Brain and Language **70,** 287–293 (1999)
Article ID brln.1999.2153, available online at http://www.idealibrary.com on IDEAL®

NOTES AND DISCUSSION

Laterality Effects in the Processing of Syllable Structure

Judith Meinschaefer,* Markus Hausmann,† and Onur Güntürkün†

**Sprachwissenschaftliches Institut and †AE Biopsychologie, Ruhr-Universität Bochum, D-44780 Bochum, Germany*

Recent phonological research has shown that the syllable plays a major role in the phonology of German. The present study investigates laterality effects in the processing of syllable structure by means of dichotic presentation of German word pairs that differ in number of syllables, but that differ minimally in the phonemes they comprise (e.g., BREIT and BEREIT). Results showed a sex difference in laterality for the processing of the experimental stimuli, with a greater right-hemispheric lateralization in men and a more bilateral organization in women.

Key Words: language; syllables; speech perception; sex differences; hemispheric asymmetries.

INTRODUCTION

It is a long-known fact that various aspects of speech and language processing are lateralized in the human brain, with phonemic processing predominantly activating left-hemispheric neural substrates (Studdert-Kennedy & Shankweiler, 1970) and prosodic processing assumed also to involve right-hemispheric areas of the brain (Blumstein & Cooper, 1974; Weintraub, Mesulam, & Kramer, 1981; Shipley-Brown, Dingwall, Berlin, Yeni-Komshian, & Gordon-Salant, 1988). The present study addresses the question of whether laterality effects can be demonstrated for the processing of aspects of syllable structure in native speakers of German.

Address correspondence and reprint requests to Judith Meinschaefer at Fachgruppe Sprachwissenschaft, Fach D 185, Universität Konstanz, D-78457 Konstanz, Germany. Fax: +49-7531-88-4160. E-mail: judith.meinschaefer@uni-konstanz.de.

Supported by the Deutsche Forschungsgemeinschaft through its graduate program KOGNET and its Sonderforschungsbereich NEUROVISION. We also wish to thank Dr. Susanne Sterbing for technical assistance with the recording of the stimuli, and two anonymous reviewers for helpful comments on an earlier version.

0093-934X/99 $30.00

Based on analyses of the nondistinctive neutral vowel in German, whose distribution is determined by the syllable structure of a sequence of phonological segments (as in alternations like atm*e*n ‘‘to breathe’’ and At*e*m ‘‘breath’’), it has been argued that the syllable is a relevant category in the phonology of German (Giegerich, 1985; Hall, 1992; Wiese, 1996). This raises the possibility that speakers of German reconstruct the syllable structure of a word or sentence in language comprehension.

However, it must be noted that in German the syllable structure is predictable from the phonemic structure of a word and lexically not distinctive. In order to test whether a hypothetical syllable-related processing mode may be lateralized, a dichotic listening experiment was conducted, using German word pairs as stimuli that contrasted maximally in their syllabic structure, more precisely in their number of syllables, but that differed minimally in phonemic structure, i.e., that differed in the presence versus absence of a nondistinctive neutral vowel, such as the German words *breit* (‘‘broad’’) and *bereit* (‘‘ready’’).

Under the hypothesis that the right hemisphere is specialized for the processing of nondistinctive features of words and sentences, such as some aspects of sentence prosody, while the left hemisphere is specialized for the processing of distinctive features, such as consonantal place of articulation (Packard, 1986; Moen, 1993), one should expect a right-hemispheric specialization for the processing of lexically nondistinctive syllable-related properties of words. This was tested in the present study.

In previous studies on laterality for language, sex differences have repeatedly been reported, with men usually showing greater lateralization for language than women (McGlone, 1980; Shaywitz, Shaywitz, Pugh, Constable, Skudlarski, Fulbright, Bronen, Fletcher, Shankweiler, Katz, & Gore, 1995; Hausmann, Behrendt-Körbitz, Kautz, Lamm, Radelt, & Güntürkün, 1998). For this reason, the present study will address the issue of whether greater cerebral lateralization for males than for females can also be demonstrated for the specific linguistic function that is investigated here.

METHODS

Subjects

Forty-eight right-handed subjects participated in the study (24 males, mean age 30 years, range 21–37 years; 24 females, mean age 26 years, range 19–37 years). All subjects were students of linguistics or psychology at the University of Bochum. Hand preference was assessed using the Edinburgh Handedness Inventory (Oldfield, 1971). Dextrality and sinistrality are denoted by scores of +100 and −100, respectively. Male subjects possessed a mean laterality quotient of +89 (range 60–100) and female subjects of +87 (range 60–100). All subjects were native speakers of German and reported no hearing difficulties.

