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# Between-session intra-individual variability in sustained, selective, and integrational non-linguistic attention in aphasia

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ABSTRACT

A number of studies have identified impairments in one or more types/aspects of attention processing in patients with aphasia (PWA) relative to healthy controls; person-to-person variability in performance on attention tasks within the PWA group has also been noted. Studies using non-linguistic stimuli have found evidence that attention is impaired in this population even in the absence of language processing demands. An underlying impairment in non-linguistic, or *domain-general*, attention processing could have implications for the ability of PWA to attend during therapy sessions, which in turn could impact long-term treatment outcomes. With this in mind, this study aimed to systematically examine the effect of task complexity on reaction time (RT) during a non-linguistic attention task, in both PWA and controls. Additional goals were to assess the effect of task complexity on between-session intra-individual variability (BS-IIV) in RT and to examine *inter*-individual differences in BS-IIV. Eighteen PWA and five age-matched neurologically healthy controls each completed a novel computerized non-linguistic attention task measuring five types of attention on each of four different non-consecutive days. A significant effect of task complexity on both RT and BS-IIV in RT was found for the PWA group, whereas the control group showed a significant effect of task complexity on RT but not on BS-IIV in RT. Finally, in addition to these group-level findings, it was noted that different patients exhibited different patterns of BS-IIV, indicating the existence of inter-individual variability in BS-IIV within the PWA group. Results may have implications for session-to-session fluctuations in attention during language testing and therapy for PWA.


## 1. Introduction

Although aphasia is typically considered to be a disorder in language processing, the cognitive abilities of patients with aphasia (PWA) have come under increasing investigation over the course of the past several decades. Cognition in aphasia is an inherently important line of research, given the existence of a number of theoretical and developmental cognitive-psycholinguistic models positing a strong interconnectedness and functional overlap between language and cognition in healthy individuals (e.g. Vygotsky, 1962; Luria and Yudovich, 1971). Gaining a better understanding of cognition in PWA will enable researchers and clinicians to develop, modify, and implement rehabilitative language treatments that take cognitive abilities into account, thereby maximizing individual patients' long-term potential for improvement.

Among the areas of cognition that have been examined in PWA, *attention* is a skill worth particular consideration. To begin with, attention – arguably the most basic of the cognitive processes – has been found to be impaired in PWA relative to healthy controls (Robin and Rizzo, 1989; Tseng et al., 1993; Erickson et al., 1996; Murray et al., 1997; Murray, 2000, 2012; Hunting-Pompon et al., 2011). Additionally, it has been compellingly argued that language knowledge is largely preserved in aphasia and that the observed language deficit is a result of impaired attentional processes (Hula and McNeil, 2008), a theory which underscores the importance of investigating this particular cognitive skill in PWA. Finally, and on a somewhat different note, attention may play an important role in language rehabilitation. Not only has attention been shown to be predictive of long-term functional recovery after stroke (Mysiw et al., 1989; Robertson et al., 1997), evidence from the aphasia literature has also suggested that cognitive abilities such as attention may successfully predict language therapy outcomes (Lambon Ralph et al., 2010). Our primary motivation for the current study is that an underlying impairment in attention may negatively impact a wide variety of skills and situations (see Fig. 1).

Most models frame attention as a *domain-general* resource that may be drawn on for a variety of tasks, both linguistic and non-

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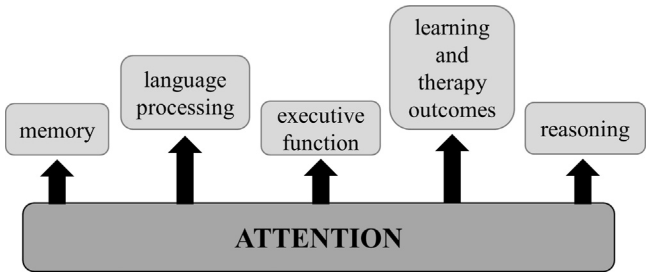


**Fig. 1.** Theoretical schematic illustrating support provided by domain-general attention to other cognitive/linguistic processes.

linguistic (e.g. Posner and Petersen, 1990; Mirsky et al., 1991; Petersen and Posner, 2012; Cohen, 2014). The most direct way of measuring attention in language-impaired individuals, therefore, is to bypass the language system through the use of non-linguistic tasks. Studies using non-linguistic tasks to investigate attention in aphasia have consistently found evidence of attentional deficits in PWA. Robin and Rizzo (1989) used simple arrows, dots, and auditory pulses and found a significantly impaired ability to orient attention in PWA relative to controls. In a later study, Erickson et al. (1996) investigated the effect of a dual-task condition on primary task performance in PWA, using non-linguistic sound identification as the primary task and the Wisconsin Card Sort Task (also non-linguistic) as the secondary task. Results showed that not only did PWA perform more poorly during the dual-task condition than the single-task condition, they also performed consistently poorer than control subjects. Additionally, Laures et al. (2003) examined arousal and vigilance in PWA and controls and found evidence of impaired performance by the PWA group in both linguistic and non-linguistic contexts, suggesting that attention is similarly impaired in linguistic and non-linguistic tasks in this population. Results like these point to the existence of a basic, domain-general attentional impairment in PWA, one that could have negative implications for many other skills.

With this in mind, the goal of the current study is to gain a fuller understanding of the nature of this impairment by systematically investigating several different types of non-linguistic attention. Though a number of attentional models have been proposed, we will refer here to Sohlberg and Mateer's (2001) clinical model, which is based on the highly predictable stages of recovery from brain injury and is widely referenced in the aphasia literature. One of its central features is a hierarchical complexity in which less complex types of attention are prerequisites for more complex types. The most basic type of attention in this model is *focused attention* (responding discretely to specific stimuli), followed by the more complex *sustained attention* (sustaining consistent responses to stimuli during continuous activity). Next is *selective attention* (maintaining a cognitive set in the face of distracting stimuli), followed by *alternating attention* (shifting between tasks or features), and finally, the most complex type, *divided attention* (simultaneously responding to multiple attentional demands). The experimental task used in the current study is rooted in this model, particularly in its framing of sustained and selective attention.

