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Research Report

LEFT-HEMISPHERE ADVANTAGE FOR CLICK CONSONANTS IS DETERMINED BY LINGUISTIC SIGNIFICANCE AND EXPERIENCE

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Abstract—*Left-hemisphere (LH) superiority for speech perception is a fundamental neurocognitive aspect of language, and is particularly strong for consonant perception. Two key theoretical aspects of the LH advantage for consonants remain controversial, however: the processing mode (auditory vs. linguistic) and the developmental basis of the specialization (innate vs. experience dependent). Click consonants offer a unique opportunity to evaluate these theoretical issues. Brief and spectrally complex, oral clicks exemplify the acoustic properties that have been proposed for an auditorily based LH specialization, yet they retain linguistic significance only for listeners whose languages employ them as consonants (e.g., Zulu). Speakers of other languages (e.g., English) perceive these clicks as nonspeech sounds. We assessed Zulu versus English listeners' hemispheric asymmetries for clicks, in and out of syllable context, in a dichotic-listening task. Performance was good for both groups, but only Zulus showed an LH advantage. Thus, linguistic processing and experience both appear to be crucial.*

A central aspect of the neurocognitive specialization for language is the left-hemisphere (LH) superiority for producing and comprehending not only syntax and morphology, but also the phonological elements of speech. Identifying how the relevant neural system handles phonological segments is thus crucial to understanding the biological foundations for human language. The focus of the present report is on the LH advantage for speech perception, which is most clear-cut for consonants (Shankweiler & Studdert-Kennedy, 1967; Zatorre, Evans, Meyer, & Gjedde, 1992). The biological significance of this LH consonant advantage is attested by its presence even in early infancy (Best, Hoffman, & Glanville, 1982; Molfese, Burger-Judisch, & Hans, 1991).

We report findings relevant to two central theoretical debates over the mechanisms of speech perception: a processing-mode debate regarding the general versus specialized nature of the neural system involved and a developmental-origins debate over whether the system's functions are innately determined or are tuned by experience. Both debates lie at the heart of much contemporary research on the neuro-behavioral specializations that permit organisms to respond rapidly and efficiently to biologically significant information. This research includes investigations into the neural bases of visual and auditory attention (Posner & Petersen, 1990), neurosensory plasticity (Rosenzweig & Bennet, 1996), differentiated functions of the cerebral hemispheres (Corballis, 1991), and the neurocognitive basis of language (Caramazza & Hillis, 1991).

Accounts of the LH superiority for consonants diverge along the lines of those two debates.[1] At one side of the processing-mode debate is the view that general-purpose auditory mechanisms are responsible, via selective responsiveness to certain acoustic properties regardless of whether the stimuli are speech or the listener is human (e.g., Diehl & Kluender, 1989). Particularly relevant is a proposed LH auditory specialization for rapid temporal processing of brief, transient, spectrally complex acoustic elements, especially the rapid formant transitions between stop consonants and vowels (e.g., Schwartz & Tallal, 1980). Some researchers have hypothesized that experience with formant transitions in speech tunes this sort of auditory mechanism (Belin et al., 1998).

At the other side of the processing-mode debate lies the view that the LH is specialized for handling specifically linguistic information, including the phonetic features of consonants (e.g., Liberman & Mattingly, 1989). The developmental version of this view is that experience shapes the specialized mechanism's functioning to fit the linguistic properties of the native language (Fromkin, Krashen, Curtiss, Rigler, & Rigler, 1974).

The current study was motivated by a developmental linguistic model positing that language-specific phonological experience constrains perception of nonnative phonemic contrasts according to their degree of phonetic similarity to native phonemes (Perceptual Assimilation Model, or PAM). Nonnative consonants are perceptually assimilated to native categories when possible, being heard as phonological elements and handled as linguistic information. Discrimination is poor when contrasting nonnative consonants are assimilated equally into a single native category, substantially better when they are assimilated as good versus poor members of the category, and excellent when they are assimilated to different categories (Best, 1994). However, certain nonnative consonants may be so discrepant from the native phonological system that they are perceived as nonspeech. Because such cases are processed nonlinguistically, discrimination is good to excellent, depending on general-auditory rather than on phonological distinctiveness (Best, McRoberts, & Sithole, 1988).

