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Hemispheric processing of vocal emblem sounds

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Vocal emblems, such as *shh* and *brr*, are speech sounds that have linguistic and nonlinguistic features; thus, it is unclear how they are processed in the brain. Five adult dextral individuals with left-brain damage and moderate–severe Wernicke's aphasia, five adult dextral individuals with right-brain damage, and five Controls participated in two tasks: (1) matching vocal emblems to photographs ('picture task') and (2) matching vocal emblems to verbal translations ('phrase task'). Cross-group statistical analyses on items on which the Controls performed at ceiling revealed lower accuracy by the group with left-brain damage (than by Controls) on both tasks, and lower accuracy by the group with right-brain damage (than by Controls) on the picture task. Additionally, the group with left-brain damage performed significantly less accurately than the group with right-brain damage on the phrase task only. Findings suggest that comprehension of vocal emblems recruits more left- than right-hemisphere processing.

Keywords: Vocal emblems; Aphasia; Left brain-damage; Right brain-damage; Language.

For much of the century and a half of neurolinguistic study, it has been generally understood that the left hemisphere (LH), and particularly its perisylvian area, is 'responsible' for language. Broca (1861) had noted that his patient Leborgne, called 'Tan' because he only spoke this nonsense word plus a curse, had lost all his language from a large LH lesion. A series of cases with similar LH lesions permitted Broca (1865) to conclude compellingly that left anterior regions were responsible for the production of language. Broca's contemporary, Hughlings Jackson, considered the obverse of Broca's analysis, reminding his readers that even patients who had lost their language abilities, their ability to pantomime, and some understanding of symbolism, often retained a small repertoire of recurrent utterances. He distinguished a 'superior' level of speech that included 'propositionizing' (the use of utterances that state facts) from an 'inferior' level that included 'automatic' and 'emotional' utterances. Automatic/emotional utterances, he claimed, often remained intact in individuals with aphasia, and included common expressions such as 'yes', 'no', 'please', 'go away',

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'oh', oaths, and obscenities (Hughlings Jackson, as cited in Critchley & Critchley, 1998, p. 93). He believed that sites for automatic/emotional speech were in both hemispheres.

Van Lancker and Cummings (1999) have argued that the reason curses (and, presumably, other formulae) may be spared in aphasia is that they are non-analytic speech patterns associated with the right-hemisphere (RH), distinct from the sequential, analytic speech associated with the LH. Van Lancker Sidtis (2008) makes reference to the dual processing model, which posits that language is generally processed in the LH, but that a subcortical circuit in the RH facilitates formulaic expression. Support for this model includes observations of interjections such as *wow* preserved in individuals with aphasia, while the ability to produce interjections is lost by some individuals with right or subcortical brain damage.

A unique class of communicative sounds, vocal emblems (VEs) (Efron, 1941/1972), such as *shh* for 'Be quiet' and *brr* for 'It's cold', seem to defy the LH/RH dichotomy, as such sounds have both linguistic and nonlinguistic qualities. They are word-like in that they are short symbolic utterances with agreed-upon meanings. However, unlike most words, they are usually produced in isolation and not in a sentence. Moreover, they are distinct in that they may consist of sounds that are not part of a language's phonological inventory and do not follow the language's phonotactic constraints. For example, the vocal emblem *tsk, tsk* is produced by a dental click, which is not an English speech sound and does not contain the vocalic nucleus of a typical syllable. In addition, intonation can be a salient feature of VEs (e.g., *uh-oh*). Lastly, physical gestures (e.g., putting a finger to one's lips for *shh*) and specific facial expressions (e.g., grimace for *pee-uw*) conventionally accompany certain VEs.

From these observations, it is not clear how VEs are processed, i.e., whether they are processed similarly to most words (requiring primarily LH processing) or to nonlinguistic intonation (see Wong, 2002, for an overview) and formulaic utterances (requiring primarily RH processing; e.g., Van Lancker and Cummings, 1999). As there is little literature precisely on the items we consider, we review studies that have examined the processing of symbolic gestures (unaccompanied by sound) and varieties of communicative sounds.

In a functional Magnetic Resonance Imaging (fMRI) study, Xu, Gannon, Emmorey, Smith, and Braun (2009) examined whether two categories of symbolic gestures: (1) emblem gestures (such as raising one's finger and producing the facial expression for 'I've got it', rather than ones including vocalizations like those studied here) and (2) pantomimes (e.g., threading a needle), are processed by the same cerebral system as spoken language. Twenty healthy dextral native English-speaking adults observed video clips of an actor performing pantomimes, emblem gestures, and clips of her uttering spoken glosses corresponding to the stimuli. Common areas of activation when participants processed the symbolic gestures and spoken language were more abundant than areas uniquely activated by symbolic gestures or spoken language. Symbolic gestures, including emblems, were processed overall similarly to speech, primarily in the LH, although some areas of activation unique to gestures were evident in both hemispheres. The authors suggest that the left perisylvian network maps symbols and meanings in a universal sense, whether this occurs in the vocal-auditory or in the gestural-visual domains.[1]

It remains possible that, to some degree, different symbols and gestures may activate brain regions differentially, as the data of Xu et al. (2009) suggest. In their fMRI study, Gallagher and Frith (2004) considered two categories of symbolic gestures: instrumental gestures, i.e., those calling for an action (e.g., 'be quiet'); and expressive gestures (e.g., 'it's cold'). Watching instrumental gestures activated the LH in regions associated with language and imitation in healthy adult listeners. However, watching expressive gestures activated the anterior paracingulate cortex, the amygdala and temporal poles bilaterally, as well as the right superior temporal sulcus. Knutson, McClellan, and Grafman (2008) further found that watching more provocative gestures (such as a fascist salute) activated more prefrontal and limbic areas than did socially meaningful gestures that are less provocative, such as waving. Furthermore, Montgomery and Haxby (2008) reported that hand gestures and facial expressions activated the mirror neuron system differentially, with social hand gestures showing

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[1] They note that signs used in American Sign Language and in all sign languages that have been studied are unlike emblems in that these conform to lexical, phonological and syntactic rules similar to spoken language and thus their comprehension and production understandably elicit activity patterns in the perisylvian areas mostly indistinguishable from those activated by the comprehension and production of spoken language (MacSweeney, Capek, Campbell, and Woll, 2008).

bilateral representation with greater activation of the left inferior parietal lobule and facial expressions showing greater bilateral activation of the frontal operculum.

