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Research Report

Hemispheric asymmetries in the perceptual representations of words

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ARTICLE INFO

Article history:
Accepted 19 October 2007
Available online 7 November 2007

Keywords:
Hemispheric difference
Perceptual symbol
Language comprehension
Laterality
Right-hemisphere damage
Left-hemisphere damage

ABSTRACT

The representation of words in sentences can involve the activation and integration of perceptual information. For example, readers who are asked to view pictures of objects relating to a word in a sentence are influenced by perceptual information in the sentence context-readers are faster to respond to a picture of a whole apple after reading, “There is an apple in the bag,” than after reading, “There is an apple in the salad.” The purpose of this study was to examine how the two cerebral hemispheres use perceptual information about words as a function of sentence context. Patients who had damage to the left or right hemisphere and age-matched control participants read sentences that described, but did not entail, the shape or state of an object. They then made recognition judgments to pictures that either matched or mismatched the perceptual form implied by the sentence. Responses and latencies were examined for a match effect – faster and more accurate responses to pictures in the match than mismatch condition – controlling for comprehension ability and lesion size. When comprehension ability and lesion size are properly controlled, left-hemisphere-damaged patients and control participants exhibited the expected match effect, whereas right-hemisphere-damaged participants showed no effect of match condition. These results are consistent with research implicating the right hemisphere in the representation of contextually relevant perceptual information.

1. Introduction

The retrieval of contextually relevant word meanings is an essential feature of language comprehension. Consider the meaning of the word *lamb* across different sentence contexts. The word entails features in the sentence “Mary had a little lamb” that are different from those in the sentence “Mary ate a little lamb”. Recent theories of sentence processing suggest that understanding the meaning of a word in a sentence involves the activation of contextually relevant perceptual information (Barsalou, 1999; Glenberg and Kaschak, 2002; Kaschak et al., 2005; Solomon and Barsalou, 2004; Stanfield and Zwaan, 2001; Zwaan et al., 2002). According to this literature, ‘perceptual representations’ refer to knowledge about how an object looks, feels, sounds, smells, etc. These representations are stored in the same or neighboring brain

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doi:10.1016/j.brainres.2007.10.088

regions used to experience and act on objects According to some theories, perceptual representations are required for language processing and are activated routinely.

Although the necessity of perceptual representations for language comprehension is controversial, we know that these representations are sometimes activated and can play an important role in the performance of certain tasks. In one study, Glenberg and Kaschak (2002) had participants judge the sensibility of an action (e.g., close/open the drawer) when the response modality was in the same direction as the described action and when it was in the opposite direction (toward/away from the body). The dependent measure was "action–sentence compatibility" (i.e., the interaction between implied sentence direction and the direction of the actual, physical response). Reaction times were slower when responses required movement in the opposite direction of the one implied in the sentence than when it required a response in the same direction. This occurred for action-based sentences (open/close drawer) and for sentences that referred to physical transfer (e.g., Andy delivered the pizza to you). Remarkably, the effect was also observed for the transfer of abstract entities (e.g., "The policeman radioed the message to you"/"You radioed the message to the policeman"). These data suggest that at least some linguistic constructions are grounded in a perception/action-based system (Glenberg and Kaschak, 2002).

Picture recognition judgments have also been used to investigate the relation between perceptual representations and language comprehension (Kaschak et al., 2005; Stanfield and Zwaan, 2001; Zwaan et al., 2002). Zwaan and his colleagues found that participants who received a sentence that implied the shape of an object (e.g., "There is an egg in the pan") were faster to recognize a subsequent picture when it matched the shape implied in the sentence (e.g., a fried egg) than when it mismatched (e.g., a whole egg) (Zwaan et al., 2002). Although studies such as these do not rule out the possibility that language processing also involves amodal representations, they are strong evidence that comprehension involves the activation of perceptual information when this information is relevant for the performance of a task (e.g., picture recognition).

Our goal in this study was to examine the activation and use of perceptual information in the two cerebral hemispheres. Our focus was on whether or not the right hemisphere (RH) plays an important role in the perceptual representation of words. Evidence from the object recognition and visual processing literature as well as studies of RH contributions to high-level comprehension processes suggests that it may.

Numerous studies using behavioral, neuroimaging, and neuropsychological techniques have demonstrated that the RH makes unique contributions to the processing of visual stimuli. Marsolek and colleagues used behavioral techniques to demonstrate a RH advantage for the recognition of specific exemplars of shapes, such as individual pianos, etc. (Marsolek, 1995, 1999; Marsolek and Burgund, 1997). Their behavioral results have been supported and extended with neuroimaging techniques (Koutstaal et al., 2001; Vuilleumier et al., 2002). In one study, Koutstaal et al. (2001) hypothesized that the right fusiform cortex processes comparatively more specific visual-form information about previously encountered objects than does the left fusiform cortex. The usual reduction in neural activity that is observed when participants view repeated objects was less pronounced in the right fusiform than in the left when different exemplars from the same category were presented at test. This has been interpreted as support for RH "exemplar-specific" processing mechanisms.