Click consonants are such a case. A small number of southern African languages, including Zulu, employ phonologically contrastive clicks, produced by creating a small area of suction in the mouth and releasing it abruptly at the tongue (e.g., "tsk" sound) or lips (e.g., kiss sound), a rapid production akin to that for stop consonants (Ladefoged & Traill, 1994). Such oral clicks constitute nonlinguistic sounds for speakers of languages such as English, who perceive them as nonspeech noises (Best et al., 1988). Thus, clicks have linguistic significance in only a few languages and are heard as consonants only by speakers of those languages. Clicks instantiate the acoustic properties crucial to the hypothesized auditory specialization (Fiez et al., 1995;

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[1] Space constraints limit us to general descriptions; specific published arguments may be more complex and nuanced.

Schwartz & Tallal, 1980): They are brief (<< 50 ms), are spectrally complex, and have rapid acoustic variation. When produced in syllables, they have rapid formant transitions, like stop consonants. However, click bursts can also be produced in isolation or excised from syllables, so that formant transitions are eliminated while the properties of brevity and spectral complexity are retained. Isolating the clicks should enhance their nonspeech quality for nonnative listeners, yet they may remain identifiable as consonants to native listeners.

Thus, click consonants offer an interesting opportunity to evaluate the information processing and developmental bases of the LH consonant advantage.[2] Previous reports of LH processing variations compared consonants differing on critical acoustic dimensions (e.g., Schwartz & Tallal, 1980), confounding hemispheric processing differences with interhemispheric transfer differences for the targeted properties (Shankweiler & Studdert-Kennedy, 1967). Comparing hemispheric asymmetries for clicks in Zulu versus English speakers evaluates speech versus nonspeech perception for acoustically identical stimuli. Moreover, previous research on linguistic experience focused on tonal properties of vowels (Van Lancker & Fromkin, 1973), failing to address the proposed LH specialization for auditory temporal processing (Schwartz & Tallal, 1980).

Differential theoretical predictions can be made about the LH advantage and general performance levels among Zulu versus English listeners. On the one hand, an experience-independent, general-auditory mechanism should yield LH superiority for both groups' perception of the clicks' brief, spectrally complex acoustic features, regardless of perception as speech versus nonspeech, with the caveat that if formant transitions are crucial, both groups should show LH superiority only in syllable context. If a general-auditory LH mechanism is tuned by experience, LH bias for click perception should be seen only in Zulu listeners, especially in the syllable context they usually experience, and they should show higher overall performance than English listeners for clicks in the syllable context. Neither group should show LH or performance-level advantages on isolated clicks because the groups differ negligibly in experience with isolated clicks.

On the other hand, an experience-independent linguistic mechanism should yield LH superiority only for linguistic processing of the clicks, which should be enhanced by the more speechlike syllable context. But if the LH bias is experience dependent, then only Zulu listeners should show this bias, and their overall performance for click syllables should be better than the overall performance of English listeners. Zulus should also show an LH advantage for isolated clicks if and only if they perceive them as consonants. PAM predicts similar overall performance on isolated clicks in either case because English listeners perceive clicks nonlinguistically (Best et al., 1988).

To evaluate these possibilities, we conducted a dichotic-listening test[3] of hemispheric asymmetries for clicks presented in isolation and in syllables. On each trial, different click stimuli were simultaneously presented to the two ears, and recognition of right- versus left-ear targets was assessed. A right-ear advantage is standardly interpreted as LH processing bias, attributed to predominantly contralateral connections between auditory periphery and functionally asymmetrical cortical regions or to a contralateral relation between unilateral attention and asymmetrical hemispheric activation (e.g., Milner, Taylor, & Sperry, 1968).

