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Investigating Attentional Allocation With Eye Tracking During Category Learning in People With Aphasia

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Studies have identified deficits in attention in individuals with aphasia in language and nonlanguage tasks. Attention may play a role in the construction and use of language, as well as in learning and the process of rehabilitation, yet the role of attention on rehabilitation is not fully understood. To improve the understanding of attention and learning in aphasia, this study replicated an experiment that utilized category learning to examine attentional allocation. Ten individuals with aphasia subsequent to left hemisphere stroke and 20 age-matched controls completed a computer-based category learning task while eye gaze data were collected using an eye tracker. Stimulus items comprised 4 features that differed in the reliability with which they predicted category membership (referred to as their diagnosticity). In this study, no differences were observed between individuals with aphasia and control participants on behavioral measures of accuracy and response time, though accuracies overall were lower than those of prior studies examining this task in young adults. Eye gaze data demonstrated that over the course of training, controls and individuals with aphasia learned to reduce the number of looks to the feature of lowest diagnosticity, suggestive of optimized attentional allocation. Eye gaze patterns, however, did not show increased looking or look times to all features of highest diagnosticity, which has been seen in young adults. Older adults and individuals with aphasia may benefit from additional processing time or additional trials during category learning to optimize attention and behavioral accuracy. Findings are relevant to consider in clinical settings where visual stimuli are presented as instructional, supporting, and/or compensatory tools. **Key words:** *aphasia*, *attentional allocation*, *category learning*, *eye tracking*

APHASIA has been historically described as a deficit of language processing and expression. Although linguistic inefficiencies remain the primary area of weakness, researchers have increasingly recognized the contributions of other nonlinguistic cognitive processes in the profile of a person with aphasia, including deficits in attention (Marshall, Basilakos, & Love-Myers, 2013; Murray, 1999, 2012), executive functioning (Fucetola, Connor, Strube, & Corbetta, 2009; Glosser & Goodglass, 1990; Lesniak, Bak, Czepiel, Seniow, & Czlonkowska, 2008; Purdy, 2002), memory (Burgio & Basso, 1997; Potagas, Kasselimis, & Evdokimidis, 2011), and visuospatial skills (Helm-Estabrooks, 2002). Language therapy utilizes principles of linguistic organization and retrieval to restore and rebuild language access. Nonlinguistic cognitive processes not only shape clients' engagement with a task but also impact the linguistic processing itself.

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Of particular relevance to this study is attention. Studies have demonstrated that individuals with aphasia often present with attention deficits relative to controls (Erickson, Goldinger, & LaPointe, 1996; Heuer & Hallowell, 2015; Hunting-Pompon, Kendall, & Moore, 2011; Laures, 2005; Laures, Odell, & Coe, 2003; Murray, 2000, 2012; Murray, Holland, & Beeson, 1997; Peach, Newhoff, & Rubin, 1993; Petry, Crosson, Rothi, Bauer, & Schauer, 1994; Robin & Rizzo, 1989; Tseng, McNeil, & Milenkovic, 1993; Villard & Kiran, 2015; 2017) and, furthermore, that increased individual variability in attention abilities may exist relative to controls (Villard & Kiran, 2015, 2018). Reduced attention has been measured in contexts that require language (Murray, 2000, 2012; Murray et al., 1997; Petry et al., 1994; Tseng et al., 1993) and also in nonlanguage tasks (Erickson et al., 1996; Hunting-Pompon et al., 2011; Laures, 2005; Laures et al., 2003; Peach et al., 1993; Robin & Rizzo, 1989; Villard & Kiran, 2015, 2017, 2018). Deficits in attention have been hypothesized by some to be at the root of lexical retrieval deficits (Hula & McNeil, 2008; Hula, McNeil, & Sung, 2007; McNeil, Odell, & Tseng, 1991; Silkes, McNeil, & Drton, 2004).

In addition to impacting language function and use, attention plays a critical role in focusing on tasks in rehabilitation to support the process of recovery (Villard, 2017; Villard & Kiran, 2015, 2018). Some study results demonstrate that individuals with greater attention abilities produce greater outcomes (Lambon Ralph, Snell, Fillingham, Conroy, & Sage, 2010; Mysiw, Beegan, & Gatens, 1989; Robertson, Ridgeway, Greenfield, & Parr, 1997). This may be in part due to the fact that aphasia intervention requires auditory and visual attention as individuals with aphasia listen to auditory stimuli and/or clinician feedback and instruction while looking at pictures or written prompts (Villard, 2017). Attending to and integrating these domains are critical for rehabilitation to progress.

