Research Article

More Than the Verbal Stimulus Matters: Visual Attention in Language Assessment for People With Aphasia Using Multiple-Choice Image Displays

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Purpose: Language comprehension in people with aphasia (PWA) is frequently evaluated using multiple-choice displays: PWA are asked to choose the image that best corresponds to the verbal stimulus in a display. When a nontarget image is selected, comprehension failure is assumed. However, stimulus-driven factors unrelated to linguistic comprehension may influence performance. In this study we explore the influence of physical image characteristics of multiple-choice image displays on visual attention allocation by PWA.

Method: Eye fixations of 41 PWA were recorded while they viewed 40 multiple-choice image sets presented with and without verbal stimuli. Within each display, 3 images

(majority images) were the same and 1 (singleton image) differed in terms of 1 image characteristic. The mean proportion of fixation duration (PFD) allocated across majority images was compared against the PFD allocated to singleton images.

Results: PWA allocated significantly greater PFD to the singleton than to the majority images in both nonverbal and verbal conditions. Those with greater severity of comprehension deficits allocated greater PFD to nontarget singleton images in the verbal condition.

Conclusion: When using tasks that rely on multiple-choice displays and verbal stimuli, one cannot assume that verbal stimuli will override the effect of visual-stimulus characteristics.

Auditory and written language comprehension is vital to virtually every aspect of interpersonal interaction. It also supports decision making and planning for social, educational, and professional goals, desires, and needs. Valid and reliable assessment of language comprehension is therefore crucial for people with aphasia (PWA). Language comprehension for PWA is frequently evaluated using multiple-choice image displays and verbal stimuli. Participants are asked to choose the image that best corresponds to the verbal stimulus in a display comprising a target and one or more nontarget (foil) images. It is assumed that choosing a foil reflects a failure to

comprehend the verbal stimulus. This assumption is problematic due to the many potentially confounding factors not related to comprehension that may influence performance on a multiple-choice task. For example, deficits in visual perception (Berryman, Rasavage, & Politzer, 2010) and visual processing efficiency (Azouvi et al., 2006; Beaudoin et al., 2013; Fisk, Owsley, & Mennemeier, 2002; Lachapelle, Bolduc-Teasdale, Ptito, & McKerral, 2008) are common confounding factors in individuals with neurological disorders. We use the term *potentially* confounding factors because during the actual process of assessment we often cannot be sure of just which factors are influencing a given person's responsiveness. It is always important to consider whether attributing a lack of response or an incorrect response to poor comprehension is valid.

Potentially Confounding Factors When Multiple-Choice Displays Are Used to Index Comprehension

Accurate responses during language-comprehension tasks that rely on multiple-choice image displays require several abilities in addition to intact comprehension ability. A process-analysis approach allows one to consider all of

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the component processes required to respond during an assessment task, analyze the abilities required to carry out those processes, and consider which of those abilities are and are not truly relevant to the construct under study (Hallowell, 2016). Several published studies have indicated how potentially confounding factors may threaten the validity of multiple-choice assessment for PWA (e.g., Hallowell, 1999; Hallowell, Wertz, & Kruse, 2002; Heuer & Hallowell, 2009). Several processes occur simultaneously at different stages of multiple-choice task completion (see Figure 1 for a summary of these processes and abilities). For example, processing of visual and auditory stimuli may occur simultaneously but precede processes related to target-image selection. Potential confounds include a host of visual, auditory, motoric, memory, attention, speed-of-processing, and executive-function deficits. Those deficits tend to occur with greater frequency and severity in individuals who have had a stroke or brain injury in general, and PWA in particular (Azouvi et al., 2006; Beaudoin et al.,

2013; Fisk et al., 2002; Robin & Rizzo, 1989; Tatemichi et al., 1994).

Some potentially confounding deficits in people with neurological disorders may not influence performance during simple multiple-choice tasks but become apparent during more complex tasks (Villard & Kiran, 2015). Such deficits can compromise performance, especially when nonlinguistic aspects of the task are not well controlled. To ensure that valid inferences regarding language deficits can be made, the linguistic and non-linguistic processes required to successfully perform such a task must be evaluated. Given that visual attention is a fundamental prerequisite to accurate multiple-choice task performance, it is especially important to explore its influence on tasks that are purported to index comprehension. The purpose of this study was to explore the influence of physical image characteristics of multiple-choice image displays on allocation of visual attention for PWA.

Figure 1. Diagram of processes involved in multiple-choice task performance during auditory comprehension assessment. Adapted from *Aphasia and Other Acquired Neurogenic Language Disorders: A Guide for Clinical Excellence* (p. 325), by B. Hallowell, 2016. San Diego, CA: Plural. Copyright 2016 by Plural Publishing. Adapted with permission.