In summary, processing of symbolic gestures not accompanied by sound appears to show bilateral representation of some regions associated with language and other areas not associated with language. However, less is known about the processing of vocal emblems (e.g., *shh*, *brr*) – sounds that can be understood without use of the visual modality by healthy individuals. A body of research related to vocal emblem sounds has been reported in the realm of nonverbal environmental sound recognition, e.g., the sound of a cow mooing or a bell ringing. In three studies involving participants with various lesion sites post-CVA (Saygin, Dick, Wilson, Dronkers, & Bates 2003; Schnider, Benson, Alexander, & Schnider-Klaus, 1994; Spinnler &Vignolo, 1966), findings suggested that the LH is heavily involved in processing environmental sounds. However, there is controversy as to whether the RH is also involved. For example, Schnider et al. (1994) supported bilateral involvement and Spinnler and Vignolo (1966) reported that individuals with RBD performed similarly to Controls on recognizing environmental sounds.

Onomatopoeias, another class of symbolic sounds with characteristics of words and environmental sounds, are used frequently in Japanese speech, particularly in conversations with young children. In an fMRI study, Hashimoto et al. (2006) found that nouns (i.e., types of animals, e.g., *Zou* [elephant]) activated the left anterior superior temporal gyrus (STG), while animal sounds (e.g., owl's hoot) activated the left inferior frontal gyrus and the bilateral superior temporal gyrus. However, onomatopoeic sounds (e.g., *gwa-gwa* [onomatopoeia for sound made by duck]) resulted in activation of several brain regions, including the left inferior frontal gyrus and the bilateral superior temporal sulcus. The authors suggest that these onomatopoeic sounds may be a 'bridge' between the processing of animal sounds and of nouns (p. 1762).

In the only fMRI study that has included vocal emblem sounds, Dietrich, Hertrich, Alter, Ischebeck, and Ackermann (2008) examined native German listeners' processing of German interjections. These interjections involved sounds considered to have different lexical and prosodic loads. An example of an interjection with a high lexical load was *pfui* (yuck), which is a word found in dictionaries and one whose meaning can be understood even when uttered in a neutral tone. An interjection with a low lexical load was *a* (ah), which, when uttered in a neutral tone is simply a vocalic sound, but when uttered in a prolonged manner with a rising-falling intonation, can signal a pleasant experience. Both were uttered in neutral-affect and in high-affect modes, distinguished by 'neutral' vs. 'affective/emotional' prosody. Overlapping bilateral activation was revealed for heavily lexical and prosodic interjections, although a stronger prosodic load activated the right temporal lobe.

Evidence of RH dominance has been found for tasks involving non-linguistic intonation such as pitch discrimination (Robin, Tranel, & Demasio, 1990) and affective prosody (Heilman, Scholes, & Watson, 1975). Van Lancker (1980) proposed a scale of LH to RH specialization associated with intonation, with lexical tone being most linguistic and affect/voice quality being least linguistic. The more linguistic the intonational contrast is (e.g., 'This is *your* pencil' as opposed to someone else's), the more it is lateralized to the LH and the less linguistic the contrast (e.g., higher pitch to indicate joy), the more it is associated with the RH.

As most of the limited evidence points to LH processing for emblem-like sounds, environmental sounds, and even pantomimes, it seems likely that *vocal* emblems, which include agreed-upon phonological forms, would be processed primarily in the language areas, consistent with Dietrich et al.'s (2008) findings. On the other hand, if bilateral or RH representation characterizes onomatopoetic sounds (Hashimoto et al., 2006), and utterances that are dependent on intonation (Dietrich et al., 2008) and interjections such as *wow* may be preserved in individuals with aphasia (Van Lancker Sidtis, 2008), processing VEs may require more extensive RH activation.

The aim of this study was to address the question of whether processing of VEs is analogous to the processing of words (relying primarily on the LH) or whether more RH participation is evident (as is the case for nonlinguistic intonation). Our goal was to employ classic neurolinguistic subtractive reasoning to further elucidate hemispheric responsibilities for processing such category-defying sounds.

The comprehension of VEs by two groups of participants with brain damage was investigated: individuals with exclusively LH damage affecting the language areas, and individuals with predominantly RH damage.[2] Their comprehension was compared to that of a Control group of age-matched participants with no brain damage. The project consisted of two tasks to determine participants' abilities to comprehend VEs. The picture task investigated whether participants could indicate the appropriate setting in which they would expect to hear each emblem. The response sheet consisted of pictorial (photographic) materials, as we assumed that the ability to point to photographs would be spared for participants with left brain damage (LBDs). The phrase task evaluated participants' comprehension via verbal translation of the VEs, as we assumed that the required verbal skills would be spared for individuals with right brain damage (RBDs).