In addition to deficits in attention surfacing in individuals with aphasia, impairments in learning have been observed in domains such as category learning (Vallila-Rohter & Kiran, 2013, 2015), explicit sequence learning (Schuchard & Thompson, 2014), auditory (Goschke, Friederici, Kotz, & Kampen, 2001) and visual artificial grammar learning (Christiansen, Kelly, Shillcock, & Greenfield, 2010), and word and sentence learning (Ettlinger & Moffett, 1970; Grossman & Carey, 1987; Gupta, Martin, Abbs, Schwartz, & Lipinksi, 2006; Martin & Saffran, 1999). Other study findings have demonstrated intact learning in individuals with aphasia, with people with aphasia showing the ability to learn novel words (Kelly & Armstrong, 2009; Tuomiranta et al., 2011; Tuomiranta, Grönroos, Martin, & Laine, 2014; Tuomiranta, Rautakoski, Rinne, Martin, & Laine, 2012), artificial grammars (Glass, Gazzaniga, Premack, 1973; Schuchard & Thompson, 2017), or sequences implicitly (Schuchard & Thompson, 2014). Contradicting findings across studies that examine learning suggests that variability arises in aphasia and that learning within this population is sensitive to stimulus manipulations, meriting further study. Sensitivity to stimulus manipulations and learning conditions is not unique to aphasia and has been observed in other clinical populations such as Parkinson's disease, Huntington's disease, and amnesia (Ashby, Noble, Filoteo, Waldron, & Ell, 2003; Koenig, Smith, Moore, Glosser, & Grossman, 2007; Knowlton, Ramus, & Squire, 1992; Shohamy, Myers, Onlaor, & Gluck, 2004).

In a study by Vallila-Rohter and Kiran (2013), individuals with aphasia were asked to learn to categorize animal exemplars into two categories based on the probabilistic overlap of visual features with two prototypes. Results indicated that although some people with aphasia showed evidence of learning, many did not learn and, as a group, they performed less accurately than an age-matched control group. Accuracy of categorization did not correlate with language and/or cognitive ability. A follow-up study (Vallila-Rohter & Kiran, 2015) examined the strategies utilized during learning. Strategy analyses revealed that many people with aphasia used suboptimal strategies during learning, attending to a single stimulus dimension rather than basing responses on multiple stimulus dimensions. Poor performance may have resulted from impaired learning mechanisms but may also have been related to a reduced ability to examine and process multidimensional visual stimuli.

Thus, building upon previously documented deficits in attention and learning in aphasia, the current study replicated an experiment first conducted by Rehder and Hoffman (2005) to examine visual attention in individuals with aphasia and age-matched controls through the course of a category-learning task. In the study by Rehder and Hoffman (2005), young adults sorted stimuli into two categories while eye-tracking data were collected. Category membership was based on the combination of four features—head, wing, tail, and foot—arranged around a central rectangular body. Importantly, two of the features were highly diagnostic, meaning that they were highly predictive of category membership. In contrast, the remaining features were classified as being of medium and low diagnosticity, indicating that they less consistently predicted category membership. Participants showed a pattern of optimized attentional allocation as learning progressed. Although all features were fixated at the onset of learning, over time, fixations increased to features of high diagnosticity and decreased to the feature of lowest diagnosticity reflecting changes in attentional allocation through the course of learning.

In this study, which replicated Rehder and Hoffman's (2005) methods, we hypothesized that older adults would show the patterns previously observed, corresponding to an increase in frequency and duration of eye gazes to features of high predictive value alongside decreased eye gazes to features of low predictive value. In contrast, we hypothesized that people with aphasia would not show optimized attentional allocation and would rather either fixate on all features equally throughout learning or exhibit a tendency to fixate on one or two dimensions only.

METHODS

Participants

Thirty participants completed the study. Ten were right-handed individuals with aphasia (seven men, three women) in the chronic stage of recovery from a single left hemisphere stroke. Participants with aphasia ranged in age from 36 to 63 years ($M = 54.5$, $SD = 8.5$) and averaged 72 months poststroke (range: 6–97 months). Individuals with aphasia completed the Western Aphasia Battery—Revised (WAB-R; Kertesz, 2006) to classify aphasia and completed the Cognitive Linguistic Quick Test (CLQT; Helm-Estabrooks, 2001) to characterize nonverbal cognitive processing and visual perceptive skills (see Table 1). The average WAB Aphasia Quotient of enrolled participants was 86.79 ($SD = 8.6$), with nine subjects classified as anomic and one subject classified as having conduction aphasia. The WAB scores range from 0 to 100, with 0 indicating the most severe language impairments and scores 93.8 and above corresponding to language within normal limits.

