encode visual information and the time to operate on the encoded data (Just & Carpenter, 1976). Eye tracking has been used to study cognitive and linguistic processes, such as auditory comprehension (Cooper, 1974; Hallowell, 1999, 2012; Hallowell et al., 2002; Tanenhaus, Magnuson, Dahan, & Chambers, 2000; Tanenhaus, Spivey-Knowlton, Eberhard, & Sedivy, 1995), semantic priming (Odekar, Hallowell, Kruse, Moates, & Lee, 2009), phonological priming (Meyer & van der Meulen, 2000), working memory (Ivanova & Hallowell, 2012), grammatical processing (Cho & Thompson, 2010; Choy & Thompson,

2010; Dickey, Choy, & Thompson, 2007; Lee & Thompson, 2011a, 2011b; Thompson, Dickey, & Choy, 2004; Thompson, Dickey, Choy, Lee, & Griffin, 2007), and lexical activation (Yee, Blumstein, & Sedivy, 2004), in people with and without aphasia. There is robust evidence that visual and auditory input interacts early on in language comprehension tasks and that language comprehension can be studied while linguistic input is taking place using eye tracking in individuals with and without neurogenic impairment.

Eye-tracking protocols also have been used to study bottom-up processes of visual attention due to influences of physical stimulus characteristics such as color and complexity, as well as semantic conveyance features, such as concept frequency and concreteness of concepts conveyed, regardless of whether a verbal stimulus is presented (Andrews & Coppola, 1999; Hallowell, Douglas, Wertz & Kim, 2004; Heuer & Hallowell, 2007, 2009). If eye-tracking indices are sensitive to changes in complexity of visual stimulus properties and linguistic stimuli, it is logical that they may be sensitive to changes in processing load over time, while participants are listening to auditory stimuli and simultaneously looking at visual stimuli.

1.5 Purpose

The goal of this study was to develop and assess the construct validity of a new dual-task method to assess attention allocation during auditory linguistic processing using eye tracking. The purpose of the new method is to address key potential confounds, and thus threats to validity, associated with existing methods. It was important to test the validity of this novel eye-tracking method by replicating results that have been reported repeatedly in previous dual-task studies designed to assess attention allocation: (a) a significant increase in attention demands for dual-tasks compared to single-task performance, (b) a significant increase in attention demands with an increase in stimulus complexity within single and dual tasks; and (c) a significant

difference in performance between individuals with and without aphasia. The new method entails use of eye-tracking measures recorded during a visual search task, in which participants are trained to find a visual target in a display that includes one target and three nontarget foils, and a sentence comprehension task in which sentences are presented auditorally. Attention demands are manipulated by varying the complexity of each of the two tasks. Changes in attention demands are indexed through performance on the visual search task via eye tracking, using the dependent measure Proportion of Fixation Duration on the Target (PFDT).

PFDT is the total duration of fixations on a target image, divided by the total of fixation durations on all images in the display. Greater PFDT has been observed for target images that correspond to a verbal stimulus than for nontarget images that do not correspond to a verbal stimulus in multiple-choice image displays (Dahan, Magnuson, & Tanenhaus, 2001; Hallowell, 1999; Hallowell et al., 2002; Heuer & Hallowell, 2007, 2009; Ivanova & Hallowell, 2012; Odekar et al., 2009). PFDT has also been reported as a dependent measure in visual search tasks without verbal stimuli, designed to assess the degree of stimulus control in multiple-choice image displays (Hallowell, Douglas, Wertz & Kim, 2004; Heuer & Hallowell, 2009). Ranging from 0 to 1, higher values indicate that participants fixate proportionately longer on a target image compared to foils when looking at a given display. A chance level of PFDT attention to the target would be indexed by a value of .25 for a four-image display.

Using the eye-tracking-based method for indexing attention allocation described here, when task demands are increased a decrease in PFDT is expected. An increase in task demands will cause a decrease in cognitive processing resources, which is indexed by a decrease in fixation duration allocated to target compared to foil images. This decrease will be greater within more cognitively demanding tasks compared to less demanding tasks (comparing dual to single

tasks, and complex to simple stimuli). Comprehension of the verbal stimuli is assessed by presenting a second image display including one target image that corresponds to the verbal stimulus and three nontarget foil images. For an overview and examples of the two tasks, simple and complex stimuli, and single- and dual-task condition, see Figure 1. Approval for this research was granted by the Institutional Review Board at Ohio University.

Figure 1. Overview and examples of the tasks, stimulus complexity, and conditions.

2. Methods

2.1 Participants

2.1.1 Participants with aphasia. Thirty-three participants with aphasia were recruited. Aphasia was defined as follows: an acquired neurogenic communication disorder that may affect speaking, auditory comprehension, reading, and writing. It is not a sensory deficit, a general intellectual deficit, or a psychiatric disorder (Hallowell & Chapey, 2008). Language abilities were assessed using the Western Aphasia Battery (WAB-R, Kertesz, 2006). Inclusion criteria were (a) status as a native speaker of English; (b) presence of aphasia (diagnosis verified through a certified speech-language pathologist and confirmed by participants and/or their caregivers) due to a stroke (verified through medical records); (c) passing of a central visual acuity screening, as determined by correctly identifying five out of five symbols in the Lea Symbols

Line Test (Precision Vision) at a viewing distance of 0.6 m; (d) passing of a color vision screening as determined by correctly identifying three of three images of the “Color Vision Testing Made Easy” (Waggoner, 1994), (e) passing of visual neglect screening entailing line bisection and clock drawing, and (f) passing of a binaural pure tone hearing screening at 500, 1000, and 2000 Hz at 30 dB SPL). Participants were allowed to wear contact lenses or glasses during screenings and the subsequent eye tracking session. See the Appendix for information about the participants’ age, years of education, medical history and WAB scores. Prior to the experimental tasks participants completed a training for the single and dual task. All participants had to complete 6 of 10 single-task training trials and 8 of 12 dual-task training trials correctly to meet training criteria and to move on to the experimental tasks.