Top-Down and Bottom-Up Influences on Visual-Search Tasks

Multiple-choice assessment using multiple images or written words entails visual search, which comprises top-down and bottom-up processes. Top-down processes refer to image selection on the basis of the observer's knowledge (in the case of multiple-choice assessment, semantic interpretation of a spoken or written verbal stimulus). Top-down selection of a target image is typically considered to be under the voluntary control of the observer during visual search (Theeuwes, 2010), although this is not necessarily the case (Hallowell et al., 2002; Hutchison, Balota, & Ducheck, 2010; Rush, Barch, & Braver, 2006; Wolfe, Butcher, Lee, & Hyle, 2003). In the case of a multiple-choice task, the respondent intentionally uses linguistic information to guide the selection of the corresponding image. In contrast, bottom-up influences of physical image characteristics influence stimulus salience and affect early visual processing (Theeuwes, 2010). Examples of bottom-up influences on visual-search performance include color (Green & Anderson, 1956; Wolfe, 2000), size (Nagy & Sanchez, 1990), orientation (Bergen & Julesz, 1983; Foster & Ward, 1991; Moraglia, 1989), and luminance (Itti & Koch, 2001; Nothdurft, 2002) of the visual stimuli. Bottom-up processing may influence visual attention during a multiple-choice task regardless of the verbal stimulus, and the respondent may be unaware of that influence.

In auditory and written comprehension-assessment tasks that include multiple-choice image displays and verbal stimuli, the goal is to index the top-down influence of the verbal stimulus. However, it is important to consider that target-image selection is based on a combination of top-down and bottom-up processes. For example, in response to the auditory verbal stimulus "red" in a simple task of searching for a red target among green distractors, a person ideally deliberately searches for an item that matches the semantic content associated with the spoken word. In actuality, he or she may select the target solely on the basis of the salience of the bottom-up physical stimulus property of color (red target) in the display without even attending to or comprehending the verbal stimulus. When PWA are assessed using multiple-choice tasks, it is commonly assumed that top-down processes completely override the bottom-up processes involved in image selection. However, especially without careful visual-stimulus control, this assumption may not necessarily be valid.

There are several factors that influence stimulus salience of target images, including specific image characteristics and image-display design factors. For a review of specific image characteristics that have been shown to influence visual attention, see Heuer and Hallowell (2007). Issues related to image-display design may influence visual-search demands. For example, visual-search demands increase when more physical stimulus characteristics are shared between targets and foils; the more similar the stimuli, the greater the attention allocation required to distinguish them from each other (Duncan & Humphreys, 1989; Treisman & Gormican, 1988). In the alternative, foil salience may be increased

by reducing the similarity between distractors and the target stimulus, reducing visual-search demands (Duncan & Humphreys, 1989; Nagy & Sanchez, 1990; Wolfe et al., 2003). Target salience may also be increased by reducing the number of foil items in a display (Wolfe et al., 2003). Increasing the number of stimuli presented in a multiple-choice display yields greater complexity overall, and thus potential for distraction (Bennett & Jaye, 1995). Increasing the visual complexity of images within the display also increases visual-search demands in multiple-choice tasks (Davis, Shikano, Peterson, & Michel, 2003), a fact that is often not effectively addressed in the design of image displays that are part of traditional assessment batteries (Heuer & Hallowell, 2007).

Given that PWA tend to have challenges in allocating limited attentional resources (Murray, 1999, 2012; Robin & Rizzo, 1989), it is especially important to consider how visual-attention demands may confound multiple-choice task performance during comprehension assessment. Overall, PWA have been shown to be less likely than people without neurogenic impairment to make use of explicit visual and auditory cues that might help them allocate attention more efficiently to linguistic targets (Murray, 1999; Robin & Rizzo, 1989). Compared with people without neurologic deficits, PWA are less likely to strategically allocate cognitive resources according to varying task demands (Tseng, McNeil, & Milenkovic, 1993). They are less likely to apply strategies such as trading off speed of processing to maintain accuracy (Heuer & Hallowell, 2015; Murray, Holland, & Beeson, 1997). Attention deficits may interact with deficits in working-memory capacity (Caplan & Waters, 1995; Caspari, Parkinson, LaPointe, & Katz, 1998; Friedmann & Gvion, 2003; Ivanova, Dragoy, Kuptsova, Ulicheva, & Laurinavichyute, 2015; Ivanova & Hallowell, 2012, 2014) and executive functions (Frankel, Penn, & Ormond-Brown, 2007; Fridriksson, Nettles, Davis, Morrow, & Montgomery, 2006; Murray, 2012; Penn, Frankel, Watermeyer, & Russell, 2010; Purdy, 2002) to influence actual language-comprehension abilities. Such deficits may affect performance on language-comprehension assessment tasks in ways that may not be relevant to true receptive abilities.

Eye-Tracking Measures of Top-Down and Bottom-Up Processes

Eye-tracking methods have been shown to be effective for indexing top-down and bottom-up influences during language processing as well as free viewing. Top-down processes are highlighted in the visual-world paradigm (e.g., Cooper, 1974; Tanenhaus, Spivey-Knowlton, Eberhard, & Sedivy, 1995) and comprehension-assessment studies (e.g., Hallowell, 1999, 2012; Hallowell et al., 2002). People tend to look at visual stimuli that correspond to a spoken message when images and the spoken message are presented simultaneously. Bottom-up processes have been described and indexed using eye tracking in studies about the impact of physical stimulus characteristics on the allocation of

visual attention in multiple-choice image displays. The proportion of total viewing time that a person allocates to images within a multiple-choice display when there is no accompanying verbal stimulus serves as an index of the degree to which physical stimulus characteristics influence eye-fixation patterns (Heuer & Hallowell, 2007, 2009, 2015). Several studies have used eye-tracking measures to yield information about processing demands of visual scenes and multiple-image displays by varying those visual displays in terms of levels of complexity (Henderson & Hollingworth, 1999; Henderson, Weeks, & Hollingworth, 1999; Heuer & Hallowell, 2015; Judd, Ehinger, Durand, & Torralba, 2009; Thiessen, Beukelman, Ullman, & Longenecker, 2014; Wilkinson & Light, 2011; Yarbush, 1967).