An additional and central dimension of the current project is its focus on intra-individual variability (IIV); that is, the degree of fluctuation in a single individual's performance over time. Increased IIV on cognitive tasks relative to healthy controls has been identified in a wide variety of clinical populations, including traumatic brain injury (Stuss et al., 1994; Bleiberg et al., 1997) and dementia (e.g. Hultsch et al., 2000; Murtha et al., 2002), as well as both Alzheimer's Disease and Parkinson's Disease (Burton et al., 2006). However, little is known about IIV in cognitive task performance in aphasia, despite the fact that substantial IIV in performance on language tasks has been reported in this population (Ryalls, 1986; Glosser et al., 1988; Freed et al., 1996). The current study examines, for the first time, IIV in non-linguistic attention processing in aphasia. More specifically, we examine day-to-day fluctuations in task performance, or *between-session intra-individual variability* (BS-IIV). We suggest that BS-IIV could play a critical role in therapy outcomes, as language therapy is typically delivered over the course of many sessions spanning several weeks or months and presumably requires consistent attention from session to session.

To summarize, the overarching framework of the current study is that the successful execution of domain-general sustained attention is a prerequisite for domain-general selective attention, that the successful execution of both of these is required for more complex attentional processes, and that fluctuations in attention across sessions may substantially influence any or all of these processes. The goal of the current study was to use non-linguistic tasks as a means to systematically examine the nature of domain-general attention processing in aphasia, with a particular focus on intra-individual variability. We propose that understanding domain-general attention in PWA is of critical importance, as this basic skill may underlie a variety of other tasks and situations. The aims of the current study were as follows:

1. To examine the effect of task complexity on reaction time (RT) in non-linguistic attention in PWA, as well as in a small group of age-matched healthy control participants. We hypothesized that both PWA and age-matched controls would show relatively longer RTs as task complexity was increased.
2. To examine the effect of task complexity on BS-IIV in RT during a non-linguistic attention task. We expected that PWA would, in general, show a greater degree of BS-IIV than controls. We also expected that PWA would show a higher degree of BS-IIV as task complexity was increased.
3. To look at patient-to-patient, or *inter*-individual, variability in BS-IIV in non-linguistic attention. We expected to find evidence of substantial *inter*-individual variability in BS-IIV within the PWA group.

## 2. Methods

### 2.1. Participants

Eighteen patients with stroke aphasia (PWA, 12 male, mean age=60.3, SD=8.25) and five age-matched neurologically unimpaired control participants (controls, 2 male, mean age=63.4, SD=7.50) participated in the study (see Table 1). Participants were recruited through advertising and word of mouth. PWA completed several standardized assessments measuring language/cognitive abilities: the Western Aphasia Battery (WAB, Kertesz, 1982), the Cognitive-Linguistic Quick Test (CLQT, Helm-Estabrooks, 2001), and the Boston Naming Test (BNT, Kaplan et al., 2001). The mean Aphasia Quotient (AQ) for PWA was 77.3 out of 100, with a range of 21.2–98.9. The mean CLQT composite score was 80% with a range of 10–100%, and the mean Attention sub-score on the CLQT was 75%, with a range of 18–97%. The mean BNT percent correct was 37.5% with a range of 1–100%. No participants who had been diagnosed with either dementia or Parkinson's Disease were enrolled. This study was approved by the Institutional Review Board at Boston University.

### 2.2. Stimuli

The computerized experimental task included visual and auditory stimuli. Visual stimuli consisted of a large black dot which

**Table 1**
Demographic and standardized testing information for PWA (P1–P18) and controls (NC1–NC5).

| Participant | Age | Sex | MPO | Lesion information | WAB AQ | Aphasia type | BNT | CLQT composite |
|---|---|---|---|---|---|---|---|---|
| P1 | 47 | M | 48 | L MCA++ | 96.3 | Anomic | 55 | 19 |
| P2 | 55 | F | 9 | L MCA++ | 93.9 | Anomic | 60 | 20 |
| P3 | 66 | M | 29 | L MCA | 93.7 | Anomic | 44 | 19 |
| P4 | 74 | M | 13 | L MCA/ACA | 50.5 | Transcortical Motor | 10 | 14 |
| P5 | 69 | M | 23 | L MCA | 96.6 | Anomic | 60 | 19 |
| P6 | 56 | M | 147 | R MCA | 94.2 | Anomic | 48 | 20 |
| P7 | 61 | M | 52 | L MCA | 91.2 | Anomic | 57 | 19 |
| P8 | 53 | M | 120 | L MCA/ACA | 50 | Broca's | 13 | 14 |
| P9 | 68 | M | 21 | L MCA++ | 95 | Anomic | 46 | 17 |
| P10 | 74 | M | 14 | L MCA/ACA | 89.5 | Transcortical Motor | 54 | 16 |
| P11 | 54 | M | 34 | L PCA plus old R cerebellar infarct | 91 | Anomic | 28 | 16 |
| P12 | 64 | F | 89 | L MCA++ | 86.5 | Transcortical Motor | 36 | 16 |
| P13 | 59 | F | 73 | L MCA | 98.9 | Anomic | 59 | 20 |
| P14 | 67 | F | 66 | L MCA++ | 43.9 | Broca's | 6 | 13 |
| P15 | 63 | F | 99 | L MCA++ | 53.4 | Conduction | 9 | 16 |
| P16 | 50 | M | 186 | L MCA | 57.3 | Broca's | 39 | 11 |
| P17 | 56 | M | 13 | L MCA | 87.2 | Anomic | 50 | 17 |
| P18 | 50 | F | 31 | L MCA++ | 21.2 | Global | 1 | 2 |
| NC1 | 54 | F | – | – | – | – | – | – |
| NC2 | 62 | F | – | – | – | – | – | – |
| NC3 | 71 | M | – | – | – | – | – | – |
| NC4 | 71 | M | – | – | – | – | – | – |
| NC5 | 59 | F | – | – | – | – | – | – |

*Note:* MPO=months post onset. L=left; R=right; MCA=Middle Cerebral Artery; ACA=Anterior Cerebral Artery; PCA=Posterior Cerebral Artery. ++with subcortical involvement (e.g. basal ganglia and/or thalamus). WAB AQ=Western Aphasia Battery Aphasia Quotient (highest possible score=100). BNT=Boston Naming Test (highest possible score=60). CLQT composite=Cognitive-Linguistic Quick Test composite score (highest possible score=20).

appeared on either the left or right side of the screen; auditory stimuli consisted of a double tone played through headphones in either the left or right ear. Each stimulus or set of two simultaneous stimuli was presented for 600 ms.