One participant with aphasia was excluded because of suspected presence of dementia, based on behavior during screenings and follow-up conversation with a caregiver. Six were excluded because they did not pass training criteria for the visual search single-task condition, resulting in 26 participants for single-task conditions. Two participants were excluded after completion of the single task because they did not pass training criteria for the dual-task condition, resulting in 24 participants for the visual dual-task condition. Data of one participant were excluded from analysis of the comprehension dual task due to recording difficulties, resulting in data of 23 participants in the comprehension dual-task condition. A Mann-Whitney U test was conducted to compare the groups of included and excluded participants for the WAB AQ ($U = 44.00, p = .28$), WAB AC ($U = 46.50, p = .33$), years of education ($U = 62.50, p = .90$), and age ($U = 53.5, p = .55$). None of the comparisons revealed significant differences between the group of excluded and the group of remaining participants.

Given the focus of the study on methodological validation as opposed to aphasia classification, no specific type of aphasia was targeted for recruitment; rather, participants with a broad range of aphasia subtypes and underlying sites of lesion were sought. Aphasia subtype classification has been shown to be of questionable utility in the context of identifying specific nonlinguistic cognitive deficits associated with aphasia (Caramazza, 1984; McNeil & Kimelman, 2001; McNeil & Pratt, 2001; Wertz, 1983). Also, there is lack of evidence that attention allocation deficits manifest in any consistent ways within aphasia subtypes (LaPointe & Erickson, 1991; McNeil et al., 2004, 2005; Murray, 2002; Murray et al., 1997; Robin & Rizzo, 1988). Having each participant serve as his or her own control in a repeated-measures design allowed a direct comparison of performance between conditions across aphasia subtypes and severity levels.

2 1.2 Participants without aphasia. For the primary study, thirty-three control participants without neurogenic impairment who had not participated in the pilot study were recruited in the Athens, Ohio community. All underwent a cognitive screening, the Mini Mental State Exam (MMSE, Folstein, Folstein & McHugh, 1975). To be included participants had to obtain a score of at least 23 out of 30 on the MMSE and pass the vision and hearing screening criteria described above. Independent-samples t-tests indicated no significant differences in age between the aphasia group ($M = 56.81$, $SD = 12.15$) and the control group ($M = 54.56$, $SD = 16.57$), $t(58) = .59$, $p = .56$. Similarly, there was no significant difference in years of post-secondary education between the participants with aphasia ($M = 4.74$, $SD = 2.75$) and the control group ($M = 5.73$, $SD = 3.00$), $t(58) = -1.32$, $p = .19$. Five young adults free of neurogenic impairment participated in the pilot study (described below).

2.2 Stimuli

2.2.1 Visual stimuli for the visual search task. Sixty multiple-choice displays were created, each including one image in each corner. Three of these images were foils and one was the target that differed in terms of geometrical design. Thirty simple visual search displays were created, including images in which the three foils were exactly the same and the target differed in terms of geometric design. Thirty complex displays were created including three identical foils, each having a different orientation; the rationale for this was based on the findings of Shepard and Metzler (1971), who demonstrated that mental rotation may increase the cognitive load of the visual search task. See Figure 1 for examples of simple and complex image displays. The location of the target image and the foils was counterbalanced across the 60 trials. The sequence of simple and complex trials was randomized.

2.2.2 Visual stimuli for the comprehension task. Sixty displays containing simple visual stimuli that were controlled in terms of color (red, blue, white and green); size (small and large) and shape (circle and square) were created. The design of these displays was based on research by Hallowell et al., (2002), showing the feasibility of using similar displays to assess auditory comprehension using eye tracking. In each image two visual stimuli were presented. One image in each display corresponded to the sentence (the target image) while three images were foils. Their semantic relationship to the target was objectively defined as follows: If the target was “green square and red circle,” one foil was “red square and green circle” (reverse of the target), one foil was “green square and blue circle” (one color is wrong), and one foil was green circle and red circle (one shape is wrong). The location of the targets and foils was counterbalanced across the 60 trials.

2.2.3 Sentence stimuli for the comprehension task. Sixty sentence comprehension stimuli were created. Thirty were simple and 30 were complex. Sentence characteristics systemically controlled included: number of words, syllables, propositions, verbs (per Rochon, Waters, & Caplan, 1994 and Thompson & Shapiro, 2007), and word frequency. Simple and complex sentences had approximately the same number of words/syllables and the same number of verbs. Simple sentences had a simple subject-verb-object sequence (e.g., “*The green circle is by the red square.*”), while complex sentences included a center-embedded prepositional phrase (e.g., “*The circle by the red square is green.*”). The fact that complex syntax increases cognitive processing demands, thus increasing the complexity of the sentence stimuli, is well established (Gordon & Lowder, 2012; Just & Carpenter, 1993; Traxler, Morris, & Seely, 2002; Roland, Dick, & Elman, 2007). The copula verb “is” was used across all sentence stimuli, the colors, sizes and shapes provided in section 2.2.2, and the prepositions “next to” and “by” were the only words used in the sentence stimuli. See Figure 1 for examples of simple and complex sentence stimuli and a corresponding visual display.