Twenty participants were right-handed controls (10 men, 10 women) ranging from 51 to 76 years of age ($M = 63.1$, $SD = 7.0$) with no history of neurological disease, psychological disorder, or developmental speech, language, or learning disabilities. We recruited more controls than individuals with aphasia, as in addition to comparing performance between individuals with aphasia and controls, we aimed to compare results with those from the original study by Rehder and Hoffman (2005). Rehder and Hoffman (2005) studied attentional allocation in undergraduate students. We were interested in comparing results from older adults in the current sample with previously published results collected from undergraduate participants. Control participants completed the Mini-Mental State Examination to screen for cognitive decline and had to be within the normal range of cognition (24 and above) to be eligible. Cognitive Linguistic Quick Test measures of cognitive ability were also obtained.

Table 1. Participant characteristics

	WAB AQ	Age	Attn	Mem	EF	VS
Control 1		64	200	185	33	97
Control 2		67	205	171	31	99
Control 3		65	187	164	26	87
Control 4		65	186	163	24	87
Control 5		64	205	167	33	101
Control 6		57	202	166	32	98
Control 7		58	205	170	30	99
Control 8		62	195	172	30	91
Control 9		52	201	153	31	91
Control 10		71	194	170	27	91
Control 11		64	204	165	31	100
Control 12		72	186	171	31	94
Control 13		75	198	169	29	91
Control 14		75	209	178	32	101
Control 15		50	208	171	31	102
Control 16		54	194	163	32	93
Control 17		61	208	172	32	102
Control 18		58	197	156	29	93
Control 19		59	210	185	33	100
Control 20		59	200	166	31	97
Person with Aphasia 1	95.6	61	207	170	30	101
Person with Aphasia 2	93.4	58	201	152	27	95
Person with Aphasia 3	85.8	53	200	143	27	102
Person with Aphasia 4	89.5	60	187	125	28	92
Person with Aphasia 5	92.4	36	198	158	30	96
Person with Aphasia 6	85.9	63	191	117	27	96
Person with Aphasia 7	80.9	53	194	138	28	98
Person with Aphasia 8	94.3	63	206	158	30	104
Person with Aphasia 9	73.2	47	194	144	27	97
Person with Aphasia 10	74.9	50	198	147	25	98

Note. WAB AQ stands for the Western Aphasia Battery Aphasia Quotient, a measure of severity of aphasia. Attn, Mem, EF, and VS stand for attention, memory, executive functions, and visuospatial skills, respectively, as measured on the Cognitive Linguistic Quick Test (CLQT).

Because of the visual nature of the task and the eye-tracking paradigm, participants could not miss more than two symbols per quadrant on the CLQT Symbol Cancellation Task to be eligible. Participants who wore bifocals or hard lenses incompatible with the eye-tracking system were ineligible to participate.

Experimental setup

Participants were seated approximately 50 cm from a 53- × 30-cm computer screen with 1,920 × 1,080 resolution and 120 Hz refresh rate. Eye fixations were captured using an SR Eyelink 1000 Plus Eye Tracker (SR Research, Canada) with a sampling rate of 1,000 Hz and a noise-limited spatial resolution better than 0.01°. A temporal threshold of 100 ms was used to determine a fixation. Monocular data were gathered with head position stabilized via chin rest. Images presented on the computer screen occupied a 12° of visual angle. At the start of testing, eye gaze was calibrated using nine-point calibration and validation. Drift corrects offering the opportunity for recalibration were programmed throughout the experiment, specifically at the beginning of the training phase, between Blocks 10 and 11 of training, and prior to the testing block.

Stimuli

As noted previously, the experimental task was a replication of Rehder and Hoffman's (2005) study. Experimental stimuli were provided by Dr. Rehder and consisted of 16 color line drawings of "insects," each with four features (head, tail, foot, and wing) arranged around a central rectangular body. Each feature was approximately 4° in width and height and had two possible variations, coded as 1 or 0. For example, the head could be circular or an elongated pentagon, the wing could be a triangle or crescent (see Figure 1). Each animal was labeled by its four binary dimensions (e.g., 0100, 0110, 1110).