### 2.3. Experimental task

The experimental task was created and administered using E-Prime 2.0 software (Psychology Software Tools, Pittsburgh, PA; www.pstnet.com). The task comprised five separate conditions, each of which was designed to differ minimally from the others in terms of its complexity and/or the modality of the target stimuli. Conditions 1, 2, 3, 4, and 5 were designed to measure, respectively, sustained visual attention (this condition is referred to hereafter as SUSTAINED-V), sustained auditory attention (SUSTAINED-A), selective visual attention (SELECTIVE-V), selective auditory attention (SELECTIVE-A), and auditory-visual integrational attention (INTEGRATIONAL-A/V). While auditory-visual integrational attention – defined here as attention to congruency between visual and auditory information – is not an attentional type per se, we consider it to reflect a type of processing that is often required during language therapy sessions, where patients are asked to attend simultaneously to auditory and visual stimuli that contain similar messages (e.g. to look at a picture of an object while listening to the clinician say the object's name aloud).

In order to minimize response demands, participants were instructed during each condition to press “E” if the target stimulus was on the left, “R” if the target stimulus was on the right, and the spacebar if the target stimulus was absent. Participants were asked to rest the middle and index finger of their left hand on the “E” and “R” keys, respectively, on a QWERTY keyboard, and rest their thumb on the spacebar. One participant, P6, had left-sided hemiplegia, so used his right hand instead. For all conditions, participants were instructed to press “E”, “R”, or the spacebar to respond to each stimulus following a fixation. During Condition 1 (SUSTAINED-V), only visual stimuli were present. The participant was instructed to press “E” if they saw a dot on the left side of the screen, “R” if they saw a dot on the right side of the screen, and to press the spacebar if they saw no dot. During Condition 2 (SUSTAINED-A), only auditory stimuli were present. The participant was instructed to press “E” if they heard a tone on the left, “R” if they heard a tone on the right, and to press the spacebar if they heard no tone. During Condition 3 (SELECTIVE-V), visual and auditory stimuli were presented simultaneously. The participant was instructed to attend only to the visual stimuli, pressing “E” if they saw a dot on the left, “R” if they saw a dot on the right, and the spacebar if they saw no dot. During Condition 4 (SELECTIVE-A), visual and auditory stimuli were presented simultaneously. The participant was instructed to attend only to the auditory stimuli, pressing “E” if they heard a tone on the left, “R” if they heard a tone on the right, and the spacebar if they heard no tone. Finally, during Condition 5 (INTEGRATIONAL-A/V), visual and auditory stimuli were again presented simultaneously. The participant was instructed to attend to both sets of stimuli, pressing “E” if they saw a dot and heard a tone that were *both* on the left, “R” if they saw a dot and heard a tone that were *both* on the right, and the spacebar if they saw a dot and heard a tone that were on different sides from each other.

Each condition contained three un-scored items, followed by 48 randomized scored items, each of which began with a fixation. The duration of the fixation was randomly jittered between 1400, 1600, 1800, and 2000 ms so that the participant would not be able to predict exactly when the next item would occur. The fixation was followed by the 600 ms stimulus or set of two simultaneous stimuli (or, when the target was absent during SUSTAINED-V and SUSTAINED-A, a blank screen). After the disappearance of the stimuli, the participant was then presented with a blank screen for 3000 ms, allowing a total of up to 3600 ms to make a response. See Fig. 2 for a visual depiction of items during each condition.

Across all five conditions, of the 48 scored items, 16 had “E” (left) target responses, 16 had “R” (right) target responses, and 16 had target spacebar responses. For SELECTIVE-V as well as for SELECTIVE-A, half of the items containing the target stimulus also contained a distractor stimulus on the same side as the target

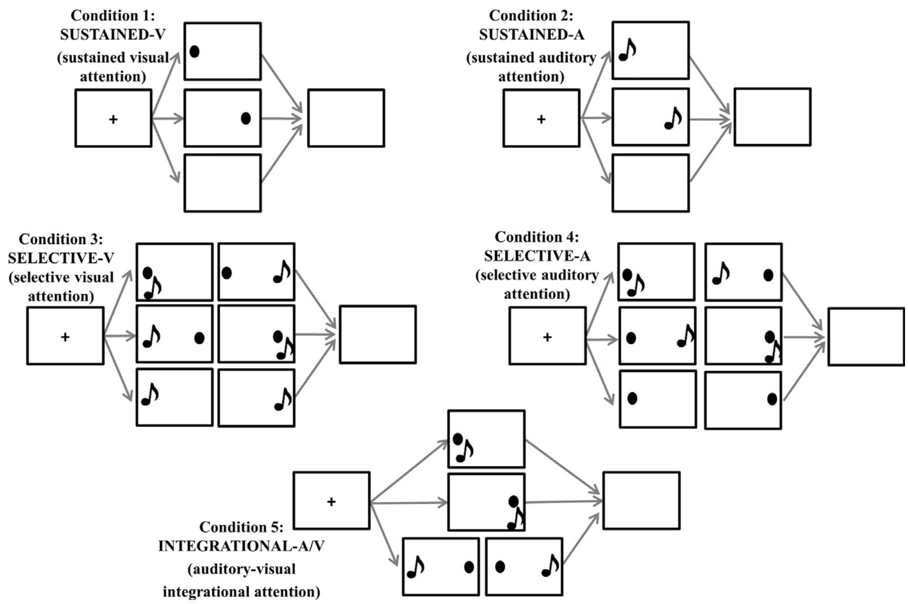


**Fig. 2.** Experimental task conditions. Dots indicate a black dot on the right or left side of the screen. Musical notes indicate a tone played in either the right or left ear.