2.3 Procedure

Dual tasks tend to pose novel demands on participants. They are unlike everyday cognitive communicative tasks. They require that the participant understand complex instructions. This may be confounding for individuals with aphasia because of comprehension deficits, and not necessarily because of attention allocation deficits. Thus, a training protocol was developed to familiarize all participants with each task. Low verbal comprehension and production requirements were ensured by using only simple, short instructions, plus gestures and visual examples. A training sequence to introduce the task was followed by a practice sequence, allowing participants to practice the visual search single task and both dual-task conditions. To

ensure that all participants were equally familiar with the procedures, they were required to pass a criterion of 60 % accuracy for practice trials prior to continuing with the actual experimental procedures. Procedures were identical for individuals with and without aphasia. The only unpracticed condition was the single comprehension task. Results of previous studies have demonstrated that no explicit instructions are required when using a multiple-choice image displays and a corresponding verbal referent in eye-tracking protocols to index comprehension (Hallowell, 1999, 2012; Hallowell et al., 2002; Heuer & Hallowell, 2009, Henderson, Shinkareva, Wang, Luke, & Olejarczyk, 2013; Huettig & Altmann, 2011). That is, without any instruction to look in any particular way, when presented with a verbal stimulus and corresponding visual stimuli, participants tend to allocate greater proportions of total fixation time to the image that corresponds to the verbal stimulus. See Figure 2 for the sequence of training and testing procedures.

1. Training single visual search	4 examples & 10 practice trials
2. Testing single visual search	30 simple & 30 complex trials

Figure 2. Sequence of training and testing procedures.

2.3.1 Training for the single visual search task. Participants were presented a multiple-choice image display of the same design as that for the visual search task (See Figure 2). The display was presented initially for three seconds to ensure that participants had time to look at all images in the display. Eye-tracking studies on stimulus-driven influences on visual attention in multiple-choice displays with individuals without neurogenic impairment have shown that 3000 ms is a sufficient time interval to process similar multiple-image displays (Heuer & Hallowell, 2007, 2009). After three seconds the examiner instructed the participant to "look at the different image" while she pointed to the target image. This was repeated three times so that each

participant was given a total of two examples of simple visual search tasks and two examples of complex visual search tasks.

Next, five simple and five complex practice trials were presented as the examiner observed eye movements online on a computer screen. She tallied whether participants found and remained fixated on the target images during the visual search task. If the participant chose a foil instead of a target image, the examiner showed that display again and gave the following feedback: “You looked at this image” (pointing at the participant’s incorrect choice). “This is the different image” (pointing to the correct target image). “Look at the different image.” All participants had to complete three simple and three complex practice trials (6 of 10) correctly to meet training criteria and to move on to the single visual search task.

2.3.2 Single-task condition visual search task. Sixty trials were presented, each lasting 4000 ms to ensure enough time to view the displays for individuals with aphasia. Peripheral vision was controlled by presenting the images at a distance of at least 20 degrees of visual angle apart, one in each of the four corners of the 17-inch computer screen (Hallowell et al., 2002). Each image subtended a 3.5- by 3.5-inch square of the visual display. Participants were instructed to “Look at the different image.”

2.3.3 Single-task condition comprehension task. Sentence stimuli spoken by an adult male native speaker of English were recorded in a soundproof booth using a high-quality dynamic microphone. Each verbal stimulus was digitized (22 kHz, low-pass filtered at 10.5 kHz), normalized for intensity, and stored on the stimulus presentation computer. The sentence comprehension stimulus was presented through loudspeakers while participants looked at a blank computer screen for 4000 ms. Next, a multiple-choice image display was presented as seen in Figure 2. This display was presented for twice as long as the verbal stimulus (3000 ms) plus one

second, rounded up to the next full second, resulting in a 7000 ms duration. This time span ensures that participants had enough time to process the verbal stimulus, potentially rehearsing the verbal stimulus subvocally, and look at the corresponding image display (Hallowell et al., 2002). Participants were instructed to: “Listen carefully to the words.” See Figure 2 for an illustration of a single trial of the listening task.

2.3.4 Dual-task training. Participants were instructed to: “Look at the different image and listen carefully to the words.” Next, they were presented the visual search task and the sentence stimulus simultaneously. After three seconds the examiner pointed to the target image in the visual search task display. Next, the multiple-choice image display with the target image corresponding to the sentence stimulus was presented. This procedure was repeated three times so that each participant had been given two examples of simple visual search tasks with simple verbal stimuli and two examples of complex visual search tasks with complex verbal stimuli.

Next, 12 practice trials were presented, including four simple trials (simple sentence and visual stimuli), four complex trials (complex visual and sentence stimuli) and four mixed trials (mixed complexity of visual and sentence stimuli). The examiner tallied whether participants found and remained fixated on the target images during the visual search task. Feedback for the visual search dual task was the same as for the single-task condition. Participants were required to complete 8 of 12 trials correctly to continue with the experimental dual-task condition. Eye fixations during practice trials were observed online by the examiner.