We hypothesized, based on the research reviewed above, that RBDs would score more accurately overall than the LBDs and less accurately than Controls. That is, regardless of the modality of response (pictures or phrases), the processing of VEs is likely to be more robustly represented in the LH than in the RH and therefore to be most difficult to comprehend for LBDs – especially those with lesions compromising their verbal comprehension. However, because bilateral representation may also occur with VEs, and processing emblems that have stronger affect might recruit regions in the RH, RBDs were expected to perform less accurately than Controls on both tasks. As well, we predicted that RBDs would perform more accurately on the phrase task than on the picture task and that LBDs would perform more accurately on the picture task than the phrase task, simply because verbal responses are less difficult for individuals with RBD than individuals with LBD, and the reverse is true for pictorial material.

We asked whether specific items would differentiate the two brain-damage groups, either differentiating between those VEs with vs. without emotion as Dietrich et al. (2008) had, or between VEs that are instrumental vs. expressive (Gallagher & Frith, 2004) or provocative vs. not (Knutson et al., 2008) or social vs. facial, as Montgomery and Haxby (2008) suggested. As well, we considered whether error patterns would distinguish the two groups. We predicted that the errors of the LBDs would be more different from any made by Controls than would those of the RBDs.

METHODS

Participants

Two experimental groups with focal hemispheric damage (left or right), namely, five dextral LBDs with moderate–severe Wernicke's aphasia, five dextral RBDs and a control group of five normal healthy adults were included in the study (see Tables 1 and 2 for their individual and group demographic data and Table 3 for the stroke and neurological information). Table 4 lists the Boston Diagnostic Aphasia Examination (BDAE)-Short Form (Goodglass, Kaplan, & Barresi, 2001) scores of the participants with brain-damage on the comprehension and other subtests, to demonstrate the deficits in comprehension in the LBD relative to those of the RBDs, who performed very accurately on almost all of the subtests.

Participants were included based on the following criteria: having spoken American English for most of their life,[3] demonstrating normal hearing for conversational purposes,[4] good vision (or corrected), no prior neurological or psychiatric history (apart from RBD 5; see footnote 3), and sufficient comprehension to follow directions (based on a recent speech-language pathologist report and performance on the BDAE-Short Form [Goodglass et al., 2001] comprehension subtests). Additionally, all control participants

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[2] All RBD participants except #5 had exclusively right damage; Participant 5 had a minor stroke six years prior to our testing, which had resulted in temporary right-sided weakness but had no consequences for his language abilities. We included him in the study when our analyses indicated his scores were within the range of the other RBDs.

[3] Four of our RBDs (though none of our LBDs) were multilingual. Because their performance as individuals and as a group was significantly superior to that of the LBDs, we have to assume that their non-monolingual status did not impair their performance on the VEs. One of these multilingual patients in the RBD group (#5) had not spoken substantial English until he immigrated to the U.S. at age 30. Recall that as well, he had had a minor stroke with mild right-sided weakness, which resolved completely. We included him as his data fell within the range of the other RBD participants.

[4] Two or three participants in each of the three groups did not pass the hearing screening at 50dB at all frequencies in the speech range. When addressing within-group comparisons, we determined that these individuals did not perform the least accurately in their group. Crucially, poor hearing scores did not preclude excellent performance on the VE tasks by Controls 3 and 4, nor for RBDs 1, 2 and 3, so we conclude that poor hearing cannot be the cause of the poor performance by LBDs 2 and 3.

TABLE 1
Individual Participant Background Information

Group	*Ps*	*M/F*	*Age*	*Ed*	*Bilin*	*MMSE*	*Hand*	*Hearing*	*Vision*
LBDs	L1	F	65	12	No		R	Pass	Glasses
	L2	M	57	19	No		R	Fail at 4K AS	Right hemianopia
	L3	M	70	8	No		R	Fail at 2K and 4K AS	Glasses
	L4	F	78	14	No		R	Pass	Glasses
	L5	M	68	16	No		R	Pass	Glasses
RBDs	R1	M	70	19	Yes-German, Hebrew, Yiddish, French, Spanish		R	Fail at 500, 1K, 4K AS & AD	Glasses
	R2	F	87	7	No		R	Fail at 500, 1K, 4K AS and AD	Glasses
	R3	M	75	16	Yes-Spanish		R	Fail at 1K, 4K AS and AD	Glasses
	R4	F	82	12	Yes-Yiddish		R	Pass	Glasses
	R5	M	60	12	African languages: L1=Hausa, Shanti, Tri, Ga, and L2=English from age 30		R	Pass	Glasses
Control	1	F	77	19	No	30-pass	R	Pass	Glasses
	2	M	82	19	No	30-pass	R	Pass	Glasses
	3	F	76	16	No	30-pass	R	Fail at 4K (both)	Glasses
	4	F	77	16	No	30-pass	R	Fail at 4K (both)	Glasses
	5	M	83	19	No	28-pass	L	Pass	Glasses

Key: Ps = participant number, Age (in years), M/F = male/female, Ed = education in years, Bilin = bilingual status, MMSE = *Mini-Mental State Examination,* conducted only for the Control group; passing score was 26 out of 30 points, Hand = handedness, L = left-handed, R = right-handed, Hearing = hearing screening (pass < 50 dB, fail > 50 dB; K = 1000 Hz, AD = right, AS = left, both = both ears), Vision (self-report).

passed the Mini-Mental State Exam (MMSE) (Folstein, Folstein, & McHugh, 1975), with scores greater than 26, indicating normal functioning of speech-language and memory skills. Site of lesion in the groups with brain damage was determined on the basis of clinical findings and supplemented by neuroradiological data, e.g., magnetic resonance imaging (MRI) or computerized tomography (CT) scans. Each participant group with brain damage consisted of three males and two females; the control group consisted of two males and three females.