(congruent), while the other half of the items containing the target stimulus also contained a distractor stimulus on the opposite side as the target (incongruent). For INTEGRATIONAL-A/V, half of the items in which the target stimulus (i.e., congruent auditory and visual stimuli) was absent contained a dot on the left and a tone on the right, while the other half contained a dot on the right and a tone on the left. Both accuracy and reaction time (RT) data were collected by E-Prime.

### 2.4. Procedures

Testing was conducted in a quiet room at Boston University, or occasionally in the participant's home if they were not able to travel to the testing site. Prior to the administration of each condition, participants were given instructions about target stimuli and corresponding button press responses, followed by a series of practice items in order to ensure comprehension and set acquisition. Auditory stimuli were presented at a comfortable level for each participant. Each participant completed the experimental task (including each of the five conditions) on four different non-consecutive days: Session 1, Session 2, Session 3, and Session 4 (5 Conditions x 4 Sessions = 20 administrations for each participant; see Fig. 3). The order of administration of SUSTAINED-V and SUSTAINED-A was counter-balanced across participants, as was the order of administration of SELECTIVE-V and SELECTIVE-A. INTEGRATIONAL-A/V was consistently the final condition administered, as the structure of that condition builds upon the structures of the other four. Experimental conditions were identical for PWA and controls.

### 2.5. Data analysis

Total accuracy was calculated for each participant's performance during each session. Next, reaction time *z*-scores (zRT)

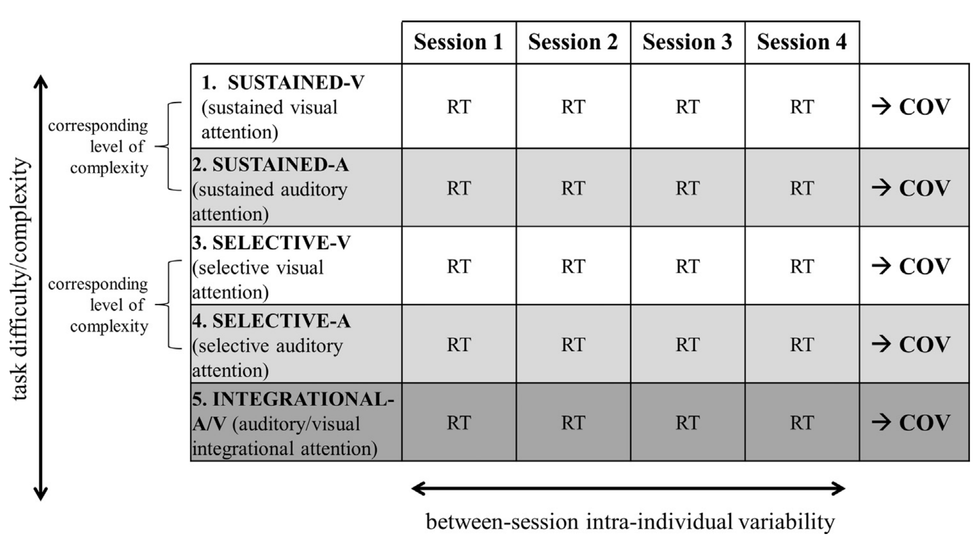


**Fig. 3.** Administration of experimental task conditions and calculation of COV (coefficient of variation; see Section 2.5).

were calculated for each participant (collapsed across conditions and sessions), using only correct "E" and "R" responses that occurred within a predetermined acceptable time period (350–2500 ms; 99.4% of all correct raw RTs for "E"/"R" responses fell within this range). Finally, in order to examine BS-IIV, five COVs (coefficient of variation) were calculated for each participant, one for each of the five conditions. Each COV was calculated using the following formula: COV$=s$(Session$_i$ mean raw RT)/$\bar{x}$(Session$_i$ mean raw RT), where $i=$Session 1–4 and "mean raw RT" refers to mean raw RT for correct "E"/"R" responses that occurred between 350 ms and 2500 ms.

## 3. Results

### 3.1. Accuracy

Accuracy was generally found to be high across participants and conditions (see Table 2). The binomial distribution model was used to more closely analyze accuracy for each participant. In order to demonstrate above-chance performance on a given condition during a given session, a participant would need to achieve at least a 50% accuracy level (48 items, a 33% chance of guessing correctly on any single item, $\alpha=0.01$). All control participants achieved accuracy levels of 50% or higher on each administration of each condition, as did the majority of PWA. Several PWA achieved lower than 50% accuracy in one or two instances; we chose to include these participants' data in subsequent analyses because despite isolated instances of chance-level accuracy, they had consistently demonstrated satisfactory understanding of the practice items.

### 3.2. Effects of session and condition on mean zRT

The next analysis looked at the impact of both session and condition on task performance in PWA. In order to avoid the ceiling effects associated with high accuracy levels, zRTs were used. P4 could not be included in this analysis due to a missing data point. An alpha level of. 0.05 was used for this and all subsequent statistical tests. An R-ANOVA examining the effect of Session (1–4) as a repeated measure and Condition (1–5) on mean zRT was performed. A significant effect of Condition was found ($F$ (4, 80)$=$76.10, $p<0.001$; see Fig. 4a). There was no significant effect of Session ($F$ (3, 240)$=$1.70, $p=0.17$) and no Session by Condition interaction effect ($F$ (12, 240)$=$1.42, $p=0.16$). Tukey post-hoc analyses revealed an effect of complexity, such that each *selective* attention condition elicited significantly higher mean zRTs than its corresponding *sustained* attention condition (i.e., PWA were slower on SELECTIVE-V than SUSTAINED-V, $p<0.001$; and slower on SELECTIVE-A than SUSTAINED-A, $p<0.001$). Post-hoc analyses also revealed a modality effect, such that each *auditory* attention condition elicited significantly higher mean zRTs than its corresponding *visual* attention condition (i.e., PWA were slower on SUSTAINED-A than SUSTAINED-V, $p<0.001$; and slower on SELECTIVE-A than SELECTIVE-V, $p<0.001$). Additionally, INTEGRATIONAL A/V elicited higher mean zRTs ($p<0.05$) than each of the other four conditions.