METHOD

Participants

The listeners were right-handed[4] native speakers of American English, Zulu, or Xhosa.[5] (Zulu and Xhosa are closely related southern African tone languages with identical click consonant inventories; Ladefoged & Traill, 1994.) Americans (8 male, 8 female) had a mean age of 19.4 years (range: 18–28 years). None had any experience with click consonants or African languages. South Africans (5 male, 5 female) had a mean age of 28.3 years (range: 20–35 years); all were fluent in English and several other languages. Informed consent was obtained prior to testing, and participants' rights were protected in accordance with ethical guidelines of the American Psychological Association and American Psychological Society.

Stimulus Materials

A female Zulu speaker was recorded producing click + /a/ nonsense syllables with high tone multiple times for each of the target clicks. We used the nine nonnasal clicks: three places of articulation (dental, lateral, palatal), each with three different voicing values (prevoiced, voiceless unaspirated, voiceless aspirated) (see Fig. 1). Five tokens were selected per category, matched for overall duration, fundamental frequency and contour, and vowel quality. All syllables were waveform-edited to 285 ms. Voice onset times ranged from 31 to 35 ms for prevoiced clicks, 55 to 70 ms for voiceless unaspirated clicks, and 120 to 145 ms for voiceless aspirated clicks. The other acoustic measures are summarized in Table 1.

We equated the loudness of the click bursts, as verified by 16 naive American English listeners. The vocalic portions had already been equated (Best et al., 1988). For the excised-click context, only the first 50 ms was retained from each syllable. The excised click included the click burst plus the silence, aspiration, or low-amplitude pitch pulses just following closure release.

Procedure

Listeners completed two test conditions of 216 trials each: excised clicks and click + /a/ syllables. The excised-click condition always

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[2] Previous reports on asymmetries for clicks have used mechanical clicks, which lack some crucial acoustic attributes found in human oral clicks. Mechanical clicks may elicit an LH processing advantage (Davis & Wada, 1978), although one study yielded a right-hemisphere advantage (Berger-Gross & Bruder, 1984), another a lack of asymmetry (Neville, 1974).

[3] Physiological measures are often preferred, but dichotic listening has the benefit of portability, dictated by our need to travel widely to test sufficient numbers of native Zulu speakers. Dichotic performance may underestimate functional asymmetry, but does correlate well with certain physiological measures of hemispheric activation (e.g., Davidson & Hugdahl, 1996).

[4] All were strongly right-handed for writing and drawing, the manual skills most predictive of LH language specialization, and for at least five out of seven other unimanual skills in the Edinburgh Handedness Inventory (Oldfield, 1971).

[5] Some were native speakers of Zulu ($n = 6$), others of Xhosa ($n = 4$). All but one of each group were also fluent in the other language from early childhood; the exceptions reported extensive early exposure. Mean performance was equivalent between Zulu and Xhosa natives.