Neuropsychological studies of patients with damage to RH cortices also support the claim that the RH exhibits exemplar-specific processing mechanisms during visual perception. The RH contribution to visual form-specific processing has been documented in case studies of patients with damage to right occipitotemporal cortex leading to prosopagnosia (an impaired ability to recognize specific faces), with damage to right occipitotemporal cortices, and with right occipital resections (Farah, 1991; Gabrieli et al., 1995; Gauthier et al., 1999; Swick and Knight, 1995; Vaidya et al., 1998; but see Yonelinas et al., 2001).

The RH also appears to play a nontrivial role in the execution of high-level processes during language comprehension. Some of the most convincing evidence for its role in language processing comes from studies of right-hemisphere-damaged (RHD) patients. These patients do not exhibit the classic aphasia syndromes characteristic of left-hemisphere-damaged (LHD) individuals. Instead, language dysfunction in the RHD population includes problems such as tangential conversation, poor topic maintenance, and difficulty in making bridging inferences – inferences that are necessary for integrating ideas in extended discourse (Beeman, 1998; Brownell and Martino, 1998; Brownell et al., 1986; Chiarello, 2003; Harden et al., 1995; Tompkins et al., 2000, 2004). Research on RHD patients' language and communication abilities has documented a variety of discourse problems, including the comprehension of figurative language and humor (Bihrle et al., 1986; Van Lancker and Kempler, 1987; Wapner et al., 1981), indirect requests (Hirst et al., 1984), and metaphor (Winner and Gardner, 1977). This population also has problems identifying themes of stories (Hough, 1990; Joanette et al., 1986; Rehak et al., 1992) and producing coherent narratives (Marini et al., 2005). Together, this body of research has led some researchers to suggest that the RH plays a significant role in the comprehension of language at the discourse level. Despite the consensus among researchers that the RH plays a role in high-level language comprehension, the precise nature of its contribution has yet to be specified.

1.1. *Experiment*

In the current study, we used a picture recognition task to examine the activation of perceptual information during sentence processing (Lincoln et al., 2007; Stanfield and Zwaan, 2001; Zwaan et al., 2002). The logic of the paradigm is that picture recognition should be facilitated to the extent that perceptual information relevant to the picture is activated during the comprehension of a preceding sentence.

Patients and age-matched control participants read sentences that contained descriptions implying the shape or state of an object (e.g., "There is an apple in the bag."; "There is apple in the salad."). They then received a picture that was either congruent or incongruent with the shape implied by the sentence (e.g., a whole apple versus a chopped apple). Previous studies have found a "match effect"; participants are faster to verify pictures when they are consistent with the shape implied by the sentence than when they are inconsistent (Stanfield and Zwaan, 2001; Zwaan et al., 2002). The match effect is interpreted as evidence that perceptual information about the specific exemplar of the object was activated during sentence comprehension. Our goal in this study was to determine if the right and left hemispheres differ in the use of perceptual information that is activated during language processing.

We hypothesized that the RH may be more important for the representation of perceptual information during sentence processing than the LH given evidence for RH strengths in perceptual processing tasks in conjunction with its role in high-level language processing. Specifically, we hypothesized that RHD patients would show a weaker match effect than the LHD patients even though the latter group is aphasic and has impairments in sentence processing.

Brain-damaged patients show considerable variability in their performance on language and cognitive tasks for many reasons, including the size of their lesion and differences in residual abilities. We examined these differences by including two variables in our analyses; comprehension ability (as measured by vocabulary scores on the Nelson–Denny Reading Test) and lesion size. We included comprehension ability in addition to lesion size because recent evidence suggests that it is a better predictor of patients' sentence understanding than is either hemisphere or lesion size (Baynes et al., 2006). Thus, we also hypothesized that patients with high Nelson–Denny Reading scores may show a larger match effect than patients with low scores, irrespective of the hemisphere (right/left) or size of their lesion.

2. Results

We analyzed the reaction time and accuracy data in two ways. In one set of analyses, we conducted repeated measure ANOVAs to compare patient performance with control group performance. Group (RHD, LHD, control) was a between-participant variable and match condition (match, mismatch) was a within-participant variable. We also conducted a set of regression analyses on the patient data to examine performance controlling for verbal comprehension and lesion size.