Training stimuli consisted of nine exemplars drawn from the 16 total possible stimuli/feature combinations (five Category A trained items: 1110, 1010, 1011, 1101, 0111; four Category B trained items: 1100, 0110, 0001, 0000). The selection of nine items for training is rooted in prior category-learning work designed to distinguish between prototype and exemplar theories of learning (see Nosofsky & Zaki, 2002, for more details). Prototype theories suggest that category decisions are based on the similarities between a stimulus item and the most central or typical item of a category (the category prototype). Even if not presented in training, a category prototype is thought to be acquired through gradual exposure to category regularities. In contrast, exemplar theories suggest that category decisions are driven by the similarity of one stimulus item seen in training to others. The 5-4 category structure produces within-category items that differ in their expected categorization accuracies based on prototype versus exemplar theories. These predictions are best elucidated by focusing on categorization predictions from Category A stimulus items: 1110 and 1010. From the perspective of prototype theory, stimulus 1110 (of Category A) is very similar to prototype A (1111), differing on only one feature dimension. In contrast, stimulus 1010 differs from the prototype by two feature dimensions. Prototype theories predict a higher A categorization of item 1110 than of item 1010. In contrast, exemplar theories suggest that categorization is based on the similarity of training items with other within-category trained items, rather than with an imagined prototype. From the perspective of exemplar theory, therefore, stimulus 1010 shares three features with two Category A stimulus items (1110 and 1011) and a maximum of two features with Category B items. In contrast, stimulus 1110 shares three features with one Category A stimulus (1010) and with two Category B stimuli (1100 and 0110). Thus, exemplar theorists predict higher A categorization of item 1010 than item 1110. In this manner, the 5-4 category structure allows for comparisons of

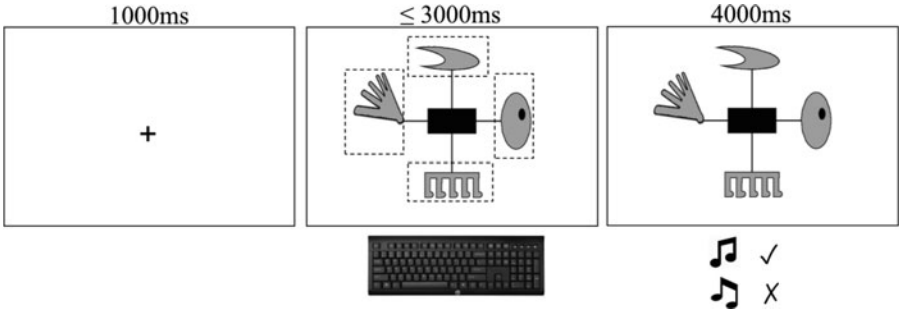

Figure 1. Sample training trial showing a stimulus animal with four features: head (medium diagnosticity), tail (low diagnosticity), wing (high diagnosticity), and foot (high diagnosticity). Boxes identify areas of interest and indicate that eye gaze data from this interest period were analyzed.

prototype versus exemplar approaches to learning. In this study, we replicated this design to remain consistent with Rehder's original study, but analyses of learning strategy are beyond the scope of the this manuscript and underpowered.

As in the study by Rehder and Hoffman (2005), the features wing and foot were highly diagnostic, meaning that the feature dimension independently predicted category membership on 77% of trials. The head feature predicted category assignment on 66% of trials and was considered of medium diagnosticity. The tail had low diagnosticity and predicted category membership independently on 55% of trials. Two task versions were created to account for the fact that five animals were trained in one category and four in the other. In one task version, the triangular wing was coded to be most frequently associated with a correct response of A. In the alternate task version, the crescent wing was most frequently associated with a correct response of A. Task versions were counterbalanced across participants.

Procedures

The experimental task was first explained verbally to participants using a script and accompanying printed handouts with pictures. Participants were given the opportunity to ask questions and clarification. Participants then received computer-based instructions that allowed them to practice indicating responses via button press and familiarized them with the timing of the task and feedback presentation. Participants were told that they must classify animals as belonging to one of two categories by pressing the 1 or 2 key, respectively. Because many people with aphasia who experience a left hemisphere stroke have right-sided weakness, all participants were instructed to make responses with their left hand. Auditory feedback was provided after each trial in the learning phase in the form an ascending two-tone chime (correct), or descending two-tone chime (incorrect). Participants heard these sounds several times before the task to set volume levels and ensure recognition and comprehension of feedback signals.

The task was composed of two phases: training and testing. In training, each trial started with a 1,000-ms fixation cross in the center of the screen. A stimulus item then appeared on screen and participants had up to 3,000 ms to make a button press to indicate the item's category membership. A time limit was imposed to introduce relative consistency to the amount of time spent looking at stimuli. Without response limitations, some participants might have studied stimuli for much longer than others. Auditory feedback was provided immediately via headphones and the stimulus item remained on screen for an additional 4,000 ms after feedback (see Figure 1). All nine training stimuli were presented in random order within each block. Training concluded when participants either completed 21 blocks (189 trials) or reached criterion. Criterion was defined as completing two consecutive blocks without error.