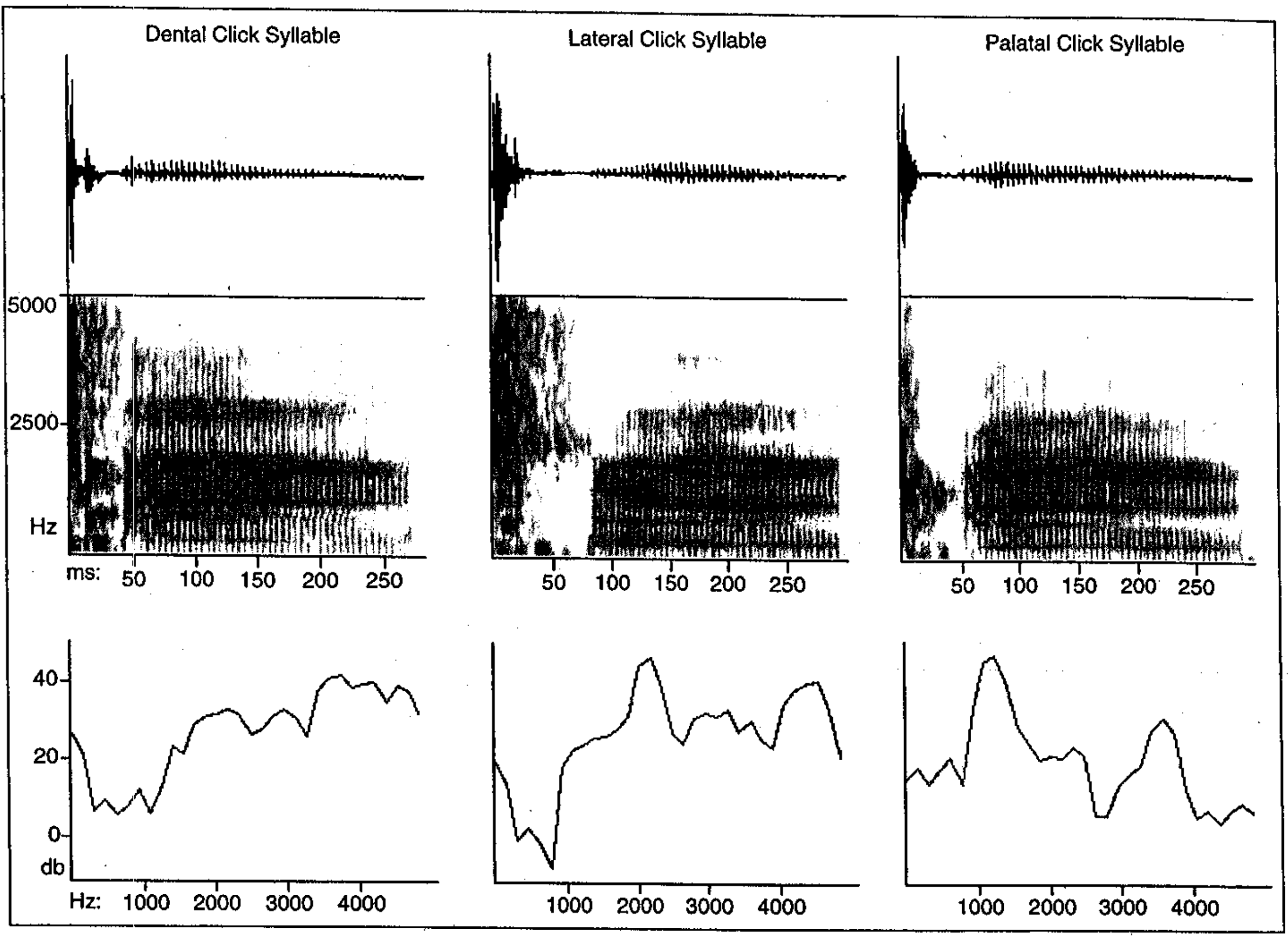

Fig. 1. Acoustic patterns of example syllables of the dental, lateral, and palatal clicks. The top row shows waveforms of the amplitude-modified voiceless unaspirated clicks at each place of articulation. The middle row shows wide-band spectrograms of the same syllables. The bottom row shows spectral sections of the click bursts of those same syllables, taken at the peak amplitude of each click.

came first, to provide the purest test of nonlinguistic processing for English listeners. The speech origin of the excised clicks was not mentioned in task instructions. However, Zulu listeners spontaneously recognized the sounds as click consonants, whereas English listeners perceived them only as nonspeech sounds.[6]

On each trial, participants attended to one ear of a dichotic stimulus pair, then judged whether the attended-ear target matched each of four subsequent binaurally presented probes.[7] The dichotic clicks always differed from one another in both voicing and place of articulation. Either no, one, or two probes per trial matched the target; participants were told any number of probes might match, to provide statistical independence of judgments for each probe. Thus, the response "match" was scored as a hit when it was correct and as a false alarm when it was incorrect; the response "mismatch" was either a correct rejection or a miss. Chance level for each probe was a probability of .5 for "match" responses. Half the matches were physically identical to the target (physical match, PM); the other half involved a different token of the target category (category match, CM), requiring somewhat more abstract judgments.

