

Relatively few studies have examined eye-movement control in patients with aphasia and alexia (but see, Thompson, et al., 2007, 2009; Dickey et al., 2007, 2009). Nevertheless, all visual-cognitive tasks, including reading and many language tasks, require the dynamic control of eye-movements (Just & Carpenter, 1980; Rayner, 1998, 2009; Rayner & Pollatsek, 2013). Eye-tracking has proven useful for studying attention, reading, memory, and search in normal individuals, and provides a means for evaluating online cognitive processing (Henderson, 2006, 2013; Land & Hayhoe, 2001; Schutz et al., 2011). Eye-tracking in persons with aphasia has the potential to answer a variety of clinical and basic science questions about aphasia. However, eye-movements in this population must first be characterized more generally.

Sensory-motor problems are common in patients with aphasia and alexia, but it is unclear if they present with normal eye-movement control. If eye-movement control is impaired in aphasia and acquired alexia, it may contribute to the overall impairment. Currently, reading impairments in individuals with aphasia are attributed to a language-based etiology and traditional assessment and treatment approaches have been developed with this view in mind. However, many individuals with chronic alexia demonstrate negligible benefit following treatment (Cherney 2004, 2010), suggesting there may be additional contributing factors (e.g. oculomotor control).

Previous research has shown that healthy individuals' mean saccade amplitude and mean fixation duration are modulated by task requirements (Rayner, 2009; Rayner & Pollatsek, 2013). In the present study, we asked two questions: 1) Are eye-movement behaviors in individuals with aphasia related to behavioral assessment scores and lesion size? If so, this may suggest some of the reading impairments may be attributable to oculomotor deficits; and 2) How is saccade amplitude and fixation duration modulated by task, stimulus type and group (persons with aphasia vs. healthy-controls)?

The present study sought to characterize saccadic eye-movements of individuals with aphasia by comparing their performance on various eye-tracking tasks to healthy-control participants, and by investigating the relationship of their eye-movements with behavioral assessments and lesion size. Ten individuals with chronic aphasia (4 women; 5 Anomic, 4 Broca's, 1 Wernicke's) and 42 college-aged controls (additional individuals with aphasia and age-matched controls are currently being recruited) participated in the present study. Demographic information and scores for behavioral measures are shown in *Table 1*.

All participants completed the eye-tracking protocol described below. Individuals with aphasia completed a vision screening; healthy-control participants reported normal speech and language skills, and normal or corrected to normal vision. The eye-tracking protocol consisted of four tasks, each taking approximately twelve-minutes: scene memorization, in which participants were instructed to memorize images of real-world scenes; visual search, in which participants were instructed to search for an "O" embedded in a real-world scene; reading, in which participants were instructed to read paragraphs of text; pseudo-reading, in which participants were instructed to "read" through pseudo-texts (each letter was replaced by a geometric shape; Henderson & Luke, 2012; Luke & Henderson, 2013; Nuthmann et al., 2007). We treated scene memorization and visual search as two *Scene* conditions and reading and pseudo-reading as two *Reading* conditions. These tasks were chosen as each has been used extensively to study eye-movement control, and the relationship of eye-movements to memory, attention, reading, and various other areas of cognition in normal individuals (Huey, 1908; Dafoe et al., 2007; Henderson et al., 2007; Brockmole & Henderson, 2006; Najemnik & Geisler, 2005; Luke et al., 2012; Henderson & Smith, 2009; Luke & Henderson, 2013). Together, these tasks allow for a

comprehensive characterization of reading and non-reading eye-movements in individuals with aphasia.

The relationship between eye-movements and behavioral assessment scores were explored using Pearson's correlations. Larger saccade amplitude in reading was generally associated with greater impairment, as indicated by the WAB-R reading subtest ($p=.072$), RCBA ($p=.114$), and lesion size ($p=.01$). Given that previous research suggests saccade amplitude decreases as reading difficulty increases (Rayner, 1998; Rayner et al., 2006), the eye-movements measured during reading may not exclusively represent natural language processing. Surprisingly, the opposite pattern emerged for pseudo-reading, smaller saccade amplitude was associated with greater impairment as indicated by the WAB-R AQ only ($p=.037$). We are currently exploring if these opposing saccade amplitude effects can be explained by lesion location. Consistent with previous dyslexia research, which suggested that fixation durations tend to increase with overall impairment (Elterman, et al 1980; Rayner, 1978, 1985; Rubino & Minden, 1973), fixation durations tended to increase with lesions size, however, this only reached significance for the visual search task ($p=.04$).

A repeated measures ANOVA revealed a significant interaction of task and group in mean saccade amplitude (see Figure 1; $f(3,50)=4.68$, $p=.006$), suggesting that the mean saccade amplitude of individuals with aphasia differed across task from those of healthy-controls. A within group ANOVA revealed a main effect of task for healthy-control participants ($f(3,41)=18.86$, $p<.001$), suggesting they adapted their saccade amplitude to task requirements. However, individuals with aphasia did not significantly change their mean saccade amplitude with task ($f(3,9)=.411$, $p=.683$), suggesting individuals with aphasia are not making task specific eye-movements.