LBDs and RBDs were recruited from various hospitals, nursing homes, and outpatient facilities in the northeastern region of the USA. The authors' colleagues, e.g., speech-language pathologists, neurologists, and/or other allied health professionals, facilitated the recruitment process by referring patients directly to the researcher or distributing fliers with detailed information of the study to potential participants. Written consent was given by participants in order for them to take part in the study. Monetary compensation was provided for their participation.

Gender distribution, age (mean: LBDs: 68, RBDs: 75, Controls: 79 years), and years of education (mean: LBDs: 14, RBDs: 13, Controls: 18) were similar across the three groups. Fisher's exact tests (one-tailed) were conducted and found to be not significant when comparing: LBDs vs. Controls (Gender: $p = .500$, Age: $p = .103$, Education: $p = .262$), RBDs vs. Controls (Gender: $p = .500$, Age: $p = .500$, Education: $p = .262$), and LBDs vs. RBDs (Gender: $p = .738$, Age: $p = .500$, Education: $p = .500$).

Procedures

Before a meeting was scheduled with a potential participant, a telephone screening was conducted to assure his or her appropriateness for the study. Prior

TABLE 2
Group Background Information

Participants	*LBDs*	*RBDs*	*Controls*
Gender	3 M, 2 F	3 M, 2 F	2 M, 3 F
Age			
Mean (SD)	67.6 (7.6)	74.8 (10.5)	79 (3.2)
Median (Range)	68 (78–57)	75 (87–60)	77 (83–76)
Education			
Mean (SD)	13.8 (4.1)	13.2 (4.5)	17.8 (1.6)
Median (Range)	14 (19–8)	12 (19–7)	19 (19–16)
MMSE			
Mean (SD)	NA	NA	29.6 (0.9)
Median (Range)			30 (30–28)

Key: Standard deviations in parentheses, LBDs = participants with left brain damage, RBDs = participants with right brain damage, M = male, F = female, Age (in years), Education (in years), MMSE, Mini-Mental State Examination (for control group only, passing score was 26 out of 30 points), NA = not applicable).

to the experiment, the first author gathered further information by speaking with the participant or family member and conducting a hearing screening, using a Welch-Allyn audioscope. Participants with brain damage were then administered the auditory and reading comprehension subtests of the BDAE-Short Form (Goodglass et al., 2001), to assess their level of severity and type of aphasia and to ensure adequate comprehension at the word and phrase level. The control group was administered the MMSE (Folstein et al., 1975) to ensure normal functioning of speech-language and memory skills.

For the experimental testing, we explained what we meant by the term ‘emblem’ and gave several examples that were not included among the stimuli.

Task 1: Picture task

In Task 1, the picture task (emblem-to-photograph matching), the researcher presented an emblem sound (e.g., *shh*) that was then followed by four photographs: a photograph of an appropriate setting (e.g., a library) and three other photographs (e.g., different vocal emblem settings such as snow, which would serve as the photograph for *brr*). Participants were given the following instructions: ‘You will hear an emblem. Then you will see four pictures. Please point to the picture that shows a situation in which you would expect to hear the emblem’. The researcher recorded participants’ choices on a scoring sheet.

Task 2: Phrase task

In Task 2, the phrase task (emblem-to-written stimulus matching), presentation of an emblem sound (e.g., *shh*) was followed by four phrases written on separate cards (e.g., ‘Be quiet’, and three other foils of phrases describing different VEs, e.g., ‘I’m thinking’, ‘That stinks’, ‘That’s disgusting’). The researcher gave the following instructions: ‘You will hear an emblem. I will then show you four cards with different phrases. Please point to the phrase that best describes what the emblem means’.

For both tasks, five practice items were first given before the test items, in order to familiarize the participant with the experimental task. As well, appropriate modifications were made, particularly

TABLE 3
Participant Stroke/Neurological Information

Group	*Ps*	*Severity*	*TPO*	*Localizing Information*	*Prior Neurological History*
LBDs (Wernicke):	L1	Mild-Moderate	1	LH	No
	L2	Severe	12	L-MCA	No
	L3	Severe	5	LH	No
	L4	Severe	24	L-craniotomy	Yes-tumor left temporal
	L5	Severe	32	L-frontal	No
RBDs:	R1	Moderate	160	RH	No
	R2	Mild-Moderate	3	R-frontal	No
	R3	Mild	1.5	R-MCA	No
	R4	Mild-Mod	60	R-perisylvian	No
	R5	Mild	2	RH	Mini-stroke

Key: Ps = participants, LBDs = participants with left brain damage, RBDs = participants with right brain damage, L = left, R = right), Severity = of aphasia (mild, moderate, severe), TPO, time post onset in months, localizing information (left hemisphere (LH) or right hemisphere (RH); middle cerebral artery (MCA).

TABLE 4
Participant Scores and Group Mean, and Standard Deviation, Median, and Range on the *Boston Diagnostic Aphasia Examination (BDAE)-short form*

				RC:					
Participants	*AC: BWD (16)*	*C (10)*	*CIM (6)*	*BSR (8)*	*P-WM (4)*	*BOWR (15)*	*ORS (5)*	*Comp (3)*	*SP (4)*
L1	16	8	3	6	3	15	4	2	3
L2	7	0	2	8	1	3	0	2	3
L3	7	2	0	8	2	0	0	1	3
L4	10	2	0	8	4	12	1	0	1
L5	13	2	1	8	4	15	3	1	3
Mean (SD)	10.6 (3.9)	2.8 (3.0)	1.2 (1.3)	7.6 (0.9)	2.8 (1.3)	9 (7.0)	1.6 (1.8)	1.2 (0.8)	2.6 (0.9)
Median (Range)	10 (16–7)	2 (8–0)	1 (3–1)	8 (8–6)	3 (4–1)	12 (15–0)	1 (4–0)	1 (2–0)	3 (3–1)
R1	16	10	6	8	4	15	5	3	4
R2	15.5	9	3	8	3	15	5	2	3
R3	16	10	5	8	4	15	5	3	4
R4	15	10	5	8	3	15	5	2	3
R5	15	9	2	8	3	15	4	0	3
Mean (SD)	15.5 (0.5)	9.6 (0.5)	4.2 (1.6)	8 (0)	3.4 (0.5)	15 (0)	4.8 (0.4)	2 (1.2)	3.4 (0.5)
Median (Range)	15.5 (16–15)	10 (10–9)	5 (6–2)	8 (8–8)	3 (4–3)	15 (15–15)	5 (5–4)	2 (3–0)	3 (4–3)