To facilitate attention to the target ear and maximize the probability of a right-ear advantage, we blocked trials in each test context for attended ear (left or right), preceded each block by three 600-Hz tones of 100 ms in the attended ear, and presented one such tone 150 ms before each trial (Mondor & Bryden, 1991). Blocks contained 20 trials (interstimulus interval = 2 s; intertrial interval = 4 s; interblock interval = 6 s). Order of blocks (left ear first or right ear first) was counterbalanced within each language group. Listeners were tested in quiet rooms, using Sennheiser HD230 headphones and a TEAC R616X cassette tape deck. Before each test session, output gain was adjusted to a signal-to-noise ratio of 57 ± 3 dB at each earphone.

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[6] Therefore, although the excised clicks were originally included to test nonlinguistic processing, they were ultimately more important for evaluating the influence of formant transitions on linguistic versus nonlinguistic processing asymmetries.

[7] Binaural probes bore one of five relationships to the target: same place of articulation but different voicing, different place but same voicing, different place and voicing, intrusion of the unattended-ear item, and target match.

Table 1. *Mean temporal and spectral measures for the click bursts at the three places of articulation*

Acoustic measure	Place of articulation Dental	Lateral	Palatal
Click duration (ms)	35.21	28.63	19.53
Highest-amplitude spectral peak			
Click onset (Hz)	4557	4529	1124
Click amplitude peak (Hz)	4566	4355	1156
Click offset (Hz)	1538	4476	1156
Second-highest-amplitude spectral peak			
Click onset (Hz)	3248	2485	3093
Click amplitude peak (Hz)	119	2453	3093
Click offset (Hz)	440	2420	3093

RESULTS

The data were summarized by ear attended, match type (PM vs. CM), and condition (excised clicks vs. syllables) for each subject, then transformed to A' values, which estimate perceptual sensitivity by controlling for observer bias under conditions of perceptual uncertainty (Grier, 1971). Analysis of variance on Language × Ear × Match Type × Condition, and simple effects tests of the significant interactions, yielded several important findings[8] (Fig. 2, Table 2). Not surprisingly, performance was poorer for excised clicks than syllables; the difference was smaller for English listeners than for Zulu listeners because the English listeners had lower syllable performance. An overall right-ear advantage (LH superiority) was qualified by an interaction with language, revealing a reliable overall right-ear advantage only among Zulu listeners.

Separate analysis for excised clicks found an overall right-ear advantage qualified by an interaction with language, which revealed a reliable advantage only in Zulu listeners (Figs. 2a and 2b). Notably, overall performance levels for excised clicks were equal for the two language groups. In contrast, the Zulus outperformed the Americans on the syllables (Figs. 2c and 2d). An overall right-ear advantage was qualified by language and match type. Only Zulus showed a reliable right-ear advantage, and only for CM probes, because their left-ear performance (right hemisphere) was better on PM than on CM probes. English listeners showed no ear or match-type effects for either condition (excised clicks vs. syllables).[9]