2.1. *ANOVA results*

Tables 1 and 2 contain the mean accuracy (proportion correct) and reaction time data as a function of group and match condition, respectively. Our analysis of the accuracy data revealed a reliable effect of group, $F(2,33)=4.90$, Mse=.02, $p=.01$, and a marginal effect of match condition, $F(1,33)=2.88$, MSe=.01, $p=.10$. As can be seen in Table 1, control participants were more accurate than were either of the patient groups. In addition, all groups were somewhat more accurate in the match than in the mismatch condition.

Table 1 – Mean accuracy scores (proportion correct) as a function of match condition and group

	Match condition			
	Match		Mismatch	
LHD	.90	(.09)	.85	(.12)
RHD	.84	(.10)	.83	(.18)
Controls	.97	(.10)	.93	(.08)

Standard deviation appears in parentheses.

Table 2 – Mean reaction times as a function of match condition and group

	Match condition			
	Match		Mismatch	
LHD	580.8	(216)	581.5	(201)
RHD	700.4	(265)	673.0	(209)
Controls	522.2	(174)	575.8	(210)

Standard deviation appears in parentheses.

Our analysis of the reaction time data revealed a reliable interaction between group and match condition, $F(2,33)=4.54$, MSe=2233, $p=.02$. Participants in the control condition showed a reliable match effect, $F(1,33)=7.72$, MSe=2233, $p=.01$, responding faster in the match than in the mismatch condition. In contrast, neither of the patient groups showed a difference between match and mismatch conditions, $F<1$ and $F(1,33)=2.01$, MSe=2233, $p=.17$, LHD and RHD groups, respectively.

2.2. *Regression results*

The patients in this study were heterogeneous with respect to their lesion size and residual language abilities. Therefore, we conducted a series of regression analyses to examine their performance on the picture recognition task controlling for these variables. Our criterion measures were difference scores. The difference score for accuracy was calculated as the proportion correct in the match condition minus the proportion correct in the mismatch condition. The difference score for reaction time was latency in the mismatch condition minus latency in the match condition. Thus, the match effect was always indicated by a positive difference score. We used three predictor variables in these analyses: hemisphere (RHD/LHD), comprehension ability (scores on the Nelson–Denny reading comprehension test), and lesion size (number of voxels encompassed by the patient's lesion).

Descriptive information concerning the patients' comprehension scores and lesion sizes appears in Table 3. Comprehension scores were higher in the RHD group than in the LHD group, $F(1,22)=4.77$, MSe=6048, $p=.04$. Lesion size, however, did not vary as a function of hemisphere, $F<1$. The correlations among comprehension performance, lesion size, and hemisphere with accuracy and reaction time appear in Table 4. Comprehension ability diminished as a function of lesion size and left-hemisphere location. Lesion size and hemisphere were not reliably correlated.[1]

[1] The heterogeneity of the patients' lesion locations is an important consideration when doing patient studies. Due to the small number of patients in this study, examination of lesion location within the RH or LH was not revealing. Adding additional participants, making voxel-based lesion–symptom mapping (Bates et al., 2003) possible and analyzing subgroups of patients grouped by lesion location within the hemisphere may be useful in further understanding the nature and region of the RH contributions to this task. Differences in lesion location may be important in the final understanding of the mismatch effect.

Table 3 – Demographic information for patients

Patient	Age (years)	Education (years)	TPO (months)	ND Vocab (%)	Lesion size (voxels)	WAB-AQ
Left hemisphere patients						
1	59	12	40	12	12,655	66.9
2	69	14	61	6	10,248	91.9
3	47	16	142	97	6991	100
4	46	16	41	6	6677	77.6
5	65	16	162	16	28,656	65.4
6	61	16	136	63	10,637	84.4
7	54	16	115	2	13,159	72.2
8	55	16	69	87	2584	98.6
9	52	16	55	24	15,876	82.7
10	63	14	223	1	22,062	72.8
11	66	12	212	1	34,184	77.2
12	48	20	104	34	15,002	91.6
Averages:	**57.1**	**15.3**	**113.5**	**29.1**	**14,894.3**	**81.8**
Right hemisphere patients						
13	76	12	60	43	23,099	–
14	71	12	54	14	20,217	–
15	67	13	57	5	36,643	–
16	66	12	26	20	5919	–
17	61	13	124	95	10,974	–
18	64	16	27	99	5343	–
19	55	14	45	90	438	–
20	56	14	58	85	2234	–
21	60	16	75	43	1687	–
22	73	18	77	97	26,695	–
23	78	12	84	86	17,573	–
24	48	12	19	17	n/a	–
Averages:	**64.6**	**13.7**	**59.0**	**57.8**	**13,711.1**	
Controls						
1	69	14	–	97	–	–
2	66	17	–	97	–	–
3	54	18	–	92	–	–
4	65	14	–	93	–	–
5	56	13	–	98	–	–
6	60	15	–	85	–	–
7	60	18	–	74	–	–
8	52	13	–	95	–	–
9	61	14	–	85	–	–
10	61	15	–	70	–	–
11	53	14	–	87	–	–
12	60	14	–	20	–	–
Averages:	**59.8**	**14.9**		**82.8**		

TPO, time post onset; ND Vocab, Nelson–Denny Vocabulary Subtest; WAB-AQ, Western Aphasia Battery – Aphasia Quotient; n/a, not available; Lesion size represents the number of voxels in the patient's normalized lesion site.