Stimulus Material

The test material consisted of eight German word pairs (see Table 1). The two items of each word pair differed in the number of syllables they consisted of, but they differed minimally in

TABLE 1
List of Stimulus Words

Dichotic pair	Word 1, n syllables	Word 2, $n + 1$ syllables
1	Breit	Bereit
2	Braten	Beraten
3	Bleibt	Beleibt
4	Blieben	Belieben
5	Greift	Gereift
6	Grast	Gerast
7	Gleiten	Geleiten
8	Glitten	Gelitten

phonemic structure and stress: both words were made up of the same sequence of phonemes, except for an additional neutral vowel (as the first vowel in the English words *beret, canoe*) in the second word of a pair, and both words were stressed on the same syllable.

For the recording of the stimulus material, all 16 test words were embedded into the same neutral sentence. This list of 16 sentences was read aloud by a female voice four times, recorded in a sound-proof booth with a microphone (Sennheiser MD 735) and a tape recorder (Philips), and then digitized (16 bit, sampling rate 44.1 kHz) with a computer (Power Macintosh 6100/66). The resulting four versions of each of the 16 test words were stored on a computer hard disk. For each dichotic word pair the two most similar (with respect to intonation and length) items were selected out of four recordings for each of the two items of a pair. These two items were digitally edited and synchronized for length and intensity. To minimize the influence of stimulus length on perceived number of syllables, the length of the two items was edited such that the length of the resulting dichotic stimulus lied between the duration of item 1 and item 2. For the dichotic alignment of the stimuli, broadband spectrograms of the stimulus words were calculated and the respective onsets of articulatory release (i.e., onset of aspiration or voice) were synchonized. Besides the alignment of stimulus onset, the offsets of the stressed vowel were synchronized, and the word final consonant sequence was edited to be identical. All stimuli tended to produce a single auditory percept localized in the center of the head. Each dichotic stimulus was preceded and followed by 50 ms of zero intensity. The mean duration of the dichotic stimuli was 503 ms. The duration of the stimuli ranged from 414 to 608 ms.

Procedure

Testing took place in a quiet room and on an individual basis. Before test administration, subjects had to complete the handedness questionnaire. The experiment instructions were presented in written form on the computer monitor. Subjects were naive with regard to the objective of the experiment and were instructed to pay attention to both ears. The stimuli were presented with the same computer as used for digitizing, storage, and editing and a pair of stereo headphones (Sennheiser HD 475). The output was calibrated to 65 dB SPL. In each trial, the dichotic presentation of the stimulus word pair was followed by the visual presentation of the written word forms of the two stimulus words of a pair on the computer monitor, one on each side of the screen. Subjects were instructed to indicate which one of the two visually presented words they had heard by pressing either the left button with their left hand (if they had heard the word which was subsequently presented on the left side of the screen) or the right button with their right hand (if they had heard the word which was subsequently presented on the right side of the screen). Visual displays of the two words were separated by a 3-cm blank space. The two response alternatives remained on the computer screen until the subject

TABLE 2
Conditions in Which Each Dichotic Word Pair Was Presented

	Auditory stimulus		Visual response choice	
Condition	Left ear	Right ear	Left half	Right half
1	Word 1	Word 2	Word 1	Word 2
2	Word 1	Word 2	Word 2	Word 1
3	Word 2	Word 1	Word 1	Word 2
4	Word 2	Word 1	Word 2	Word 1

responded by pressing a key. However, only responses within the first 5 s after onset of visual presentation were scored.

In order to control for word effects and visual field effects on response choice, each of the eight dichotic pairs was presented under four conditions (see Table 2). The experiment consisted of four blocks of 32 trials, resulting in a total of 128 trials. Order of stimulus presentation was randomized for each subject and for each block. Prior to each experiment, 16 randomized practice trials were carried out. Trials were separated by a 300-ms intertrial interval. Headphone orientation was reversed after each block (i.e., after 32 trials, not taking into account the practice trials); half of the subjects started with headphone orientation A (right ear = right channel), and half of the subjects with orientation B (right ear = left channel), resulting in two possible sequences, ABAB and BABA. In order to minimize the influences of word class and word frequency differences between the two words of a dichotic pair on the subject's response choice, the experiment was preceded by the presentation of 64 priming items that were visually presented on the computer screen in randomized order. The visual displays of the priming words remained on the screen until the subjects pressed a key, initiating the presentation of the next word. The list of priming items consisted of (i) the 16 stimulus words. Additionally, for each stimulus word (ii) two related words were included: (a) one semantically related word (e.g., SCHMAL (‘‘narrow’’) for the word BREIT (‘‘broad’’)) and (b) one morphologically related word (e.g., BREITE (‘‘breadth’’) for the word BREIT (‘‘broad’’)). In addition, (iii) eight word pairs (i.e., 16 words) were included whose elements contrasted in the same or a similar way as the stimulus words (e.g., GLEICHT and GELAICHT), but which were not used as stimuli.