Key: Auditory comprehension (AC) subtests: Basic Word Discrimination (BWD), Commands (C), Complex Ideational Material (CIM), Reading comprehension (RC) subtests: Basic Symbol Recognition (BSR), Picture-Word Matching (P-WM), Basic Oral Word Reading (BOWR), Oral Reading of Sentences (ORS), Comprehension (Comp), Sentences and Paragraphs (SP)
Minimum score is zero and maximum score for each subtest is in parentheses.

for the LBDs, e.g., simplified instructions with added gestures were given if the participant was demonstrating difficulty understanding the standard version of task directions. Furthermore, if modifications for the phrase task were needed, e.g., if individual participants were unable to read the phrases, the researcher read the written phrases aloud to them, asking after each if it was the correct answer for the emblem they had heard. Lastly, all stimuli were arranged for some RBD participants in a vertical fashion, although no visual neglect was reported for any of them.

Stimuli

For both tasks, after the 5 practice items, 24 test items were given (see Appendix A for the complete list of VE practice and test items). The stimuli used in the study were selected based in part on vocal versions of emblems collected by Johnson, Ekman, and Friesen (1981). The VE items were recorded on a CD at a loudness level of 20 dB root mean square (rms) below full scale, except for two items, *psst* and *shh*, which were normalized to 30 dB below full scale for better audibility. These two stimuli sounded more natural at the lower level, as these are typically low-intensity sounds. The loudness level of all spoken phrases was equalized at 25 dB below full scale. The VEs were presented to the listeners by the researcher via a CD player and speakers to amplify the sounds as needed. The participants were able to listen to the VEs again, as often as necessary to make a decision (which required mostly one to two repetitions), and, if needed, a verbal model was provided to supplement the CD recording.

The response sheets consisted of either color photographs (for the picture task) or verbal phrases that were written on large white index cards (for the phrase task).

Statistical analysis

The statistical analyses conducted involved the following: first, a median test was performed on the combined results from both groups on each of the picture and the phrase tasks. For each task, we ranked, then split the data at the median, to determine how many participant scores from each group fell above or below the median. Then a non-parametric Fisher's exact test was conducted as it is used to compare small samples, namely when frequency data in each cell is five or less. A 2 × 3 Fisher's exact test (two-tailed, $p < .05$) was calculated to compare the three groups on each task. When a significant difference was found, further analysis included a comparison of each two-group comparison using a 2 × 2 table (one-tailed, $p < .02$) in order to identify between which two groups the difference lay. A stricter criterion for significance was set ($p < .02$) for the follow-up 2 × 2 calculations in order to exclude Type I errors. Additionally, within-group differences, of performance on the two tasks, were calculated for each group using a 2 × 2 Fisher's exact test.

RESULTS

Findings revealed that the Controls made errors (on six items in the picture task: *ah-ha*, *huh*, *uh-uh*, *whoops*, *ow*, *uh-huh*, and two items on the phrase task: *nanananana* and *uh-uh*), we considered that the items on which their errors were made were problematic. Indeed, on all but one of these erred-on items, at least one brain-damaged patient had made an error as well. Furthermore, in eight out of the nine errors made by the Controls, there was at least one participant with brain damage who also erred on that item in the same modality, and in seven out of the nine errors at least one participant from each brain-damage group erred. This suggests that these items were confusing and/or that they may have more specific and defined meanings making them more prone to errors. We thus eliminated those items from their respective tests in order to fairly compare the performance of the participant groups. Thus ceiling performance for the Controls was a score of 18 for the picture task and 22 for the phrase task. (Table 5 shows each participant's scores after removing the items that the Controls erred on.)

For each group comparison, the median test ranked data are presented in Table 6. A 2 × 3 Fisher's exact test (two-tailed, $p < .05$) resulted in the following.

Statistical findings

Between-group findings

Results of the 2 × 3 Fisher's exact test revealed a significant difference among the three groups (LBDs, RBDs, and Controls) on both the picture ($p = .02$) and phrase ($p = .002$) tasks. Follow-up testing of 2 × 2 calculations was conducted on the picture and phrase data separately to identify where the difference lay. Results revealed that on the picture task, the LBD group ($p = .004$) and RBD group ($p = .004$) performed statistically less accurately than the Controls, but there were no significant differences between the LBD and RBD groups ($p = .500$) (see Figure 1). On the phrase task, there were significantly lower scores for the LBD group than the Controls ($p = .004$) and the RBD group ($p = .02$), but the RBDs did not perform significantly differently from the Controls ($p = .222$).

In sum, the statistical findings revealed that the LBDs performed less accurately than the Controls

TABLE 5

Group Performance on the Vocal Emblem Tasks After Removing Items (Six on the Picture Task, and Two on the Phrase Task) that the Controls Erred on from an Original Sample of 24 Test Items. Scores (number correct and percent correct) for participants with left brain damage (LBDs), right brain damage (RBDs), and matched-Controls, on the vocal emblem picture and phrase tasks. All the LBDs performed more accurately on the picture, than phrase task, while all the RBDs (except RBD 4) performed more accurately on the phrase, than picture, task.