2.3.5 Dual-task condition. Sentence comprehension stimuli were presented during the visual search task. Duration of sentence comprehension stimuli and timing of visual displays was the same as for each single task (see Figure 1). The order of simple and complex visual search image displays and simple and complex sentence comprehension stimuli was randomized. There

were 20 simple visual search displays with 20 simple sentences, 20 complex visual search displays with 20 complex sentences, and 20 mixed trials including 10 simple visual search displays with 10 complex sentences, and 10 complex visual search displays with 10 simple sentences. For the single-task conditions simple and complex stimuli were presented in random order. The order of trials was counterbalanced such that half of the participants engaged in trials in a sequence that was reversed relative to the other half.

2.3.6 Eye-tracking procedures. Eye movements were monitored and recorded using an LC Technologies Eyegaze Edge remote pupil center/corneal reflection system at 60 samples per second. The system is noninvasive. No part of the equipment was in contact with participants except for the chin rest used to stabilize the head. Participants were seated in front of a computer screen. A brief eye-movement calibration process required that they look at a sequence of blinking dots on the computer screen. Customized software (Stimulus Presenter 1.2, Kruse, 2008a), was used to present the stimuli.

2.4 Pilot study

A pilot study with five adults, age 23 to 29, mean 28.8 years) free of neurogenic impairment was conducted to (a) determine the effectiveness of training procedures; (b) verify appropriate stimulus presentation duration; and (c) validate stimulus complexity of simple and complex visual stimuli. All participants passed training criteria. Results validated training procedures and the differences in complexity of the visual search stimuli as indexed by a significant paired samples t-test ($t(29) = -5.46, p < .001$) comparing PFDT allocated to simple and complex visual displays. Results indicated that the mean PFDT allocated to the simple displays ($M = .81, SD = .08$) was significantly greater than that allocated to the complex displays ($M = .70, SD = .13$). Participants indicated that instructions and training procedures were easy to

follow and that there was enough time to look at all stimuli. This feedback, in addition to the eye fixation data, confirmed that the procedures were appropriate in terms of clarity and duration for control participants.

2.5 Analysis

Customized software (iAnalyze, Kruse, 2008b) was used to extract the data and calculate eye-tracking measures. Eye fixations were defined a priori as having relative stability within 4 degrees vertically and 6 degrees horizontally for a minimum duration of 100 ms (Manor & Gordon, 2003). Fixations allocated to the target and the three foil images were included in the analysis. Data collected during each complete trial for the visual search single and dual task conditions were analyzed (from stimulus onset to 4000 ms). For the comprehension single and dual task condition data collected over each 7000 ms trial duration were analyzed. SPSS 14.0 was used for statistical analysis.

2.6 Hypotheses

Hypotheses are stated in terms of expected differences according to attention demands. With an increase in attention allocation demands a decrease in the dependent measure PFDT was expected and significant group effects were hypothesized. Data collected during the visual search task were analyzed to reflect the attention allocation process. The comprehension task, a secondary task, was implemented to ensure that participants allocated attention to the two tasks during dual-task conditions. That is, participants had to engage in both visual search and listening to auditory sentences. Exploratory analyses were planned to study potential interactions according to groups.

Hypotheses about changes in attention allocation in response to changes in task and stimulus complexity

1. PFDT would be significantly lower for the visual search dual-task versus the visual search single-task condition.
2. PFDT would be significantly lower for the complex compared to the simple visual search task in the single-task condition.
3. There would be a significant decrease in PFDT corresponding to levels of complexity in the dual-task visual search. Simple stimuli are simple visual stimuli presented simultaneously with simple linguistic stimuli; complex stimuli are complex visual stimuli presented simultaneously with complex linguistic stimuli; medium stimuli contain a simple visual and a complex verbal stimulus or vice versa.
4. The degree of decrement between and within dual-and single-task processing may or may not be similar between the two groups. Thus, this was tested as a nondirectional hypothesis.

Hypotheses about the performance on the comprehension task in response to changes in task and stimulus complexity

5. PFDT would be significantly lower for the dual-task compared to the single-task condition of the comprehension task.
6. PFDT would be significantly lower for complex compared to simple verbal stimuli in the single-task condition.
7. PFDT would be significantly lower during the dual-task condition of the comprehension task for complex visual and verbal stimuli compared to simple visual and verbal stimuli.

Validation of PFDT as an index of comprehension

8. PFDT on the single comprehension task would be significantly correlated with auditory comprehension deficits.

Analyses were planned to validate that participants actively engaged in the comprehension task, and to examine the relationship between eye-tracking indices of comprehension and standardized auditory comprehension (WAB-R AC) scores.

3. Results

See Figure 3 through 8 in the supplemental online materials for bar graphs showing results for hypotheses 1 through 7.