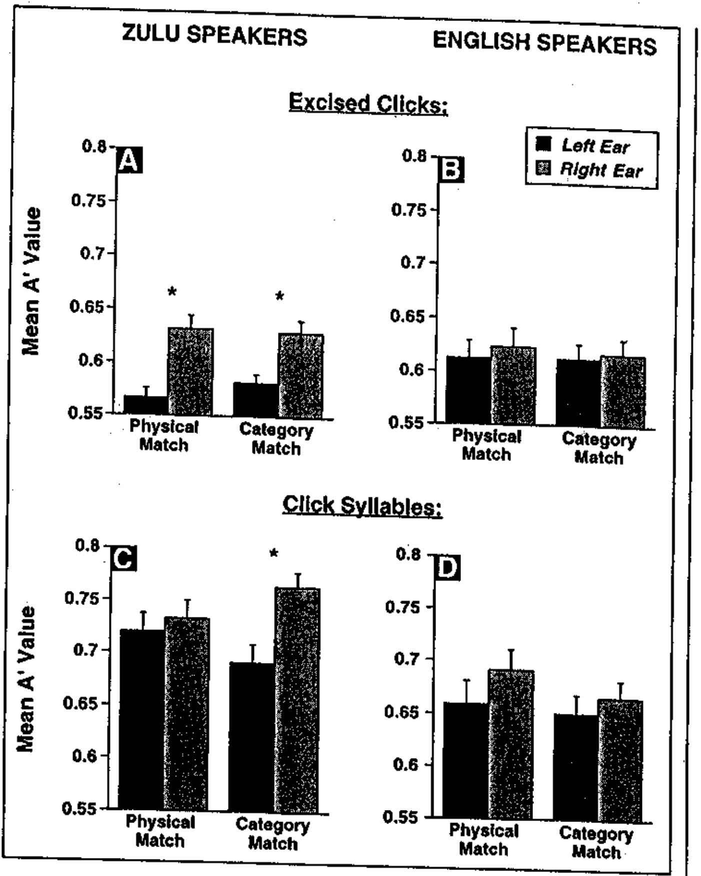

Fig. 2. Mean A' values for performance of the Zulu and English listeners on left-ear targets versus right-ear targets in the excised-clicks condition (a, b) and in the click-syllable condition (c, d). Asterisks indicate statistically significant differences between the left and right ears.

DISCUSSION

The right-ear advantage in Zulu listeners alone, the equal group performance on excised clicks, and the better performance by Zulu than English listeners on syllables are, together, consistent with the hypothesis of experience-dependent linguistic specialization of the LH. That is, LH superiority for consonant perception is not determined simply by the acoustic properties of the stimuli. Zulu listeners perceived even the excised clicks as consonants, and showed a right-ear advantage on them despite the lack of formant transitions. However, although click syllables contained formant transitions, English listeners failed to show a significant right-ear advantage, and even Zulu listeners lacked one for the PM condition. Thus, rapid formant transitions do not appear to be critical to the LH advantage.

The Zulus' lack of a right-ear advantage in the PM condition is puzzling given their right-ear advantage in all three other cells. Neither the linguistic nor the general-auditory model alone predicts this pattern. Perhaps RH nonlinguistic processing can contribute equally with LH linguistic processing for simple auditory-identity judgments (PM condition), but only when the stimulus can be maintained in short-term memory, as in the full syllables.

The most coherent interpretation of the full pattern of findings is that LH superiority on the dichotic matching task depends on attention to linguistically significant information, rather than acoustic information such as formant transitions or spectrally complex

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[8] Preliminary analyses revealed no significant effects involving sex, so that factor was eliminated from final analyses.

[9] Power differences are unlikely to account for between-group differences in right-ear advantage because there were more English than Zulu subjects (16 vs. 10) and the English error terms were equal to or smaller than the corresponding Zulu terms, with one exception (Ear × Match Type, isolated clicks) for which Zulus had a smaller term but a nonsignificant effect.

Table 2. *Significant effects of ear, language, and match type in overall analyses and in separate analyses for excised clicks and for syllables*

Significant effect	*F*	*df*	*p*
Main analysis			
Condition	36.60	1, 24	.0001
Condition × Language	6.67	1, 24	.02
Ear	15.27	1, 24	.001
Ear × Language	4.17	1, 24	.05
Simple effect of ear: Zulu	11.88	1, 9	.01
Ear × Language × Match Type	4.77	1, 24	.04
Ear × Condition × Match Type	4.49	1, 24	.05
Ear × Language × Condition × Match Type	8.35	1, 24	.01
Excised clicks			
Ear	9.71	1, 24	.005
Ear × Language	5.74	1, 24	.025
Simple effect of ear: Zulu	12.35	1, 9	.001
Syllables			
Language	4.22	1, 24	.05
Ear	6.37	1, 24	.02
Ear × Language × Match Type	12.48	1, 24	.002
Simple effect of Ear × Match Type: Zulu	7.43	1, 9	.02
Simple effect of ear for category-match probes: Zulu	11.05	1, 9	.01
Simple effect of match type for left ear: Zulu	5.58	1, 9	.05

Note. Only significant effects are listed; all other effects were nonsignificant.

transients.[10] Linguistic significance in this case depends on experience with clicks as phonological elements.