With respect to accuracy on the picture recognition task, the regression model was reliable, $F(3,19)=3.27$, MSe=.01, $p=.04$. The standardized regression coefficients appear in the left column of Table 4. Lesion size was the only reliable predictor of the match effect. Patients with small lesions were more likely to show a match effect than were patients with large lesions.

The regression model for the reaction time data was also reliable, $F(3,19)=5.35$, MSe=3558, $p<.01$. The standardized regression coefficients appear in the right column of Table 4. All three variables were reliably related to the match effect. Patients with small lesions were more likely to show a match effect than were patients with large lesions and patients with high comprehension scores were more likely to show the effect than patients with low scores. Interestingly, hemisphere was a reliable predictor of the effect when the effects of lesion size and comprehension ability were controlled. Patients with LHD were more likely to show a match effect than were patients with RHD.

3. Discussion

Our goal in this study was to examine how the two cerebral hemispheres represent perceptual information about words in sentence contexts. We hypothesized that the RH may have a special role for two reasons. First, several studies have shown that the RH has strengths with respect to the processing of perceptual information, particularly in picture processing tasks (Koutstaal et al., 2001; Marsolek, 1995, 1999; Marsolek and Burgund, 1997; Vuilleumier et al., 2002). Second, the RH

Table 4 – Effects of hemisphere, lesion size, and comprehension ability on accuracy and reaction time differences in the match and mismatch condition

Predictor	Standardized regression coefficients	
	Accuracy	Reaction time
Hemisphere	0.12	−.53**
Lesion size	−.60**	−.40*
Comprehension ability	−0.07	.80**

*$p<.05$.
**$p<.01$.

has been implicated in the ability to integrate incoming information with previous discourse, such as the ability to make inferences (Bihrle et al., 1986; Brownell et al., 1986; Hough, 1990; Nichelli et al., 1995; Rehak et al., 1992; Robertson et al., 2000; St George et al., 1999; Van Lancker and Kempler, 1987; Wapner et al., 1981; Winner and Gardner, 1977). The match effect relies on an inference about the shape of an object after reading a sentence. For example, the sentence, *The egg was in the pan*, has no explicit description of the state or shape of the object. Readers must infer from world knowledge that an egg in a pan is more likely to be shaped like a fried egg than a whole one. Numerous studies have documented that RHD patients have difficulty in tasks requiring the generation of inferences (Beeman, 1993; Brownell and Martino, 1998; Chiarello, 2003; Tompkins et al., 2000).

The results that we obtained in this study provide partial support for our hypothesis about the role of the RH in representing perceptual information about words. Our initial analyses showed that only control participants demonstrated a match effect, responding faster to pictures in the match than mismatch condition. Both patient groups were impaired on the task, showing no response differences in the match and mismatch condition. We did find a reliable effect of hemisphere, however, when we controlled for lesion size and comprehension ability. LHD patients demonstrated a reliable match effect even though these patients were aphasic, with impairments in sentence processing. In contrast, the RHD patients showed a lack of sensitivity to the perceptual match between the sentence meaning and the picture.

The influence of hemisphere on the match effect differs from the result of a previous study using a similar paradigm. Lincoln et al. (2007) had college students read sentences and then respond to pictures that were congruent or incongruent with perceptual information implied in the sentences. The pictures were presented to the LH or RH in a divided visual-field paradigm. They found evidence for a match effect in both hemispheres. If both hemispheres are capable of activating and using perceptual information in this task, why did RHD patients in the current study fail to show a match effect?

One possible answer to this question is that the unique contribution of the RH to this task may involve the RH's role in strategic and integrative processes. Functional imaging studies have implicated the dorsolateral and medial prefrontal cortex (PFC) in the RH as a source of response decision and inhibition processes (Garavan et al., 1999; Konishi et al., 1998; Swainson et al., 2003). Although the LH may have the capacity to represent perceptual information about words in sentences, the RH-DLPFC may play a role in responding to the pictures appropriately. Future studies could address this possibility in two ways. One would be to design a task in which the activation of perceptual information was required, but response conflict was minimized. This might be possible using a task such as property verification (i.e., Subjects respond yes/no to an object's properties such as "Does a gorilla have a face?"; "Does a bicycle have a road?"). Alternatively, studying a cohort of patients with PFC lesions would be another means of investigating the role of strategic processing and response conflict monitoring in the picture recognition task.[2]

Additionally, when reconciling the outcomes of this research and Lincoln et al. (2007), the difference in the results between the two studies is not entirely unexpected as the earlier paper is a divided visual-field study on young-normal participants in contrast to the current patient research. The reaction time values in the earlier paper far exceed the inter-hemispheric transfer time for information and it is likely that results in that study (and in many others) reflect relative contributions to the tasks they assess. The LH may show the match effect based on a RH contribution that occurred earlier in the processing stream In contrast, in a lesion study aspects of RH processing are entirely eliminated and this results in a loss of the match effect in that group. The LH group, with an intact RH, still produces a match effect despite more language deficits.