3.1 Performance during the Visual Search Task

3.1.1 Comparison of performance in the single-and dual-task conditions during the visual search task. A mixed two-way repeated measures ANOVA with the within-subject factor task (single and dual task) and the between-subject factor group (control group and individuals with aphasia) was conducted, to compare whether indices of attention allocated to the visual search task differed between the single- and dual-task conditions. Significant main effects were observed for task, $F(1,55) = 17.89, p < .001, \eta^2 = .25$, and for group, $F(1, 55) = 30.83, p < .001, \eta^2 = .36$. The interaction was nonsignificant, $F(1,55) = .59, p = .45, \eta^2 = .01$. Post-hoc paired-samples t-tests were conducted to explore the performance of each group separately. PFDT was significantly different for the single versus dual visual search task for participants with aphasia $t(23) = 4.06, p < .001$ and for control participants $t(32) = 2.39, p = .012$.

3.1.2 Comparison of performance in the simple and complex visual stimulus conditions in the single-task condition during the visual search task. A mixed two-way repeated measures ANOVA with the within-subject factor complexity (simple and complex visual stimuli) and the between-subject factor group (individuals with aphasia and controls) was

conducted for PFDT for the complex versus simple visual search single-task conditions.

Significant main effects were observed for complexity, $F(1,57) = 249.26, p < .001, \eta^2 = .81$, and for group, $F(1, 57) = 28.35, p < .001, \eta^2 = .34$. The interaction between group and stimulus complexity was nonsignificant, $F(1,57) = 4.14, p = .053$. Paired-samples t-tests were conducted to explore separately the effect of complexity on each participant group. Results indicate significant differences in PFDT for the simple versus complex visual stimuli in the single visual search task for individuals with aphasia, $t(25) = 10.36, p < .001$, and control participants, $t(32) = 12.73, p < .001$.

3.1.3 Comparison of performance in the simple, medium, and complex stimulus conditions in the dual-task condition during the visual search task. A mixed two-way repeated measures ANOVA with the within-subject factor complexity (simple, medium, and complex stimuli) and the between-subject factor group (individuals with aphasia and control participants) was conducted to explore whether the eye-tracking indices reflected that attention demands were greater in the visual search dual-task with increased complexity. Significant main effects were observed for complexity, $F(2,110) = 74.59, p < .001, \eta^2 = .57$, and for group, $F(1, 55) = 22.30, p < .001, \eta^2 = .29$. The interaction between group and stimulus complexity was nonsignificant $F(2,110) = .88, p = .42$.

Significant F tests were followed up with pair-wise comparisons by group. A Holm p -value correction was used to control for familywise alpha at .05. For individuals with aphasia F tests were significant for the simple-complex stimulus contrast, $t(23) = 7.34, p < .001$, and the medium-complex stimulus contrast $t(23) = 7.05, p < .001$. Similarly, for control participants, F tests were significant for the simple-complex stimulus contrast, $t(32) = 7.90, p < .001$, and the medium-complex stimulus contrast $t(32) = 7.77, p < .001$.

3.2 Performance during the Comprehension Task

For the analysis of comprehension task performance, it was important to include only data from trials for which there was evidence that participants understood the verbal stimulus; that is, it was important to interpret attention specific to trials in which comprehension was accurate. Thus, prior to the comprehension task analysis, data for trials in which participants were unlikely to have comprehended the verbal stimulus were eliminated. To determine whether participants comprehended the verbal stimulus, a cut-off score for PFDT of .35 was implemented. The cut-off score is based on an ideal 90% confidence interval for PFDT being greater than .25, the ideal chance value if nothing about the target attracted disproportionate visual attention (Hallowell et al., 2002). For PFDTs below .35 it is unlikely that the verbal stimulus was understood; thus, values for trials in which PFDTs for the comprehension task were below .35 were excluded. A cutoff at .35 is a conservative estimate to ensure that extreme outliers and responses that clearly did not indicate a comprehension response were removed from the data set. For comparison, the mean PFDT for control participants is $M = .81$ ($SD = .07$), indicating that participants understood the comprehension stimuli in the dual-task condition. See Table 1 for a summary of trials for which data were retained for analysis. A greater proportion of trials remained included for control participants compared to individuals with aphasia across tasks and levels of complexity. Further, the decrease in proportion of included trials for comparisons of simple to complex trials, and single- to dual-task performance, was steeper for individuals with aphasia compared to control participants.

Table 1

Number and Proportions of Included Trials after Elimination of Trials with PFDT below .35 for the Comprehension Tasks Sorted by Task, Stimulus Complexity, and Group

Task and Complexity	Participants with Aphasia Raw data (proportion)	Control Participants Raw data (proportion)
Single task	N = 26	N = 33
Simple (30 trials)	430/780 (.55)	899/990 (.91)
Complex (30 trials)	332/780 (.43)	875/990 (.88)
Dual task	N = 23	N = 33
Simple (20 trials)	218/460 (.47)	568/660 (.86)
Medium (20 trials)	180/460 (.39)	593/660 (.90)
Complex (20 trials)	173/460 (.37)	543/660 (.82)

3.2.1 Comparison of performance in the single-and dual-task conditions during the

comprehension task. A mixed two-way repeated measures ANOVA with the within-subject factor task (single and dual task) and the between-subject factor group (control group and individuals with aphasia) was implemented to test whether the eye-tracking indices captured expected differences in attention demands allocated to the single- compared to the dual-task condition. Significant main effects were observed for task, $F(1,54) = 18.85$, $p < .001$, $\eta^2 = .26$, and for group, $F(1,54) = 63.91$, $p < .001$, $\eta^2 = .54$. The task by group interaction was nonsignificant $F(1,54) = 1.29$, $p = .26$. Paired-samples t-tests were conducted to explore separately each group's performance. Results indicate a significant difference in PFDT

comparing single-to dual comprehension task for control participants $t(32) = 4.01$ $p < .001$, and for individuals with aphasia $t(22) = 2.60$, $p = .005$.