In the testing phase that immediately followed training, participants categorized trained items and the seven items not previously seen in training (1001, 1000, 1111, 0010, 0101, 0011, 0100) to probe generalization of learning to novel items. The 16-item test set was presented twice in randomized order. Once again, a fixation point appeared in the middle of the screen for 1,000 ms, after which a stimulus appeared. Participants had unlimited time to respond and the subsequent trial was triggered after a button press response was made. No feedback was provided in testing.

Dependent measures

Behavioral data were collected on accuracy, reaction time, and number of blocks to reach criterion (two consecutive blocks without error). Two eye-tracking measures were derived on the basis of fixation data within areas of interest (AOIs). Areas of interest were drawn around the four features of the stimuli. These AOIs were polygons encompassing the total area of the feature on the screen. Shape and size of each AOI varied to capture the associated feature but were controlled for distance from the central body. Eye-tracking analyses were conducted only over the interest period from onset of stimulus to response in order to better understand what features participants inspected to make responses. Two dependent measures were derived and averaged across trials in a block: number of observations and proportion log fixation time. *Number of observations* indicated the number of times a dimension was fixated during a trial. For this measure, two sequential fixations to a single dimension were aggregated into a single "observation." To compute *proportion log fixation time*, log fixation time was first measured as the total number of milliseconds that a dimension was fixated by trial and averaged over block. Because of the nonnormal nature of fixation time data, fixation times were log-transformed. Then, eight average log fixation times were calculated for each participant to compare fixations to features of varying diagnosticity and to make comparisons early and late in training: Head early log fixation, Tail early log fixation, Wing early log fixation and Foot early log fixation time, Head late log fixation, Tail late log fixation, Wing late log fixation, and Foot late log fixation time. Averages for early training were computed by averaging data from training Blocks 1, 2, 3, and 4 (early). Data from training Blocks 18, 19, 20, and 21 contributed to averages for late phases of training. Data for each participant were converted to a proportion log fixation based on the average log fixation time to a specific feature divided by the total log fixation time to all features (Figure 2).

Examination of individual participant data revealed that many participants focused on one feature of high diagnosticity and not the

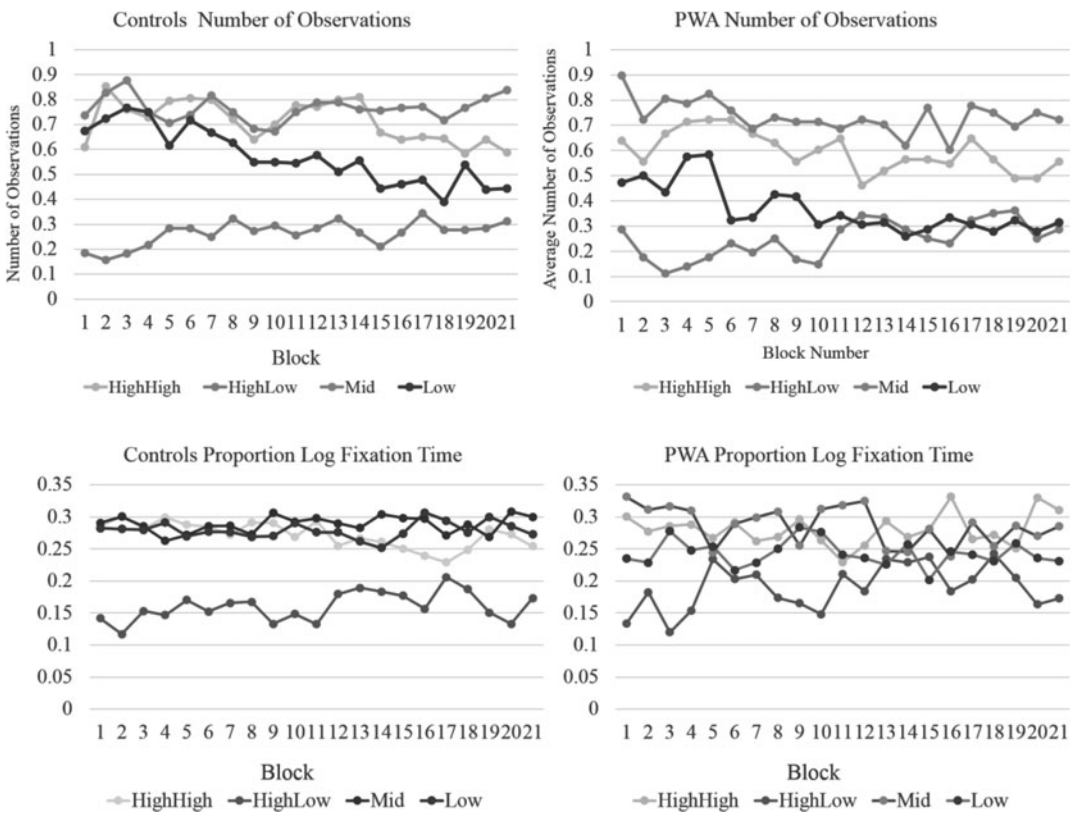

Figure 2. Number of observations and proportion log fixation time results for control participants (left) and individuals with aphasia across 21 blocks of learning. PWA = participants with aphasia.