The knowledge gained through linguistic experience may take the form of abstract phonological features and their rule-governed patterns or of articulatory gestures (Best, 1994). In either case, the present results are consistent with other findings indicating that perception of linguistic information is different from simple auditory perception. For example, adults and infants recognize the articulatory commonalities among visual, haptic, and auditory displays of an utterance without prior experience (Fowler & Dekle, 1991; Walton & Bower, 1993). In deaf sign-language users, the LH regions that are normally committed to aural-oral speech instead become devoted to visual-gestural sign language (e.g., Neville, Mills, & Lawson, 1992).

The present findings also may bear on current scientific debate over the cause of developmental reading impairments. Learning to read in an alphabetic system requires recognition of how print characters map to phonological elements in spoken words; thus, the two major theoretical accounts of developmental reading deficits focus on speech-perception skills. Specifically, one account assumes that speech perception depends on specialized LH linguistic processes; it posits that developmental reading difficulty reflects a linguistically based phonological impairment (e.g., Gathercole & Baddeley, 1990; Mody, Studdert-Kennedy, & Brady, 1997). The other account instead assumes that speech perception is handled by general-auditory mechanisms. It posits that the deficits of reading-disabled children result from a general-auditory deficiency in processing rapidly changing acoustic features (Tallal et al., 1996). In that the present findings support the view that speech perception depends on linguistic rather than general-auditory processes, they are more compatible with the phonological account of reading deficits.

Most important, the findings constrain accounts of the neurocognitive mechanisms for speech perception. Neither general-mechanism nor experience-independent accounts of LH superiority for perception of consonants are supported. The results on perception of click consonants require an experience-dependent LH mechanism specialized for handling linguistic information.

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REFERENCES

Belin, P., Zolbovicius, M., Crozier, S., Thivard, L., Fontaine, A., Masure, M.-C., & Samson, Y. (1998). Lateralization of speech and auditory temporal processing. *Journal of Cognitive Neuroscience, 10,* 536–540.

Berger-Gross, P., & Bruder, G.E. (1984). Dichotic listening in the morning and evening. *International Journal of Neuroscience, 22,* 277–282.

Best, C.T. (1994). Learning to perceive the sound pattern of English. In C. Rovee-Collier & L. Lipsitt (Eds.), *Advances in infancy research* (Vol. 9, pp. 217–304). Norwood, NJ: Ablex.

Best, C.T., Hoffman, H., & Glanville, B.B. (1982). Development of infant ear asymmetries for speech and music. *Perception & Psychophysics, 31,* 75–85.

Best, C.T., McRoberts, G.W., & Sithole, N.M. (1988). Examination of perceptual reorganization for nonnative speech contrasts: Zulu click discrimination by English-speaking adults and infants. *Journal of Experimental Psychology: Human Perception and Performance, 4,* 45–60.

Caramazza, A., & Hillis, A.E. (1991). Lexical organization of nouns and verbs in the brain. *Nature, 349,* 788–790.

Corballis, M.C. (1991). *The lopsided ape: Evolution of the generative mind.* New York: Oxford University Press.

Davidson, R.J., & Hugdahl, K. (1996). Baseline asymmetries in brain electrical activity predict dichotic listening performance. *Neuropsychology, 10,* 241–246.

Davis, A.E., & Wada, J.A. (1978). Speech dominance and handedness in the normal human. *Brain & Language, 5,* 42–53.

Diehl, R.L., & Kluender, K.R. (1989). On the objects of speech perception. *Ecological Psychology, 1,* 121–144.

Fiez, J.A., Raichle, M.E., Miezin, F.M., Petersen, S.E., Tallal, P., & Katz, W.F. (1995). PET studies of auditory and phonological processing: Effects of stimulus characteristics and task demands. *Journal of Cognitive Neuroscience, 7,* 357–375.