3.2.2 Comparison of performance in the simple and complex verbal stimulus conditions in the single-task condition during the comprehension task.

A mixed two-way repeated measures ANOVA with the within-subject factor complexity (simple and complex verbal stimuli) and the between-subject factor group (individuals with aphasia and control participants) was conducted to assess whether the eye-tracking measure captured an increase in attention allocation comparing simple to complex stimuli in the single-task condition. A significant main effect was observed for group, $F(1, 57) = 68.25$, $p < .001$, $\eta^2 = .55$. The main effect for complexity was nonsignificant, $F(1, 57) = .37$, $p = .56$, $\eta^2 = .006$.

3.2.3 Comparison of performance in the simple, medium, and complex stimulus conditions in the dual-task condition during the comprehension task.

A mixed two-way repeated measures ANOVA with the within-subject factor complexity (simple, medium, and complex stimuli) and the between-subject factor group (individuals with aphasia and controls) was conducted to explore whether eye-tracking indices of attention during the language comprehension task reflected an increase in attention allocation demands due to increased complexity in the simultaneously presented verbal and visual stimuli. Main effects were observed for stimulus complexity, $F(2, 108) = 14.75$, $p < .001$, $\eta^2 = .22$ and for group, $F(1, 54) = 50.47$ $p < .001$, $\eta^2 = .48$. The group by complexity interaction was also significant $F(2, 108) = 7.02$, $p < .001$, $\eta^2 = .12$. Significant F tests were followed up with pair-wise comparisons by group. A Holm p -value correction was used to control for familywise alpha at .05. For individuals with aphasia F tests were significant for the simple-medium stimulus contrast, $t(22) = 4.89$, $p < .001$, and the simple-complex stimulus contrast $t(22) = 2.88$, $p = .005$. For control

participants only the simple-medium stimulus contrast was significant $t(32) = 2.36, p = .013$. **3.3**

Performance of Participants with Aphasia

Pearson's correlation coefficients were computed to assess the relationship between aphasia severity, as indexed by the WAB-R Aphasia Quotient (AQ), auditory comprehension deficit severity, as indexed by the WAB-R Auditory Verbal Comprehension Score (AC), and eye-tracking attention allocation measures (PFDT) in the single-and dual-task conditions. Significant correlations between PFDT and WAB-R AQ, and PFDT and WAB-R AC were observed for simple sentences in the single comprehension task, and for all complexity conditions in the dual comprehension task. No significant correlations between PFDT and WAB measures were observed for any of the visual search conditions. Results are summarized in Table 2.

Table 2

Correlations of PFDT for the Single-and Dual-task Visual Search and Comprehension Conditions and Standardized WAB-R AQ and AC scores

Condition	Complexity	<u>WAB-R AQ Score</u>		<u>WAB-R AC Score</u>	
		<i>r</i>	<i>p</i>	<i>r</i>	<i>p</i>
Visual Search task					
Single	Simple	.10	.65	.26	.21
	Complex	.05	.83	.20	.36
	Overall	.08	.72	.24	.25
Dual	Simple	-.07	.75	-.07	.75
	Medium	.20	.35	.20	.35
	Complex	-.21	.33	-.21	.33

	Overall	-.14	.51	-.14	.51
Comprehension task					
Single	Simple	.62**	.003	.58**	<.001
	Complex	.19	.34	.12	.56
	Overall	.44*	.02	.35	.08
Dual	Simple	.43*	.04	.46*	.03
	Medium	.72**	< .001	.64**	.001
	Complex	.72**	< .001	.67**	.001
	Overall	.73**	< .001	.69**	< .001

Note. WAB-R AQ Score = Western Aphasia Battery Aphasia Quotient; WAB-R AC Score = Western Aphasia

Battery Auditory Verbal Comprehension Score. * $p < .05$. ** $p < .01$

4. Discussion

4.1 Eye-tracking Indices of the Visual Search Single-and Dual-task Performance

The novel eye-tracking method effectively captured greater attention demands of the visual search dual task compared to the visual search single task, as reflected by a decrease in PFDT from single- to dual-task processing. Consistent with the results for single versus dual tasks, the method was effective in capturing significant differences in attention allocation corresponding to differences in stimulus complexity in the visual search single and dual task, as indexed by a decrease in PFDT from simple to complex stimulus conditions. Significant group differences were observed consistently for people with and without aphasia. Participants with aphasia had more difficulty than individuals without aphasia with allocating attention efficiently to the target image, even without the presence of a verbal stimulus in the single visual search task. Post-hoc analyses revealed that differences between and within dual- and single-task

processing were similar between the two groups. Both groups consistently exhibited a decrease in PFDT with an increase in task demands.