Participant	*Picture Task: Number correct*	*Percent correct: %*	*Phrase Task: Number correct*	*Percent correct: %*
L 1	13	72	15	68
L 2	17	94	16	73
L 3	14	78	14	63
L 4	13	72	11	50
L 5	9	50	10	45
Mean (SD)	13 (2.8)	73 (15.8)	13 (2.6)	60 (11.9)
Median(Range)	13 (17–9)	72 (94–50)	14 (16–10)	63 (73–45)
R 1	15	83	22	100
R 2	13	72	19	86
R 3	16	89	22	100
R 4	16	89	16	72
R 5	12	67	16	72
Mean (SD)	14 (3.8)	80 (21.1)	19 (5.4)	86 (24.3)
Median(Range)	15 (16–12)	83 (89–67)	19 (22–16)	86 (100–72)
Controls	18 (0)	100 (0)	22 (0)	100 (0)

TABLE 6
Ranked Scores of the Group Comparisons and the Number of Participants Scoring Above the Median (5 Participants/Group) on Both Tasks, After Items on Which Controls Made Errors were Removed

Group Comparisons:	*LBDs*	*RBDs*	*LBDs and RBDs*	*LBDs and Controls*	*RBDs and Controls*	*LBDs, RBD,s, and Controls*
Scores:	9	12	9	9	12	9
	10	13	10	10	13	10
	11	15	11	11	15	11
	13	16	12	13	16	12
	13	16	13	13	16	13
	14	16	13	14	16	13
	14	16	13	14	16	13
	15	19	14	15	18	14
	16	22	14	16	18	14
	17	22	15	17	18	15
			15	18	18	15
			16	18	18	16
			16	19	18	16
			16	22	18	16
			16	22	18	16
			16	22	22	16
			17	22	22	17
			19	22	22	18
			22	22	22	18
			22	22	22	18
						18
						22
						22
						22
						22
						22
						22
Median:	13.5	16	15	17.5	18	16
Range:	17–9	22–12	22–9	22–9	22–12	22–9
PICTURE TASK: # of LBDs performing above the median	2	1	0	1		
# of RBDs performing above the median	0	2	0	2		
PHRASE TASK: # of LBDs performing above the median	3	1	0	0		
# of RBDs performing above the median	3	5	3	3		

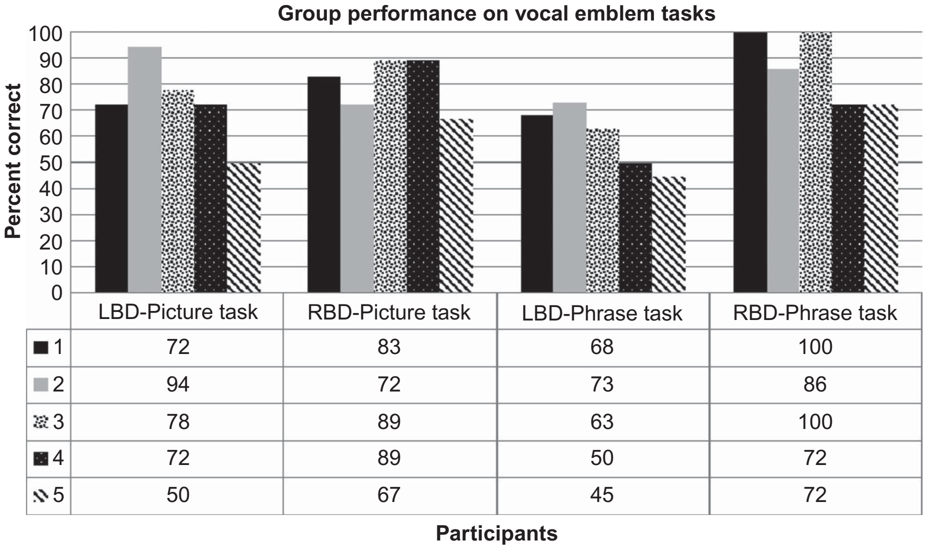
Key: bold = median scores, LBD=left brain damage, RBD=right brain damage; The Controls performed at ceiling (Score of 18 on the picture task and 22 on the phrase task). Maximum possible score is 18 on the picture task and 22 on the phrase task.

on both tasks and less accurately than the RBDs only on the phrase task; the RBDs performed less accurately than the Controls only on the picture task.

Within-group findings

Results of the 2 × 2 Fisher's exact test, comparing performance on task (picture, phrase) for each group, revealed no significant differences for the LBDs ($p = .897$) although the RBDs approached significance ($p = .080$). Thus the LBDs performed consistently across the two VE comprehension tasks, regardless of modality of presentation (picture or phrase), while the RBDs tended to perform more accurately on the phrase task than the picture one (see Figure 1).

Next, we compared the LBD and RBD groups' performance each in their better response-modality (i.e., the verbal task for RBD and the phrase task for RBD), examining both group and individual performance in order to reduce response-modality effects and focus on VE comprehension. Again, we considered performance only on those items on



	LBD-Picture task	RBD-Picture task	LBD-Phrase task	RBD-Phrase task
■ 1	72	83	68	100
▒ 2	94	72	73	86
▨ 3	78	89	63	100
▩ 4	72	89	50	72
▧ 5	50	67	45	72

Figure 1. Scores of Participants with Left Brain Damage (LBDs) and Right Brain Damage (RBDs) on the Picture and Phrase Vocal Emblem Task

Performance (percent correct) on each vocal emblem task (picture, phrase) between and within groups (LBDs vs. RBDs) is shown. Overall, participants between groups performed similarly on the picture task but differently on the phrase tasks, and participants within each group performed similarly on the picture and phrase tasks, although the RBDs tended to do better on the phrase, as compared to the picture task (with exception of RBD 4).

which all the Controls performed at 100%. In this analysis, we used percentages because, once the control group-error data were removed, there were different numbers of items for the two response-modalities, namely 18 and 22 on the picture and phrase tasks, respectively.