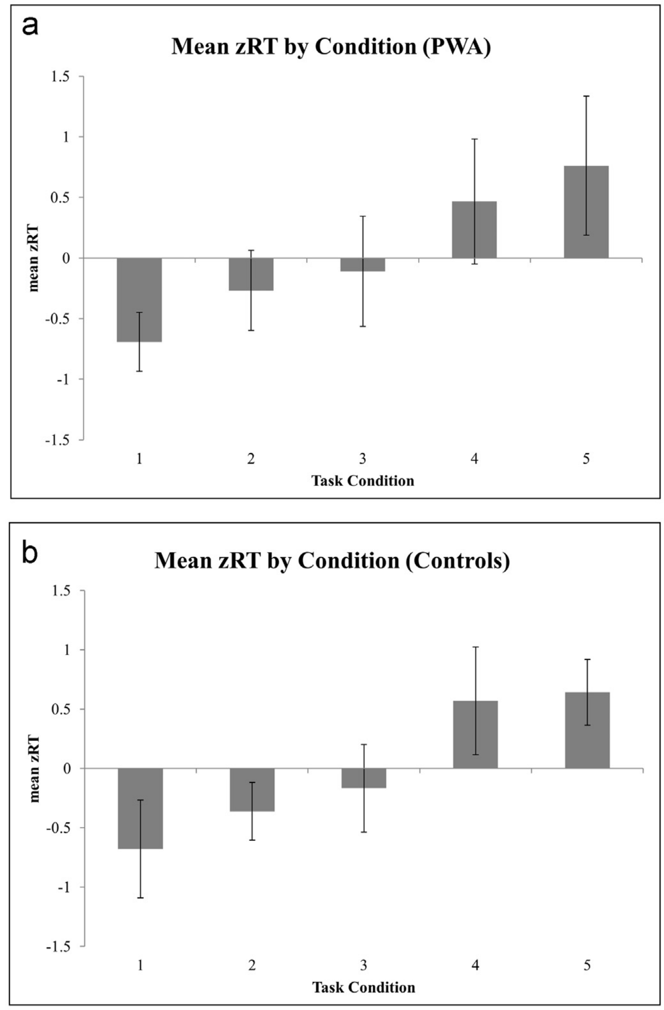


**Fig. 4.** Mean zRTs by condition for PWA (a) and controls (b). R-ANOVA post-hoc results and significance levels are described in the text. Error bars indicate standard deviations. Task Condition 1: SUSTAINED-V; Task Condition 2: SUSTAINED-A; Task Condition 3: SELECTIVE-V; Task Condition 4: SELECTIVE-A; and Task Condition 5: INTEGRATIONAL-A/V.

Next, a corresponding R-ANOVA examining the effect of Session (1–4) as a repeated measure and Condition (1–5) on mean zRT was conducted for the control group. Once again, a significant effect of Condition was observed ($F$ (4, 20)$=$34.97, $p<0.001$; see Fig. 4b). Tukey post-hoc analyses revealed an effect of complexity (controls were slower on SELECTIVE-V than SUSTAINED-V, $p=0.01$; and slower on SELECTIVE-A than SUSTAINED-A, $p<0.001$), as well as a partial modality effect (controls were slower on SELECTIVE-A than

**Table 2**
Mean accuracy levels for each participant group on each experimental task condition.

| | **SUSTAINED-V** (%) | **SUSTAINED-A** (%) | **SELECTIVE-V** (%) | **SELECTIVE-A** (%) | **INTEGRATIONAL-A/V** (%) |
|---|---|---|---|---|---|
| **PWA** | 96 | 95 | 94 | 85 | 88 |
| **Controls** | 99 | 99 | 100 | 99 | 99 |

*Note*: Exceptions to the above-chance 50% accuracy cutoff are as follows: P4 achieved 27% accuracy during SUSTAINED-A, Session 2, P16 achieved 46% accuracy during INTEGRATIONAL-A/V, Session 1 as well as 31% accuracy during SELECTIVE-A, Session 3, and P18 achieved 43% accuracy during SELECTIVE-A, Session 1, as well as 39% accuracy during SELECTIVE-V, Session 4.

**Table 3**
Coefficients of variation (COVs) for PWA (P1–P18) and controls (NC1–NC5) on each experimental task condition.