Heuer and Hallowell (2009) examined how the control and manipulation of four physical image characteristics affects visual attention when those images are viewed with and without an accompanying verbal stimulus. They indexed allocation of visual attention by studying eye fixations in individuals without neurological impairment. The task differed from a typical word–picture matching task in that only one physical image characteristic was manipulated in one of the three images at a time, strategically controlling bottom-up processes. By contrast, in typical word–picture matching tasks top-down processes are typically manipulated via the verbal stimulus; bottom-up characteristics tend not to be methodically manipulated. In fact, word–picture matching tasks tend to involve multiple complex images that differ from one another in visual complexity. Characteristics manipulated included size, shape, orientation, and luminance. Those characteristics were selected because they are objectively quantifiable and can be controlled independently of semantic-content conveyance factors.

The authors presented multiple-choice image displays composed of three simple images. For each display, two of these images were identical simple shapes (majority images) and one image varied from these two with respect to one image characteristic (singleton image). Displays were presented under a nonverbal and a verbal condition. In the nonverbal condition, only the visual stimuli were presented. In the verbal condition, a word was presented auditorily at display onset and participants were instructed to look at the image that corresponded best with the word. For half of the displays the word corresponded to the singleton, and for the other half of the displays the word corresponded to the majority images. Participants fixated longer on the singleton than the majority images in both conditions. Thus, the singleton image received greater visual attention than the majority images even in the presence of a verbal stimulus. Allocation of attention was influenced by visual salience of individual images within multiple-choice displays even when the verbal stimulus was easily understood. The fact that a verbal stimulus may not completely override the influence of stimulus-driven aspects even in individuals without neurogenic impairment is important. The risk of bottom-up confounds on comprehension assessment is likely to be greater in PWA due to the common concomitant nonlinguistic

deficits already described and to deficits in correctly perceiving the incoming linguistic input.

Aims of the Current Study

The purpose of this study was to investigate the influence of bottom-up (stimulus-driven) processes on visual attention, as indexed by eye tracking, in PWA during a verbal and a nonverbal condition. The stimuli and procedures are similar to those in a study by Heuer and Hallowell (2009), which incorporated adults without neurological disorders. The same physical image characteristics (size, luminance, color, and orientation) were manipulated to explore the effects of bottom-up influences on visual attention with and without verbal stimuli. Indices of visual attention are quantified as the proportion of fixation duration (PFD) allocated to singleton and majority images within each display.

The following hypotheses were addressed:

1. In the nonverbal condition, PWA will allocate greater PFD to a singleton image than to the three majority images in a four-image set.
2. In the verbal condition, PWA will allocate greater PFD to target singleton images than to target majority images.
3. In the verbal condition, PWA will allocate greater PFD to nontarget singleton images than to nontarget majority images.
4. The severity of comprehension deficits and overall severity of aphasia in PWA will be related to the degree to which the singleton image attracts visual attention. People with greater language-comprehension deficits and greater overall severity of aphasia will allocate greater PFD to the minority image in the verbal and the nonverbal conditions.

Findings as predicted in the first three hypotheses would complement findings from previous studies with people without neurological disorders, indicating that physical stimulus characteristics influence visual attention during viewing of multiple-choice displays in verbal and nonverbal conditions (Heuer & Hallowell, 2007, 2009). It is important to confirm whether such influences are observed in PWA. Findings as predicted in the fourth hypothesis would suggest that the greater the severity of a person's language-comprehension deficits, the more likely it is that bottom-up influences (physical stimulus characteristics) will compete with the top-down influence of the verbal stimulus.

Method

Participants

Approval for this research was granted by the institutional review boards at Ohio University and the Center for Speech Pathology and Neurorehabilitation in Moscow,

Russia. Forty-one participants with aphasia due to stroke or traumatic brain injury were recruited from the Center for Speech Pathology and Neurorehabilitation in Moscow. The diagnosis was based on a definition of aphasia as an acquired neurogenic impairment of “language modalities including speaking, listening, reading, and writing; it is not the result of a sensory deficit, a general intellectual deficit, or a psychiatric disorder” (Hallowell & Chapey, 2008, p. 3). The diagnosis of aphasia was documented by an independent certified speech-language pathologist and/or neuropsychologist who was a native speaker of Russian. The presence of lesions in participants with aphasia was verified by radiologists’ interpretation of neuroimaging scans (computer tomography and/or magnetic resonance imaging).