Median scores for the LBDs in their better response modality (picture task) averaged 72%; for the RBDs in their better modality (phrase task), averaged median was 86% (and the Controls are, by definition in this analysis, at 100%) (see Table 7). By this analysis, too, the performance of the RBDs as a group was closer than that of the LBDs to that of the Controls (two RBDs performing the same as the Controls), while the performance of the LBDs as a group (even in their better modality), was less accurate than that of the Controls. This analysis suggests that the LBDs were less accurate in their better modality (pictures) than the other two groups: the RBDs in their better modality (phrases) and the Controls, who, were at 100% correct for both response modalities.

When we compared individuals' percentages correct in each response modality within the groups, we found that all five LBDs performed more accurately on the picture task than on the phrases. For the RBDs, all except RBD 4 showed the opposite performance, i.e., better performance on the phrase task than the picture task. (RBD 4: picture 89%, phrases 72%, see Figure 1). None of the demographic or comprehension measures differentiated RBD 4 from the rest of the RBD participants, however.

Item analysis

An error analysis permitted us to test the extent to which between-item differences might account for the group findings. Recall that Dietrich et al. (2008) found certain German emblems (i.e., those they said bore intonation) to rely more on the RH – resulting in bilateral processing, than items that did not have intonation. However, we abandoned our attempts to divide our (American English) emblems into the categories of 'plus intonation' and 'minus intonation' for the following reasons: Because intonation is carried by vowels, all of the VEs that include vowels (e.g., in *ta*-*da*) could contain intonation. As all of our VEs with vowels seem to be produced with a characteristic intonation and/or vocal quality (e.g., the *da* in *ta*-*da* is frequently sung), none could be assigned to the 'minus intonation' category. Even the few American English VEs that do not contain vowels and therefore cannot be said to possess intonation (e.g., *shh*) need to be produced in a particular manner.

TABLE 7
Median and Range Scores for Participants with Brain Damage in their Better Response Modality

Group	*LBDs' Scores (%) on Picture Task*	*RBDs' Scores (%) on Phrase Task*	*Controls' Scores (%)*
	50	72	100
	72	72	100
	72	86	100
	78	100	100
	94	100	100
Median Score:	72	86	100
Range Score:	94–50	100–72	100–100
Number of Participants Scoring similar to Controls:	0	2	

The left brain damage group (LBDs) in their better response modality (picture task) averaged 72% and the right brain damage group (RBDs) in their better modality (phrase task) averaged 86%. This analysis reveals that even in their better modality, the LBDs perform even less accurately than the RBDs (in their better modality) and the Controls.

For example, the production of *shh* is not simply the production of the palatal fricative – its duration is longer than the sound spelled *sh* in 'typical words', and lips are more rounded (and the emblem is accompanied by a serious facial expression). Thus dividing the VEs into those with and without intonation did not appear to characterize the items adequately.

Instead, in order to explore item-type differences that might be explained by provocativeness, social function, or an instrumental vs. expressive dichotomy, we divided the items into those on which two or more participants (e.g., 2 vs. 5, 3 vs. 1), within each brain-damage group for each response-modality separately, performed differently. Then we compared the groups for the items on which such a difference was obtained, reasoning that if specific VEs discriminated the groups, while others did not, we would see similar items discriminating the groups for both response modalities. The only overlap was the word *huh?*; thus, the patterns yielded are not likely to be due to performance on the individual VE items, nor any of the characteristics mentioned at the beginning of this paragraph, but, rather, to performance on the VE-processing task more generally.

We also divided the items for each group into those items that seemed easy (i.e., four or five [out of five] participants performed correctly on both tasks for that item) or difficult for the group (i.e., zero to two participants performed correctly on both tasks), which would eliminate response modality as a factor and permit us to consider classifying those specific VE items that were particularly easy to comprehend from those that were particularly difficult. The items that were particularly easy for the LBDs by this measure (*ouch*, *ow*, *ew*, *yaay*, and *yuck*) are a subset of the items that were particularly easy for the RBDs (*ouch*, *ow*, *ew*, *yaay*, *yuck*, *shh*, *ta-da*, *wow*, *wolf-whistle*, *yum*, *ich*, *ummm*, *brrr*). There were remarkably few items that were particularly difficult across modalities by this measure. For the LBDs, only *uh-oh* and *uh-huh* were difficult across modalities. For the RBDs, none were. For the Controls, there were no difficult items by this measure – all items would have counted as 'easy' for them.

Confusion matrix analysis

We examined the confusion patterns of errors made by LBDs and RBDs to those made by the Controls. The goal was to see if there were distinctive patterns of substitutions that would discriminate between the two brain-damage groups. The LBDs were far more consistent in their substitutions than were the RBDs, e.g., there were nine instances of the same confusion by different LBDs (*darn → aha; nanananana → ich; uh-uh → nanananana; huh → brr; uh-huh → ouch; shh → hmm; ta-da → whoops; nanananana → ow; umm → yuck*) and only one instance of the same confusion for RBDs (*hmm → ahem*).