| Participant | SUSTAINED-V COV | SUSTAINED-A COV | SELECTIVE-V COV | SELECTIVE-A COV | INTEGRATIONAL-A/V COV |
|---|---|---|---|---|---|
| P1 | 0.059 | 0.079 | 0.096 | 0.153[a] | 0.172[a] |
| P2 | 0.058 | 0.233 | 0.202[a] | 0.170[a] | 0.079[a] |
| P3 | 0.035 | 0.066 | 0.090 | 0.020 | 0.035 |
| P4 | 0.042 | 0.076 | 0.102 | 0.104 | 0.103 |
| P5 | 0.062 | 0.122[a] | 0.089 | 0.155[a] | 0.099 |
| P6 | 0.063 | 0.060 | 0.050 | 0.056 | 0.110 |
| P7 | 0.091 | 0.047 | 0.126 | 0.070 | 0.217[a] |
| P8 | 0.068 | 0.245[a] | 0.052 | 0.207[a] | 0.309[a] |
| P9 | 0.061 | 0.027 | 0.188 | 0.181[a] | 0.117 |
| P10 | 0.063 | 0.121[a] | 0.088 | 0.142 | 0.143[a] |
| P11 | 0.023 | 0.022 | 0.051 | 0.150 | 0.078 |
| P12 | 0.061 | 0.076 | 0.081 | 0.115 | 0.118 |
| P13 | 0.014 | 0.100 | 0.055 | 0.075 | 0.066 |
| P14 | 0.098 | 0.094 | 0.131 | 0.148 | 0.074 |
| P15 | 0.047 | 0.054 | 0.188 | 0.032 | 0.097 |
| P16 | 0.063 | 0.091 | 0.010 | 0.207[a] | 0.235[a] |
| P17 | 0.203 | 0.144[a] | 0.235[a] | 0.072 | 0.111 |
| P18 | 0.104 | 0.147[a] | 0.166 | 0.212[a] | 0.184[a] |
| NC1 | 0.140 | 0.045 | 0.053 | 0.104 | 0.073 |
| NC2 | 0.206 | 0.069 | 0.134 | 0.098 | 0.048 |
| NC3 | 0.032 | 0.085 | 0.080 | 0.103 | 0.074 |
| NC4 | 0.103 | 0.054 | 0.061 | 0.089 | 0.098 |
| NC5 | 0.037 | 0.058 | 0.025 | 0.056 | 0.046 |

[a] "High" COVs, i.e. PWA COVs which were found to be significantly higher than control COVs within the same condition (Crawford and Garthwaite, 2007; Crawford et al., 2010).

on SELECTIVE-V, $p<0.001$). INTEGRATIONAL-A/V elicited higher mean zRTs ($p<0.001$) than each of the other conditions, with the exception of SELECTIVE-A. There was no significant main effect of Session ($F$ (3, 60)$=0.96$; $p=0.42$), nor was there a significant interaction effect ($F$ (12, 60)$=0.76$; $p=0.69$).

All subsequent analyses (3.3–3.6) examine BS-IIV, as represented by COV. Recall that COV is an index of session-to-session variability in mean raw RT and is calculated separately for each condition. Table 3 provides COVs for each participant in each condition. Crawford and Garthwaite's (2007; updated in Crawford et al., 2010) Bayesian approach was used to identify PWA COVs which were significantly higher than the control COVs within the same condition. Those COVs are indicated in the table and are considered to be "high"; all other COVs are considered to be "low".

### 3.3. Effect of group and condition on RT COV

Next, while the primary goal of this project was not to compare PWA to controls, a $2\times5$ ANOVA examining the effect of Group (PWA/controls) and Condition (1–5) on COV was conducted, and a significant main effect of Group was found ($F$ (1, 105)$=4.90$, $p=0.03$). The overall mean COV for PWA was .107, while the overall mean COV for controls was .079. There was no significant main effect of Condition ($F$ (4, 105)$=0.56$, $p=0.69$), nor was there a significant Group by Condition interaction effect ($F$ (4, 105)$=1.72$, $p=0.15$).

### 3.4. Effect of condition on RT COV

Next, a $1\times5$ ANOVA examining the effect of Condition on COV for PWA was performed, revealing a significant main effect ($F$ (4, 85)$=3.20$, $p=0.02$; see Fig. 5a). Tukey post-hoc analyses showed that COVs were significantly higher for SELECTIVE-A than SUSTAINED-V ($p=0.03$), as well as significantly higher for INTEGRATIONAL A/V than for SUSTAINED-V ($p=0.02$). A similar $1\times5$ ANOVA looking for the effect of condition on COV was also performed for controls; no significant result was found ($F$ (4, 20)$=0.92$, $p=0.47$; see Fig. 5b).

### 3.5. Inter-individual differences in COV within the PWA group

In addition to examining across-PWA patterns in BS-IIV, we examined *inter*-individual variability in performance within the PWA group by looking at the results of the Crawford et al. analyses. As is evident in Table 3, the conditions flagged by these analyses as "high" are not uniform from patient to patient. For example, a subset[1] of PWA (P1, P2, P7, P8, P10, P16, and P18) were found to exhibit high COVs on INTEGRATIONAL-A/V and, in many cases, on one or more of the other, less complex tasks as well. A second subset of PWA (P5, P9, and P17), in contrast, were found to exhibit low COVs on INTEGRATIONAL-A/V but high COVs on at least one of the less complex tasks. Finally, a third subset of PWA (P3, P4, P6, P11, P12, P13, P14, and P15) were found not to exhibit high COVs on any condition.

### 3.6. Associations between RT COV and performance on standardized measures

Finally, we used a bivariate Pearson correlation matrix to determine whether any of the standardized tests we administered to PWA – WAB Aphasia Quotient (AQ), BNT, CLQT – were associated with COVs on either SUSTAINED-V or INTEGRATIONAL-A/V, the simplest and most complex conditions, respectively. No significant associations were found either between SUSTAINED-V COVs and any of the other variables or between INTEGRATIONAL-A/V COVs and any of the other variables.

[1] Subsets described here are based on visual inspection of the Crawford et al. results (Table 3).