other. Although the two features of high diagnosticity were equally predictive of category membership, participants exhibited a tendency to fixate on one of the two, and the feature of focus varied across participants. To account for this discrepancy, in a manner similar to that implemented by Arbel, Feeley, and Xinyi (2019), for each participant, the feature with the higher fixation probability and log fixation time was coded as HighHigh and the other as HighLow. For each participant, one feature was coded as HighHigh on the basis of performance across all blocks. The feature wing was coded as HighHigh for seven controls and two individuals with aphasia.

Analyses

Statistical analyses were conducted in R (R Core Team, 2014). For each participant, three average accuracies were calculated: early training (average accuracy over Blocks 1–4), late training (average accuracy over Blocks 18–21), and test accuracy. Average early training response times (Blocks 1–4) and late training response times (Blocks 18–21) were also determined. Accuracy and response time were evaluated during early and late training phases as eye gaze data focus on these blocks. A series of 2 (Phase: early, late) × 2 (Group: controls, individuals with aphasia) analyses of variance (ANOVAs) were conducted to evaluate for differences in accuracy and response time.

To evaluate eye gaze behaviors, linear mixed-effects models were utilized using R package lme4 (Bates, Maechler, Bolker, & Walker, 2015) to examine dependent variables with Group (people with aphasia or controls), Diagnosticity (HighHigh, HighLow, Medium, Low), and Phase (early, late) as fixed effects, and Participant as a random effect. As Group and Diagnosticity data were categorical, it was not appropriate to model random slopes. We evaluated whether there were any significant interactions of diagnosticity and phase to gain insights into changing attentional allocation over the course of learning. Our model for the dependent variable number of observations was as follows: model = lmer (NumObservations ~ Group + DiagClass + Phase + Group*DiagClass*Phase + (1|Participant). R package lmerTest (Kuznetsova, Brockoff, & Christensen, 2017) was used to conduct ANOVAs evaluating models. For proportion log fixation time, package glmmadmb (Skaug, Fournier, Nielsen, Magnusson, & Bolker, 2011) was used to account for the use of continuous proportions as the dependent variable.

RESULTS

Behavioral results

No participants reached criterion of two consecutive blocks without error and therefore all participants completed all training trials prior to testing. Average accuracy early in training, late in training, and in testing is reported in Table 2. The 2 (Phase: early, late) × 2 (Group: controls, individuals with aphasia) ANOVA evaluating training accuracy produced a significant effect of phase $F(1, 57) = 11.32$, $p = .001$, with scores increasing from

Table 2. Average accuracies and response times across groups and training phases

	Mean	*SD*
Accuracy		
CN		
Early	51.81%	9.68%
Late	63.61%	12.29%
Test	61.42%	11.18%
PWA		
Early	57.50%	9.89%
Late	62.50%	10.90%
Test	62.60%	12.94%
RT (ms)		
CN		
Early	1491.59	187.51
Late	1496.30	346.92
PWA		
Early	1433.68	299.80
Late	1563.96	387.14

Note. CN = controls; PWA = participants with aphasia; RT = response time.

early to late training. There was no significant effect of group $F(1, 57) = 0.58$, $p = .45$, demonstrating that overall accuracy was similar for controls and individuals with aphasia. The interaction of group and phase was nonsignificant, $F(1, 57) = 1.37$, $p = .24$. A 2 (Phase) × 2 (Group) ANOVA evaluating response time produced no significant effects, suggesting that response times were similar across time for both groups of participants (see Table 2 for means and standard deviations). Nonparametric Spearman's rank-order correlations were run to evaluate the relationship between accuracy and demographic and cognitive–linguistic variables for the individuals with aphasia. There was no significant correlation between test accuracy and years of education $r_s(9) = .05$, $p = .89$, months poststroke $r_s(9) = .08$, $p = .83$, WAB aphasia severity $r_s(9) = .38$, $p = .31$, CLQT attention, r_s $(9) = .57$, $p = .09$, memory $r_s(9) = .58$, $p = .07$, executive functions $r_s(9) = .20$, $p = .58$, or visuospatial skills $r_s(9) = .45$, $p = .18$ in this limited sample.