RESULTS

For each subject the number of responses to words presented to the left ear and the number of responses to words presented to the right ear was calculated (see Fig. 1). Only responses made within 5 s after the onset of the visual response choice presentation were scored. These scores were subjected to a three-way analysis of variance, with ‘‘sex’’ (male, female) as the between-subjects factor and ‘‘ear’’ (right ear, left ear) and ‘‘word pair’’ (word pairs 1 to 8, see Table 1) as within-subjects factors. The main effects for ‘‘sex’’ and ‘‘ear’’ were not significant (sex, $F(1, 46) = .19$, n.s.; ear, $F(1, 46) = .05$, n.s.). In contrast, the interaction between sex and ear was significant ($F(1, 46) = 7.30$, $p < .01$). The two-way interaction for ‘‘ear’’ and ‘‘word pair’’ and the three-way interaction for ‘‘sex,’’ ‘‘ear,’’ and ‘‘word pair’’ was not significant (all Fs$(1,46) < .91$, n.s.). Subsequently, two separate one-way ANOVAs were conducted for each sex group. While there was

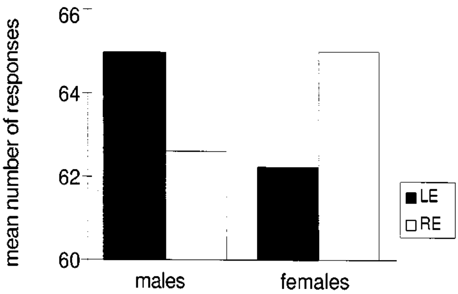

FIG. 1. Mean number of responses to words presented to the left ear (LE) or right ear (RE) for male and female subjects.

a significant effect for the factor ''ear'' in male subjects ($F(1, 23) = 5.69$, $p < .025$), there was no significant difference between both ears for female subjects ($F(1, 23) = 2.92$, n.s.).

In addition, absolute reaction times (measured from the onset of visual response choice display) for reactions to words presented to the left ear and to words presented to the right ear were measured (see Fig. 2). A three-way ANOVA with ''reaction time'' as dependent variable and ''sex'' as between-subjects factor and ''ear'' and ''word pair'' as within-subjects factors revealed no significant main effects or interactions (all Fs$(1, 46) < 2.77$, n.s.), apart from a significant main effect of the factor ''word pair'' ($F(7, 322) = 2.66$, $p < .05$) on reaction times.

DISCUSSION

The main finding was a significant sex difference in laterality for male and female subjects, with greater laterality for the task in males than in females. This result is supportive of the hypothesis of greater cerebral lateralization for receptive and productive language functions in males than in fe-

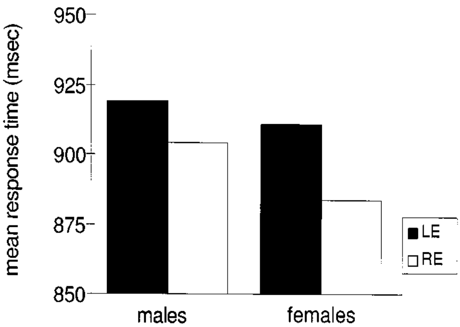

FIG. 2. Mean response time in milliseconds to words presented to the left ear (LE) or right ear (RE) for male and female subjects.

males (McGlone, 1980; Shaywitz, Shaywitz, Pugh, Constable, Skudlarski, Fulbright, Bronen, Fletcher, Shankweiler, Katz & Gore, 1995; Hausmann, Behrendt-Körbitz, Kautz, Lamm, Radelt & Güntürkun, 1998). The results of the present study indicate a right-hemispheric specialization for the task referred to as ''syllabic processing'' in male subjects, and a more bilateral representation of the neural substrates that are activated in female subjects. Thus, the observed ear advantage for males goes into the predicted direction and is consistent with the hypothesis of a right-hemispheric specialization for the processing of nondistinctive aspects of language (Packard, 1986; Moen, 1993). However, the precise nature of the hypothetical syllable-related processing function that was employed in the experimental task remains to be clarified. The observation of a sex difference in laterality should also be seen in the light of strategy effects that have been demonstrated in psycholinguistic studies on the processing of nondistinctive syllable- and stress-related properties of words and sentences, which are assumed to result from the concurrent processing of phonemic and prosodic information (Cutler, Mehler, Norris, & Segui, 1992; Sebastián-Gallés, Dupoux, Segui, & Mehler, 1992). The question of whether the sex differences in laterality which were demonstrated for the task described here might be related to the use of different processing strategies by male and female subjects awaits further experimental research.

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