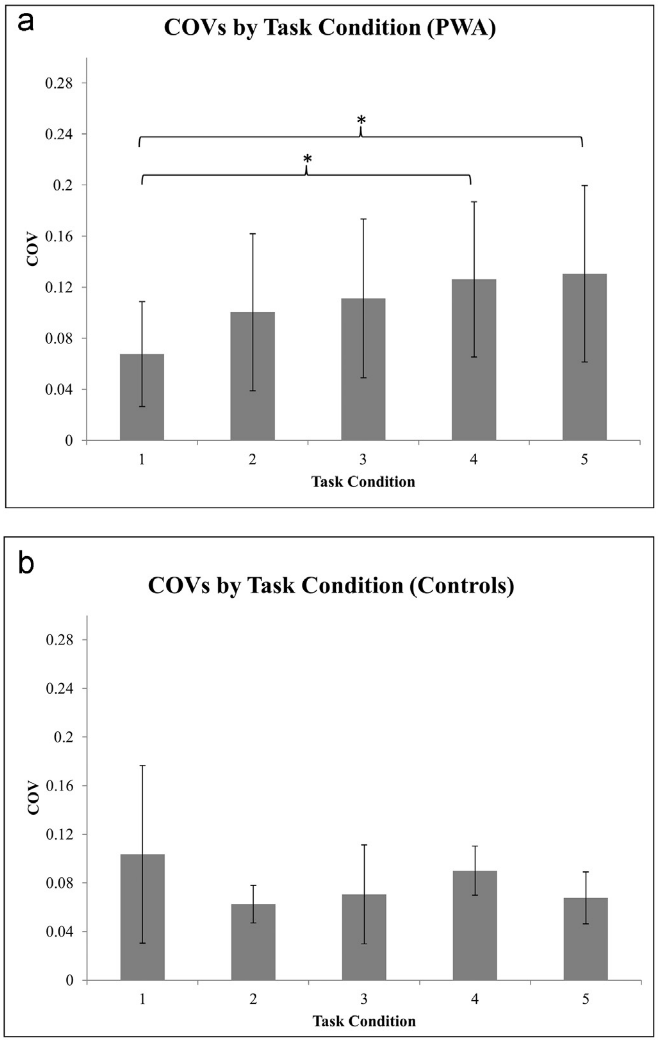


**Fig. 5.** COVs by condition for PWA (a) and controls (b). *$p < 0.05$; significance based on ANOVA post-hoc results. Error bars indicate standard deviations. Task Condition 1: SUSTAINED-V; Task Condition 2: SUSTAINED-A; Task Condition 3: SELECTIVE-V; Task Condition 4: SELECTIVE-A; and Task Condition 5: INTEGRATIONAL-A/V.

## 4. Discussion

### 4.1. Introduction

The goal of this study was to investigate domain-general attention processing in patients with aphasia and healthy age-matched controls by systematically examining performance in several types of non-linguistic attention. The study used a novel computerized task to assess five types of non-linguistic attention and included a repeated sampling design so as to assess participants'' between-session intra-individual variability in performance, a construct that has not previously been investigated in aphasia in the context of a non-linguistic task. Our aims were to assess the impact of task complexity on both RT and between-session intra-individual variability in RT, as well as to identify patient-to-patient differences in performance. The three main findings of the study, which will be discussed in greater detail below, are as follows. First, increased task complexity elicited slower RTs in both PWA and controls. Second, increased task complexity elicited increased between-session intra-individual variability in RT in PWA but *not* in controls. Third, it was noted that not all PWA exhibited similar patterns of between-session intra-individual variability, indicating the existence of substantial *inter*-individual variability within this group.

The experimental task was designed to be relatively simple so that it would be accessible to all participants. While PWA accuracy was found to be lower than that of controls, accuracy was generally above chance even for PWA, indicating that the task did not pose significant challenges for the majority of participants in terms of set acquisition or maintenance. Statistical analyses were based on RTs for correct responses within a predetermined acceptable timeframe only; these data can be assumed to reflect the speed with which participants were able to process and respond to the target stimuli.

### 4.2. Effect of task complexity on reaction time

We hypothesized that PWA would show relatively slower RTs (standardized into zRTs) on more complex than on simpler conditions. In comparing zRTs on the five conditions of the task, two patterns were observed for the PWA group, one involving task complexity and the other involving stimulus modality. The first pattern was that zRTs were slower on selective attention conditions than on corresponding sustained attention conditions. This result is in keeping with our hypothesis and is consistent with other studies showing that attention deficits in aphasia are more evident when distracting stimuli are present (e.g. Murray et al., 1997; Hunting-Pompon et al., 2011). Additionally, and also as expected, our most complex task condition, INTEGRATIONAL-A/V, elicited slower zRTs than any of the other conditions.

The second pattern that emerged for PWA involved stimulus modality; specifically, zRTs were slower on auditory attention conditions than on corresponding visual attention conditions. It is possible that this was a result of the neurological impairment; other studies have found evidence of impaired auditory attention in aphasia (Peach et al., 1994; Erickson et al., 1996). However, since we observed some evidence of a similar modality effect in the control group, we do not consider our results to provide evidence that auditory attention is impaired in aphasia to a greater extent than visual attention. An alternative explanation for slower RTs in auditory conditions across participants may be the general bias towards visual dominance in humans, a phenomenon which has been identified by a substantial body of work on the differences between the processing of auditory and visual stimuli (e.g. Posner et al., 1976). Regardless of control performance, however, the two patterns observed for PWA do suggest that the domain-general attentional system in aphasia is characterized by slowed RTs when task complexity is increased, as well as when auditory processing is required.

### 4.3. Effect of group on between-session intra-individual variability in reaction time

Our finding of a group-based difference in BS-IIV provides another important piece of information about the domain-general attention system in aphasia, namely, that it may be more susceptible to day-to-day fluctuations than the domain-general attention system in healthy individuals. We suggest that this susceptibility may in turn have implications for a wide variety of more complex tasks and situations, both linguistic and non-linguistic. While this is the first time that BS-IIV has been investigated in a non-linguistic context in aphasia, the finding that PWA exhibit more day-to-day variability than controls is not surprising, given the work that has been done on BS-IIV in other neurologically impaired populations. In a study on traumatic brain injury patients, Stuss et al. (1994) found that intra-individual differences in task performance across two different days were so substantial that a patient might easily be classified as normal on one day and impaired on another. Our finding that PWA exhibit more BS-IIV than controls suggests that stroke aphasia, like traumatic brain injury, may co-occur with difficulty maintaining consistent performance levels on cognitive tasks from day to day.