Eye-tracking results

Mean number of observations and proportion log fixation times are reported in Table 3. The linear mixed-effects model evaluating number of observations and the effect of phase, group, and diagnosticity produced a main effect of feature diagnosticity $F(3, 210) = 24.88$, $p < .001$ (see Table 4). A significant diagnosticity by phase interaction $F(3, 210) = 2.57$, $p = .05$ was produced, with number of observations to features of low diagnosticity decreasing from early to late phases for controls and individuals with aphasia. The group × phase × diagnosticity interaction was nonsignificant, $F(3, 210) = 0.09$, $p = .96$.

The beta mixed-effects model evaluating proportion log fixation time produced main effects of group $\beta = -.19$, $SE = 0.09$, $p = .048$ and feature with participants showing a

Table 3. Mean number of observations and proportion log fixation times

	Number of Observations		Proportion Log Fixation Time	
	Mean	***SD***	**Mean**	***SD***
Controls				
Early				
HighHigh	0.75	0.43	0.30	0.04
HighLow	0.17	0.22	0.13	0.08
Mid	0.81	0.45	0.28	0.06
Low	0.73	0.41	0.29	0.07
Late				
HighHigh	0.62	0.51	0.26	0.09
HighLow	0.28	0.37	0.15	0.13
Mid	0.79	0.45	0.30	0.10
Low	0.45	0.35	0.29	0.07
Individuals with aphasia				
Early				
HighHigh	0.64	0.47	0.29	0.08
HighLow	0.18	0.18	0.12	0.10
Mid	0.80	0.43	0.35	0.13
Low	0.50	0.33	0.23	0.09
Late				
HighHigh	0.53	0.46	0.30	0.23
HighLow	0.31	0.37	0.19	0.14
Mid	0.73	0.67	0.27	0.24
Low	0.30	0.29	0.23	0.19

Table 4. Summary results of mixed-effects models for number of observations and proportion log fixation time

	Number of Observations			Proportion Log Fixation Time		
	Estimate	**Standard Error**	***p***	**Estimate**	**Standard Error**	***p***
GroupPWA	− 0.08	0.09	.38	− 0.19	0.10	.05
DiagClassHighLow	− 0.54	0.09	<.001	− 1.03	0.19	<.001
DiagClassLow	− 0.07	0.09	.44	− 0.15	0.17	.36
DiagClassMid	0.10	0.09	.28	0.02	0.17	.89
PhaseLate	− 0.13	0.09	.17	− 0.26	0.17	.13
DiagClassHighLow:PhaseLate	0.24	0.13	.05	0.27	0.26	.31
DiagClassLow:PhaseLate	− 0.12	0.13	.35	0.15	0.24	.53
DiagClassMid:PhaseLate	0.09	0.13	.49	− 0.01	0.24	.95

significantly larger proportion log fixation to the feature of HighHigh Diagnosticity relative to HighLow diagnosticity $\beta = -1.03$, $SE = 0.18$, $p < .001$. There were no significant interactions (see Table 4 for coefficients and standard errors).

DISCUSSION

The purpose of this study was to examine patterns of attentional allocation in individuals with aphasia and age-matched controls during a nonlinguistic learning task using eye tracking. This was a replication of an earlier study conducted in young adults (Rehder & Hoffman, 2005); therefore, similar eye-tracking variables were evaluated.

Behavioral analyses revealed that overall accuracy rates of individuals with aphasia and control participants were similar and above chance. Both groups showed increases in performance over the course of learning and carried this over into testing phases. No participants reached criterion of two consecutive blocks without error, however, which suggests weaker overall learning performance compared with the original study by Rehder and Hoffman (2005) in which nearly half of study participants reached criterion. Findings of reduced learning are consistent with prior studies that have identified age-related deficits in category learning (Ashby et al., 2003; Bharani et al., 2016; Maddox, Pacheco, Reeves, Zhu, & Schnyer, 2010; Racine, Barch, Braver, & Noelle, 2006; Ridderinkhof, Span, & Van Der Molen, 2002). Relative to young adults, older adults often produce lower accuracies, longer response times, and slower or reduced development of optimal strategies to support learning. Studies have suggested that reduced learning may be related to reasoning, working memory, or inhibitory control deficits (Ashby, Alfonso-Reese, & Waldron, 1998; Bharani et al., 2016; Maddox et al., 2010; Racine et al., 2006). Studies that have begun to examine nonlinguistic learning in individuals with aphasia sometimes find the learning of individuals with aphasia to be reduced relative to controls (Christiansen et al., 2010; Schuchard & Thompson, 2014; Vallila-Rohter & Kiran, 2013), whereas other studies observe comparable learning across individuals with aphasia and age-matched controls (Goschke et al., 2001; Schuchard & Thompson, 2014, 2017) as we observe here. Analyses of individual participant data often reveal subgroups of individuals with aphasia who learn well and others who score within normal age-matched range (Vallila-Rohter & Kiran, 2013; Zimmerer, Cowell, & Varley, 2014). Characteristics of the learning task and of aphasia profile are likely to influence performance and likely lead to the aforementioned discrepancies.