In interpreting these results, the assumption has been made that the match effect occurs because participants generate a perceptual representation of the target object that is consistent with the situation described by the sentence. When a picture of that object consistent with the sentence is displayed, it is assumed this picture matches the mental representation and facilitates a "yes" decision. When a picture of the object that is not consistent with the situation described by the sentence is displayed, the conflict disrupts the "yes" decision potentially impacting both speed and accuracy.

However, it is possible to conceive of a non-perceptual mechanism that might yield the same pattern of match/mismatch responding. Both the sentence and the picture might instead generate a context-specific conceptual representation such as a feature list that might yield the same pattern of results. The power of an amodal language representation to model an extensive variety of conceptual circumstances is both one of its strengths and a weakness in terms of empirical verification (Machery, 2007). In this case, the current experiment can not rule out such an interpretation. One way to test the adequacy of an amodal system to generate a mismatch effect would be to repeat this experiment but replace the pictorial stimuli with words ("whole lemon", "sliced lemon"). If such an experiment did not produce a match effect, it would argue that the results reported here do reflect perceptual processing.

Our focus in this study was on the role of the RH in activating and using perceptual information during language processing. Our results, however, also revealed that the match effect was influenced by the extent of damage and preserved reading ability (i.e., Nelson–Denny scores). Participants with

[2] Using overlays of the Brodmann areas provided by MRIcro (Brett et al., 2001), we were able to determine that 4 of the 11 RH subjects had lesions that included portions of BA 46. Three additional subjects evidenced lesions in the white matter medial to BA 46. However, as many of our patients had lesions that extended beyond BA 46, no firm conclusion can be reached.

small brain lesions were more sensitive to the perceptual relation between the pictures and sentences than were participants with large lesions. Comprehension ability was related to the match effect in a similar way. Participants with high reading scores were more sensitive to the sentence–picture relation than were participants with low scores.

In summary, the current study suggests that RHD impairs the activation or use of perceptual representations during comprehension. RHD patients were insensitive to the perceptual match between a sentence and a picture. This impairment was over and above impairments that were related to lesion size and residual comprehension ability. It remains unclear if this effect is related to impairment in perceptual processing, per se, or in the use of perceptual information to perform a task. Future research that integrates patient findings such as these with behavioral and imaging studies of normal participants are needed to determine whether the RH is routinely involved in the integration of perceptual information during sentence comprehension or contributes only to the response demands of particular tasks.

4. Experimental procedures

4.1. *Participants*

Fifteen LHD participants and 17 RHD participants were recruited for this study. The patients were selected from an established participant pool of patients with isolated structural damage due to cerebral infarction, uncomplicated by medical, psychiatric, or other neurological disease. Patients underwent a multi-stage screening process: scan review to determine inclusion, medical chart review, a neurological exam with emphasis on neuropsychological evaluation (performed at least 12 months post infarction to ensure lesion and symptom stability), and completion of extensive neurolinguistic testing. Inclusionary criteria for the study included: a left or right hemisphere cerebral vascular accident (CVA), right-handed, at least 1 year post-CVA, normal or corrected-to-normal hearing, and no prior history of neurological, psychiatric or substance abuse problems.

Eight of the participants who completed the experiment were ultimately excluded. One participant had a lesion that was below our minimum-size threshold and not detectable after normalization; one had bilateral involvement due to a second stroke; one had less than minimum accuracy levels (less than 31% on experimental items), and two had less than minimum discrimination levels ($d' < 1$). Four participants had no scan information. We were able to recruit replacement participants for three of these individuals, with the exception of Subject 24. Our inclusion/exclusion procedure resulted in 12 participants with LHD (ages 46–69, $M = 57.1$; 8 males) and 12 with RHD (ages 48–78, $M = 64.6$; 8 males). Demographic information on these patients is presented in Table 3.