### 4.4. Effect of task complexity on between-session intra-individual variability in reaction time

In looking more closely at patterns of BS-IIV within the PWA group, we found, as expected, that PWA exhibited a higher degree of BS-IIV when task complexity was increased. Specifically, as can be seen in Fig. 5a, SELECTIVE-A and INTEGRATIONAL-A/V were found to elicit a significantly higher degree of BS-IIV than SUSTAINED-V (arguably the least complex condition). Controls were found not to exhibit any effect of complexity on COV.

In looking at these results together with our findings in Section 4.3, we draw two conclusions about BS-IIV in domain-general attentional processing in PWA: that PWA, as a group, exhibit a higher degree of BS-IIV than controls, and that, unlike controls, PWA also exhibit increased BS-IIV when task complexity is increased. The second of these findings aligns well with earlier work suggesting that PWA perform more poorly in dual-task vs. single task attentional paradigms (Erickson et al., 1996; Murray et al., 1997; Murray, 2000). Our results, however, add a new dimension to this discussion: while previous work had shown that one-time performance in PWA is negatively impacted by the addition of a second task (i.e. by an increase in overall task complexity), the results of the current study suggest that *BS-IIV* in performance in PWA is also negatively impacted by increases in task complexity. Both of these findings provide evidence that domain-general attention processing is different in PWA vs. in unimpaired individuals, even when language is not involved. Our results are consistent with our overall framework regarding domain-general attention, namely, that more complex types of attention build upon less complex types, and that any of these attentional processes may be impacted by day-to-day variability.

### 4.5. Inter-individual differences in intra-individual variability in RT

In addition to these across-PWA findings, the results of the Crawford and Garthwaite analyses suggest that there may also be a substantial amount of *inter*-individual variability in BS-IIV within the PWA group. This finding of inter-individual variability in attention processing is consistent with previous work suggesting that that the degree and pattern of attentional impairment differs from individual to individual in PWA (e.g. Murray, 2012). What our results add to this discussion is that not only may one-time attentional ability differ from patient to patient, but day-to-day variability in attentional ability may differ from patient to patient as well.

Finally, the results of this study do not provide support for an association between day-to-day variability in domain-general attention and overall linguistic/cognitive ability. No significant correlations were found between COVs on the simplest or most complex experimental task conditions and scores on any standardized measures. This result suggests that an individual patient's pattern of day-to-day variability in attention may not be predictable from scores on linguistic or cognitive assessments.

### 4.6. Potential implications

There are several potential implications for our results regarding BS-IIV in PWA. The first has to do with our understanding of the nature of aphasia. Aphasia has often been considered to consist of an impairment in language processing; however, McNeil and his colleagues offer an alternative theory suggesting that the observed language impairment in aphasia is a function of damage not to linguistic processes themselves but rather to more basic attentional processes that support language (McNeil et al., 1991; Hula et al., 2007; Hula and McNeil, 2008). This theory is still under debate; however, if attention does indeed underlie language, then our finding that PWA show notable BS-IIV in domain-general attention could help explain why PWA have often been observed to show variability in language performance. Our results may therefore provide some support for McNeil et al.'s theory; however, further research evaluating the possible connection between BS-IIV in attention and BS-IIV in language in PWA is still needed.

The second implication of our results involves establishing baseline scores, particularly in studies using a single-subject design. The demands of language and cognitive testing are typically complex, requiring not only auditory and visual attention, but also language processing and frequent task-switching. If complex task demands elicit substantial degrees of BS-IIV, this may impact an individual's scores on a given day of testing. These results suggest the importance of obtaining multiple baselines in which the same assessments are re-administered on several different days, in order to capture session-to-session fluctuations in performance.

Finally, our results may have implications for treatment outcomes in aphasia. It is well documented that different PWA – even those with similar deficits at baseline – often show substantial inter-individual variability in response to language treatment, making the course of a given patient's recovery difficult to predict (e.g. Lazar and Antoniello, 2008; Lazar et al., 2008). We suggest that basic attention is necessary for treatment success and, furthermore, that BS-IIV in attention could be able to help predict treatment outcomes. The expectation that an individual will improve over time as a function of treatment is based on the assumption that she is able to attend not just on a good day, but during *each session*, in order to continually build upon gains made in previous sessions. Session-to-session fluctuations in attention could, therefore, preclude rapid or steady improvement.

In the context of treatment, BS-IIV on an auditory-visual integrational attention task is of particular interest. As noted earlier, PWA are often asked during therapy to integrate together auditory (e.g. the clinician's voice) and visual (e.g. pictures, word cards, etc.) stimuli. Our results show that INTEGRATIONAL-A/V, which was theoretically our most complex condition and required participants to integrate auditory and visual stimuli, elicited the highest degree of BS-IIV in performance. We suggest that a complex, multi-modal environment such as a therapy session – which likely presents additional challenges and complexity beyond our INTEGRATIONAL-A/V condition (e.g. linguistic stimuli, shifting task demands, and additional distractions) – could tax the aphasic attentional system even further, potentially resulting in even higher BS-IIV in attention across therapy sessions. Our results therefore help lay the groundwork for future studies directly examining the associations between day-to-day fluctuations in attention and treatment success.

### 4.7. Limitations of the study

We felt it was important to always administer the auditory-visual integrational condition last because the structure of that condition built on the structures of the preceding conditions. However, this may also have caused participants to be more fatigued during this final condition. Additionally, despite the fact that we oriented participants to each successive condition and administered practice items, task-switching costs may have impacted our results.

## 5. Conclusion

This project provides information about non-linguistic attention in aphasia, as well as about between-session intra-individual variability in non-linguistic attention in this population. Our results suggest that the domain-general attention system in aphasia is taxed when task complexity is increased; additionally, we found evidence that increased task complexity elicited increased degrees of between-session intra-individual variability in performance. These findings may have implications not only for obtaining representative baseline assessment scores in patients with aphasia, but also for long-term language therapy outcomes. Future studies should directly investigate the role of attention, and of other cognitive-linguistic factors, to treatment outcomes in aphasia, so that clinicians may be able to reliably predict an individual's response to treatment and adjust treatment accordingly to maximize that individual's potential for success.

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