Results are consistent with previous dual-task studies, demonstrating a significant decrease in performance of individuals with aphasia from single- to dual-task processing (King & Hux, 1996; LaPointe & Erickson, 1991; Murray, 2000; Murray et al., 1997, 1998; Tseng et al., 1993). Results for control participants are consistent with some but not all previous studies. LaPointe & Erickson (1999) reported no significant difference for individuals without aphasia comparing single-to dual task. Murray et al., 1997 reported a significant decline in response times and accuracy of semantic judgment, lexical decision and tone perception tasks from single- to dual-task performance for control participants but to a lesser degree compared to participants with aphasia, as indexed by significant group (participants with aphasia and control participants) by condition (single and dual task) interactions. There is ample evidence in the literature that people without aphasia tend to exhibit a decrease in performance on dual tasks when compared to single tasks in terms of accuracy and response time (Blackwell & Bates, 1995; Granier et al., 2000; Hula, McNeil, & Sung, 2007; McNeil et al., 2004, 2005; Tseng et al., 1993).

While some authors have reported significant group by condition interactions some have not. Interactions were not found for the visual search task in the current study. It is possible that tasks in the current study, in which not only single versus dual tasks but also complexity within each task were manipulated, was taxing for both participant groups. Thus, this may have made the method sensitive to changes in performance even in a sample of people with no neurological impairment. Additionally, the thorough training provided prior to participation appears to have effectively familiarized both groups with the task equally well, alleviating confounds that may have otherwise resulted from problems with comprehension of task instructions. The lack of

response confounds and cognitive-linguistic confounds associated with learning a novel task might have contributed to more similar performance between the two groups. Alternatively, the lack of interactions for the visual search might be due to the fact that participants may have prioritized the visual search single and dual task, and only dedicated the remaining attention resources to the comprehension task, regardless of task demands. The fact that they received training for the visual search task might have implicitly indicated to participants that the visual search task was more important. Overall, the method indexed increases in task demands across task type, participant group, and stimulus complexity.

4.2 Eye-tracking Indices of the Comprehension Single-and Dual-task Performance

The comprehension task was conducted to reinforce equal allocation of attention resources during the dual task to the visual search and to the auditory sentence comprehension stimuli. The method effectively captured greater attention demands of the comprehension dual task compared to the comprehension single task, as reflected by a decrease in PFDT from single- to dual-task processing.

There were no significant differences observed in attention allocation corresponding to differences in verbal stimulus complexity in the single comprehension task for either group. Thus, the method was either not sensitive to changes in stimulus complexity during the single task, or the stimuli were not different enough in terms of complexity. While carefully controlled simple and complex sentences were used, it may be that prepositional phrases did not contribute to linguistic complexity within simple sentences.

In contrast, during the dual-task condition of the comprehension task, significant main effects for complexity and group were observed as well as a significant interaction. Participants with aphasia exhibited proportionately more difficulty than individuals without aphasia with

allocating attention efficiently when stimulus complexity increased, as indexed by a decrease in PFDT. Interestingly, the differences between simple and medium stimulus conditions were greater than the differences between the simple and complex conditions for both groups. Possibly, the mixed nature of the medium condition of complex visual search displays and simple comprehension task or vice versa was more challenging because it required a more flexible allocation of cognitive resources than the simple condition (simple visual search with simple comprehension task) or the complex condition (complex visual search with complex comprehension task).

Nevertheless, the method was successful in indexing differences in task demands of single- and dual-task processing and differences in attention allocation corresponding to differences in verbal stimulus complexity in participants with aphasia during the dual task. Overall significant group differences reflect differences in comprehension abilities between control participants and individuals with aphasia. The fact that differences in verbal stimulus complexity were only indexed during the dual- but not the single-task condition in individuals with aphasia, is an indicator that language deficits were not the only contributing factor, but that increased task demands during the dual task might have surpassed available attention resources in individuals with aphasia.

4.3 Relationship of Eye-tracking Attention Indices to Aphasia Severity

The WAB-AQ and AC scores correlated significantly with the PFDT of the single comprehension task for simple sentences, and all sentence types in the dual comprehension task, supporting previously reported findings that similar eye-tracking protocols lead to valid indexing of language comprehension in individuals with aphasia (Hallowell, 2009; Hallowell et al., 2002; Odekar et al., 2009). The fact that aphasia severity scores did not correlate significantly with any

of the visual search single-or dual-task conditions is consistent with Murray's (1997) study of attention allocation in individuals with aphasia using a dual-task paradigm; she also found that aphasia severity did not correlate significantly with performance on attention tasks. These findings are clinically important for two reasons. First, one cannot assume that individuals with mild aphasia only have mild attention allocation deficits or that individuals with more severe aphasia necessarily have greater attention allocation impairments. Second, clinicians should be aware that when they assess individuals with more demanding linguistic tasks, the validity of those tasks might be confounded because of the underlying attention allocation demands. Individuals might perform poorly because of attention allocation deficits, not due to linguistic competence deficits. The finding that the proportion of included trials in the comprehension task decreased with an increase in task demands from single to dual task, with a greater decline for individuals with aphasia, supports this notion.

Of course, further studies are required to confirm whether the results such as those reported here suggest a dissociation of underlying cognitive resources applied to the visual search conditions and language comprehension. Such dissociation has not been considered consistently among researchers to date. There are different opinions about whether there is one attention resource pool that fuels all cognitive processes (Kahneman, 1973) or whether attention is organized in multiple pools specifically dedicated to different cognitive processes (Caplan & Waters, 1999; Navon & Gopher, 1979).