Inclusion criteria for all PWA included passing vision and hearing screenings. Passing the visual-acuity screening required that participants identify symbols presented at a visual angle of 2° at a viewing distance of 2 ft on the Lea Symbols Line Test (Precision Vision, Woodstock, IL; Hyvärinen, Näsänen, & Laurinen, 1980). Participants had to achieve a 100% score on a color-vision screening test (Color Vision Testing Made Easy, Home Vision Care, Gulf Breeze, FL). Intactness of visual fields was screened using the Amsler grid, and functional bilateral peripheral vision was screened using a confrontation finger-counting task. Extraocular motor function and pupillary reflexes were also assessed (per Hallowell, 2008). Eyes were inspected for any pathological signs (e.g., redness, swelling, asymmetry of pupils, ocular drainage) that might suggest poor eye health and thus lead to unreliable eye tracking. Visual neglect was screened via the eye-tracking calibration procedure, which requires that participants fixate on a dot that appears in varied locations across the full horizontal and vertical range of the stimulus display area. Participants were allowed to use glasses or contact lenses, the use of which was documented. Hearing screening criteria included pure-tone responses at 500, 1000, and 2000 Hz at 30 dB SPL and accurate repetition of two examples of the auditory verbal stimuli used in the experiment, presented at 65–70 dB. All participants passed the hearing screening. One participant exhibited signs of hemianopsia identified with the confrontation finger-counting task. That participant was not excluded, because the hemianopsia did not interfere with eye-tracking calibration and recording procedures. No participants showed signs of visual neglect.

Participant ages ranged from 15 to 69 years (mean: 49.4). Education ranged from 9 to 19 years (mean: 13.9). Nine participants were women and 32 were men. All were right-handed and had one or more lesions confined to the left hemisphere. Twenty-two (54%) of the participants had ischemic strokes, six (14%) had hemorrhagic strokes, four (10%) had strokes of mixed origin, and nine (22%) had traumatic brain injury. All were at least 2 months post-onset (range: 2 months–14 years 6 months; mean: 2 years 2 months). All were native speakers of Russian. Twenty-one participants (51%) had right-sided hemiparesis. Aphasia subtype was assigned on the basis of Luria’s classification

(for background on Luria’s classification and its correspondence with Western classification systems, see Akhutina, 2016; Ivanova et al., 2015); fifteen participants (37%) were classified as having the efferent motor subtype, five (12%) sensory, nine (22%) dynamic, 10 (24%) acoustic-mnestic, one (2.4%) semantic, and one (2.4%) amnesic. (See Appendix for a description of all participants.)

The modified short form of the Russian Bilingual Aphasia Test (BAT; Ivanova & Hallowell, 2009) was administered to all participants. The revised Russian BAT is based on the short form by Paradis and Zeiber (1987). In that version, seven test items were modified from the original (for a detailed description of modified items, see Ivanova & Hallowell, 2009). The BAT is a well-known published aphasia battery that is generally used to assess expressive and receptive language abilities in individuals with bilingual aphasia. Its individual forms in various languages can be used to assess language impairment in monolingual speakers with aphasia when other standardized assessment tools are not available (Ivanova & Hallowell, 2009; Paradis & Zeiber, 1987). The modified short form of the Russian version of the BAT is one of the few published tests for aphasia (Paradis & Zeiber, 1987) for which psychometric properties have been documented in Russian (Ivanova & Hallowell, 2009). The test was administered in Russian only; participants were not expected to be bilingual to take the test. Group scores across subtests are summarized in Table 1. Although some participants achieved 100% accuracy on some of the subtests, they were included in the study because their communication characteristics met the definition of aphasia and each had a history of a left-hemisphere lesion.

Stimuli

Forty multiple-choice image displays were created, each with four images. One of the four images within each display was manipulated with regard to one stimulus feature: color, orientation, luminance, or size. The three other images within the set were controlled to have exactly the same physical image characteristics as one another. (See Figure 2 for an example of each type of image display.)

Each display contained four instances of the same shape, each shown in one of the four corners of the screen. The number of images per display was revised from three to four to create more balanced image displays in order to avoid the gap in one corner of the image display, which could potentially in itself create a visual distraction. Simple symmetrical shapes were used (diamond, square, triangle, ellipsis, rectangle, hexagon, rotated square, pentagon, trapezoid, or rhombus). The four image characteristics were objectively controlled for each shape, per Heuer and Hallowell (2009). Luminance was defined as the degree of light reflected from an image (Zwahlen, 1984), measured in candelas per square meter (cd/m^2). In the 10 displays in which luminance was manipulated, one image was darker than the others. The mean intensity for low-luminosity

Table 1. Group performance on the subtests of the Russian Bilingual Aphasia Test indexed in raw scores.

Subtest	<i>M</i> (proportion)	<i>M</i> (%)	<i>SD</i> (%)	<i>Range</i> (%)
Auditory Comprehension	65.14/80	81.43	13.13	47.5–100
Reading	32.17/46	69.94	30.06	0–100
Overall Receptive Skills ^a	97.32/126	77.24	18.57	37–100
Repetition	25.93/40	64.82	33.62	0–100
Naming	22.61/35	64.60	33.29	0–100
Metalinguistic Skills	31.24/40	78.11	25.58	0–100
Overall	177.35/241	73.59	22.50	20.75–99.17

^aOverall Receptive Skills score is a combination of Auditory Comprehension and Reading scores.

images was 46.3 cd/m², and for high-luminosity images it was 174.7 cd/m². For the 10 displays in which orientation was manipulated, one image had a vertical orientation and the remaining images had an identical horizontal orientation. Image size was the same for all display images—1,161 mm² (subtending 6.62° of visual angle at a viewing distance of 60 cm)—except for the 10 displays in which size was manipulated; in those, one image had a size of 581 mm² (1.31° of visual angle). For the 10 displays in which color was manipulated, one image was red and the remaining three were green. Displays were presented at a viewing distance of 60 cm.