In addition to the patient participants, 12 age- and education-matched controls (ages 52–69, $M = 59.8$; 5 males) were recruited from the local community. All control participants were right-handed, native speakers of English with no history of psychiatric or neurological disorder. They reported normal or corrected-to-normal hearing and vision. All participants, patients and controls, received the Nelson–Denny Reading Test (Brown et al., 1993). Nelson–Denny scores ranged from the 1st to the 99th percentiles with a mean of 56.6 and a standard deviation of 38.1. LHD patients were classified by means of performance on the Western Aphasia Battery (WAB, Kertesz, 1982). The Western Aphasia Battery – Aphasia Quotient (WAB-AQ) provides a measure of severity of language impairment. Normals regularly achieve a score of 100. A score of below 93.8 is used as an arbitrary cutoff between brain-damaged but clinically nonaphasic and those persons classified as having aphasia. In contrast, persons with profound global aphasia typically score in the range from 0 to 26. AQ scores also reflect severity within a clinical classifications for example, Broca's aphasia patients may score from 8 to 80, depending upon whether they are mildly, moderately, or severely impaired (Kertesz, 1979). We found no significant difference between the patient and control groups in age or education (all F values <1). All participants signed informed consent documents that were approved by the Institutional Review Boards of UC Davis and/or the VA Northern California Health Care System.

4.2. *Materials*

The materials consisted of a set of sentences and pictures similar to those used by Zwaan et al. (2002). Each sentence conformed to a scripted grammatical structure "There is a/an <object> <prepositional phrase>." (e.g., "There is an apple in the bag."). The sentences were constructed in pairs. Each introduced an object and included a prepositional phrase that implied (but did not entail) a specific shape or state of the object ("There is an apple in the bag." or "There is an apple in the salad."). The sentence pairs combined with the picture pairs yielded four versions of the sentence–picture combination. Examples appear in Fig. 1. Each participant received 64

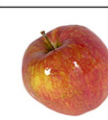
Condition	Sentence	Picture	Correct Response
Match	"There is an apple in the bag."		Yes
Mismatch	"There is an apple in the bag."		Yes
Match	"There is an apple in the salad."		Yes
Mismatch	"There is an apple in the salad."		Yes
Filler	"There are cherries on the tree."		No

Fig. 1 – Examples of match, mismatch and filler stimuli.