A more detailed language assessment than the WAB-R, tapping a broader range of stimulus complexity and tasks demands, might be more likely to correlate significantly with the measures of attention allocation explored in this study. Additionally, in the current study, although the sample included a wide range of aphasia severity, the distribution of aphasia

severity was not even (according to the WAB-R classification, 16 participants had a mild aphasia, 8 moderate and 2 severe). A relationship between comprehension deficit and attention allocation efficiency may have been more evident if there had been more individuals with more severe aphasia in the sample.

Finally a standardized assessment of attention of all participants in order to validate the eye-tracking measure would have elucidated if the performance on those tasks was due to deficits in attention allocation or comprehension difficulties.

4.4 Summary of Findings

Results support the construct validity of the novel eye-tracking method to study attention allocation in adults with and without aphasia. The method is sensitive to changes in attention demands due to varying levels of stimulus complexity in the visual search task and differences in task demands.

Eye tracking in cognitive-linguistic research has become increasingly popular because the technology has become more user-friendly, accessible, and affordable. Thus, applying eye tracking to translational research targeting clinical assessment and treatment applications for individuals with cognitive-linguistics deficits has great potential (Hallowell, 2012). This new method has strong clinical and research potential for assessing attention allocation in individuals with and without aphasia because it poses minimal response requirements, requires no verbal responses or prompting, and allows online measurement of the attention allocation process. This method may be used to assess individuals, with mild to severe attention allocation and language deficits, whose responses might be confounded due to secondary cognitive and physical impairments after brain injury. Furthermore, the current study is one of the few dual-task studies

with a large sample of individuals with aphasia enabling drawing of conclusions with greater confidence about attention allocation in individuals with aphasia.

4.3 Future Research Directions

Attention allocation is a dynamic process. Systematic time sequence analysis on selective measures in 500ms time slices from stimulus onset (i.e., 500ms, 1000ms, 1500ms, etc.) will provide insight into differences in processing over time between the two groups.

Future research should include samples of individuals with specific linguistic deficits or with specific levels of aphasia severity to address the question of how attention allocation is related to different types of linguistic deficits. A standardized attention assessment should be conducted with control participants in order to test concurrent validity of the eye-tracking measure of the attention allocation task. The Test of Everyday Attention (TEA, Ridgeway, Robertson, Ward, & Immo-Smith, 1994) might be suitable because it assesses a variety of different functions of attention, including focused, divided and sustained attention in visual and auditory modality.

Finally, assessing individuals with right hemisphere impairment (RHI) due to stroke and comparing their performance to individuals with aphasia due to left hemisphere stroke might yield important insights into the role of site of lesion on performance on the attention allocation tasks. Additionally, individuals with RHI are more likely to have attention deficits (Blake, Duffy, Tompkins, & Myers, 2002), and comparing their performance to the performance of individuals with aphasia on the visual search task might strengthen the construct validity of the new eye-tracking method.

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APPENDIX

Characteristics of Participants with Aphasia

Participants	Age	Gender	Years of edu- cation	Number of CVAs	Months post onset	Scores on the WAB-R subtests**				
						SS	AVC	R	NaWF	AQ
a2	67	female	6	1	110	19	9.6	9.1	9.4	94.2
a3	72	male	0	1	11	18	9.3	8.0	9.9	90.3
a4	22	male	2	1	22	12	7.2	6.2	7.1	65.0
a5	53	female	0	2	64	14	8.6	8.6	6.6	75.6
a7	51	female	7	1	98	19	9.6	7.2	9.3	90.1
a8	46	male	6	1	35	13	9.4	7.4	7.8	75.2
a9	62	male	6	1	30	14	9.6	8.8	7.3	78.5
a10	64	female	0	1	32	9	7.9	8.2	6.0	62.2
a12	63	female	4	1	42	12	7.4	2.8	5.0	54.4
a13	67	male	9	1	18	20	10.0	9.8	9.9	99.4
a14	55	male	7	1	45	14	9.9	9.6	8.2	83.4
a15	62	male	7	1	59	15	10.0	9.4	10.0	88.8
a16	46	male	7	2	151	19	9.1	9.1	8.4	91.2
a18	45	female	4	1	10	16	7.3	8.6	5.6	75.0
a19	60	male	4	1	125	18	10.0	9.9	8.9	93.6
a21	59	male	9	1	74	13	9.0	7.6	7.7	74.5
a22	57	male	2	1	35	15	9.4	9.0	9.3	85.4
a24	66	male	7	1	15	19	9.1	9.3	8.7	92.1

Participants	Age	Gender	Years of edu- cation	Number of CVAs	Months post onset	Scores on the WAB-R subtests**				
						SS	AVC	R	NaWF	AQ
a25	58	female	6	2	101	9	6.9	1.7	5.0	45.1
a26	70	male	8	1	66	19	9.6	10.0	9.1	95.4
a28	41	male	4	1	20	11	6.3	3.9	5.0	52.4
a29	59	male	8	1	275	12	7.8	4.0	4.7	57.0
a30	59	female	4	1	11	6	3.9	6.2	1.2	34.6
a31	60	female	4	1	68	12	8.7	6.4	8.5	71.2
a32	32	female	4	1	23	13	8.0	7.5	7.6	72.1
a33	60	male	1	2	38	15	10.0	9.1	8.8	85.8

Note. *If multiple CVAs were reported, time from the first CVA is indicated.**WAB-R subtests: SS = spontaneous speech; AVC = auditory verbal comprehension; R = repetition; NaWF = naming and word finding;