During the nonverbal condition, all 40 image displays were presented without a verbal stimulus. The verbal condition consisted of 30 trials: Orientation was not manipulated during the verbal trials, because there was no single word that unambiguously differentiated the two orientations. For instance, the terms *horizontal* and *vertical* did not consistently differentiate the two orientations of each shape. In half (15) of the 30 trials the verbal stimuli matched the

singleton image (singleton trials), and in the other half (15) they matched the majority image (majority trials). See Figure 3 for a visualization of the different presentation conditions.

The verbal stimuli were prerecorded and digitized. Verbal stimuli were spoken by a male native speaker of Russian and were recorded in a soundproof booth using a high-quality dynamic microphone that was directly connected to a computer. Each verbal stimulus was digitized (22 kHz, low-pass filtered at 10.5 kHz), normalized for intensity, and stored on a computer using Cool Edit Pro 2.1. Recordings were edited to eliminate any noise at the start and end of each stimulus. The verbal stimuli were the following single words translated into Russian: *green*, *red*, *small*, *large*, *bright*, and *dark*. They were presented at approximately 60 dB SPL, as assessed by a sound-level meter, simultaneously with each accompanying image set.

Procedure

Peripheral vision was controlled by presenting the images in the four corners of the screen, at least 20° of visual angle apart. The nonverbal condition was presented first. The 40 multiple-choice image sets were presented for 4 s each on a 43-cm computer screen in a randomized order. Each participant was given the following instruction by the experimenter, a native speaker of Russian: “Look at the images on the computer screen in whichever way comes naturally to you. You do not have to remember any of the images.” This instruction was given to discourage participants from developing an expectation that they had to perform in any particular way. Prior to the verbal condition, each participant was instructed to look at the images that corresponded best to the words (identical to instructions provided in Heuer & Hallowell, 2009). Verbal stimuli and visual displays were presented with a simultaneous onset.

Prior to stimulus presentation, participants’ eye movements were calibrated using an automatic nine-point procedure that involved looking sequentially at blinking yellow dots on a black screen from a distance of 60 cm (LC Technologies, 2011). Participants’ eye movements were monitored and recorded at 60 samples per second using an LC Technologies Eyegaze remote pupil center/corneal reflection system.

Figure 2. Examples of image displays for each type of image characteristic (clockwise from upper left): orientation, luminance, color, and size. (In the color display, the upper left diamond is red.) The three identical images within each display are the majority images. The different image is the singleton image.

Figure 3. Overview of the different presentation conditions, number of trials, and types of stimuli.

Image characteristic	Color	Luminance	Size	Orientation
Image display
Nonverbal condition (40)	$N = 10$	$N = 10$	$N = 10$	$N = 10$
Verbal condition (30)	Verbal stimuli			
Singleton trials (15)	Red	Dark	Small	
Majority trials (15)	Green	Bright	Large	

Analysis

The initial 3 s of eye-fixation recordings were used for analysis. This time window was used for consistency with the previous study (Heuer & Hallowell, 2009). Heuer and Hallowell demonstrated that this interval allows capture of the greatest difference in PFD between singleton and majority images evoked in individuals free of neurological impairment when they view similar types of multiple-choice displays. Further, a 3,000-ms time window was sufficient for PWA to engage in visual-search tasks without a verbal stimulus (Heuer & Hallowell, 2015). A fixation was defined as a stable eye position of at least 100 ms (Manor & Gordon, 2003), having relative stability within 4° vertically and 6° horizontally. Customized software (Kruse, 2008) was used to extract and calculate the eye-tracking measure. Only fixations that could be assigned to a particular image located in each quadrant in the display were considered. Fixations allocated to the center of the screen were excluded from analysis. Fixation time associated with blink artifacts and movements of the eyes between fixations was eliminated prior to analysis.

Trials in which there were no fixation data on any of the singleton or majority images were excluded. This can happen when participants look away from the images or when they fail to reach the stability threshold required for the a priori definition of fixations. Of a total of 2,870 trials across all participants and conditions, 40 trials were excluded.

Eye-tracking methods such as those implemented in this study allow for natural, spontaneous responses and are based on the assumption that participants look at the image that corresponds to the verbal stimulus regardless of whether they were instructed to or not (Hallowell et al., 2002; Henderson, Shinkareva, Wang, Luke, & Olejarczyk, 2013). For the singleton and majority target images in the verbal condition, only data from trials for which comprehension of the verbal stimulus was likely were considered. Trials to be excluded were selected on the basis of having a PFD on the target of less than .28. This cutoff value is based on a 90% confidence interval for PFD on the target

being greater than .25, which is the ideal chance value if the proportion of fixation duration were equally distributed across the target and the three remaining images in the display (Heuer & Hallowell, 2015). For PFD on the target below .28, it was unlikely that participants had understood the verbal stimulus. A total of 195 out of 1,230 trials of the verbal condition were excluded for this analysis (with one exception—Participant 9, for whom all luminance and color majority trials were excluded—the excluded trials were distributed across participants).