Fowler, C.A., & Dekle, D.J. (1991). Listening with eye and hand: Cross-modal contributions to speech perception. *Journal of Experimental Psychology: Human Perception and Performance, 17,* 816–828.

Fromkin, V., Krashen, S., Curtiss, S., Rigler, D., & Rigler, M. (1974). The development of language in Genie: A case of language acquisition beyond the "critical period." *Brain & Language, 1,* 81–107.

Gathercole, S., & Baddeley, A. (1990). Phonological working memory: A critical building block for reading development and vocabulary acquisition. *European Journal of Psychology of Education, 78,* 259–272.

Grier, J.B. (1971). Nonparametric indexes for sensitivity and bias: Computing formulas. *Psychological Bulletin, 75,* 424–429.

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[10] The three-tone tasks used by Tallal et al. (1996) and Fiez et al. (1995) and the speech-synthesizer-generated stimuli of Belin et al. (1998) fail to rule out verbal-linguistic strategies; thus, the results of those studies do not uniquely support a psychoacoustic interpretation.

Ladefoged, P., & Traill, A. (1994). Clicks and their accompaniments. *Journal of Phonetics*, *22*, 33–64.

Liberman, A.M., & Mattingly, I.G. (1989). A specialization for speech perception. *Science*, *243*, 489–494.

Milner, B., Taylor, L., & Sperry, R.W. (1968). Lateralized suppression of dichotically presented digits after commissural section in man. *Science*, *161*, 184–186.

Mody, M., Studdert-Kennedy, M., & Brady, S. (1997). Speech perception deficits in poor readers: Auditory processing or phonological coding? *Journal of Experimental Child Psychology*, *64*, 199–231.

Molfese, D.L., Burger-Judisch, L.M., & Hans, L.L. (1991). Consonant discrimination by newborn infants: Electrophysiological differences. *Developmental Neuropsychology*, *7*, 177–195.

Mondor, T.A., & Bryden, M.P. (1991). The influence of attention on the dichotic REA. *Neuropsychologia*, *29*, 1179–1190.

Neville, H. (1974). Electrographic correlates of lateral asymmetry in the processing of verbal and nonverbal auditory stimuli. *Journal of Psycholinguistic Research*, *3*, 151–163.

Neville, H.J., Mills, D.L., & Lawson, D.S. (1992). Fractionating language: Different neural subsystems with different sensitive periods. *Cerebral Cortex*, *2*, 244–258.

Oldfield, R.C. (1971). The assessment and analysis of handedness: The Edinburgh Inventory. *Neuropsychologia*, *9*, 97–113.

Posner, M.I., & Petersen, S.E. (1990). The attention system of the human brain. *Annual Review of Neuroscience*, *13*, 25–42.

Rosenzweig, M.R., & Bennet, M.R. (1996). Psychobiology of plasticity: Effects of training and experience on brain and behavior. *Behavioural Brain Research*, *78*(1), 57–65.

Schwartz, J., & Tallal, P. (1980). Rate of acoustic change may underlie hemispheric specialization for speech perception. *Science*, *207*, 1380–1381.

Shankweiler, D.P., & Studdert-Kennedy, M. (1967). Identification of consonants and vowels presented to left and right ears. *Quarterly Journal of Experimental Psychology*, *19*, 59–63.

Tallal, P., Miller, S.L., Bedi, G., Byma, G., Wang, X., Nagarajan, S.S., Schreiner, C., Jenkins, W.M., & Merzenich, M.M. (1996). Language comprehension in language-learning impaired children improved with acoustically modified speech. *Science*, *271*, 81–84.

Van Lancker, D.R., & Fromkin, V.A. (1973). Hemispheric specialization for pitch and "tone": Evidence from Thai. *Journal of Phonetics*, *1*, 101–109.

Walton, G., & Bower, T.G.R. (1993). Amodal representation of speech in infants. *Infant Behavior and Development*, *16*, 233–243.

Zatorre, R.J., Evans, A.C., Meyer, E., & Gjedde, A. (1992). Lateralization of phonetic and pitch discrimination in speech processing. *Science*, *256*, 846–849.

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