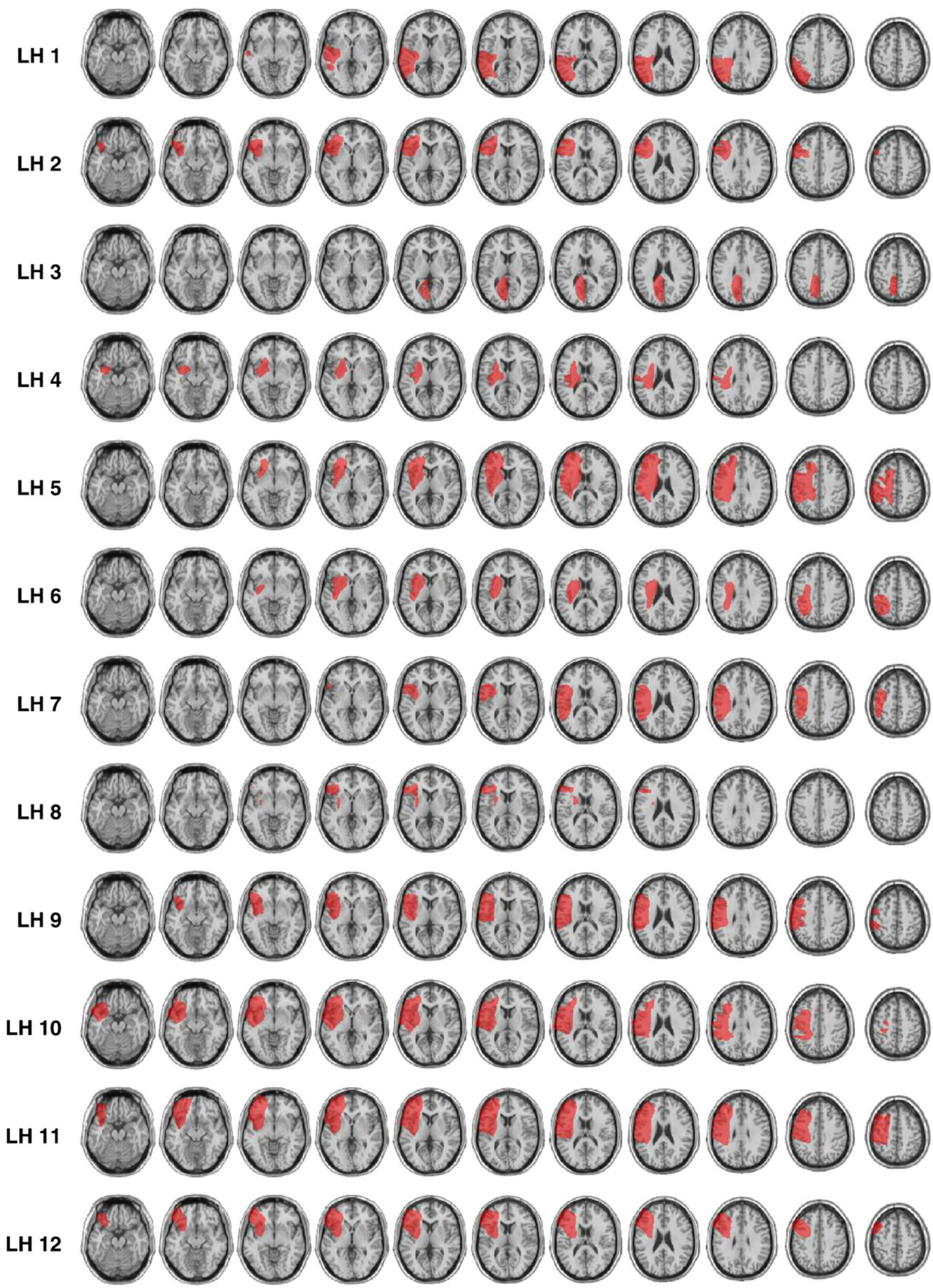


Fig. 2 – LHD patient's normalized lesions are presented on the MNI template brain. The numbers on the left side of the figure correspond to patients as listed in Table 3.

experimental sentences and an additional 64 filler sentences. Participants viewed only one version of sentence–picture combination. Filler sentences were constructed using the same grammatical structure as were the experimental sentences but were paired with a picture of an unrelated object (e.g., "There is a sandwich on the plate." <binoculars>).

The pictures consisted of color photographs from freely available clip-art packages and other internet sources. Two pictures were selected for each targeted object in the sentences (e.g., apple slices, a whole apple). Each picture was modified in Photoshop to delete all contextual information. The image was then superimposed on a white background.