Visual attention allocated to each image was indexed in terms of PFD allocated to that particular image. PFD was calculated as the total duration of all fixation allocated to a particular image divided by the total of fixation durations on all images in the display (Dahan, Magnuson, & Tanenhaus, 2001; Hallowell, 1999; Hallowell et al., 2002; Heuer & Hallowell, 2007, 2009, 2015; Ivanova & Hallowell, 2012; Knoblich, Ohlsson, & Raney, 2001; Odekar et al., 2009). Dependent measures included the mean PFD across the three majority images and the mean PFD for the singleton image. The mean PFD across the three majority images was compared against the PFD allocated to the singleton image. Paired-samples *t* tests were conducted to address the first three hypotheses. Partial correlation coefficients were computed to determine the relationship between severity of comprehension deficits and the stimulus-driven influences as indexed by PFD allocated to nontarget and target singletons (controlling for age). Data in the nonverbal and verbal conditions, as well as BAT comprehension scores, were normally distributed on the basis of visual examination of the SPSS 22 output of the Q–Q plot and the nonsignificant results of the Shapiro–Wilk test.

Results

Comparison of PFD for Singleton and Majority Images in the Nonverbal Condition

Analyses were conducted for singleton versus majority images in each condition across all the manipulated

stimulus characteristics. The mean PFD allocated to the singleton images ($M = .36$, $SD = .12$) was significantly greater than the mean PFD allocated to the majority images in the nonverbal condition ($M = .20$, $SD = .04$), $t(40) = 7.16$, $p < .001$ (two-tailed).

Comparison of PFD for Target Singleton Images and Target Majority Images in the Verbal Condition

The mean PFD allocated to the target singleton images ($M = .74$, $SD = .11$) was significantly greater than the mean PFD allocated to the target majority images ($M = .50$, $SD = .11$) in the verbal condition, $t(40) = 11.83$, $p < .001$ (two-tailed).

Comparison of PFD for Nontarget Singleton Images and Nontarget Majority Images in the Verbal Condition

The mean PFD allocated to the nontarget singleton images ($M = .28$, $SD = .15$) was significantly greater than the mean PFD allocated to the nontarget majority images ($M = .10$, $SD = .05$) in the verbal condition, $t(40) = 7.28$, $p < .001$ (two-tailed).

Relationship Between Severity of the Comprehension Deficit and PFD on the Minority Image in the Verbal and Nonverbal Conditions

Partial correlation coefficients, controlling for age, were computed between the BAT comprehension score, the BAT overall score, and the PFD allocated to the singleton image (a) in the nonverbal condition, (b) in the verbal condition when the singleton image was the target, and (c) in the verbal condition when the singleton image was not the target. A significant negative relationship was observed between the BAT comprehension and overall scores and PFD allocated to the nontarget singleton image in the verbal condition. Zero-order (full) correlations showed a similar statistically significant negative correlation between the BAT comprehension and overall scores and PFD allocated to the nontarget singleton image, indicating that age had very little influence on the relationship between BAT and PFD. Results suggest that as severity of language deficits increased, more visual attention was allocated to nontarget singleton images. Results are summarized in Table 2.

Discussion

The first hypothesis, that greater visual attention (as indexed by PFD) would be allocated to the singleton than to majority images within the nonverbal condition, was confirmed. Images that differed from the remaining images in the display with respect to one image characteristic were fixated proportionally longer. This result is consistent with results of previous studies indicating that physical

stimulus characteristics influence visual attention during viewing of multiple-choice displays in people without neurological impairment (Heuer & Hallowell, 2007, 2009).

The second hypothesis, that greater visual attention (as indexed by PFD) would be allocated to target singleton images than to target majority images in the verbal condition, was also confirmed. Despite explicit instructions to look at the image(s) that corresponded to the verbal stimulus, physical stimulus characteristics had a significant influence on visual attention in the presence of a verbal stimulus, as indicated by the significantly greater PFD allocated to the singleton target images than to majority target images. If visual attention were driven solely by the verbal stimulus (which is assumed in comprehension assessments that rely on multiple-choice image displays), no significant difference would have been observed in the allocation of PFD to singleton versus majority images in the verbal condition. This finding is consistent with results reported by Heuer and Hallowell (2009) for people without neurological impairment.

The third hypothesis, that greater PFD would be allocated to nontarget singleton images than to nontarget majority images in the verbal condition, was also confirmed. The nontarget singleton elicited significantly greater PFD than the nontarget majority images. This suggests that the singleton image is more likely to distract the viewer's visual attention when a multiple-choice image display is shown. Participants are more likely to allocate attention to the singleton when it does not correspond to the verbal stimulus. This provides evidence that the verbal stimulus does not completely override the influence of image salience in tasks that present with verbal and visual stimuli. Although it is possible that participants ignored the verbal stimulus, it is unlikely. Application of the eye-tracking method relies on the assumption that viewers will look most naturally and automatically at the image that corresponds to the verbal stimulus regardless of the absence or presence of explicit instructions. This is a robust finding among studies incorporating the visual-world paradigm (e.g., Cooper, 1974; Tanenhaus et al., 1995) and comprehension-assessment studies (e.g., Hallowell, 1999, 2012; Hallowell et al., 2002) in people with and without neurological impairment.

With regard to the fourth hypothesis, people with more severe comprehension deficits (indexed by lower comprehension scores on the BAT) and more severe aphasia overall (indexed by lower overall BAT scores) allocated greater PFD to the nontarget singleton images. This is consistent with previous findings that PWA tend to have challenges in allocating limited attentional resources (Murray, 1999, 2012; Robin & Rizzo, 1989). It appears that with increasing severity of aphasia and increasing comprehension deficits in particular, the top-down influence of the linguistic input might have less influence on allocation of visual attention by PWA as they process a verbal stimulus. Participants with more severe aphasia overall were potentially also more likely to be distracted by the bottom-up influence of the nontarget singleton images. These findings are consistent with those of Murray (2012), who reported

Table 2. Partial correlation coefficients for the singleton image and Bilingual Aphasia Test (BAT) comprehension scores in the nonverbal and verbal conditions when controlling for age.