DISCUSSION

This study examined the processing of VEs, utterances that appear word-like in their sound-meaning correspondence, but non-word-like in that they defy languages' phonological, morphological, and syntactic constraints, and rely more on intonation and on physical gestures than do typical words. RH vs. LH involvement in processing VEs was examined by the participation of LBDs, RBDs, and Controls in a picture task and a phrase task in which they were asked to match VEs (presented auditorily) with photographs depicting settings where they would expect to hear the emblem and with verbal translations respectively. The LBDs performed significantly less accurately than the Controls on both tasks and significantly less accurately than the RBDs only on the phrase task. The poor performance (73% on the pictures, and 60% on the phrases) by the LBDs was consistent even on the task in their better modality (i.e., 73% accuracy on the picture task). This suggests that the LBDs' lower performance is an indication of their difficulty in processing the VEs overall, and not simply an indication of difficulty with a response modality. Thus, it may be concluded that processing of VEs recruits primarily the LH, consistent with the findings of Dietrich et al. (2008) for German interjections and Xu et al. (2009) for emblem gestures.

The RBD group, however, performed significantly less accurately than the Controls only on the picture task, the task with which they were expected to have more difficulty. This is likely due to the more holistic processing requirements of the picture task, as such processing is an impairment characteristic of individuals with RBD. Their performance in their better modality, the phrase task, was not significantly different from Controls, as expected. Taken together, this suggests that the RBDs' lower performance on the picture task might be due to their difficulty with the response modality and not to VE processing, per se.

Van Lancker Sidtis's (2008) observation of *wow* production preserved in individuals with LBD but not by individuals with RBD or subcortical lesions, and other evidence pointing to RH and bilateral representation for emblem-like utterances, suggested that individual VEs might have different lateralization from regular words. However, we find no evidence for this, for comprehension, at least. That is, our item analysis revealed no specific characteristics of VEs associated particularly with LBDs or RBDs, but, rather, that the LBDs made more consistent substitutions and ones that truly indicated lack of comprehension than did the RBDs. Thus, on the continuum proposed by Van Lancker (1980), VEs appear to be markedly more toward the language end than the non-language communication end.

With respect to heterogeneity of hemispheric lateralization for specific items, or item clusters (instrumental vs. expressive; social vs. provocative; high vs. low affect) as proposed by various authors discussed in the Introduction, recall that our item-analysis (in which we divided the items into those on which two or more participants had performed differently) revealed that only one item occurred on both lists. This suggests that our findings arose not because certain VE items were differently processed in the two hemispheres, but rather because the LBDs generally have more difficulty processing VEs than do RBDs.

Furthermore, the results from the confusion matrix revealed a sole RBD error: substitution of *ahem* for *hmm*. This might be considered an expected confusion – these two VEs have similar phonetic properties and are not as clearly associated with delineated specific meanings as are VEs such as *shh*. In contrast, the confusions made by the LBDs are ones that seem less 'confusable', e.g., *uh-huh* (meaning 'yes') with *ouch* (meaning 'it hurts'). This could bolster our argument that the LBDs truly did not understand the meaning of these VEs, whereas this likely cannot be said about the RBDs based on their confusion pattern.

In working with patients with moderate–severe Wernicke's aphasia, clinicians often focus on stimulating language comprehension and expression to their maximal potential, while simultaneously counseling family members regarding the best way to encourage successful communicative interactions. The research presented here aimed at discovering whether LBD patients with language-comprehension difficulties would comprehend the communicative meaning of VEs, despite their moderate–severe comprehension deficits. It was anticipated that if success in understanding VEs, such as *shh* and *brr*, was demonstrated on either of the experimental tasks, then this would suggest that the linguistic information was being processed through the brain's nonlinguistic channels and thus VEs would prove a valuable complement for activities of daily living communicative exchanges. Our research findings are consistent with the notion that patients with moderate–severe

Wernicke's aphasia process VEs as they do language, regardless of task (linguistic vs. nonlinguistic). Thus, clinicians using compensatory strategies to facilitate patients' understanding of linguistic information would likely need to do the same for facilitating comprehension of these very basic forms of symbolic sounds. It is possible, though, that presenting 'provocative' emblems (Knutson et al., 2008) with exaggerated intonation (Dietrich et al., 2008) would render them easier to understand.

A limitation of our study is the small number of participants in each group and the relatively wide range of scores within the groups. To the extent that our item- and individual-analyses converge with our group analyses, however, our findings are supported. Further limitations of this study are that some of our participants had hearing losses and were not monolingual, as described in footnotes 3 and 4. Replication with more normal-hearing monolinguals would be desirable.

Neuroimaging techniques, too, could provide converging evidence of performance on vocal-emblem tasks and should circumscribe regions within the LH – which may or may not overlap fully with those for regular lexicon – that are involved in comprehending VEs. Studies of production of VEs by patients with brain damage should complement our study of comprehension of this class of communication items. Additionally, the exploration of VEs cross-linguistically would prove interesting in several regards. Different languages employ different sets of VEs, and it is possible that these reflect different subtypes in languages other than English. Languages with tone, too, might integrate intonation into their VEs somewhat differently from the way non-tone languages do, and studying VEs in such languages would, thus, further our understanding of processing of this class of sounds based on intonation characteristics.

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APPENDIX A

List of vocal emblem practice and test items

5 Practice items:	*24 Test items:*
1. Hey	1. Ah-ha
2. Phew	2. Shh
3. Boo	3. Ich
4. Ah	4. Ta-da
5. Pss	5. Darn
	6. Huh?
	7. Nanananana
	8. Ahem
	9. Pee-uw
	10. Uh-uh
	11. Wow
	12. Umm
	13. Brr
	14. Wolf whistle
	15. Ouch
	16. Uh-oh
	17. Hmm
	18. Whoops
	19. Ow
	20. Yum
	21. Ew
	22. Uh-huh
	23. Yaay
	24. Yuck