A repeated measures ANOVA again revealed a significant interaction of task and group in mean fixation duration (see Figure 2; $f(3,50)=9.45$, $p<.001$), suggesting the pattern of fixation durations across task differed in individuals with aphasia relative to healthy-controls. A within group ANOVA revealed a main effect of task on fixation duration for both healthy-controls ($f(3,41)=150.11$, $p<.001$) and individuals with aphasia ($f(3,9)=8.64$, $p=.004$). However, the healthy-control participants significantly modulated fixation durations across the two reading conditions (reading vs. pseudo-reading; $t(41)=-10.41$, $p<.001$), and across the two scene conditions (scene memory vs. search; $t(41)=4.6$, $p<.001$), whereas individuals with aphasia did *not* (reading vs. pseudo-reading; $t(9)=-1.28$, $p=.233$, scene memory vs. search; $t(9)=-2.02$, $p=.07$). This suggests that individuals with aphasia do *not* adapt their mean fixation durations within task type (reading *or* scene). However, individuals with aphasia seem to experience a stimulus-based response, reading tasks generally had shorter fixations than scene tasks (all $t(9)\geq-3.06$, all $p\leq.01$). Whereas, additional individuals with aphasia need to be recruited to confirm these data patterns, the stimulus-based response suggests there is sufficient power to detect an effect in individuals with aphasia when one is present.

The pattern of saccade amplitudes and fixation durations, in individuals with aphasia, differed from healthy-controls across task. Specifically, individuals with aphasia showed reduced variation of eye-movements across tasks relative to healthy-controls. This suggests an inability to adapt to task requirements, which likely impacts the processing of visual stimuli and integration of information within and across eye-movements. Future work with individuals with aphasia should consider the possibility that their eye-movements may not reflect language processing or task requirements as in healthy-controls, but rather are more general purpose and minimally modulated by task. Characterizing eye-movements of individuals with aphasia may

provide insight into the neurobiological correlates of alexia and potentially inform current clinical and research practices. This characterization processes will necessarily require identifying how eye-movements in individuals with aphasia vary from healthy individuals, both for language and non-language tasks. We may learn that reading deficits in this population are not attributable to language impairment alone, but rather are due to a lack of task-based adaption in eye-movement control, which may impair language processing. This would suggest that reading eye-movements in individuals with aphasia may be less representative of language processing in general.

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Table 1. Patient demographic information and assessment scores.

Patient Demographics	Mean	Range
Age	55.4 yrs	37-78 yrs
Months Post-stroke	73.5 mos	18-193 mos
Western Aphasia Battery (WAB)- R Aphasia Quotient	74.06/100	48.8-98.5
WAB-R Reading Subtest	16.54/20	12-20
Reading Comprehension Battery for Aphasia (RCBA)	82.6/100	68-97

Figure 1. Mean saccade amplitude for healthy-controls and individuals with aphasia for each task.

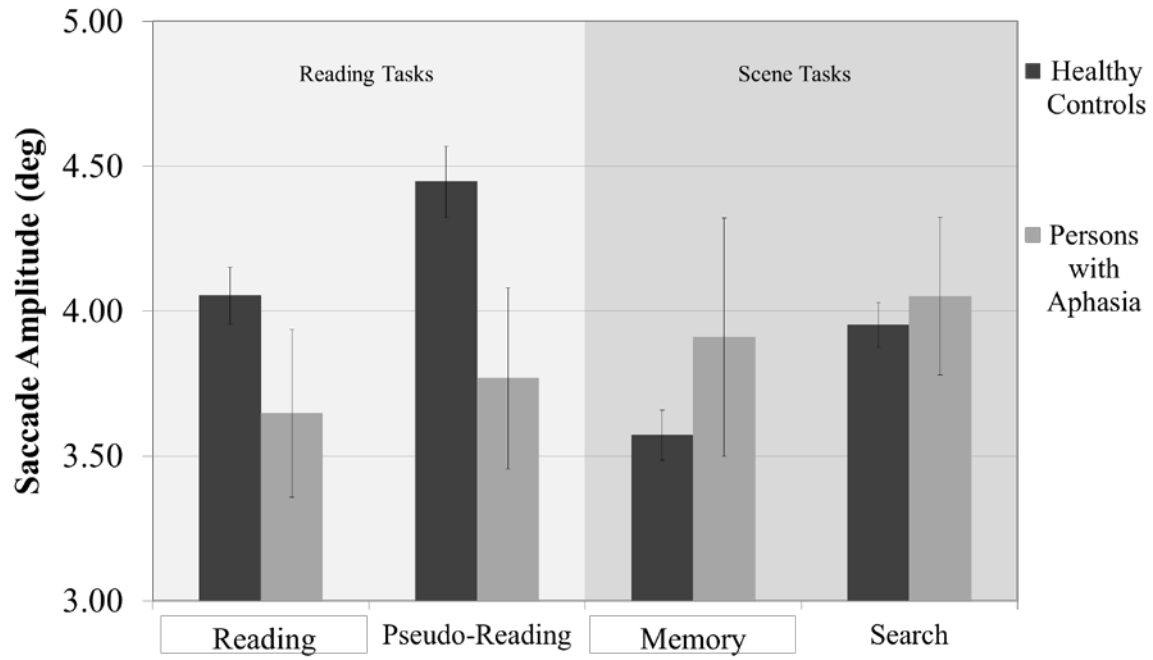


Figure 2. Mean saccade amplitude for healthy-controls and individuals with aphasia for each task.