		Mean proportion of fixed duration allocated to singleton image (<i>N</i> = 41)					
		Nonverbal condition		Verbal condition (target)		Verbal condition (nontarget)	
Control variable		<i>r</i>	<i>p</i>	<i>r</i>	<i>p</i>	<i>r</i>	<i>p</i>
None	BAT Auditory Comprehension	-.25	.15	.20	.22	-.67**	< .001
	Overall BAT aphasia score	-.23	.15	.09	.56	-.67**	< .001
Age	BAT Auditory Comprehension	-.21	.19	.30	.06	-.63**	< .001
	Overall BAT aphasia score	-.21	.20	.14	.38	-.67**	< .001

***p* < .01.

a significant correlation between aphasia severity and performance on the Test of Everyday Attention (Robertson, Ward, Ridgeway, & Nimmo-Smith, 1994) in a sample of 39 PWA. However, in that study Murray also highlighted that six PWA performed within normal limits on the test. The current finding of an association between aphasia severity and apparent bottom-up influences of stimulus characteristics is not consistent with findings by Heuer and Hallowell (2015), who reported no significant correlation between aphasia severity and eye-tracking measures used to index visual-attention allocation in a dual task. In sum, deficits in attention allocation may contribute to poorer responses in a multiple-choice comprehension task, but our findings cannot necessarily be attributed to a strong relationship between attention-allocation deficits and aphasia severity (Murray, 2004, 2012). Also, it is important to keep in mind that overall the aphasia severity score incorporates the comprehension score, so the two measures of severity are not independent—a fact that likely contributed to the similar magnitude in correlations between the two measures.

The fact that physical stimulus characteristics influenced visual attention in PWA even during the verbal condition highlights the fact that one cannot assume that the verbal stimulus will completely override the influence of visual-stimulus characteristics during auditory verbal tasks that rely on multiple-choice displays. Overall, this study conducted with native speakers of Russian with aphasia using Russian verbal stimuli successfully replicates the findings of a study with native speakers of American English without aphasia (Heuer & Hallowell, 2009). Results highlight that the observed visual stimulus-driven influences, even in the presence of a verbal stimulus, are not language specific. The findings mirror those of a similar study with people without aphasia (Heuer & Hallowell, 2009), suggesting that all people, regardless of the presence or absence of neurogenic comprehension deficits, are susceptible to the influence of image salience in multiple-choice image displays even in the presence of verbal stimuli. The experimental paradigms of these studies were not typical word–picture matching tasks commonly used to assess comprehension. Instead, the task was designed to strategically manipulate how participants allocate visual attention to simple geometric shapes (by altering one image characteristic in one of the images in each display) and to determine the influence of a verbal

stimulus on visual-attention allocation. The results still have implications for testing in clinical and research settings.

First, when an individual selects a nontarget image instead of a target image during a multiple-choice task, it is important to consider whether this might be attributable (at least in part) to poor control of physical stimulus properties among items within a display as opposed to being attributable to a comprehension deficit. This is especially the case when a person being assessed is likely to have concomitant nonlinguistic cognitive deficits. The greater the severity of comprehension deficits and overall severity of aphasia, the more susceptible PWA may be to the influence of poorly controlled physical stimulus properties among target and nontarget images, which may further confound the validity of comprehension assessment. Careful control of stimulus-driven aspects in multiple-choice image displays is vital to valid indexing of auditory processing.

Second, all people are susceptible to the influences of physical image characteristics on visual attention, regardless of the presence or severity of deficits. Visual stimulus characteristics can be strategically manipulated in assessment and treatment materials as a way to influence visual attention and to affect the likelihood that participants will identify target images within multiple-choice displays.

Limitations

The images and the verbal stimuli used in the current study were intentionally simplistic, for the sake of controlling image characteristics objectively. Typical multiple-choice images have greater complexity and involve a combination of stimulus characteristics that might disproportionately influence visual attention. In the future, generalization to more typical types of test images should be established. Further, it is important to recognize that the experimental paradigm was not the same as a typical word–picture matching task, not only in terms of response modality but also in that typical multiple-choice tasks include overt instructions regarding how participants are to respond (both of which are strengths of the proposed method). Studies including more complex and ecologically valid visual stimuli, along with carefully controlled linguistic stimuli designed to evaluate comprehension abilities, will be important in further exploration of the influence of visual attention on linguistic

processes and their interaction with cognitive and linguistic deficits in PWA. Last, although visual attention was monitored online by observing participants' fixations in real time, no measures of visual or auditory attention were collected.