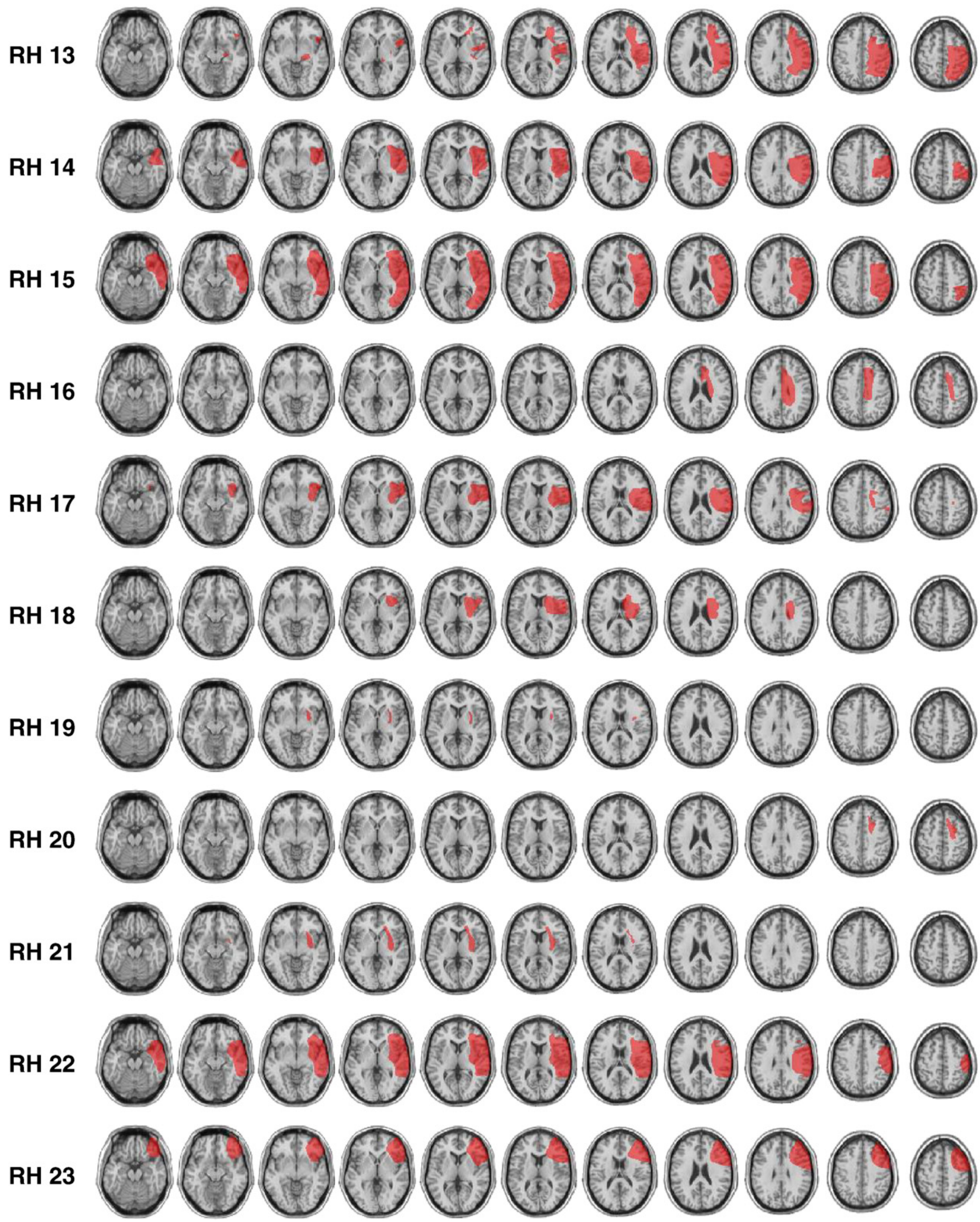


Fig. 3 – RHD Patient's normalized lesions are presented on the MNI template brain. The numbers on the left side of the figure correspond to patients as listed in Table 3. Lesion reconstruction was unavailable for patient 24.

Each image was scaled to occupy a square of 3 in. To ensure that the pictures were readily recognized the pictures were normed using a picture recognition-time[3] pretest.

We assigned each picture to one of two test lists. The lists were created such that members of a pair were assigned to different lists. The lists were balanced such that each list had the same number involving a change of state (e.g., fried egg vs. whole egg; $n=32$) and a change of posture (e.g., man standing vs. man sitting; $n=32$). The change-of-state items were further balanced such that they had equal numbers of pictures with whole/part relations: 8 items were "whole" (e.g., a whole lime); 8 items were "part" (e.g., lime slice), and the remaining 16 items had no part/whole relation (e.g., green versus brown maple leaf). These factors were considered in composing the counter-balanced lists because previous research has shown that item types unbalanced across lists may influence picture-recognition times in this task, skewing the mismatch effect (Larsen et al., 2004). Finally, the lists were balanced for picture recognition time: List 1: $M=698$ ms, min/max=526 ms/1058 ms; List 2: $M=698$ ms, min/max=547/949; ANOVA, $F(1,126)<1$.

4.3. Procedure

Participants were asked to read sentences and then to verify whether or not a target drawing depicted an object from the preceding sentence. They began the task by viewing written instructions on a laptop computer as the experimenter read them aloud. They then received nine practice trials, with feedback, to familiarize them with the task. On each practice trial, participants were asked to read the sentence and then respond to a subsequent picture. They were told to press a key labeled "yes" if the target depicted an object in the sentence and were told not to respond if the target did not depict an object from the sentence (i.e., go/no go). Participants were further informed that their reaction time (RT) was being measured and that they should make their judgments as quickly and as accurately as possible. Participants were encouraged to keep their fingers on the yes key at all times. If a participant did not complete all of the practice trials accurately, then the instructions and practice items were repeated. No participant required more than one repetition. Once participants completed the practice trials, they began the experiment.

The timing of each trial was controlled with DirectRT stimulus presentation software (http://www.empirisoft.com/directrt/). Responses and response latencies were recorded for each picture. The experimental items and fillers were presented randomly. The timing and sequence of an experimental trial was as follows: a sentence was presented in the center of the screen until the participant pressed the yes-key to indicate that they had read and understood it. All sentences were presented in white, 32 pt. font on a black screen. Each sentence was followed by a fixation point (500 ms) and then a picture. The picture was presented in the center of the screen for 150 ms, after which the participant viewed a black screen until a response was made. On 'no go' trials, the screen remained blank for 3000 ms at which time the next sentence appeared.

4.4. Lesion reconstruction

All patients had high-quality anatomical structural scans as part of their intake into the patient pool. Patient lesions were drawn manually using the lesion reconstruction software *MRIcro* (Brett et al., 2001) and reviewed for accuracy by a board-certified neurologist experienced in reconstructions, and normalized to the NMI template brain to allow for easy comparison and lesion volume analysis. Lesion volumes represent the number of voxels in the patient's normalized lesion site. The lesion reconstructions are presented in Figs. 2 and 3, with the exception of patient 24 for whom no scan information was available.

[3] Twenty subjects participated in the picture recognition pretest. Ss responded Yes/No to an object noun–picture matching task and RTs were collected and averaged. The mean error rate was very low (1.7%).

Acknowledgments

Thanks to all of the participants and their families who generously donated their time to participate in this research. We would like to thank Robert T. Knight, MD for reviewing all lesion reconstructions. We thank Juliana Baldo, Krista Schendel Parker and Natalie Kacinik for their contributions to the lesion tracings. This research was supported by NIH RO1 DC 04442 and PO1 NS 40813.

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