Examining eye-tracking results, analyses of number of observations, and proportion log fixation time revealed group differences between individuals with aphasia and controls only on number of observations. Few studies have examined eye gaze behaviors in individuals with aphasia, though Thiessen, Beukelman, Ullman, and Longenecker (2014) collected data that confirmed that people with aphasia present with fixation patterns to images of humans engaged in activity in a manner similar to that observed by prior studies in controls. Interestingly, as described in further detail later, results from our sample of older adults did not replicate all findings previously observed by Rehder and Hoffman (2005) in undergraduate-aged students. Therefore, the small sample of higher level individuals with aphasia included in this study did not differ from older control participants. These participants, however, differed from previously published data collected from young adults performing the same task.

A phase by feature interaction demonstrated that fewer looks were made to the feature of low diagnosticity (the tail) over time. This is consistent with Rehder and Hoffman (2005) and suggests an ability to optimize looking behaviors through the course of learning. Rehder and Hoffman (2005) additionally found that young adult participants produced more and longer fixations to features of high diagnosticity, particularly in the end of training. In contrast to Rehder and Hoffman (2005), current study results demonstrated elevated number and duration of fixations to one of the features of high diagnosticity but not to both. Studies have identified age-related deficits in visual scanning (e.g., Madden, 2007; Zanto & Gazzaley, 2014) and switching (see Wasylyshyn, Verhaeghen, & Sliwinski, 2011). It may be that older individuals had difficulty scanning the four stimulus features or that once they selected features to attend to, the process of shifting attentional allocation to features of high diagnosticity was reduced. Studies have also found reduced inhibition in older adults (Glisky, 2007; Hasher & Zacks, 1988; Hedden & Park, 2001; Salthouse & Meinz, 1995; Sweeney, Rosano, Berman, & Luna, 2001; Valeriani, Ranghi, & Giaquinto, 2003). To focus attention, distractors must be inhibited, a process that has been shown to decline with aging and may have played a role in observed results. Number and proportion of fixations to the feature head were high throughout training in our study. Rehder and Hoffman (2005) also saw relatively high fixations to the head (of medium diagnosticity), which they attributed to its increased salience due to the eye. In the study by Rehder and Hoffman (2005), however, participants showed a gradual decrease in attentional allocation to the head feature of time, which we did not observe. The increased salience of the eye may be difficult to inhibit, allowing for a shift of attention to other, more diagnostic, features.

LIMITATIONS

The sample size included in this study limits the conclusions that can be drawn from results. Furthermore, individuals with aphasia were relatively homogeneous with most presenting with anomic aphasia and relatively low severities as determined by aphasia quotient. Future studies should examine attentional allocation and learning behaviors from a wider sample of individuals with aphasia to determine whether behaviors change as a function of aphasia type or severity. In addition, in the future, stimuli could be modified to reduce the salience of the head, given that this feature (of medium diagnosticity) was looked at on many trials in our sample as well as in the sample collected by Rehder and Hoffman (2005). Interestingly, features of high diagnosticity were on top and below the central body and medium and low diagnosticity features were on the horizontal axis. Visual scanning often takes place from left to right in the act of reading, which may have influenced results. Future studies should manipulate the distribution of high diagnosticity features to determine whether position influences gaze behaviors.

CONCLUSION

Clinically, the current findings draw attention to the importance of considering the visual demands and visual complexity of materials in therapy. In this study, eye gaze behaviors of older adults and individuals with aphasia showed some optimized looking, but this was limited in comparison with prior studies examining the same task in young adults. Older adults and individuals with aphasia may have more difficulty inhibiting distractors and/or shifting visual attention to visually meaningful information. Thus, clinicians may consider using simplified materials that do not include distractors or may provide instruction as to the optimal attentional allocation. The current sample included individuals with mild severities of aphasia. Some therapy tools utilized to support communication for individuals with more severe deficits, such as those utilizing alternative and augmentative communication devices, are likely to incorporate complex visual arrays. Further research is needed to understand how individuals with aphasia engage with such platforms and whether there are ways to enhance factors such as attentional allocation.

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