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Appendix (p. 1 of 2)

Individual Characteristics of Participants With Aphasia

Participant	Age (years)	Gender	Education (years)	Time since onset (years;months)	Site of lesion	Types of aphasia (according to Luria's classification)	BAT Auditory Comprehension ^a	BAT Reading ^b	BAT Overall Receptive Skills ^c	BAT Overall ^d
1	68	M	16	0;11	Parietal, occipital, posterior temporal lobe	Sensory, acoustic-mnestic, semantic	61	42	103	187
2	19	M	9	5;5	Frontal lobe	Dynamic, acoustic-mnestic, efferent motor	64	36	100	189
3	59	M	13	0;6	Temporal lobe	Sensory, acoustic-mnestic	76	45	121	219
4	66	F	16	0;7	Frontal, anterior temporal lobe	Acoustic-mnestic, efferent motor	77	40	117	224
5	45	M	16	0;4	Parietal, occipital lobe	Acoustic-mnestic, efferent motor	73	43	116	229
6	59	M	16	0;2	Temporal lobe	Acoustic-mnestic, efferent motor	79	43	122	233
7	30	M	13	0;11	Parietal, occipital, temporal lobe, subcortical area	Efferent motor, afferent motor, sensory	38	10	48	50
8	52	M	16	3;4	Frontal, temporal lobe	Dynamic, acoustic-mnestic, efferent motor	58	29	87	172
9	29	M	16	0;3	Parietal, occipital lobe	Dynamic, efferent motor, afferent motor	80	45	125	239
10	53	M	16	0;2		Acoustic-mnestic	68	39	107	202
11	54	M	11	3;3	Frontal, temporal lobe	Dynamic	68	41	109	213
12	36	M	13	0;10	Temporal, occipital lobe	Acoustic-mnestic, sensory, amnestic	58	24	82	152
13	58	F	9	0;10	Parietal, anterior temporal lobe	Efferent motor	73	42	115	215
14	57	F	13	7;6		Efferent motor, dynamic	68	43	111	210
15	55	F	13	2;6	Frontal, anterior temporal lobe	Acoustic-mnestic, sensory	77	43	120	232
16	58	M	12	2;8	Prefrontal, parietal lobe	Efferent motor	70	35	105	207
17	45	M	16	1;9	Frontal lobe, basal ganglia	Efferent motor, afferent motor, dynamic	62	11	73	128
18	50	M	12	1;4	Parietal, occipital, posterior temporal lobe	Sensory, acoustic-mnestic	61	35	96	180
19	52	M	13	1;7	Parietal, posterior temporal lobe	Acoustic-mnestic, efferent motor, dynamic	71	45	116	215
20	50	M	13	2;5	Parietal, temporal lobe	Sensory, acoustic-mnestic	51	23	74	135
21	54	M	16	2;5	Frontal lobe	Efferent motor, afferent motor	66	40	106	177
22	31	M	16	2;8		Acoustic-mnestic, efferent motor, semantic	66	43	109	210
23	52	M	16	2;0		Dynamic, efferent motor, afferent motor	71	30	101	146

Appendix (p. 2 of 2)

Individual Characteristics of Participants With Aphasia.

Participant	Age (years)	Gender	Education (years)	Time since onset (years;months)	Site of lesion	Types of aphasia (according to Luria's classification)	BAT Auditory Comprehension ^a	BAT Reading ^b	BAT Overall Receptive Skills ^c	BAT Overall ^d
24	69	M	16	6;7	Frontal, anterior temporal lobe	Efferent motor, afferent motor	66	35	101	184
25	48	M	16	0;2	Frontal, posterior temporal	Acoustic-mnestic	76	44	120	232
26	34	M	11	0;5	Frontal lobe	Efferent motor, afferent motor	45	13	58	62
27	66	M	16	0;10	Parietal, temporal lobe	Dynamic, acoustic-mnestic, afferent motor	72	35	107	201
28	31	M	9	14;6	Frontal, temporal lobe	Acoustic-mnestic, efferent motor, dynamic	68	33	101	187
29	49	F	13	0;8	Frontal lobe	Efferent motor, afferent motor	80	46	126	238
30	57	M	19	1;5	Frontal, temporal, parietal lobe	Efferent motor, afferent motor, dynamic	44	9	53	87
31	50	M	11	0;11		Sensory, acoustic-mnestic, dynamic	57	11	68	109
32	60	F	16	1;0	Parietal, temporal lobe	Efferent motor	73	42	115	224
33	52	M	13	4;4	Prefrontal, parietal, temporal lobe	Dynamic, efferent motor, acoustic-mnestic	66	34	100	190
34	61	M	16	2;7	Left temporal lobe, right occipital lobe	Amnestic	75	43	118	231
35	58	M	16	3;3	Occipital, posterior temporal lobe	Dynamic, efferent motor	47	0	47	85
36	47	M	11	1;3	Temporal, parietal, occipital lobe	Efferent motor, afferent motor	59	18	77	81
37	53	F	13	1;2	Frontal lobe	Efferent motor, afferent motor	48	0	48	79
38	55	M	11	1;4	Prefrontal, parietal, temporal lobe	Dynamic, efferent motor	65	41	106	189
39	26	F	16	0;10	Frontal, parietal, temporal lobe	Efferent motor, afferent motor, acoustic-mnestic	62	37	99	165
40	15	M	9	1;1	Parietal, temporal lobe	Semantic, acoustic-mnestic, efferent motor	74	43	117	226
41	63	F	16	0;10		Efferent motor, afferent motor	58	8	66	133

^aThe Auditory Comprehension subtest of the Bilingual Aphasia Test (BAT) included the following subtests: Word–Picture Matching, Understanding of Simple and Semicomplex Commands, Verbal Auditory Discrimination, Syntactic Comprehension, and Listening Comprehension. The maximum score was 80. ^bMaximum score: 46. ^cMaximum score: 126. ^dMaximum score: 241.